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UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE PATENT TRIAL AND APPEAL BOARD

CANADIAN SOLAR, INC.,	:	
	:	
Petitioner,	:	
	:	IPR2024-01038
versus	:	Patent No.
	:	11,251,315 B2
MAXEON SOLAR PTE, LTD.,	:	
	:	
Patent Owner.	:	

DEPOSITION OF
DAVID L. CARROLL, PH.D.

8:59 a.m.
June 18, 2025

CONDUCTED REMOTELY

Job No.: 587647
Pages: 1 - 216

Stenographically Reported By:
Susan DiFilippantonio, RPR, RMR, California CSR 14383

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I N D E X

WITNESS/EXAMINATION	PAGE
DAVID L. CARROLL, PH.D.	4
EXAMINATION	4
BY MR. PETERSON	
DISCLOSURE	209
CERTIFICATE OF REPORTER	213
SIGNATURE OF DEPONENT	215

E X H I B I T S

Exhibit 2021, Declaration of David	15
L. Carroll, Ph.D., In Support of	
Patent Owner's Response	

1 (Wednesday, June 18, 2025 8:59 a.m.)

2 THE COURT REPORTER: Today is June 18,
3 2025 and the time is 8:59 a.m.. We are on the
4 record.

5 DAVID L. CARROLL, PH.D.,
6 called as a witness at the instance of the Petitioner,
7 being first duly sworn, was examined and deposed as
8 follows:

9 MR. PETERSON: This is Leif Peterson on
10 behalf of the petitioner, of Sidley Austin LLP.

11 MR. SNODGRASS: And Jacob Snodgrass with
12 PVLaw on behalf of Patent Owner Maxeon and the
13 witness.

14 EXAMINATION

15 BY MR. PETERSON:

16 Q. Good morning, Dr. Carroll.

17 A. Good morning.

18 Q. My name is Leif Peterson, and I represent the
19 Petitioner in these proceedings.

20 Do you understand that you are here to testify
21 regarding declarations that you've submitted in two
22 proceedings related to U.S. Patent 11,251,315?

1 A. '315, yes, sir.

2 Q. And those two proceedings are IPR 2024-01038 and
3 IPR 2024-01194. Does that sound right to you?

4 A. Yes. That's my understanding.

5 Q. Okay. And, Dr. Carroll, I'm going to refer
6 to -- do you -- or, sorry. Let me strike that.

7 Dr. Carroll, do you understand that those two
8 proceedings have been consolidated with one another?

9 A. Yes, that's my understanding.

10 Q. And so just for the record, today I'll be
11 referring to exhibits in the -- in IPR 2024-01038 unless
12 I state otherwise.

13 A. Thank you.

14 Q. Dr. Carroll, is there any reason you can't
15 testify truthfully today?

16 A. There is no reason.

17 Q. And is there anyone in the room with you today?

18 A. There is no one in the room with me.

19 Q. Okay. And obviously we're doing this over
20 computer. Are you in contact with anyone via chat or
21 cell phone or any other, you know, electronic means?

22 A. No. No. In fact, you just reminded me to turn

1 the ringer on the cell phone off. But I'm going to put
2 it away, so...

3 Q. Okay. Thank you.

4 We sent you a box of documents, which I
5 understand you have now opened. Other than those
6 documents did you bring anything else with you to the
7 deposition today?

8 A. My laptop has all sorts of things on it, but
9 they're not opened up, with the exception, of course, of
10 this patent that I have already opened. If you -- if
11 you would prefer that I close that and only use the
12 written, that's fine. That's up to you.

13 Q. Fine to keep the patent open, Dr. Carroll. I
14 would just ask you to refrain from opening anything else
15 other than what I show you. If you do open anything
16 else on your computer, please let me know. Is that
17 fair?

18 A. Okay. I -- I will make sure that everything --
19 I'm going to look to make sure everything is closed.
20 Let me see behind this window here. Okay. Down at the
21 bottom there are things. Let me make sure all of those
22 are now closed, as well. I -- I am closing everything.

1 Give me just a moment more, please, because there are
2 not things to do with this -- with this case, but work
3 that I have ongoing.

4 Okay. I apologize for the time. And that looks
5 like it.

6 Q. Okay. Thank you, Dr. Carroll.

7 A. Uh-huh.

8 Q. As -- as you mentioned, you did -- or, sorry,
9 let me strike that.

10 We sent you a doc- -- a box of documents, which
11 I believe will have everything that we'll discuss during
12 the deposition today. I will also provide them -- those
13 documents to you electronically in the chat function of
14 Zoom.

15 A. Okay.

16 Q. You can feel free to review the paper copy, if
17 it's available, or the -- the electronic copy, whichever
18 is convenient for you.

19 A. I understand.

20 Q. Okay. And just a few ground rules. You've been
21 doing a good job of this already, but I need to you
22 respond verbally to my answers, not just with a head

1 shock -- head shake or a nod because we don't have a
2 video recorder here and we have a Court Reporter that's
3 taking everything down that we say, okay?

4 A. I understand.

5 Q. And if you -- if you don't understand a question
6 that I've asked, please ask for clarification, okay?

7 A. Oh, I will.

8 Q. And if you don't ask for clarification, I will
9 assume that you understood my question, okay?

10 A. Fair enough.

11 Q. And, finally, if you need a break at any point,
12 please just let me know and we'll be happy to take a
13 break after the pending question is answered. Okay?

14 A. I understand.

15 Q. Did you speak with anyone other than counsel in
16 preparing for your deposition today?

17 A. Not other than counsel.

18 Q. What did you do to prepare for today's
19 deposition?

20 A. I spoke to counsel, Jacob Snodgrass, and
21 obviously read through the patent again.

22 Q. Did you meet with anybody other than

1 Mr. Snodgrass?

2 A. No.

3 Q. How much time would you say you spent preparing
4 for today's deposition?

5 A. Three hours.

6 Q. Was that --

7 A. Three hours in direct conversation with counsel.

8 Q. Okay. And did you spend any additional time on
9 your -- by yourself when you weren't meeting with
10 counsel?

11 A. Right. I spent several hours reading. I didn't
12 keep track of that, of how long it was.

13 Q. And you mentioned that you reviewed the -- the
14 patent; is that correct?

15 A. That's right.

16 Q. And if I refer to the patent 11,251,315 as the
17 '315 Patent will, you understand what I'm referring to?

18 A. Yes.

19 Q. And that is the patent at the center of these
20 proceedings, correct?

21 A. That's correct.

22 Q. Other than the patent, did you review any

1 materials in preparation for the deposition?

2 A. There are a number of references and things that
3 I have read, some of which are exhibits that you
4 provided that are -- are -- not that you provided but
5 that -- that the Maxeon people provided. And then some
6 are references just for my own particular interest
7 because, of course, I work in this field and I'm
8 interested in it. So I don't know if that would count
9 as preparation for the proceedings or just reading due
10 to interest, but I did read several things that touch
11 upon these topics, when I knew that I was going to be
12 deposed.

13 Q. Did you review any materials that had -- had not
14 been marked as an exhibit in these proceedings?

15 A. Oh, yes.

16 Q. And what prompted you to do that?

17 A. My interest.

18 Q. Have those -- has review of those materials
19 altered your opinions in this case?

20 A. No.

21 Q. And you haven't submitted a new declaration
22 citing any of those materials, correct?

1 A. All of the materials that I use to justify the
2 positions that I've cited are cited in the declaration
3 that you have.

4 Q. And do you recall which material -- which
5 additional materials that had not been cited in your
6 declaration you -- were considered by you after --
7 sorry. Let me strike that.

8 Do you recall which materials you considered in
9 preparation for your deposition that had not been marked
10 as exhibits in these proceedings?

11 A. I can -- I can -- I can find them. So I can --
12 I can -- but in terms of telling you the names on the
13 individual publications, I don't recall what those names
14 are. I would have to look them up. They're on my
15 computer. However, they are after the -- those things
16 that I was looking at were after the priority date of
17 these -- of the patents and so would not really be
18 appropriate for use in, I think, making judgments about
19 what '315 is about.

20 Q. Okay. So those -- am I correct in understanding
21 that those materials, you reviewed out of interest, not
22 to inform your opinions regarding the patentability of

1 the '315 Patent?

2 A. That's correct. Everything that informed my
3 opinion about the '315 Patent has been cited in my
4 declaration.

5 Q. And do you generally recall what the topic of
6 the additional references you reviewed was?

7 A. Yes. The topic that I was interested in was
8 plasma-enhanced CBD of oxide thin films and the
9 contaminants therein. The new use of high-purity
10 siloxane gases is something of interest to me for making
11 those thin films.

12 Q. Dr. Carroll, have -- do you have -- other than
13 this case, have you testified as an expert in patent
14 litigation previously?

15 A. So I have acted as an expert witness and I have
16 given declarations. I have not had to go before a judge
17 to do that. I don't know why.

18 Q. Have you ever been deposed?

19 A. This -- I -- this process is the first time I've
20 done this process.

21 Q. Okay. So my --

22 A. I've had -- I've had to give declarations of --

1 of patent things before in several cases, but I suppose
2 that -- and this is only my guess -- that those got
3 settled out of court.

4 Q. I understand. So you've submitted declarations
5 of the type that you submitted in this case previously,
6 but you've never been deposed on those declarations?

7 A. That's -- that's exactly right, yes.

8 Q. And how many times have you authored
9 declarations?

10 A. In the last ten years, I think I've done three.

11 Q. And do you recall generally what the topic of
12 those three declarations were?

13 A. I do. I -- I'd -- I don't know if I'm allowed
14 to tell you what they are because I did sign
15 nondisclosure agreements with the people that had me do
16 them. So I -- I simply don't know what my -- what I'm
17 allowed to say. I'm sorry.

18 Q. Without getting into the specifics of the -- the
19 patents or the parties, can you say whether any of those
20 three prior declarations dealt with solar technology?

21 A. Yes; one did.

22 Q. Okay. Have you ever been retained as an expert

1 by Maxeon before this case?

2 A. No.

3 Q. Okay. Have you ever worked with Maxeon in some
4 other capacity before this case?

5 A. No.

6 Q. How about SunPower; have you ever worked with
7 SunPower in any capacity?

8 A. No.

9 Let me qualify, please: Not to my knowledge.
10 Because sometimes companies change names, they're bought
11 by other companies and so forth. So -- but the entity
12 SunPower, the entity Maxeon, I've never done anything
13 for.

14 Q. And just definitionally, when I refer to Maxeon,
15 do you understand that I'm referring to the Patent Owner
16 in these proceedings?

17 A. Absolutely, yes.

18 Q. And if I refer to Canadian Solar, or CSI, will
19 you understand that I'm referring to the Petitioner in
20 this proceeding?

21 A. Yes.

22 Q. Dr. Carroll, I'm going to drop into the chat

1 Exhibit -- Exhibit 2021, which is your declaration filed
2 in support of Patent Owner's response. You should have
3 a paper copy in the materials we sent you.

4 A. Okay.

5 (Exhibit 2021, Declaration of David L.
6 Carroll, Ph.D., In Support of Patent Owner's
7 Response, was marked for identification.)

8 THE WITNESS: All right. And I just
9 click on this to see it?

10 BY MR. PETERSON:

11 Q. If you click on it, I believe it will download
12 for you.

13 A. Yep. Do you want me to open this?

14 Q. Yes, please.

15 A. I now have it open.

16 Q. Dr. Carroll, do you recognize Exhibit 2021 as
17 the declaration of David L. Carroll, Ph.D. in support of
18 Patent Owner's response in the consolidated proceedings
19 IPR 2024-01038 and IPR 2024-01194?

20 A. Give me a moment.

21 Yes, this appears to be the one that I -- that I
22 filed. I haven't read the whole thing, but this appears

1 to be it, yes.

2 Q. And if you look at the last page, it's dated
3 April 8, 2025, and your signature appears, correct?

4 A. Yes, that is my signature.

5 Q. Did you review the entirety of Exhibit 2021
6 before signing the declaration?

7 A. Absolutely. Absolutely.

8 Q. And does this declaration contain all of your
9 opinions in this case?

10 A. It contains all of my opinions about the
11 questions that I was asked, yes.

12 Q. You aren't expressing any opinions in these
13 proceedings that aren't disclosed in Exhibit 2021,
14 correct?

15 A. That's correct.

16 Q. Are you aware of any errors in the declaration?

17 A. I am not aware of any errors in the declaration.

18 Q. And you haven't provided any corrections to the
19 declaration since submitting it, correct?

20 A. I have not.

21 Q. Did you prepare the declaration yourself?

22 A. The parts that have to do with the scientific

1 discovery, the scientific interpretation, the
2 interpretation of historical scientific literature, I
3 wrote and sent to the -- the attorneys. The attorneys
4 helped me craft the parts that have to do with all that
5 legal language that you guys like to use, because
6 it's -- I speak other foreign languages, but I don't
7 speak that one. That one's hard.

8 Q. That's fair.

9 So you relied on counsel for legal
10 understandings, but the scientific opinions contained in
11 the declaration were your own, correct?

12 A. That's exactly right.

13 Q. How much time did you spend preparing your
14 declaration?

15 A. Give me a moment because I -- it -- the exact
16 amount of time that I spent on -- on preparing this is
17 on my computer because they asked me to keep track of
18 time. I will say roughly ten hours.

19 Q. And at a high level and without getting into any
20 discussions you may have had with counsel about your
21 declaration, can you describe the process that you
22 undertook to form the opinions that are disclosed in

1 Exhibit 2021?

2 A. The process that I undertook to form my
3 opinions?

4 Q. Yes.

5 A. So in many cases, the -- I was asked to comment
6 upon whether or not some statement or -- or some --
7 something that's being put forward was -- was true or
8 not true, or whether or not it was related to something
9 that was -- was -- you know, that was occurring in one
10 of the pieces of literature; so to compare sources of
11 literature to -- to compare sources of knowledge, and in
12 those particular cases -- I'm sorry?

13 Q. Sorry. I was just clearing my throat. I
14 apologize.

15 A. So in those particular cases, the process that I
16 typically would use was, of course, relying on my own
17 knowledge of these things, because in -- in -- for many
18 of the points being made, I was there, I was -- I worked
19 on this, as well. I have an expertise in those -- in
20 those areas and I was -- I specifically published in
21 those areas. So I'm well aware of what the situation
22 was at the time that these -- that these patents were

1 being -- were being filed.

2 Then, to make sure that my memory was correct, I
3 looked at the references, not only that I was provided
4 but the references which I knew -- that is, the research
5 groups and the people that I knew were leading the field
6 at the time -- to make sure that my memory was clear on
7 what we did and when we did it.

8 So after I did that, I would write back to the
9 attorneys what my opinions were about the questions that
10 they specifically had asked. Then we would call, and I
11 would explain the -- the technical jargon because, of
12 course, there's a lot of technical jargon that's used --
13 what that technical jargon was and what it meant so that
14 they had a full understanding of what my position was.

15 Does that answer your question?

16 Q. I think so. Just a couple of follow-ups.

17 When you referred to your -- you know, your
18 personal involvement in the field, what was being done
19 around the time, are you referring to the 2014 time
20 period?

21 A. I am.

22 Q. Okay. And can you describe what your

1 involvement in the solar technology field was in the
2 2014 time period?

3 A. At that time I was heavily involved in the
4 commercialization through a company called Camel City
5 Solar -- the commercialization of the -- of a technology
6 called fiber cell. So it is a silicon solar cell which
7 is built that has pyramidal architecture structures,
8 what have you, on top that helps to improve the
9 reflective and absorption capabilities of a solar cell.
10 And so I'm very much aware of what we were doing to the
11 front surfaces of silicon and things of that nature
12 during that time, and that was what we were struggling
13 with.

14 But my experience with the oxides and stuff
15 stretch back considerably further than that, to the
16 1980s.

17 Q. Okay. Can you describe that experience that you
18 say stretches back to the 1980s, with respect to oxides?

19 A. With respect to oxides? Well, in the 1980s and
20 the early '90s it was primarily the case that we used
21 thermal oxides as a way of forming barriers and so forth
22 that are used in silicon. Thermal oxides eventually

1 gave way to PECDD systems because we found that we could
2 make those oxides more dense and so forth. In order to
3 do that, we had to figure out exactly what it was that
4 was causing the defects that occurred in the oxides,
5 because that would significantly modify -- diffusion and
6 so forth -- through the oxide as we gathered materials.

7 And so, in fact, I guess it was '84 was the
8 first talk that I ever gave on this, using Raman
9 spectroscopy to identify oxidant defects in silicon
10 dioxide grown on silicon wafers for use in solar cells.
11 And after that, my thesis was on defect-induced electron
12 trapping in oxide thin films grown on silicon dioxide,
13 and so -- and then from there it naturally grew into the
14 work that we did eventually with Camel City Solar.

15 Is that -- is that --

16 Q. Yes. And I just wanted to follow up. You
17 mentioned, I think, in the 1984 time frame that you
18 were --

19 A. I think it was 1984, yes.

20 Q. Sure.

21 In the 1980s, let's say, you were interested in
22 studying the effects on oxides with respect to

1 gettering; is that correct?

2 A. So in that particular case, it's not
3 specifically with respect to gettering; it affects
4 gettering. So if there are oxygen defects, we knew at
5 the time that the gettering that would occur through the
6 oxide would be affected. So the diffusion links and the
7 diffusion times would change drastically if there are
8 significant defects. So what kind of defects would do
9 what was of interest to everyone at the -- in that time
10 frame.

11 Q. Sure.

12 So in that time frame, it sounds like the
13 industry was gettering metal impurities through silicon
14 oxides and was studying the effect that defects in the
15 oxide may have on the ability to getter; is that right?

16 A. At that time frame, the idea was that -- and the
17 concern that we had was a slightly different kind of
18 gettering. So what we were most concerned with was what
19 was happening to the dopants that we were putting in.
20 Everyone was implanting boron at that time. The boron
21 could come out under subsequent heat treating, and
22 that's what we were really talking about.

1 Now, the word "gettering," the term, is used
2 broadly and has become more defined in later years to
3 mean specifically the expulsion of impurities, but at
4 that time it meant the movement of anything through
5 the -- through the oxide. So the definition of the term
6 has changed.

7 Q. In the 1980s time frame that you were
8 discussing, when you referred to gettering, it could
9 have meant -- sorry. Let me strike that.

10 In that 1980s time frame, if I'm understanding
11 you correctly, gettering referred to both dopants
12 flowing through the oxide but also metal impurities
13 flowing through the oxide; is that right?

14 A. That's a difficult question to answer because we
15 only -- we were only concerned at that time with boron.
16 So most people were talking about boron. I'm not aware
17 of anybody talking about the removal of anything else.

18 But, you know, I will say that, generally
19 speaking, at that time we used as pure of a piece of
20 silicon as we could get for those studies. So there
21 would have been extraordinarily low concentrations of
22 anything else.

1 Q. And what -- when you refer to the studies, were
2 those academic studies?

3 A. Those were academic studies.

4 Q. And what process did you go through to obtain a
5 very pure silicon just for purposes of those studies?

6 A. That would be gradient heat zone refinement.

7 Q. Can you describe what that process entails?

8 A. Sure.

9 So what you do in zone refinement, if you begin
10 to slowly pull a crystal out of -- out of a melt, if you
11 structure it in such a way so that there's a strong
12 gradient in temperature, you're going to drive most of
13 the impurities from one zone, from the hotter zones,
14 into the purer zones, leaving behind a piece of crystal
15 which has a lower concentration of impurities that would
16 normally occur in nature. So this is a nonequilibrium
17 process, and so you can achieve concentrations of
18 impurities below what nature would have you do. This is
19 why we're able to create silicon as the most perfect
20 crystal that mankind has ever created, is through the
21 use of zone refining. And we can get concentrations in
22 those crystals so low that they are far below our

1 detectability limits. So it's quite an achievement.

2 Q. How does the process you just described compare
3 to the process that is used for commercial solar-grade
4 silicon substrates?

5 A. So the processes that are used -- the processes
6 that are used for commercial grade materials for
7 commercial grade silicon on rooftops and in solar that's
8 applied to concentrators and in solar that are applied
9 to outer space are different, right. So if we are
10 talking about terrestrial-based home units, what we use
11 today is different than what we used in the past.
12 Today, most really high-quality silicon is gobbled up by
13 the semiconductor industry. In order to accommodate
14 that, the silicon solar industry typically uses a lower
15 grade of silicon, and so post processing is necessary in
16 order to make these materials perform better.

17 You don't have to do that. You can use the
18 higher-quality stuff, but it will cost you more. And
19 since the primary driver in the solar industry today is
20 the dollars per watt, then it doesn't make sense to use
21 really expensive silicon.

22 This changed sometime in the 2000s, the early

1 2000s, where we began to go to lower and lower quality
2 silicon and using more and more post processing. So
3 today, if you go and you buy one, the silicon that you
4 begin with is not very high quality. But it is made to
5 perform like a high-quality silicon boule because of the
6 post processing, which is similar in some ways, right.
7 This is the so-called gettering that is a part of the
8 proceedings that we're discussing now -- is similar in
9 some ways to the zone refining.

10 Q. The phenomenon you just -- sorry. Let me strike
11 that.

12 The tendency towards lower and lower quality
13 silicon for the solar industry, you said that applies
14 today and it started sometime in the early 2000s -- mid
15 2000s. So it sounds like that would have been true in
16 2014, as well. Is that correct?

17 A. Yes, that's right. In 2014 you would have used
18 a lower-quality silicon to make the panels.

19 Q. Okay. And the -- the post processing you
20 referred to, I believe you said that would include a
21 gettering step, correct?

22 A. Yes. So typically it's a gettering step that is

1 driven by heating in some way.

2 Q. And could that heating take place as part of the
3 solar cell fabrication process?

4 A. It almost always does.

5 Q. And in that 2014 time frame, was it common for
6 the gettering process to be part of dopant diffusion?

7 A. In 2014, I believe that it was not common
8 commercially. I know that it was not common in
9 laboratories and -- and people who were doing
10 experiments.

11 Q. And how do you know that?

12 A. Because I -- I worked in silicon solar cells.
13 So what I was aware of in the various companies that
14 were making this, they were trying to do the two things
15 separately because it is not clear what will happen to
16 protective layers, oxide layers, front surface, fields
17 and so forth if you try to use heat to do both things.
18 Frequently, the impurities, metals, what have you, that
19 might be in there will interact with the dopants. That
20 interaction creates another dopant band, and that dopant
21 band can be deleterious to the device's function.

22 And so it is not -- it was not obvious at the

1 time, and it's still not wholly obvious, that one can do
2 these together from an a priori position. Now, that
3 does apply only in the caveats that I gave you, which
4 are the terrestrial-based systems. When you talk about
5 materials that we send in orbit, those are far, far more
6 expensive and they use really good silicon to begin
7 with.

8 Q. In the 2014 time frame or before, do you recall
9 literature discussing the simultaneous gettering and
10 dopant diffusion process?

11 A. In the 2014 time frame, there was literature in
12 which both of these things happened at the same time.
13 To my recollection, most of the time this was
14 accidental, and it led to both good outcomes and poor
15 outcomes. And so to my recollection at the time, the
16 thought was that it was not easy to predict when it led
17 to advantageous outcomes.

18 Q. We were talking about in 20-- 2014, for
19 terrestrial purposes, the solar industry typically
20 starting with low, low-quality silicon substrates. Do
21 you recall that?

22 A. I do recall that. And it's lower-quality

1 substrates. We -- I mean, you can't use really poor
2 silicon no matter what you do.

3 Q. Sure.

4 And do you have knowledge of what the typical
5 mental impurity concentration would be in those
6 low-quality substrates?

7 A. I do not have a direct memory of the numbers for
8 the concentrations, other than to say something greater
9 than 10 to the 15 or so. However, that's an overall
10 number. Of course, the mental concentrations would
11 include all such impurities, which could be nickel, iron
12 cobalt, moly and so forth. And depending on exactly
13 what the growth mechanisms that were used, you would end
14 up with different types of materials in the silicon.

15 So to answer your question, even if I did
16 remember exactly what the prefactor number was, it would
17 still depend very strongly on exactly who produced the
18 silicon.

19 Q. In the -- let me strike that.

20 In the '315 Patent, there is not an indication
21 of who produced the silicon that was used for that
22 study, correct?

1 A. That's correct.

2 Q. And do you recall reviewing a patent publication
3 that was -- that's been referred to as Li, L-I?

4 A. I do remember leading Li.

5 Q. Okay. And for the record, Li is Exhibit 1005.

6 A. Uh-huh.

7 Q. Do you recall whether Li indicated who supplied
8 the silicon substrate that was used in that reference?

9 A. I do not recall. I don't think so, but I don't
10 recall.

11 Q. You mentioned that metal impurities would
12 include iron, but it could also include other metals
13 like cobalt, and I think you listed some others. Is
14 that correct?

15 A. That's right.

16 Q. And nickel was another one, right?

17 A. That's correct.

18 Q. Of the metal -- common metal impurities that
19 you're aware of for silicon substrates, how does the
20 diffusivity of those metal atoms compare to iron?

21 A. Many of them can diffuse as much as an order of
22 magnitude faster. Iron forms multiple bonds, not only

1 with silicide -- forming silicides, but also oxides, and
2 that can cause a problem. Iron also interacts with
3 boron, which can cause a problem. Those interactions
4 tend to slow it down, so iron can be relatively slow.
5 The same is true if you have chromium.

6 So some of them are very similar to iron and
7 some of them are much faster than iron. But iron tends
8 to represent the lower limit of diffusivity.

9 Q. And when we refer to "diffusivity," that, in
10 layman's terms, speaks to the ability of the atom to
11 move in silicon when it's heated, correct?

12 A. In layman's terms, yes, it is the coefficient
13 that is used in Fick's law for diffusivity.

14 Q. And so if I'm understanding your testimony
15 correctly, iron is the metal impurity that probably
16 moves the slowest of any of the metal impurities that
17 are common in silicon substrates; is that right?

18 A. It represents the lower end of diffusivity, yes.
19 I don't know if it's the lowest, because that would
20 depend a little bit on a couple of things, but it
21 certainly is on the lower end of -- of the mobility,
22 yes.

1 Q. In terms of concentration, do you have any
2 knowledge regarding how the typical concentration of
3 iron compares to the concentration of other elements,
4 like cobalt or nickel?

5 A. Yes. So iron is typically an order of magnitude
6 higher than the other ones. The reason for that is
7 simply that iron is in the growth vessels that you use
8 to make the silicon. So it's in all the stainless
9 steel. It's in everything. So you tend to get it in
10 there.

11 Q. When you were doing your work in the 1980s
12 studying thermal oxides, were you aware that the metal
13 concentration in the silicon substrate was a concern
14 that could impact efficiency of the cell?

15 A. So if I understand your question correctly,
16 you're using metal here as meaning impurities other than
17 the dopants that we put in.

18 Q. Yes. Yes. I'm referring to metal that would be
19 in the silicon substrate after it's -- after it's grown
20 or as part of its growth process.

21 A. Yes. So it was well known at the time that such
22 impurities would impact the -- would impact the mobility

1 of carriers and cause recombination in bulk. However,
2 what was realized later was that the dominant part of
3 the effects would be any -- any of these carriers -- or,
4 sorry, any of these impurities that occurred along the
5 surfaces, because the surface recombination was
6 dramatically more effective at decreasing cell
7 performance than was the bulk. That was over --

8 Q. And in that time frame, was it known that one
9 way to reduce the number of metal impurities in the
10 silicon substrate would be to getter those impurities
11 out of the substrate?

12 A. So in this case you're using the word
13 "gettering," but gettering simply means to remove it.
14 And, of course, removing it would be good. However, if
15 you mean gettering it through the use of thermal
16 techniques and things like that, right, which -- like I
17 described a little while ago, that was just becoming
18 understood at the time, and it wasn't clear that you
19 could getter it out of the silicon in a way that didn't
20 damage the silicon.

21 So I would say that our understanding at that
22 time of the removal processes of impurities was still

1 relatively in flux -- I don't mean a pun there -- and so
2 I would not say that it was understood that gettering,
3 in the sense that you currently mean, was a way that one
4 would have to treat this in a manufacturing process.

5 Q. I understand.

6 So in the 1980s, the concept of heating the
7 substrate to remove impurities through gettering was
8 just starting to be understood, right?

9 A. I would say that that's correct, yes.

10 Q. And by 2014, that process was much better
11 understood -- that's 25 years later -- right?

12 A. Yes, I believe that it was.

13 Q. When I asked my question a few questions ago,
14 you mentioned the distinction between metal impurities
15 that are in the silicon substrate and metal impurities
16 that are put there intentionally. Can you explain what
17 you mean by that?

18 A. Yes. I'm sorry, I should explain that
19 sometimes, right, we parse terms in physics, and many
20 times we refer to anything that is not hydrogen as a
21 metal. So when we talk about borons and phosphors and
22 things of that nature, we don't normally think of those

1 atoms as being in the groups that are considered metals,
2 but the actions that they have within a dopant -- as a
3 dopant within a silicon matrix make them -- make them
4 create metallic behavior for the silicon, and some
5 people sometimes call those metals.

6 So if you're talking about iron, moly, chromium,
7 nickel, right, we all understand those as being atoms
8 that, in their condensed form, are metals, whereas you
9 would not necessarily think that of, let's say,
10 potassium or lithium, but they too are metals. And so
11 that's why I just wanted to make sure that -- you know,
12 it's habit in my case to make sure that the term is
13 precise.

14 Q. Okay. So if I'm understanding, sometimes the
15 n-type or p-type dopants that you introduced into, say,
16 an emitter, those by themselves can be considered
17 metals; is that right?

18 A. That's what I'm saying.

19 Q. And a dopant can be considered a type of
20 impurity, correct?

21 A. Well, I think that's -- so it is harder to
22 answer that because one has to have the context of what

1 someone's talking about. If you look at literature and
2 they talk about impurities in solar cells, they almost
3 never include the idea that a dopant is an impurity,
4 right, the dopant was also meant to be there, and they
5 are referring to impurities as the things that they
6 don't want. However, if one takes the point of view of
7 pure statistical mechanics, an impurity is anything that
8 is not monatomic. So it really depends on the context
9 in which you use the term.

10 Q. I see. I just want to take a look at paragraph
11 37 of your declaration, which is Exhibit 2021.

12 A. Okay. Just -- oh, that one's up here.
13 Paragraph 37, you said?

14 Q. Yes. It's on page 20.

15 A. That's 101. What is on...

16 I see why you label the paragraphs now.

17 Q. Yes.

18 A. "Doping is the introduction of a charged
19 impurity into a substrate."

20 Is that what you mean?

21 Q. Yes.

22 And so this is consistent with your testimony

1 that a dopant can sometimes be considered an impurity,
2 right?

3 A. In -- in the definition that's being used in
4 this -- this way right here. This is the way a
5 physicist would talk, yes.

6 We -- we do have to make that distinction,
7 because a lot of times literature -- for instance, one
8 of the IEEE's, they use impurity a different way.

9 Q. You mentioned work that you did for a company --
10 I think it was called Camel Solar; is that right? Camel
11 City Solar?

12 A. Camel City Solar.

13 Q. And that was for a commercial product; is that
14 right?

15 A. That's right. That's right. Ultimately, they
16 went bankrupt, so they're not here anymore, and the
17 technology was sold.

18 Q. Do you know who it was sold to?

19 A. No, sir, I don't.

20 Q. How long did you -- let me strike that.

21 How long were you involved in the work that
22 Camel City Solar was doing?

1 A. Three years.

2 Q. And can you describe the extent of your
3 involvement?

4 A. Yes. So I was the Chief Technical Officer, so I
5 was responsible for designing the solar cells and I was
6 responsible for getting the main production line, the
7 line that makes the big panels -- for getting that up
8 and running.

9 Q. Okay. So you were actually involved in the
10 manufacturing process for the solar cell that Camel City
11 Solar was intending to commercialize; is that right?

12 A. That's exactly right, yes.

13 Q. Okay.

14 A. And at the same time, I was also a professor at
15 Wake Forest and I had release time to do this work for
16 the -- for the company, so...

17 Q. Prior to your work at Camel City Solar, had you
18 worked in solar cell fabrication outside of an academic
19 context?

20 A. Not outside of an academic context.

21 Q. And in an academic context, can you describe
22 your experience with solar cells specifically?

1 A. So my experience with solar cells involves both
2 organic and inorganic solar cells. It stems from my
3 work with organic solar cells. I had connections with
4 people like Konarka and so forth. At the same time that
5 they were doing the work that they were doing, we were
6 developing an organic solar cell based upon a new
7 architecture for light gathering. That work led to -- a
8 little while -- while -- we were recognized as the
9 highest-performance organic solar cell in the world, and
10 we held that for some time, I believe it was, until we
11 were eventually eclipsed about four years ago.

12 Those solar cells, you make them -- you make
13 them into larger panels. They are very similar to the
14 silicon ones, except that the absorber is not silicon,
15 it is a -- it's a type of thiophene polymer that's
16 painted on. So we did a lot of that. Many of the
17 graduate students and post-docs that I produced at that
18 time have gone on to continue that work in their own
19 spaces.

20 In terms of --

21 Q. So when you're referring to an organic solar
22 cell, that's a carbon-based substrate in --

1 A. That's right, a semiconducting polymer.

2 Q. Okay. Sorry. Please allow me --

3 A. Although we did build some of them in which we
4 made heterostructures of polymer and silicon.

5 Q. Okay. And I think you also mentioned that you
6 had experience in academia with inorganic solar cells,
7 right?

8 A. That's exactly right. So we did -- we did two
9 types of inorganic solar cells, one based in silicon --
10 these are the alpha silicon hydrides, so the amorphous
11 silicon systems, and then crystalline silicon systems.
12 So some that were very, very similar -- and, in fact,
13 the patents that we're discussing use a very similar
14 mechanism that we developed for capturing the light.
15 The others were the flexible ones that you see, the ones
16 that are made on stainless. And so we built both of
17 those and did pretty -- pretty extensive work in that
18 area.

19 Q. What time frame was this?

20 A. That would have been right at 2010 to 2014,
21 2015, so in that period.

22 Q. Okay. And you mentioned that the -- the silicon

1 systems that you were working with had -- were similar
2 -- had a similar mechanism to the '315 Patent. Can you
3 explain what you meant by that?

4 A. Oh, just the structuring of the front surface,
5 that's all. So the structuring the front surface -- so
6 these are -- these solar cells are -- you know, they
7 face the sun, right. You don't want the sun to bounce
8 off, so you create a texture on the surface, and that
9 texture prevents the reflectivity of the material from
10 giving up all the power, right. You want to capture
11 more of it. And so they use a particular type of
12 structure. We developed a particular type of structure.
13 There was several of them going around at the time.

14 Q. So are you referring to the texturing of the
15 front surface?

16 A. Yes.

17 Q. And with those solar cells that you were
18 developing, was the work focus primarily on the front
19 surface?

20 A. Well, we were developing a whole solar cell,
21 right, so we had the -- the entire thing had to be --
22 had to be considered. My job was not just the front

1 surface. We did have people that focused on that. But
2 we -- my job was to consider how all of this integrated
3 into a panel, so -- because, remember that the pieces
4 that you use are relatively small compared to the size
5 of the panel.

6 Q. Was this a back-contact solar cell?

7 A. We used -- in the first product, it was a front
8 and back-contact system. In the second product, it went
9 to all back contact.

10 Q. And do you recall how the -- let me strike that.

11 On the front surface, do you recall the steps
12 that were taken to dope or passivate that surface?

13 A. Oh, yes, I recall it.

14 Q. Yeah. Can you --

15 A. There were --

16 Q. Can you tell us about that?

17 A. There were multiple steps.

18 I'm sorry?

19 Q. Can you tell us about that?

20 A. I can -- I can tell you in general terms,
21 because much of this is still patented and some of it's
22 trade secret. But in general terms, you use a -- a

1 dopant that -- what we used at that time was a -- it was
2 a slurry, so it was -- the dopant was contained in a
3 liquid that was placed on the system and then driven
4 into the system through the use of a high temperature.

5 The -- the contacts that were made generally
6 involved the production of amorphous silicon over top of
7 that, with a heavy dopant placed into that. And then on
8 top of that, we would put -- I think we -- if I remember
9 correctly, I think it was chromium that we were with at
10 that time, and then aluminum on top of that, right,
11 because you had to have an adhesive -- an adhesive
12 layer. So the metal that you put down sticks better if
13 you use chromium on there. It makes it lasts longer.
14 We used a native oxide on the top of that, which was
15 grown by hot-wire CVD to protect everything. And then
16 that was structured using -- using a -- an etching
17 process, which is -- it's a -- not -- it's a
18 heterogenous etching so that it etches pyramids.

19 So that's the way that it was done. So it was
20 done in steps, and you begin with this -- putting down
21 the dopants that you want and driving them in.

22 Q. Do you recall the concentration --

1 A. Does that answer your question?

2 Q. Yes, it does.

3 Do you recall the concentration that was used at
4 the front surface for the dopants?

5 A. So, yeah, that -- so that's a very -- that's a
6 very detailed -- that involves a very detailed answer,
7 because when you say "concentration," the concentration
8 changes as you go in. The way in which it changes
9 determines how well the cell -- how well the cell is
10 going to function. So if I say, oh, well, let's start
11 off at the dopant level that gives you -- that makes the
12 silicon metallic all together, right -- so this is the
13 generate doping -- everyone knows that that's about 10
14 to the 18 or so. And you don't necessarily want
15 everything to be completely degenerate as you go into
16 the system, right. I don't want a piece of metal in the
17 front of -- it will block the light. So you have to
18 have that fall off, and you have to have it fall off in
19 a gradient in such a way that you enhance the
20 performance and don't decrease it.

21 So when you say what is the concentration,
22 that's a -- that's a very difficult question because I

1 have to -- have to know where you mean that
2 concentration to be taken and how you mean that
3 concentration to be changing. It will all matter as to
4 how the device performs.

5 Q. Do you recall what the concentration was at the
6 surface of the silicon substrate?

7 A. So at the very surface of that substrate, the
8 concentration after treatment, after you have driven
9 everything in, would have been at or about 10 to the 18.

10 Q. And you recall -- sorry. Let me strike that.

11 The -- you also mentioned that there was a
12 silicon oxide passivation layer placed on top of
13 everything else on the front surface. Did I get that
14 right?

15 A. That's exactly right. The silicon oxide is used
16 to protect it.

17 Q. Can you describe what you mean by "used to
18 protect it"? What's the function of that silicon oxide
19 layer?

20 A. So the silicon oxide has several things that it
21 has to do to protect the silicon below. First of all,
22 you want to stop further oxidation, right, because if

1 you oxidate -- if you oxidize down past the contacts,
2 then you're going to relieve the contacts from making
3 intimate contact to the substrate. So if I allow this
4 thing to sit in just raw oxygen like in the atmosphere,
5 eventually that oxygen will get in there, deteriorate
6 the contacts, and it won't work. So the lifetime is
7 reduced.

8 So what you do is you make a nice dense layer of
9 silicon on top of it, because then it has to go through
10 that piece of glass before it gets down to the rest of
11 it. The second thing that it does is that, generally
12 speaking, the -- by putting those dopants in that front
13 region, what you're going to do is you're going to make
14 the silicon very sensitive to UV radiation. So you
15 don't want to create defects due to the absorption of
16 very-high-energy photons, and so, of course, you have
17 about a 200 -- 180-to-200-nanometer cutoff of glass for
18 the -- for radiation. So you're going to get rid of
19 most of the super-high-energy photons that would have
20 damaged the silicon. So it's serving two different
21 purposes.

22 Q. Do you recall what the thickness of the silicon

1 oxide layer was in your solar cell?

2 A. Yes. We almost always went to something more
3 than 200 nanometers.

4 Q. And do you recall why you chose 200 nanometers
5 as the thickness of the silicon oxide?

6 A. Right. So that's -- that's the wavelength
7 roughly of the light that you're blocking, so that works
8 well for that. And it ends up being a -- well, it ends
9 up being the -- sort of the minimum you can get away
10 with and still have it protect everything. I don't want
11 to put more than that on there because it costs me
12 money.

13 Q. You mentioned a bit ago that you were studying
14 one solar cell that was a front contact and a back
15 contact, and then I think you said it transitioned to
16 all back contact. Do I have that right?

17 A. Yes, that's right. Both were considered during
18 this time to see which implementation would be most
19 advantageous for the fiber cell architecture we were
20 using on the front.

21 Q. Was the front surface dopant concentration that
22 you used, which I believe you said was 10 to the 18th --

1 was that the same for both versions of the solar cell?

2 A. My recollection is that at that time that was
3 true for us, true for what we were considering. There
4 may have been a difference of 1, 2, 3 times to the 18.
5 These are rough numbers because, of course, once you
6 drive them in and then you put oxides on them, there is
7 a slight variation. So it's hard to say exactly, but I
8 would say in both cases roughly 10 to the 18.

9 Q. Was this work that you were doing at Wake
10 Forest?

11 A. Part of it was at Wake Forest. Part of it was
12 at Clemson, before I moved here. I moved here in 20- --
13 2003 and we were still in organics at that time mainly.

14 Q. So the solar cell that we've been discussing --
15 the solar -- sorry. Let me strike that.

16 The solar cell we've been discussing, can you
17 again remind us what that time frame is?

18 A. So the last one that we're talking about, Camel
19 City Solar, that was about 2010 to 2014, 2015, something
20 like that, yeah.

21 Q. And the work -- the solar cell that transitioned
22 from front and back contact to all back contact, what

1 time period was that?

2 A. That would've been toward the end of its time,
3 so that would've been about 2014, 2015, somewhere in
4 there. That's a rough guess.

5 Q. Dr. Carroll, have you ever met CSI's expert,
6 Dr. Banerjee?

7 A. Not that I remember, no. I know of him, of
8 course.

9 Q. In what context do you know of him?

10 A. Well, of his work, his publication record. I've
11 read papers from him.

12 Q. And do you have any -- well, let me strike that.

13 Based on his publications in the field, do you
14 have any doubts about his qualifications as an expert in
15 solar technology?

16 A. No, not particularly, no.

17 Q. And have you found his -- his published work to
18 be reliable?

19 A. The stuff that I've read, yes.

20 Q. Do you recall the context in which you would've
21 read Dr. Banerjee's work?

22 A. I honestly don't recall the context. I'm sorry.

1 The reason for that is simple: There's more than one
2 Banerjee and sometimes they get confusing.

3 Q. Okay. Just to be clear, we're -- we're
4 referring to Dr. Sanjay Banerjee.

5 A. No, I know who we're talking about here. But in
6 my memory there's also a Banerjee that does a lot of
7 work with quantum computers, so...

8 Q. Do you recall how you were retained for this
9 matter?

10 A. For this -- you're talking about the initial --
11 so I am --

12 Q. Let me -- let me just clarify. I was just
13 curious how you -- if you recall how you were retained
14 for this IPR proceeding.

15 A. Okay. So if -- so I was retained before this
16 IPR got -- got shoved into the -- from two to one,
17 right? And so that originally was done by IMS. They're
18 a service that does this for attorneys, I guess, and
19 they interviewed me and they asked me for my -- they
20 asked me for my CV and they asked me for some
21 references. And so I gave them those things, and then
22 they came back and said, Would you be interested in

1 doing this?

2 And I said yes, I would look at it. And then
3 they sent me materials. And then I had to comment on
4 whether or not I thought I was qualified to do it.

5 Q. And do you recall approximately what time frame
6 that would've been where you were -- when you were
7 originally contacted?

8 A. Oh, I think it was last year-ish, roughly at
9 this time.

10 Q. Have you ever spoken to anyone at Maxeon?

11 A. Oh, no. Not at Maxeon, no.

12 Q. And do you recall ever speaking to anyone that
13 was employed by SunPower?

14 A. I don't recall ever meeting anybody from
15 SunPower.

16 Q. One of -- a couple of the references at issue in
17 this case have an author or inventor named Richard
18 Swanson. Do you know him?

19 A. Not personally, but of course I've read the
20 references.

21 Q. Had you heard of Richard Swanson prior to this
22 case?

1 A. Yes, I had. He's -- he's known in the field of
2 silicon solar cells.

3 Q. Okay. Maxeon has previously referred to him as
4 the father of solar technology in the United States.
5 Are you aware of that?

6 A. I don't know that I've read them saying that,
7 but certainly he's extremely well known.

8 Q. And why is he extremely well known?

9 A. Because the -- the basic advent of solar cells
10 based upon silicon really wasn't good enough to
11 commercialize it. It cost too much to do those things.
12 Most of his work has focused on doing the things that
13 make it commercially viable. And so a lot of us,
14 including myself, think that it would not have been
15 possible to have solar technology on your rooftops if --
16 if we didn't have someone that did all that, that
17 figured out ways around the expensive parts and made it
18 possible for us to do the things that we do now.

19 So I think that's probably why people are, you
20 know, somewhat deferent to him, because it was quite
21 important in creating the industry.

22 I don't know if I'm fully answering your

1 question, so you --

2 Q. Oh, sorry. I'm just processing your answers.

3 When you said that people are somewhat deferent
4 to Dr. Swanson because of his work in creating the
5 industry, what do you mean by deferent?

6 A. Oh, I mean that we simply pay a certain amount
7 of respect to that. You need to respect the things that
8 he says and things, because he's sort of earned that.
9 He's been right a lot of times, in other words. That's
10 not to say that you take someone's word at face value,
11 right. That's not the nature of science. But
12 nevertheless, if he believes that this or that or the
13 other is the case, then we look at it carefully because
14 he has been right a lot.

15 Q. Dr. Carroll, in your report, one of the opinions
16 you provide is that Canadian Solar's petition failed to
17 demonstrate that metal impurities would inherently be
18 present in the emitter region of Li. Do you recall
19 that?

20 A. Yes.

21 Q. You don't dispute that Li discloses an emitter
22 region, correct?

1 A. So I -- I would say that in the definition that
2 we're using, what people are referring to as emitters in
3 the way that we're talking about it currently, that Li
4 does disclose such a region.

5 Now, that has to be taken contextually because
6 the thing that people call emitter region sometimes
7 includes heavily doped silicon that's underneath the
8 contact, sometimes it does not. There's a number of
9 ways in which it is discussed. So when you say -- and I
10 know it sounds as though I'm parsing terms. I don't
11 mean to. It's just that the language varies across the
12 contextual pieces that you've got. Whether you're
13 talking to lawyers, scientists, engineers, chemists,
14 what they refer to as an emitter region and what they
15 don't refer to as an emitter region can differ.

16 So you have to be a little careful when you read
17 the literature and say which one is which. I believe
18 that as I read Li, the region that he's discussing would
19 be what we are calling currently an emitter region.

20 I'm not usually so pedantic. It's just that
21 we're talking across different fields.

22 Q. Sure.

1 And so I just want to make sure I understand.
2 For purposes of assessing whether Li discloses the
3 limitations of the '315 Patent, you are not disputing
4 that Li discloses an emitter region as that terms is
5 used in Claim 10 of the '315 Patent.

6 A. Let me just look real fast, please, because I --
7 I don't have the claim numbers memorized.

8 Q. And just for the record, the patent is
9 Exhibit 1001.

10 A. Yeah. Please just give me a moment.

11 Where did that go? Oh, yes. Yes, I believe
12 that's right. I believe that it -- Li does disclose an
13 emitter region which is similar to the one that is
14 described -- similar to the one that is described in
15 Claim 10.

16 Q. And your report also provides the opinion that
17 the petition failed to demonstrate that implementing Li
18 with a front surface dopant concentration, as recited in
19 Claim 10, would have been obvious. Do I have that
20 right?

21 A. Implementing -- say that one more time, please.
22 I'm sorry.

1 Q. Sure.

2 Is it -- is it your -- sorry. Let me strike
3 that.

4 Your report provides the opinion that the
5 Petitioner fails to demonstrate that implementing Li
6 with a dopant concentration of approximately less than
7 or equal to 2 times 10 to the 18th cubic centimeters in
8 the front portion of the silicon substrate, correct?

9 A. Uh-huh. Your -- so what you said doesn't sound
10 like a question. What are you -- what are you asking?

11 Q. I'm -- I'm just trying to understand which
12 portions of the Petitioner's obviousness argument you
13 are disputing, and I believe that there are two. One is
14 metal impurities in the emitter region?

15 A. That's right.

16 Q. And the second is the front dopant
17 concentration; is that right?

18 A. I understand, yes. So you're asking me whether
19 or not I believe that Li is -- if I were going to use
20 Li, that it would've been obvious to someone skilled in
21 the art -- as defined by the definitions in my
22 declaration that I was told to use, whether or not it

1 would've been obvious to them that you needed to use 2
2 times 10 to the 18 on the front surface to form a front
3 surface field. Is that what you're asking?

4 Q. Correct.

5 A. Right. And it is my opinion that that would not
6 have been obvious to someone skilled in the art. And
7 there are good reasons why I believe that, but I -- it
8 is my opinion that it would not necessarily have been
9 obvious.

10 Q. And other than with respect to the front dopant
11 concentration and the presence of metal impurities in
12 the emitter region, you don't dispute that Li discloses
13 the other limitations of the asserted claims, correct?

14 A. I -- I believe that is correct. Please tell me
15 what other limitations that you -- that you're meaning.

16 Q. Well, we can take a look at Claim 10 in
17 Exhibit --

18 A. All of those are in Claim 10?

19 Q. Yes.

20 A. Yes. For the ones in Claim 10, that's correct.
21 I don't dispute that Li would have no problem
22 implementing those.

1 Q. And you don't -- you also do not dispute -- let
2 me strike that.

3 With respect to the dependent claims, which are
4 Claims 11 through 16 and 19, your report doesn't provide
5 an opinion disputing the obviousness of those
6 limitations, correct?

7 A. So the -- I was not asked specifically to look
8 at the -- any limitations to do with 11 through -- what
9 did you say, 15?

10 Q. 11 through 16 and Number 19.

11 A. And 19.

12 Probably because as I look at these, this is
13 simply describing n-type dopants and p-type dopants as
14 they are used traditionally in solar cells. So I would
15 not expect that they would be -- that they would be
16 limitations in anything to do with the claim upon which
17 they are dependent, which is Claim 10, with the
18 exception of the concentration as we've already stated
19 and the metal impurities as we have stated.

20 Q. So your analysis focuses on those two
21 limitations, the metal -- the metal impurities and the
22 front dopant concentration, with respect to Claim 10,

1 correct?

2 A. Well, in a way, yes; but in a way, no, because
3 the dependent claims now -- if -- if I dispute, let's
4 say, the concentration, then that dispute would also
5 fall upon the dependent claims. So I would not phrase
6 it quite the way you did, because, yes, I would dispute
7 those dependent claims where it comes to that particular
8 concentration and so on.

9 Q. Sure.

10 So you disputed the obviousness of the dependent
11 claims based on the two limitations that you've noted
12 are missing in Claim 10, correct?

13 A. Precisely.

14 Q. This might be a good time for a short break.

15 A. Okay. That sounds fine.

16 Now, do we stay on -- leave everything going
17 on and I can --

18 MR. PETERSON: Let's go off the record.

19 COURT REPORTER: Off the record at 10:18.

20 (Recess.)

21 THE COURT REPORTER: Back on the record
22 at 10:28.

1 BY MR. PETERSON:

2 Q. Okay. Welcome back, Dr. Carroll.

3 A. Thank you. And thank you for the break.

4 Q. No problem.

5 Other than getting a fresh cup of coffee, did
6 you review any materials or have any discussions
7 concerning this case during the break?

8 A. None. None whatsoever, no.

9 Q. I'm going to, for the record, drag the '315
10 Patent into the chat. I believe you already have it in
11 front of you --

12 A. I do.

13 Q. -- but it's Exhibit 1001.

14 Dr. Carroll, you understand that Exhibit 1001,
15 the '315 Patent, is the patent at issue in this case,
16 right?

17 A. Yes, I do.

18 Q. And we were just reviewing some of the
19 challenged claims, which are Numbers 10 through 16 and
20 Number 19, correct?

21 A. Yes, we just reviewed those.

22 Q. At a high level, can you describe what the '315

1 Patent is directed to?

2 A. At a high level I can. So the '315 Patent is a
3 patent that describes a very specific structure of solar
4 cell and the way to achieve that structure. That
5 structure has enhanced lifetime and enhanced passivation
6 for greater efficiency. So in this case, the lifetime
7 being governed, of course, by the functional lifetime of
8 the device and the efficiency being governed by the --
9 or the word "efficiency" meaning that the ability of the
10 device to produce power from -- from the solar spectrum.

11 In -- disclosed in it is a unique way of
12 creating the structures that do this. So in that sense,
13 while what's being patented here is a device, it
14 embodies in some way a process of making it, as well.

15 So that would be my summary, I guess, in a
16 nontechnical way, and it's not meant as a legal
17 statement, so -- because I'm not a lawyer.

18 Q. So looking at the -- at the claims of the '315
19 Patent and -- we can look at Claim Number 10.

20 A. Sure.

21 Q. It does not place any limitation on the
22 efficiency of the solar cell, correct?

1 A. This patent does not, no. The efficiencies
2 are -- are -- that -- of interest are held in the
3 figures, I think.

4 Q. And there's -- similarly, in Claim 10 there's no
5 requirement that the solar cell have a certain enhanced
6 lifetime, correct?

7 A. Yeah, that is correct -- well, there's no
8 requirement of a lifetime, of a specific lifetime.

9 Q. And Claim 10 also doesn't require a specific set
10 of steps to be taken in order to construct the claimed
11 solar cell, right?

12 A. Well, therein I would say that I would have to
13 disagree with you a little bit. It depends on exactly
14 what you mean here. But there are some parts in Claim
15 10 where it talks about having this thing facing the
16 sun, so on and so forth, but then you'll notice that it
17 talks about having the silicon substrate with a dopant
18 concentration of a certain amount; substrate meaning, of
19 course, the stuff that you began to build the solar cell
20 on. Then afterwards it says "a dielectric region formed
21 over such a substrate," which to my mind means that that
22 came secondarily. So you form something over something

1 when that first thing exists.

2 And so I would say that there is a set of steps
3 that are implied in 10.

4 Q. Other than an ordering of the -- a relative
5 ordering of the layers of the solar cell --

6 A. Over than that.

7 Q. -- there is not a specific set of manufacturing
8 processes that are required to take place in order to
9 form the solar cell recited in Claim 10, correct?

10 A. Recited in Claim 10, no, there's not a specific
11 set of manufacturing processes which are stated there.
12 They -- they may very well be implied, but they are not
13 stated.

14 Q. You haven't offered any opinions on claim
15 construction with respect to any of the challenged
16 claims, correct?

17 A. My understanding of what claim construction
18 means, then that is correct. But my understanding is a
19 novice's understanding of the legal term.

20 Q. And you understand that for purposes of your
21 opinions, you are assessing the '315 Patent from the
22 perspective of a person of ordinary skill in the art in

1 December 2014, correct?

2 A. Yes, that's absolutely correct.

3 Q. And you say that you had that -- at least that
4 knowledge -- level of knowledge -- sorry. Let me strike
5 that.

6 You say that you had at least that level of
7 knowledge and experience of a person of ordinary skill
8 in the art at that time period, correct?

9 A. I had at least the knowledge and experience
10 which is outlined in -- in this as the knowledge and
11 experience that you are requiring. Yes, I did.

12 Q. And that would have been based at least in part
13 on the work we describe -- we discussed before the
14 break, with your design and manufacture of various types
15 of silicon solar cells, correct?

16 A. In part, yes.

17 Q. If you'll look at the cover of the '315 Patent.

18 A. Yes, I will.

19 Q. Do you see at the top left, under Number 71, the
20 applicant is listed as SunPower Corporation?

21 A. Yes, I see that.

22 Q. And one of the inventors right underneath that,

1 at Number 72, is David D. Smith. Do you see that?

2 A. Yes.

3 Q. Do you recall that David Smith is also a named
4 inventor of the Li prior art reference?

5 A. Yes, I believe that he is. That's right.

6 Q. And I believe you point out in your declaration
7 that SunPower was also the assignee of the Li patent,
8 correct?

9 A. I do not see the assignee listed on the patent.

10 Q. Sure. Let me help you out. If you could take a
11 look at paragraph 53 of your declaration, Exhibit 2021.

12 A. Paragraph 53 of my declaration. Oh, paragraph
13 53 of my declaration.

14 Okay. Yes. So in this, I do state that Li is
15 -- the Li patent is issued -- is -- the assignee is
16 SunPower, which is -- I -- which is something I had
17 forgotten that I had known. But I would have known it
18 not from the Li patent itself, because it's not listed
19 there.

20 Q. Right.

21 I believe what you reference as Exhibit 20- --
22 2027 is the patent at issue from --

1 A. Yeah, yeah, yeah, you're right. You're right,
2 it is from 2027. Yes, you're right. Sorry.

3 Q. And so just so we're on the same page, the '315
4 Patent and Li both list SunPower as the assignee or
5 applicant, correct?

6 A. Yes.

7 Q. And David Smith is listed as an inventor on both
8 the '315 Patent and Li, correct?

9 A. Yes.

10 Q. Okay. Focusing again on the '315 Patent, do you
11 agree that Figure 5 of the '315 Patent depicts a
12 back-contact solar cell?

13 A. 315. And you want Figure 5?

14 Q. Yes.

15 A. Yes, it does. I see it, uh-huh.

16 Q. And a back-contact solar cell would fall within
17 the scope of the -- of Claim 10 of the '315 Patent,
18 right?

19 A. It would fall within the scope of Claim 10, yes.

20 Q. Please take a look at column 1 of the '315
21 Patent.

22 A. (Complying.) 315. On the first page?

1 Q. Column -- column 1 of the specification.

2 A. Column 1. Okay. I have it.

3 Q. Okay. And looking at the text in column 1 from
4 about lines 35 to 40, do you see that the '315 Patent
5 states that one of its goals was to reduce the cost of
6 manufacturing?

7 A. Yes. It says that it is -- the goal is more
8 precisely to reduce the cost of manufacturing and
9 increase the efficiency of the solar cell. So they
10 would want to do those things together.

11 Q. Sure.

12 And would you say that those were generally
13 recognized goals in the solar industry as of 2014?

14 A. Yes.

15 Q. And would you say that those have always been
16 goals in the solar industry, based on your experience?

17 A. Yes. Based on my experience, they would
18 certainly be goals.

19 Q. And I believe we -- we've talked about this
20 earlier, but one way in which you can reduce the cost of
21 solar cells is to use lower-quality silicon, correct?

22 A. Yes, generally speaking, uh-huh. However, that

1 does come with a caveat, because at some point the
2 quality of the silicon becomes low enough that you will
3 damage it by trying to get anything out of it, and so
4 you no longer lower the cost. So it's always a fine
5 balance as to what you can get away with.

6 Q. Are you familiar with the distinction between
7 multicrystalline silicon and single-crystal silicon?

8 A. Yes, of course.

9 Q. And based on your experience, is
10 multicrystalline silicon generally less expensive than
11 single-crystal or monocrystalline silicon?

12 A. Based on my experience, yes, it is, usually.

13 Q. And is the level of metallic impurities that
14 would be present in multicrystalline silicon generally
15 higher than you would see in a single-crystal silicon?

16 A. Now, say that one more time, please.

17 Q. Sure.

18 Is the level of metal impurities that you would
19 expect to see in multicrystalline silicon generally
20 higher than what you would expect to see in
21 single-crystal silicon?

22 A. Okay. Using the definitions that we just

1 discussed for the word "metal" impurities, then I would
2 say that there is no general statement that one can
3 make, because it depends on how the polycrystalline or
4 the multicrystalline has been grown. One can grow it
5 using MOCVD, PECVD, plasma -- plasma-coupled CVD.
6 There's -- there are many different ways to make it.

7 The industry has been shifting in many ways, and
8 so one of the shifts that one would want is to move away
9 from processes which introduce iron into the system. So
10 you can produce multicrystalline silicon with almost no
11 iron at all in it. And so that is a direction which
12 people are trying to reduce the costs of, and they have
13 been somewhat successful.

14 In 2014, it was already known that we could
15 produce very, very pure polycrystalline, or what you're
16 calling multicrystalline silicon, and in those very,
17 very pure systems, it is the lower performance -- the
18 thing that makes it cheaper is the fact that the
19 interfaces interrupt carrier lifetimes, not necessarily
20 the defects that are -- that come about due to the
21 metallic impurities.

22 And so I would say that it would be dangerous to

1 make a general statement about the concentrations of
2 metals in polycrystalline silicon because I know from my
3 own experience and from the work that we do here at this
4 laboratory even today, that you can make polycrystalline
5 silicon with concentrations of metals that are well
6 below detectability.

7 Q. And just so we're on the same page, when you
8 refer to polycrystalline, is that the same as
9 multicrystalline?

10 A. Yes. When I refer to it, yes.

11 Q. Okay. You don't dispute that as of 2014,
12 multicrystalline silicon was used in the majority of
13 silicon solar cells, right?

14 A. It was very popular, yes. I can't say about the
15 majority because I don't know what the market was
16 exactly in 2014. There was an inflection because of the
17 advent of the epi cut silicon. So epi cut was very --
18 becoming very popular at that time. It saved silicon.
19 It was more expensive, but it lasted longer.

20 So I am not sure when the alpha silicon
21 hydroxide -- hydroxyls went out, but somewhere in there
22 would have been the inflection point.

1 Q. Metal impurities were known to be a cause of
2 recombination in silicon semiconductors, right, in 2014?

3 A. Oh, absolutely. Sure.

4 Q. And recombination is one factor that will
5 decrease the efficiency of a solar cell, correct?

6 A. That's right. The technical term that we use in
7 science is "bad."

8 Q. And by 2014, gettering was a known way to remove
9 metal impurities from silicon semiconductors, right?

10 A. Yes. Thermal gettering, uh-huh.

11 Q. The '315 Patent does not purport to have
12 invented gettering, correct?

13 A. Yes, that's correct. It doesn't -- it doesn't
14 say that it invented gettering.

15 Q. The phenomenon that metal impurities can be
16 removed from silicon substrate by heating the substrate
17 was known before the '315 Patent, right?

18 A. Yes. At that point it certainly was.

19 Q. Earlier today we were discussing the concept of
20 an emitter region. Do you recall that?

21 A. Yes, I do.

22 Q. Can you tell us what -- in the context of the

1 '315 Patent, what is an emitter region?

2 A. In the context of the '315 Patent, that -- let
3 me say that, generally speaking, when you talk about
4 something that is an emitter, right, you're talking
5 about a source of some sort of a charge, normally.

6 Now, in these particular cases for solar cells,
7 these solar cells are picking up charge, right. So this
8 is -- when you say something is the source of a charge,
9 what you mean, of course, is the compensation charge.
10 In the case of an emitter region, however, it isn't the
11 contact -- the emitter contact that you're actually
12 talking about. What you're talking about is a piece of
13 material which has been heavily doped so that it makes
14 the potential barriers for that charge to go from the
15 bulk into the contact region smoother, and therefore you
16 no longer have reflections to the motion of that charge
17 one way or the other. Emitter regions have to bridge
18 the gap between the metal that the charge will end up in
19 and the silicon in which the charge was created.

20 So we refer to emitter regions, then,
21 specifically as the region of that bridge. They're
22 usually hundreds of nanometers thick of some sort, and

1 they might involve either direct dopant -- that is, a
2 dopant concentration which is constant across them -- or
3 they may involve a dopant concentration which changes --
4 that is, is a gradient as it enters the lower
5 concentration of the silicon itself. That's what an
6 emitter region does.

7 Q. And I think you mentioned in your answer that an
8 emitter region is usually heavily doped, right?

9 A. Generally speaking, you want to make it as
10 heavily doped as you can get away with, without changing
11 the overall band structure of the material. So when we
12 say "heavily doped," there is a limit to what you may
13 do, because if you turn it into another compound, then
14 you've defeated its purpose.

15 Q. Do you have a -- an approximation of what
16 concentration would typically be used to form an emitter
17 region? And let me just -- let me strike that and then
18 restart it.

19 Do you have an idea of the approximate
20 concentration that would typically be used to form the
21 emitter region, in terms of the dopant concentration?

22 A. So the answer is, no, I don't. The reason for

1 that is that the emitter region also has to be balanced
2 with the overall architecture of the device that you're
3 using. If you're using a front-surface field which has
4 concentrations of 10 to the 18 or so, that implies a
5 very specific field strength at the front of that
6 system. You need to make sure and balance -- to some
7 degree balance what that field strength is in the
8 emitter. So the emitter region needs to be of the order
9 of 10 to the 18 or so in that case.

10 So the device must be balanced, and so that
11 means that the emitter region itself needs to be as
12 highly doped as you can make it, but it also has to
13 respect whatever the balance of the dopant is elsewhere
14 in the device.

15 Q. Prior to 2014, had you personally experienced or
16 seen publications concerning the use of doped
17 polysilicon as an emitter for a solar cell?

18 A. I've seen those publications, but I cannot
19 recall if they were precisely prior to 2014. In that
20 time period, I would say that I believe that there are
21 publications to that effect, but publications come out,
22 and when you talk about a publication, they can be

1 reviewed for a year or two. So was it 2014 or was it
2 2012, you know, or did it get submitted in 2014 and
3 actually get published in 2015; that level of parsing, I
4 don't recall.

5 Q. I believe you mentioned earlier that in the
6 2000 -- in the 1980s there may have been concerns about
7 gettering metal impurities out of the silicon substrate
8 because they may cause damage to the silicon substrate.
9 Did I get that right?

10 A. They may cause damage to the structure, right.
11 So in this case, not just the silicon substrate, but it
12 would have been damage to the interface between that and
13 the native oxide that would sit on it.

14 Q. Were there any other perceived disadvantages to
15 undertaking a thermal gettering process to remove metal
16 impurities from the silicon substrate?

17 A. Yes, there were. The difficulty that most
18 people were concerned about was the morphology of the
19 oxide layer itself. So you have to provide enough
20 energy -- that is, at a high enough temperature -- to
21 remove the material that you're trying to getter. As
22 you do that, you are also subjecting the -- the silicon

1 to -- or the silicon dioxide to that temperature. The
2 silicon dioxide is kind of like tofu; it moves around a
3 lot. It does not necessarily take upon itself one
4 morphology and keep it; as I heat it, it will change.
5 It will form pinholes. It would do all sorts of things.
6 So imagine that that material is very mobile.

7 And so the concern is that as I begin to heat
8 this thing up to remove the gettered material, that I
9 might change the silicon dioxide in a way that makes it
10 useful to me. Now, the answer to that would be, okay,
11 well, then do it in oxygen. That way you never reduce
12 the silicon dioxide. Then what you do is drive deeper
13 and deeper and deeper oxidation, locking up the iron or
14 whatever it is you're gettering, into the oxide layer,
15 where it's permanently going to reside. Because
16 essentially you're creating -- in the case of iron,
17 you're creating rust.

18 So those were the concerns that we had at the
19 time. And I might add that those concerns carried over
20 into the 2000s, even after we began using the processes
21 that -- like PECVD to create denser films. It was still
22 a concern, because if I process it in oxygen or if I

1 process it in a vacuum, I have -- I have problems.

2 Q. As of the early 2010s, there was literature
3 reporting that metal impurities can be gettered from
4 silicon substrates simultaneously with, for example,
5 phosphorus diffusion processes, correct?

6 A. There were. However, let me say that, if I am
7 understanding which one of the references you're talking
8 about -- because there were multiple references that did
9 this -- in almost all of them they showed that the
10 gettering process could also lead to an interaction of
11 the metal with the dopant. And that -- that was a big
12 problem, because that -- that particular species, the
13 ionic species, sits in the band gap of the silicon. So
14 that's a -- that's a trouble.

15 So -- so the question then becomes, is -- even
16 though you can getter at the same time, is there any way
17 that you could find to prevent this other process from
18 happening. And so both things were reported in the
19 literature that I'm aware of.

20 Q. Before 2014 there were also reports of using
21 undoped polysilicon to getter metal impurities from a
22 silicon substrate, correct?

1 A. Yes.

2 Q. Is it consistent with your understanding that
3 doping of the polysilicon would increase the amount of
4 gettering that would be achieved relative to the use of
5 undoped polysilicon?

6 A. So you're asking me whether or not the gettering
7 would be more efficient or faster if you used doped
8 material versus undoped material.

9 Q. Correct.

10 A. Right. And according to Fick's law, it would
11 not make any difference. It's a concentration-dependent
12 process. So it is the concentration of the thing that
13 you are gettering on either side of the regions -- into
14 the regions that you wish to getter it that matters. So
15 what I have to have is a large concentration of the bad
16 stuff on one side and no bad stuff on the other side, to
17 make it go fast. If there's a little bit of bad stuff
18 on the other side, it goes slowly. If there's the same
19 amount of bad stuff on both sides, then it doesn't go at
20 all.

21 Q. Do you agree that gettering is a function of
22 time and temperature?

1 A. So as you've defined gettering, the removal of
2 it, then time and temperature are tied together. It
3 goes faster as the temperature is higher. Both of them
4 are aspects of gettering. So, yes, gettering depends on
5 them in that sense.

6 Q. So all else being equal, a higher temperature
7 equates to more gettering than a lower temperature,
8 right?

9 A. If one can say all else being equal, then yes.
10 But -- but not all else is always equal. So just take
11 that context to heart. That's really important.

12 Q. Sure.

13 And all else being equal, heating for a longer
14 time will result in more gettering than heating for a
15 shorter time, correct?

16 A. So -- so that's an interesting -- that is an
17 interesting question, actually, because the -- as the
18 two concentrations approach one another in size, the
19 gettering slows down. As it slows down, it does so
20 exponentially. There is a point at which even though
21 you might say theoretically there's a gettering process
22 going on, there is no way to prove it because it is well

1 below the limits of detectability of any modern
2 instrument.

3 Q. So there may come a point in time at which
4 increasing the time doesn't result in more gettering
5 because the concentrations have equalized, for example?

6 A. Precisely. You understand, uh-huh.

7 Q. As of 2014, would a person of ordinary skill in
8 the art have known that gettering is a general function
9 of time and temperature?

10 A. As of 2014, they would have known this about
11 gettering, yes.

12 Q. So if that person needed to increase the amount
13 of gettering of metal impurities from a silicon
14 substrate, he or she would know that she could increase
15 the time or the temperature of the heating process,
16 right?

17 A. Purely for the process of gettering, yes.
18 That's not taking into account the other things that you
19 might be doing for the longer time.

20 Q. I want to take a look at Exhibit 1025, which is
21 a publication by Ramappa. It should be in your printed
22 materials. I'm also dropping it in the chat.

1 A. Let me see 10- -- 1025. Okay. I have -- I have
2 Ramappa in my hand.

3 Q. Ramappa is one of the references you discuss in
4 your declaration related to gettering of iron through
5 silicon oxide, correct?

6 A. Yes, it is.

7 Q. And Ramappa shows that some metal impurities
8 pass through a 120-nanometer-thick silicon oxide layer,
9 even despite some pileup at the interface between the
10 silicon oxide and the substrate, correct?

11 A. Okay. Please say that one more time --

12 Q. Sure. So I'm --

13 A. -- so that I can really understand your
14 question.

15 Q. Sure. So I am looking at Figure 5 of Ramappa,
16 which is on page 3776. And I just want to see if you
17 agree that Ramappa shows that some level of metal
18 impurities, specifically iron, pass through a
19 120-nanometer-thick silicon oxide layer even despite
20 pileup at the interface between the silicon substrate
21 and the silicon oxide.

22 A. So I would say that taken on face value, this

1 graph is intended to show you that some level of iron
2 does make it through the silicon dioxide layer. The
3 caution that I would give you is that the lines are
4 theoretical. The silicon -- the numbers that are being
5 used for the -- the squared or the crosses, the round
6 dots and the squares, those numbers are coming from two
7 distinct measurements, and those -- the measurements
8 that are most important that you notice is DLTS. DLTS
9 is also sensitive to other things that are in the
10 material, including defects, which silicon does have.

11 I say that because the iron concentration here
12 is 10 to the 11, which is extraordinarily difficult to
13 measure, and in 1999 very difficult to measure. We can
14 do it now using really, really high-resolution
15 techniques, but to my -- to my knowledge, in 1999 we
16 would have had trouble making the statement that this
17 was absolutely a concentration of iron.

18 However, it is intended to show you that. That
19 is what Ramappa is claiming it is.

20 Q. Now, focusing on Figure 5 --

21 A. Uh-huh.

22 Q. -- the left portion of this graph, where it says

1 "SiO₂," that's the silicon oxide, right?

2 A. Yes.

3 Q. And that -- at the very bottom, the 100 --
4 sorry, 1200 angstroms, that's 120 nanometers, correct?

5 A. 120 nanometers, that's correct.

6 Q. That's the thickness of the oxide layer, right?

7 A. That's correct, uh-huh.

8 Q. And then the part on the right of Figure 5,
9 where it says "Si," that's the silicon substrate,
10 correct?

11 A. Yes, that's the silicon substrate.

12 Q. And the line between them, that would be the
13 interface between the silicon oxide and the silicon
14 substrate, correct?

15 A. That is right. That is supposed to be the
16 interface.

17 Q. Okay. And a 120-nanometer-thick silicon oxide
18 is approximately 100 times thicker than the silicon
19 oxide that is disclosed in Li, correct?

20 A. I think it's approximately, yes.

21 Q. Li discloses a 1-to-2-nanometer-thick silicon
22 oxide, correct?

1 A. 1 to 2 -- yeah.

2 Q. So somewhere between, you know, 50 and 100 times
3 thicker, correct?

4 A. Uh-huh. Uh-huh.

5 Q. Is it your understanding that the silicon
6 substrate that was utilized in Ramappa's experiment was
7 an undoped substrate?

8 A. Let me remind myself, but I believe that's
9 correct. So my understanding is that, yes, it was
10 initially undoped.

11 Q. Ramappa doesn't report any results reporting
12 what the pileup effect at the oxide interface would have
13 been if the substrate had been doped, does it?

14 A. This -- this reference does not, no.

15 Q. Now, in your declaration, in paragraph 60 you
16 used Ramappa to show the effect of pileup at silicon
17 oxide interfaces. Do you recall that?

18 A. Yes.

19 Q. And the calculation that you walk through in
20 paragraph 60, that's a hypothetical calculation using
21 Ramappa, right?

22 A. Yes.

1 Q. You didn't conduct an actual experiment to
2 confirm that this level of pileup at the oxide
3 interfaces would be observed in a solar cell that's
4 described in Li, right?

5 A. I did not, no.

6 Q. Okay. And you can -- you know that you didn't
7 do an actual experiment, because paragraph 60
8 necessarily has some assumptions that you had to make,
9 including the beginning impurity concentration in the
10 substrate, right?

11 A. That's correct.

12 Q. And under the assumptions that you articulate in
13 paragraph 60, you calculate that a small number of iron
14 impurity atoms would gather through the silicon oxide
15 and into the polysilicon, correct?

16 A. Yes, that's correct.

17 Q. At the bottom of page 33 in paragraph 60 --

18 A. Oh.

19 Q. -- you said that the amount that would getter
20 through the silicon oxide interfaces would be, quote,
21 "less than the concentration that can be detected by any
22 reasonable detection means."

1 Do you see that?

2 A. Yes.

3 Q. And when you were referring to "reasonable
4 detection means," what did you mean by that?

5 A. Well, there are means that you can use that we
6 would have available to us in most laboratories like
7 mine, which tend to be nondestructive. They are
8 electron-dispersive spectroscopy, X-ray, photoelectron
9 spectroscopy and so forth. There are a number of them.
10 Those have detection limits which are significantly
11 larger than what you would need for this. And so that's
12 one thing.

13 However, there are some destructive means where
14 you essentially take the system, evaporate the whole
15 thing, and then look at the gas, right. In those cases
16 you can detect slightly lower levels. And today we are
17 at a point where we would be able to see levels this
18 small. However, at the time of Ramappa, you would not
19 have been able to do that. Those -- those techniques
20 had not been refined to that point.

21 Q. How about in 2014?

22 A. In 2014 I don't think that they were

1 commercially available, but some laboratories were doing
2 them, including one here at Wake Forest.

3 Q. So you're not saying that the level of irons --
4 the iron that you report in paragraph 60 would be
5 completely undetectable using any means, just using
6 commercially available means that wouldn't destroy the
7 solar cell, they would be difficult to detect, right?

8 A. They would have been extraordinarily difficult
9 to detect, yes.

10 You have to understand, when we talk about
11 something that is that difficult to detect, we give you
12 a sigma number so that we can tell you the confidence of
13 detectability. In these cases, you would be within one
14 or two sigma of -- of the -- of certainty that you had
15 detected it. The standard for the field is six sigma.
16 So that's how far away you would still be even using the
17 best detectability at your disposal in 2014.

18 Q. And you are not providing an opinion in your
19 declaration that no metal impurities whatsoever would
20 getter through these 1-to-2-nanometer silicon oxide
21 layer and into the polysilicon layer, correct?

22 A. No, I am not.

1 Q. Okay. Let's look at -- sorry. In fact, you
2 recognize that some small amount of iron -- iron
3 impurities would get through that silicon oxide
4 layer, correct?

5 A. I'm saying that it is likely.

6 Q. Let's look at Liu 1 and Liu 2, which are
7 Exhibits 1028 and 1029. I'll drop them in the chat, but
8 they should be in your printed materials.

9 A. Liu. And you want -- you said -- okay. So it's
10 the two Liu references that you gave me, then?

11 Q. That's correct, Exhibits 1028 and 1029.

12 A. Yes, that's right. I see it. I have them, yes.

13 Q. Thank you.

14 I'd like to start with Liu 1, which is
15 Exhibit 1028.

16 A. Yes.

17 Q. And it states on page 2275 that -- and I'm
18 looking at the second paragraph -- "A doped
19 polycrystalline silicon film with a thin silicon oxide
20 interlayer is one of the most common and effective
21 approaches to fabricating passivating contacts in
22 silicon solar cells," right?

1 A. Right.

2 Q. And then in the next column -- I'm looking at
3 the last paragraph -- it says, "It is recently reported
4 that certain types of polysilicon passivating contacts
5 can achieve effective impurity gettering during contact
6 formation while maintaining their excellent passivating
7 contact quality."

8 Do you see that?

9 A. I see it, yes.

10 Q. Do you agree with those statements?

11 A. Well, that's an open-ended question. Do I agree
12 with those statements?

13 The first thing -- the first statement, "a
14 dopant polysilicon film with thin film oxide interlayer
15 is the most common and effective approach to
16 fabricating" -- that statement, I would agree with when
17 it comes to the manufacture of solar cells. So it was
18 used in 2018 when this was done. And, yes, I do agree
19 with that.

20 The second thing is a -- "recently reported that
21 certain types of polysilicon passivating contacts can
22 achieve effective impurity gettering." Okay. So I

1 would say, first of all, that the sentence structure
2 here is wrong. The polysilicon passivating -- they do
3 not achieve impurity gettering. Gettering is achieved
4 through a gradient of temperature and a gradient of
5 concentration, so that is what the causal effect is, not
6 the fact that it's polycrystalline or what have you.
7 And this is stating that this can go through thin
8 passivating films.

9 And the -- -- the whether or not that is true
10 depends very strongly on reference 8 and 9. I would say
11 that it had been reported at that time that people had
12 achieved some gettering through these -- through this
13 region, and I would say that the -- the hyperbole of
14 being -- it being effective and maintaining excellent
15 passivating contact quality is subjective. The reason
16 is, if you look at 8 and 9, you will see that the -- the
17 passivating contact quality depends very much on whether
18 or not you have left any of the metals in those oxides
19 or whether or not you have been effective in removing
20 them. That depends very much on how you grew the oxide.

21 So I would give this a qualified "I agree," but
22 only a qualified one, because it has not taken into

1 account half of the publications that they themselves
2 cite.

3 Q. Looking at Figure 1, which is on page 2276 of
4 Exhibit 1028.

5 A. Oh, yes, uh-huh.

6 Q. This shows the -- a flowchart of the
7 experimental procedures that were used by Liu in Liu 1,
8 correct?

9 A. So you're claiming that the Figure 1 is what the
10 process of Liu and not Liu?

11 Q. Sorry. No, no. I am referring -- sorry. Let
12 me just level set here.

13 A. Sure.

14 Q. I'm just trying to understand if it's your
15 understanding that Figure 1 depicts the experimental
16 procedures in constructing the solar cell that are
17 described in the rest of this reference.

18 A. Ah, yes. It describes what was done in this
19 paper, yes.

20 Q. Yes.

21 Okay. And you can see here that in the top
22 portion, it is described that Liu 1 utilized silicon

1 substrates with a bulk contamination of iron of 10 to
2 the 14 per cubic -- per cubic centimeter, right?

3 A. That's exactly right, yes.

4 Q. And then it appears that it formed either a
5 phosphorus-doped or boron-doped polysilicon region on
6 that substrate, with a silicon oxide layer in between,
7 correct?

8 A. Yes, that's right.

9 Q. And Liu 1 in the second column on this page
10 reports that the oxide thickness was around 1.3 to
11 1.4 nanometers?

12 A. 1.3 to 1.4, that's right.

13 Q. So that thinness range of 1.3 to 1.4 nanometers
14 is within the range described in the Li patent, which is
15 Exhibit 1005, right?

16 A. The Li patent, yes, that's right. That's what
17 he claims that his oxides need to be, yes.

18 Q. To your understanding, would a
19 1.3-to-1.4-nanometer silicon oxide be considered a
20 tunnel oxide?

21 A. So that's a -- that's a -- needs context, as
22 well. I'm sorry. I apologize for being so careful, but

1 the language is really important. A tunnel oxide in the
2 context of a -- tunneling transistors and tunneling
3 devices, then yes. That oxide is the thickness which is
4 typically used and referred to as the tunnel oxide, yes.

5 Q. And then I'd like to look at Figure 2, which is
6 on the next page, page 2277.

7 A. Uh-huh.

8 Q. And this appears to be showing a microscopic
9 depiction of the stacking of the layers that we just
10 discussed, with a layer constituting the silicon, a
11 polysilicon layer, and then a silicon oxide layer in
12 between, right?

13 A. Yes, that's correct.

14 Q. And based on the positioning of that silicon
15 oxide interlayer, there would be two interfaces between
16 the polysilicon and the silicon substrate, right? There
17 would be an interface between the oxide and the
18 substrate and then an interface between the oxide and
19 the polysilicon, right?

20 A. Yes.

21 Q. So any metal impurities that pass through the
22 silicon substrate and into the polysilicon in Liu 1

1 would need to go through both of those interfaces,
2 correct?

3 A. Yes, if it makes it all the way -- I'm sorry,
4 say -- say the starting and the ending positions again.
5 Say that again.

6 Q. Yeah. So to the extent that Liu 1 reports
7 gettering of iron from the silicon substrate and into
8 the polysilicon, that iron would have to pass through
9 both interfaces?

10 A. Yes, that's correct. Yes, of course. Assuming
11 that those interfaces remain contiguous.

12 Q. Okay. Now I'd like to look at Figure 4, which
13 is on the next page, 2278.

14 A. Ah, yes.

15 Q. Okay. Now, in Figure 4, the line that appears
16 between the region on the right that says "Si substrate"
17 and the region in the middle that says "Poly-Si," that
18 would be where the silicon oxide is located, right?

19 A. That's correct. There is a silicon oxide there.
20 There is also a silicon oxide on top of the poly-si,
21 most likely.

22 Q. And this graph, Figure 4, shows that iron passed

1 through the silicon substrate, through the silicon oxide
2 and both of its interfaces, and into the polysilicon for
3 the phosphorus-doped polysilicon, right?

4 A. So you want to say that this is showing the iron
5 concentration going from -- okay. So you -- you're
6 looking at the red line; is that correct?

7 Q. That is correct.

8 A. Okay. And that red line, the iron is starting
9 at, you're claiming, the PSG layer, going through the
10 polysilicon and into the silicon; is that correct? Is
11 that what you're saying?

12 Q. No. No. The opposite.

13 So I'm saying -- there's a line that says "Fe"
14 and it points to the left. Do you see that?

15 A. The line that says "Fe," right, and they want
16 you to use the left -- the left axis. That's correct.

17 Q. Right.

18 And so Figure 4 shows that iron passes from the
19 silicon substrate, through the oxide and both of its
20 interfaces, and into the polysilicon, correct?

21 A. Uh-huh, yes, sort of. So let me qualify that a
22 little bit. Again, this -- you know, the data that

1 you're -- that this graph is showing is showing a noise
2 level at 10 to the 16, and that noise level is exactly
3 the same as the noise level where it says "no iron." So
4 does the red line show iron in the silicon substrate or
5 does it show no iron in the silicon substrate?

6 Now, I will note that this group is from
7 Australia, the university there at Australia, Australia
8 National University is known to have one of the finest
9 Rutherford backscattering groups in the world. So they
10 are very, very good at getting this kind of data. What
11 I would say is that in this particular case, this is
12 meant to show you that the iron makes it from across
13 the -- those interfaces into the silicon substrate. But
14 if you notice, the graph shows you no difference between
15 the no iron control and the one where they have
16 contaminated it on -- contaminated it on purpose with
17 iron.

18 Q. So I want to make sure I understand. I believe
19 you said that this graph shows that iron passes into the
20 substrate, but I think we established earlier that
21 they -- that Liu 1 started with an iron concentration of
22 10 to the 14 in the substrate, correct?

1 A. That's what they claim.

2 Q. Right.

3 And so this graph shows that the iron that
4 started in the silicon substrate passed through the
5 interfaces with the silicon oxide and into the
6 polysilicon, correct?

7 A. Right. And so that's what I'm saying, is you've
8 got one in which case there is no iron control. So
9 presumably they did not add iron chloride and tried a
10 dopant and get iron in there.

11 So when they say that they had 10 to the 14,
12 they must've estimated that. It has to -- it had to
13 have been, because they certainly didn't measure it.
14 This shows clearly there is no difference between the
15 one that they did nothing to and the one that they did
16 something to. And then you have an increase in iron
17 that occurs in the polysilicon. One would presume that
18 that iron somehow came from the silicon. But there is
19 no corresponding change in the silicon line on the side
20 of the silicon substrate. If the iron in that part
21 where it says "iron contaminated" in the polysilicon
22 came from the silicon substrate, then it would have to

1 be -- there would have to be some measured decrease in
2 the total iron that occurred in the silicon substrate,
3 and there was none.

4 Moreover, this is 10 to the 17 orders of
5 magnitude larger than they are claiming they put into
6 the silicon substrate. In that case, I would ask, where
7 did that iron come from? Because you claimed in this
8 experiment that you only put 10 to the 14th in there.
9 How did you get to 10 to the 17th?

10 Q. So the amount of iron that's reported in the
11 polysilicon is well above the control -- the level
12 reported for the control, correct?

13 A. Exactly. That's my problem.

14 Q. And Liu 1 reports that the amount of -- it also
15 reports the amount of phosphorus that has diffused from
16 the PSG and into the polysilicon and even shows some
17 made it into the silicon substrate, right?

18 A. Right. But phosphorus does move fast, so that
19 wouldn't --

20 Q. Right.

21 And so doesn't the higher concentration of iron
22 in the polysilicon than is reported in the silicon

1 substrate indicate that the iron initially present in
2 the substrate is now present at a higher magnitude in
3 the polysilicon after phosphorus diffusion?

4 A. So I think that's -- I think that's where --
5 where we differ. Because that's what -- that's what
6 this graph wants you to say. That is what they're
7 contention -- contending. And I would say, well, it's a
8 reasonable contention somehow. However, there is a
9 major problem, right, with the graph. And that's what
10 I'm latching onto, right. This is just purely
11 skepticism, but when I look at this and I say, well, the
12 iron that exists in polysilicon must have come from
13 silicon substrate, that that is a causal thing, then I
14 have to have had enough in the silicon substrate for
15 that to have occurred, for me to have gotten that
16 concentration of iron in the polysilicon.

17 That -- the concentration in the polysilicon is
18 enormous compared to what is in the silicon substrate.
19 It doesn't -- it doesn't get to pack up everything in
20 the silicon substrate and move it there. It's going to
21 move the iron that is close to the interface, and that
22 is at 10 to the 14 . You ended up with 10 to the 17

1 concentration, and the only way that could have happened
2 was, in this experiment you had to have had
3 contamination somewhere else.

4 So it is -- I will concede it is intended to
5 suggest that, but I would say anyone skilled in the art
6 would have said -- when they read this, they would have
7 immediately said you had iron come from someplace else,
8 and I don't know where.

9 Q. You said that you were familiar with Australian
10 National University, right?

11 A. Oh, yes, yes. They are very good.

12 Q. And you said it's well respected, right?

13 A. Oh, very much so, yes. And so, yes, you should
14 take this graph seriously. That doesn't mean that they
15 can't make a mistake.

16 Q. Let's take a look at Figure 7, which is on page
17 2279.

18 A. Sure. Yes.

19 Q. Okay. And, now, this is a -- this graph is
20 quite similar to what was reported in Figure 4, but this
21 time what's being reported is for the boron-diffused
22 polysilicon contact, correct?

1 A. That's correct.

2 Q. And would you agree with me that what is
3 intended here, what the authors are intending to show,
4 is that iron gettered from the silicon substrate through
5 the poly- -- the silicon oxide interface and into the
6 polysilicon?

7 A. Yes. That is what's intended, yes.

8 Q. Now if you could take a look at Figure 8. It is
9 on page 2280.

10 Are you there, Doctor?

11 A. I am. I'm sorry. Yes.

12 Q. And this is reporting in these bars, in gray the
13 initial iron concentration, in blue the iron
14 concentration of the silicon substrate after forming a
15 boron-diffused polysilicon contact, and then in red
16 after post-diffusion oxidation, correct?

17 A. That's correct.

18 Q. And comparing the gray bar and the blue bar --

19 A. Yes.

20 Q. -- this shows that after forming the
21 boron-diffused polysilicon contact, the amount of iron
22 remaining in the silicon substrate was less than

1 approximately 0.1 percent, correct?

2 A. Just a moment.

3 Okay. And you're claiming -- you're claiming
4 that you -- that it says what?

5 Q. So the gray bar in every one of these examples
6 is reported at 100 percent. That's what the -- the
7 column on the right says, right?

8 A. That's correct.

9 Q. So that's 100 percent of the iron that's
10 initially present in the silicon substrate, right?

11 A. Right.

12 Q. And then the blue bar shows that after forming a
13 boron-diffused polysilicon contact, approximately
14 0.1 percent or less of that iron that was initially in
15 the silicon substrate is remaining, right?

16 A. Approximately 0.1 is remaining.

17 Q. And so that means -- that implies that
18 approximately 99.9 percent of the iron initially present
19 in the silicon substrate is no longer in the silicon
20 substrate, correct?

21 A. Yes, sort of. So let me qualify my answer. It
22 says that for the volume of the substrate which is

1 accessible to SIMS, the techniques that they use. So
2 the techniques that they use are techniques which are
3 very specific. They send in -- either they use
4 secondary ion mass spectroscopy or Rutherford
5 backscattering. Both of those have penetration links
6 that are less than 100 nanometers.

7 And so when you do that and you then say, how
8 much of that boron is left in there -- or I'm sorry,
9 that iron is left in there, then, yes, then you are
10 right. But as I say, that would be what we would call
11 the self edge of the system, right; that is, the part of
12 the surface which is nearest to the surface, and that,
13 we would expect to give you some amount of iron
14 elsewhere, perhaps in the silicon substrate or at --
15 right immediately at the substrate, at the interface.

16 However -- however, it is only for that much of
17 the substrate that this counts. It does not mean
18 everything that was in there.

19 Q. Okay. So at least for the portion of the
20 substrate that the authors of Liu were able -- Liu 1
21 were able to measure, they are reporting that
22 99.9 percent of the iron initially present in that area

1 has been removed through formation of the boron-diffused
2 polysilicon contact?

3 A. That -- that seems to be what it says. And I
4 say "seems to be" because, do remember that they grew
5 the polysilicon onto the substrate using PECVD, which is
6 a reactive and high-temperature process which most
7 likely changed the concentrations at the substrate, at
8 the surface anyway. So -- so, yes, I would say under
9 that caveat, then you are correct.

10 Q. Now let's take a look at Liu 2, which is
11 Exhibit 1029.

12 A. Okay, excellent. Liu 2, "Effective Impurity
13 Gettering by Phosphor" -- "Phosphorous- and
14 Boron-Diffused Silicon." I have that now.

15 Q. Thank you.

16 Now, do you agree that -- looking at Figure 1,
17 which is on page 137, do you agree that Liu 2 uses the
18 same basic structure of the solar cell as Liu 1?

19 A. As Liu 1, yes.

20 Q. Yeah.

21 And looking at Figure 1, it appears that the
22 basic structure that's utilized Liu 2 is a sample either

1 with or without iron impurities, and then a
2 1.3-nanometer oxide layer, and then on top of that
3 formed either a boron- or a phosphorous-diffused
4 polysilicon emitter, right?

5 A. Yes, 1.3 or 4.

6 Q. Yes. And then --

7 A. And then it forms a --

8 Q. And so the basic structure is substrate and then
9 a oxide layer that is either 1.3 nanometers or
10 4 nanometers thick, and then either a boron- or
11 phosphorous-diffused polysilicon emitter, right?

12 A. Exactly. Or nitrogen. There is one in which
13 you have nitrogen anneals. But, yes, exactly.

14 Q. So starting on the first page of Liu 2, which is
15 page 136, do you see the last sentence of the first
16 paragraph is, "Nevertheless, industrial silicon wafers
17 have varying levels of purity and crystallinity and they
18 are subjected to different environments in terms of
19 contamination control"?

20 A. Yes. That is very true.

21 Q. And then it says, "Impurities such as transition
22 metals are commonly found in silicon wafers for solar

1 cells, creating recombination centers in the silicon
2 wafer bulk and therefore lowering device efficiencies."
3 Right?

4 A. Yes, it does say that.

5 Q. And then at the top of the next column, Liu 2
6 says, "Phosphorus diffusions are commonly used to
7 achieve effective impurity gettering and silicon solar
8 cell fabrication," right?

9 A. It does say that, yes.

10 Q. Now let's take a look at Figure 3, which is on
11 page 139.

12 A. (Complying.)

13 Q. And I want to start by looking at the -- the
14 text that is below the figure. And in the last sentence
15 it says, "All samples have an initial bulk iron
16 concentration of 10 to the 13th per cubic centimeter."

17 Do you see that?

18 A. Yes.

19 Q. And then what's reported in the bar graphs,
20 among other things, are experiments that were conducted
21 with different types of intervening oxide layers of
22 thickness either 0, so no -- no oxide, 1.3 nanometers or

1 4 nanometers, right?

2 A. That's correct.

3 Q. And Liu 2 also tests oxides that were either
4 grown thermally or grown chemically, right?

5 A. That's correct.

6 Q. And it compares a 1.3-nanometer chemical oxide
7 to a 1.3-nanometer thermal oxide, at least for the
8 phosphorous-diffused emitter, right?

9 A. That's correct.

10 Q. And looking at the -- I want to the focus on the
11 bar charts that are on the left, which I believe all
12 represent the phosphorous diffusion or the nitrogen
13 anneal that you mentioned.

14 A. Uh-huh.

15 Q. Okay. And for those experiments, Liu reports
16 three temperatures that were used: 780 degrees celsius,
17 which is in red; 820 degrees celsius, which is in blue;
18 and 890 degrees celsius, which is in green, right?

19 A. That's correct.

20 Q. And then for the boron diffusion, the
21 temperatures are a little bit different, with the blue
22 representing 930 degrees celsius, right?

1 A. That's correct.

2 Q. And in both charts, the scale on the right side
3 reports the percentage of the initially present
4 silicon -- iron -- sorry, let me -- let me strike that.

5 On the right side of both sets of bar charts,
6 the right axis reports the percentage of iron initially
7 present in the silicon substrate that is remaining after
8 the heating process, correct?

9 A. Remaining after the heating process, yes.

10 Q. And the reason that these percentages don't go
11 up from, say, 0 to 10 to 20 to 30 percent is that the
12 scale is logarithmic, right?

13 A. Yes.

14 Q. So I want to focus on the second set of bars in
15 the phosphorus diffusion chart. And just so we're all
16 on the same page, the text underneath the bar says
17 "Poly-Si/SiOx 1.3 nanometer chem N2."

18 Do you see that?

19 A. That's right.

20 Q. Okay. And is it your understanding that that
21 experiment is reporting a -- the -- the -- the iron
22 gettering that was observed with a 1.3-nanometer-thick

1 chemical oxide and a polysilicon layer that was undoped?

2 A. Yes.

3 Q. Okay.

4 A. I think that's right, that's undoped -- yes,
5 that's undoped. I think that's right, uh-huh.

6 Q. And for that experiment, looking at the -- all
7 three temperatures that were tested, Liu 2 reports that
8 less than 100 percent of the initially present iron in
9 the substrate is remaining after the heating process,"
10 right?

11 A. Yeah. Less than 100 percent, that's correct.

12 Q. It's somewhere between 10 percent and
13 100 percent, but it's a little difficult to tell because
14 of the logarithmic scale, right?

15 A. Yeah, that's right.

16 Q. I don't know if you're more experienced at
17 reading these logarithmic scales than I am, but can you
18 tell approximately where that green bar is in terms of
19 percentage?

20 A. I -- I cannot because it's -- the -- it's really
21 light on my printout here, so not -- not quite. But
22 it's less than 100 percent, sure.

1 Q. Okay. Now I want -- now I want to look at the
2 set of bars that is second and third from the right in
3 the portion of the -- the bar chart that discusses the
4 phosphorous -- phosphorous diffusion.

5 A. Yes.

6 Q. So just for clarity, the two that I want to look
7 at are "Poly-Si/SiO_x 1.3 nanometer chem POCl₃" and the
8 one right next to it that says "Poly-Si/SiO_x 1.3
9 nanometer chem POCl₃," okay?

10 A. Right.

11 Q. Okay. And in each of these experiments, is it
12 your understanding that they used a 1.3-nanometer
13 silicon oxide grown two ways in a phosphorous-diffused
14 polysilicon layer?

15 A. Yes. Yes.

16 Q. Okay. And the one on the left of those two
17 tests a chemical-oxide-grown silicon oxide, right?

18 A. That's right.

19 Q. And the one on the right is a thermal oxide,
20 right?

21 A. That's correct.

22 Sorry. I just had to fiddle with this.

1 Q. No problem.

2 And so I want to take a look at the green bars,
3 which are the 890-degree heating, right?

4 A. Right.

5 Q. So for samples that were heated at 890 degrees,
6 regardless of whether the oxide was grown chemically or
7 thermally, Liu 2 is reporting that approximately
8 0.1 percent or less of the iron initially present in the
9 substrate is remaining after the heating, right?

10 A. That's correct.

11 Q. Okay. Now let's look at the boron, which is the
12 set of bar graphs on the right.

13 A. Uh-huh.

14 Q. And for boron, Liu 2 tested a 1.3-nanometer
15 chemical oxide with a boron-diffused polysilicon
16 emitter, right?

17 A. That's correct.

18 Q. And at 930 degrees celsius, which is shown in
19 blue, Liu reports that less than 0.1 percent of the
20 starting iron in the substrate was remaining after the
21 heating process, right?

22 A. That's correct, yes.

1 Q. And so in both of the examples that we just
2 talked about, for the phosphorus with the 1.3-nanometer
3 oxide and for the boron with a 1.3-nanometer oxide, Liu
4 is reporting that 99.9 percent of the initial iron
5 concentration was gettered out of the silicon substrate,
6 right?

7 A. Was gettered, yes. So these -- these graphs
8 don't necessarily tell you that they were gettered out,
9 but they were gettered, yes. In other words --

10 Q. They were no longer present in the substrate?

11 A. Well --

12 Q. The portion of the sub- -- sorry. Let me -- let
13 me clarify.

14 A. Yeah. The portion --

15 Q. They were no longer present -- no?

16 A. Please, go ahead.

17 Q. They were no longer present in the portion of
18 the substrate that Liu 2 was able to measure, correct?

19 A. To the portion that Liu was able to measure --
20 oh, I'm sorry, I didn't realize I put that over the top.
21 So, yes, just give me a moment to make sure that I agree
22 with that statement, please. Just give me a second.

1 I've got to -- oh, here it is. I apologize for the
2 delay. I have glaucoma. I have to put the medicine in
3 every so often. Just one more moment, please. I'm just
4 reminding myself of something here. Okay.

5 Okay. So I'm sorry for the delay. Let me be
6 really precise. The thing that I am concerned about is
7 the phrase of your question about how you're saying that
8 this is gettered out of the silicon substrate. You can
9 getter in two different ways. You can remove the
10 material, the impurity or what have you, from a
11 substrate, right; thus it does not effect the function
12 of the substrate.

13 The second thing that you can do is you can
14 interact the material, the impurity, with another
15 impurity or dopant or what have you. What you do in
16 that case is you raise the level -- the energy level of
17 the impurity in the band structure of the substrate.
18 You place it into the conduction band so that it no
19 longer affects the carrier. That too is gettering,
20 because it is effectively gone.

21 So when you do the measurement, you have to be
22 sure that what your measurement is saying is that you

1 have removed it, either physically or you've removed it
2 electronically. Which measurement did you do? Well, in
3 this particular case, when they are showing that
4 they're -- they're doing the gettering -- they are
5 gettering this, what they are doing is that they are
6 showing you something that correlates to the lifetime of
7 carriers, which gives you an estimate of how much of
8 that material is electrically active within the
9 substrate. It may not necessarily mean that that
10 material was removed from the substrate. It didn't go
11 anywhere necessarily; that is for another measurement to
12 determine.

13 But if you say that this graph here shows me
14 that this has a concentration in the -- what's left over
15 in the silicon substrate is a certain amount, then what
16 I have to say is, well, do you mean that the
17 concentration of the physical element is left in the
18 substrate or do you mean that you have gettered it by
19 removing it electronically? You isolated it from the
20 effects that it has on -- has on the carriers.

21 The reason this is an important difference, the
22 reason this is a problem, is because you can do that

1 second process only so much. So I can take the metals.
2 I can remove that process from what they're doing in the
3 silicon so that it doesn't affect the carriers.
4 However, the more of that that I do, the more sensitive
5 this becomes to heat. Heating now becomes a real
6 problem because I'm going to generate more phonons and
7 they are going to scatter the electrons. So it only
8 works to a certain level, and that level is far below
9 the level that you would have achieved had you removed
10 it.

11 So that's why I just want to be a little careful
12 in -- when you say "this shows that this has been
13 removed from the silicon," it shows that it's been
14 isolated electronically from the carriers of the
15 silicon, okay.

16 Q. So Liu 2 reports that it -- when it is -- what
17 it is reporting is, quote, "a gettering effect." Do you
18 see that? That's the title right above Figure 3.

19 A. That's exactly right. But gettering, with a
20 definition which may be different from the definition
21 which we have been using up to now, where we have said
22 that it is removed physically, then what they may be

1 meaning here is isolated electronically. That's the
2 same thing, and they refer to it in the field as
3 gettering.

4 Q. And what Liu 2 reports in these graphs on the
5 right side --

6 A. Uh-huh.

7 Q. -- is the fraction of iron remaining in the
8 silicon substrate after the heating process, correct?

9 A. The fraction of iron that is scattering that
10 remains; not the physical atom number, but the
11 scatterers that are there. I believe that that's
12 correct, yes.

13 It's the same thing as saying if I make the iron
14 disappear to your eyes, does it really matter if it's
15 there. And you'll notice that in this, if you go to --
16 if you go under -- "the effective minority carrier
17 lifetime of the samples was measured by a WCT-120 tool
18 from Sinton Industries [sic] using either
19 quasi-steady-state photoconductance or transient
20 photoconductance decay."

21 So that's not telling you if that atom is there.
22 That's telling you whether or not that atom is acting as

1 a dopant or as an impurity.

2 Q. Okay. So we can agree that Liu 2 reports that
3 in every experiment that it reported in Figure 3, less
4 than 100 percent of the iron was remaining, right?

5 A. Less than 100 percent of the iron was doing the
6 job of -- that iron did. All of the iron might be
7 there. It just doesn't interact with the electrons.
8 Now -- yeah, that's right.

9 Q. You can't confirm -- you cannot confirm that
10 100 percent of the iron is remaining in --

11 A. You cannot confirm that -- yeah, you cannot
12 confirm that 100 percent --

13 Q. Would it be surprising to you if 100 percent of
14 the iron was remaining in the silicon substrate, despite
15 the report that 0.1 percent is remaining in many of
16 these experiments?

17 MR. SNODGRASS: Objection to form.

18 You can go ahead, Dr. Carroll.

19 BY MR. PETERSON:

20 Q. You can answer.

21 A. Oh, I can answer?

22 So would I be surprised if somebody came up with

1 an experiment that showed that all the iron was there,
2 from the type of measurement that this has made? The
3 concentration -- remind me -- just a moment. What is
4 the concentration, again, of the dopant? Sorry, I
5 should have that on the top of my head, and I don't. I
6 apologize.

7 Okay. I don't see -- oh, wait. Here it is, a
8 good dopant number.

9 All right. So if -- in the cases -- in the case
10 that the dopant is light, then, yes, it would surprise
11 me. If the dopant concentration, as they are in this
12 particular paper, is heavy, then, no, it would not,
13 because the distance to each dopant atom that you
14 interact with is shorter than the distance the iron has
15 to go to get to the interface. So the thing that is
16 most likely to occur is the thing that is the closest.
17 So what happens is, it forms a compound with all the
18 dopant.

19 Now, that doesn't mean that that's absolutely
20 what it's going to do, and it is likely that some will
21 leave the volume of silicon, but this graph does not
22 prove that.

1 Q. Okay. And there's not a single example in Liu 2
2 in which no gettering of iron is reported, correct?

3 A. That is correct, yes.

4 Q. I'd like to take a look at paragraph 70 of your
5 declaration.

6 A. Yes.

7 Q. It's Exhibit 2021.

8 A. "Liu 2 discloses configurations" therein, right?

9 Q. Yes.

10 And what you say is, "Liu 2 discloses
11 configurations where gettering into polysilicon layers
12 will not occur."

13 Do you see that?

14 A. Yes, I do.

15 Q. You aren't referring to the experiments that are
16 disclosed in Figure 3 of Liu 2, were you?

17 A. So in this particular case, the gettering that I
18 am referring to here is referring to the use of the term
19 the rest of the way through my document, which is
20 specifically the use of the term that refers to the
21 removal of the atoms.

22 Q. Okay. What in -- where in -- what were you --

1 sorry. Let me strike that.

2 A. Sure.

3 Q. What were you referring to Liu 2 as disclosing a
4 configuration into gettering into polysilicon layer --
5 layers will not occur?

6 A. So in the cases where I am referring to
7 gettering into polysilicon layers, the gettering -- as
8 I'm saying here, the gettering is not going to be -- or
9 the word that I'm using here specifically, "gettering,"
10 that word is referring to the physical removal of iron.
11 In Liu 2, you have low-temperature diffusion numbers,
12 right? Where is it? Oh, okay.

13 In Liu 2, you have low-temperature diffusion,
14 and those low-temperature diffusion numbers are
15 occurring for the thicker oxide films and even for some
16 of the ones where you have the 1.3 and heavy dopants.
17 In those cases at 780 and, I maintain, even to some
18 degree at 820, but mainly at the 780, those are going to
19 be locked up in compounds, not removed from the
20 material. So the iron didn't go traipsing across the
21 interface. The iron -- the actual atom is still there.
22 It just happens to have been compounded with phosphor or

1 boron and thus does not affect the function of the
2 device.

3 But as I said, if you do this too much, then the
4 device will not function as you want. You have to be
5 careful using that.

6 Q. So the configurations that you were referring to
7 as showing that gettering into polysilicon layers will
8 not occur were the 780-degree and 820-degree diffusion
9 temperatures?

10 A. Gettering as we understand it as removal of the
11 atom.

12 Q. And you can't say for certain that in those
13 experiments no metal impurities gettered -- in other
14 words, moved -- from the substrate and into the
15 polysilicon, correct?

16 A. We can't say for certain; that's true. But we
17 can say in -- in likelihood it should not have. It
18 should have been grabbed up by the phosphor.

19 Q. Is there any configuration disclosed in Liu 2 in
20 which you can definitively say that no metal impurities
21 gettered out of the silicon substrate and into the
22 polysilicon?

1 A. No, you can't do that. And the reason that you
2 can't is because it is likely that some atoms of iron
3 are on the very surface of the material, the substrate
4 that you grew this on. And those -- the minute you put
5 the films down, those would probably have found their
6 way across the oxide layer and into the polysilicon. So
7 you can't say that there is no, but I can say that there
8 would not have been enough to have qualified as physical
9 gettering. In other words, it would --

10 Q. What do you mean by qualify as physical
11 gettering?

12 A. Well, physical gettering in this case -- what
13 we're trying to do is exactly what you pointed out in
14 the very beginning of the conversation, where you said
15 what we're trying to do is lower the cost and raise
16 the -- and raise the efficiency, right. That process,
17 the process that we're discussing right now, would have
18 done neither of those.

19 Q. Let's take a look at the '315 Patent again,
20 Exhibit 1001.

21 A. 1001. Okay. I found it.

22 Q. Okay. And let's take a look at Claim 10.

1 A. Oh, yeah, back to Claim 10.

2 Q. Claim 10 doesn't say that the metal impurities
3 in the emitter region have to get there through physical
4 gettering, does it?

5 A. Claim 10. It says here -- okay. And you're
6 asking me -- you're asking me what about Claim --

7 Q. Claim 10 does not say that the metal impurities
8 in the emitter region have to be introduced through
9 physical gettering, correct?

10 A. Well, Claim 10 doesn't use the word "gettering"
11 at all.

12 Q. Correct.

13 A. Uh-huh.

14 Q. Okay. Let's stay on the '315 Patent and let's
15 take a look at column 3.

16 A. Column -- oh, 3 --

17 Q. Of the specifications.

18 A. At the type -- okay. Sorry. All right. That's
19 up at the top, the thing at the top. All right.

20 Q. Yes. And so I want to look at column 3, line
21 35.

22 A. Line 35, yes, here we go.

1 Q. And it says, "In an embodiment, the silicon
2 substrate can be single-crystalline or a
3 multicrystalline substrate."

4 Do you see that?

5 A. Yes.

6 Q. And what we -- I think you noted this earlier.
7 When we looked at Claim 10, it recites a silicon
8 substrate. It doesn't say multicrystalline or
9 single-crystalline, correct?

10 A. Uh-huh. Uh-huh. Uh-huh.

11 Q. The '315 Patent doesn't contain a description of
12 how the silicon substrate was manufactured, right?

13 A. Oh, no. No, it doesn't.

14 Q. And I think we talked earlier, it doesn't say
15 who manufactured the silicon substrate, right?

16 A. Yeah, that's correct.

17 Q. And the '315 Patent also doesn't contain any
18 disclosure of the starting concentration of metal
19 impurities in the silicon substrate, correct?

20 A. Yes, that's correct.

21 Q. And it also doesn't specify the ending
22 concentration of metal impurities in the silicon

1 substrate at the conclusion of the manufacturing
2 process?

3 A. Well -- so that is a statement that needs
4 qualification, because it does give you in Figure 8 and
5 9 -- it gives you a passivation and it gives you one
6 over lifetime. The one over lifetime in Figure 9 is
7 directly related to the concentration of the impurity
8 atoms, and that is shown by the reference that you just
9 had us read, Liu 2. In fact, the entire reference is
10 based upon that.

11 Q. So are you saying that the presence of metal
12 impurities as reported in the '315 Patent was determined
13 in the same way as in Liu 2?

14 A. Oh, no, I'm not saying it was determined in the
15 same way. What I am saying is from the data in Liu 2,
16 one has a specific number of metal impurities which are
17 interacting with the electrons. So when you say that
18 there is no concentration that this -- that is implied
19 by what this brings you to, well, it shows you that
20 there is a minimum concentration at least.

21 Q. Okay.

22 A. This leads to -- leads to a one over lifetime,

1 which is advantageous for the use of the devices.

2 Q. Does the '315 Patent specify how the presence of
3 metal impurities was determined?

4 A. It does not, I don't believe. I believe that
5 that is actually just in the references that they cite.

6 Q. In the '315 -- sorry. Let me -- let me strike
7 that.

8 Do you have any particular reference in mind
9 when you say that?

10 A. I don't, but I do know that the -- the
11 reference -- the -- the lifetimes that are being
12 measured, those lifetimes had to have been determined by
13 something. And I don't remember which one of the
14 references the lifetime measurement is specified in. I
15 apologize. There were a lot of papers, and it's in one
16 of them, but I don't remember which one.

17 Nevertheless, they do specify, and that would be
18 something I would expect to be true in any silicon.

19 Q. Can you clarify what you mean with that? I'm
20 not sure I follow.

21 A. Well, they're making a measurement of the
22 lifetime of carriers, right. So there's a couple ways

1 that you can do that, and we just talked about that in
2 Liu. And so they had to have used one of those. And as
3 long as the silicon is a relatively pure piece of
4 silicon, then that would be true in Liu's lab or in
5 their lab.

6 Q. In column 4 of the '315 Patent --

7 A. Yes.

8 Q. -- at line 3, it says, "In an embodiment, a
9 heating process can be performed to drive dopants from
10 the emitter dopant region to the emitter region."

11 A. Right.

12 Q. Do you see that?

13 A. Yes, indeed.

14 Q. And then in column 5, line 40, it describes that
15 "the heating can include placing the solar cell in a
16 thermal tool, e.g., a thermal furnace or oven among
17 others, and raising the temperature in the thermal tool
18 to 970 degrees celsius or above," right?

19 A. Uh-huh.

20 Q. And when you place a solar cell in an oven, it
21 heats the whole solar cell, right?

22 A. It depends on the amount of time it's in the

1 oven; but, yes, generally.

2 Q. And if you look at the next paragraph, it says,
3 "In an embodiment, the heating can be the last heating
4 step in the solar cell fabrication process. In one
5 embodiment, the heating can be the only heating step in
6 the fabrication process."

7 Right?

8 A. Yeah, uh-huh.

9 Q. So according to the '315 Patent, there can be
10 only one heating process or there could be multiple
11 heating processes used during the manufacturing of the
12 solar cell, right?

13 A. That's correct.

14 Q. In other words, one heating step could be used
15 for performing doping on the front and the back sides of
16 the solar cell simultaneously?

17 A. For performing the dopants, yes.

18 Q. Or those processes could be done separately, one
19 heating process for the front and one heating process
20 for the back, right?

21 A. That's correct, yes.

22 Q. I'm sorry to jump around, but if you'll look at

1 column 3.

2 A. Column 3?

3 Q. Yeah. And I want to start at line 31.

4 A. Okay.

5 Q. You'll see here that the -- the specification
6 describes at line 38 the formation of a dielectric
7 layer. Do you see that?

8 A. The formation -- I -- you're talking about 31 or
9 38?

10 Q. Oh, sorry. Starting at line 31, the patent
11 describes a dielectric can be formed on a silicon
12 substrate, right?

13 A. Yes, exactly, uh-huh. That's right, yes.

14 Q. And in that same paragraph, further down it says
15 that "the silicon substrate" -- sorry -- "the dielectric
16 layer can be a tunnel oxide." That's around line 38.

17 A. Uh-huh, that's right.

18 Q. And then it further says that in an embodiment,
19 the dielectric can be a silicon ox- -- a dioxide, right?

20 A. Yes, that's right.

21 Q. And finally it says, "In an embodiment, the
22 dielectric region can be grown and/or formed through a

1 thermal process," right?

2 A. Yes, that's correct.

3 Q. So that would be a thermal oxide, right?

4 A. One -- yes. They're claiming a thermal oxide,
5 yes. But there are different --

6 Q. The thickness --

7 A. -- kinds of thermal oxides, so...

8 Q. Sure.

9 And so when it refers to a tunnel oxide,
10 approximately how thick would that tunnel oxide be?

11 A. Well -- so generally speaking, we would want the
12 tunnel oxide to be somewhere in the neighborhood of 1 to
13 2 nanometers thick. If you go up -- to give you some
14 idea, for 1 volt being placed across a tunnel oxide,
15 you're going to get something on the order of 1 nanoamp
16 per square, and if I go to 10, that drops down to about
17 10 to the nanoamp per square, a little bit less. And so
18 that -- at a 10th or so per nanoamp per square, you are
19 still performing basically the function of a tunnel
20 oxide. If you go to 100 nanometers, you're now well
21 down into the sub-picoamps and this no longer functions
22 as a tunneling oxide. So you're -- that's kind of how

1 far out you can go. But you would really prefer it to
2 be around 1 to 2 nanometers.

3 Q. The '315 Patent doesn't specify the exact
4 thickness or range of thicknesses that can be used for
5 the tunnel oxide, right?

6 A. That's right.

7 Q. Okay. And you mentioned a moment ago that there
8 are various ways in which a thermal oxide can be formed,
9 right?

10 A. That's correct.

11 Q. It doesn't specify that a particular method of
12 forming a -- forming a thermal oxide needs to be used,
13 right?

14 A. No, it does not.

15 Q. Okay. And if you look at -- oh, sorry. And the
16 '315 Patent also doesn't specify the conditions that
17 were used to form the thermal oxide that appears in its
18 examples, such as those shown in Figure 11, right?

19 A. Just a moment. Let me see here. Which one is
20 figure 11? 9, 10, 11. Yes, that's correct.

21 Q. Now, look -- staying on column 3 --

22 A. Uh-huh.

1 Q. -- it says starting at line 56 that, "Although
2 the dielectric region and/or the emitter region are
3 described as being grown by a thermal process or
4 deposited through conventional deposition respectively,
5 as with any other formation, deposition or growth
6 process described or cited herein, each layer or
7 substance can be formed using any appropriate process."

8 Do you see that?

9 A. Yes.

10 Q. So the '315 Patent isn't limiting the dielectric
11 region to a thermal oxide, correct?

12 A. No, it's not.

13 Q. It could be a chemical oxide, right?

14 A. For instance, yes.

15 Q. Okay. And it says that that flexibility in how
16 to apply any layer or substance also applies to other
17 regions, like the polysilicon region -- or the
18 polysilicon emitter region, right?

19 A. Right, uh-huh.

20 Q. And that would also apply to the front -- front
21 portion of the silicon substrate that's doped, that the
22 '315 Patent is allowing for that region to be doped in

1 various ways, right?

2 A. In various ways, uh-huh.

3 Q. It's not requiring a specific type of dopant
4 drive it on the front portion, right?

5 A. No. It has to be consistent with what the
6 dopant would need to do to dope it. But, yes, you're
7 right, anything -- anything that works.

8 Q. Right. And it -- it lists chemical vapor -- it
9 says, "for example" -- sorry. Let me strike that.

10 Staying on column 3, it says, "For example, a
11 chemical vapor deposition process, low-pressure CVD,
12 atmospheric-pressure CVD, plasma-enhanced CVD, thermal
13 growth sputtering, as well as any other desired
14 technique can be used where formation is described."

15 Right?

16 A. Yes, that's exactly right, mm-hmm.

17 Q. And so the front portion of a silicon substrate
18 could be doped using a dopant drive-in process, ion
19 implantation, right?

20 A. That's correct.

21 Q. And it could use gaseous doping, right?

22 A. Yes.

1 Q. The -- looking in column 3 at line 42, this
2 paragraph describes the formation of the emitter region.
3 Do you see that?

4 A. Yes.

5 Q. The discussion of the emitter region in the '315
6 Patent doesn't include a description of the dopant
7 concentration in that region, right?

8 A. That's correct, yes.

9 Q. Now, looking at column 5, the '315 Patent says
10 at line 13 -- sorry, line 10, that "the emitter regions,
11 e.g., polysilicon regions, can be a good sink and/or
12 trap for the metal impurities 220 discussed above. A
13 gettering process can be used to trap the metal
14 impurities in the emitter regions, reducing
15 recombination within the silicon substrate and improving
16 overall solar cell lifetime."

17 Do you see that?

18 A. Yes, I see that.

19 Q. And at line 21 it says "in an embodiment,
20 heating at temperatures above 900 degrees celsius can
21 include gettering metal impurities through the
22 dielectric region, e.g., tunnel oxide, to enter the

1 emitter region, e.g., polysilicon region, as discussed
2 in detail at 106 of Figure 1 below," right?

3 A. Yes, I see that.

4 Q. And so that would entail gettering of metal
5 impurities from the silicon substrate through both
6 interfaces that the oxide layer has with the substrate
7 and the polysilicon, and into the polysilicon region,
8 right?

9 A. In this case, yes, the actual physical motion of
10 metal atoms.

11 Q. And specifically if we look at the sentence that
12 spans columns 4 and 5, the specification specifically
13 refers to metal impurities such as iron, nickel and/or
14 chromium, among others, right?

15 A. Yes, that's correct.

16 Q. That's the metal impurities that it was
17 referring to as being gettered from the substrate
18 through the dielectric and into the polysilicon,
19 correct?

20 A. These are among the ones that they claim are
21 done -- or are moved, yes.

22 Q. The patent does not require perfect gettering of

1 all impurities from the silicon substrate, right?

2 A. It does not, no.

3 Q. And, in fact, it explicitly says that some
4 impurities can remain in the substrate after the
5 gettering process has been concluded, right?

6 A. That's right.

7 Q. I want to talk about the Figure 11 examples,
8 which are described in column 8 of the patent. At least
9 starting in column 8.

10 A. Okay, I'm on column 8.

11 Q. The '315 Patent describes four processes that
12 were used as examples, right? There is example A, B, C
13 and D?

14 A. Yes.

15 Q. Those examples don't disclose the type of
16 silicon substrate that was used for the experiments,
17 right?

18 A. That's correct.

19 Q. And they don't disclose the starting
20 concentration of metal impurities in the silicon
21 substrate, right?

22 A. Insofar as it gives you a concentration that is

1 measuring the atom percentage, no. But of course it
2 does show you a graph that shows you improvement in
3 lifetimes, so that gives you some idea of what the
4 concentration was.

5 Q. You haven't said what the starting concentration
6 of these exam- -- of metal impurities in the substrate
7 used in examples A through D was in your declaration,
8 correct?

9 A. I have not, no. I did not calculate it.

10 Q. Okay. The examples don't disclose whether the
11 silicon substrate that was used was a multicrystalline
12 or a single-crystalline silicon substrate, right?

13 A. That's correct.

14 Q. And the examples also don't disclose whether the
15 silicon substrate was cleaned before the dielectric
16 layer was formed, right?

17 A. For that graph, I believe that's correct, yes;
18 it does not.

19 Q. The examples don't disclose the method in which
20 the dielectric layer was formed. I think we discussed
21 that earlier, right?

22 A. That's correct.

1 Q. And they don't disclose the thickness of the
2 dielectric layer that was used in any of the examples,
3 right?

4 A. That's correct.

5 Q. The examples do not disclose the time that was
6 used for the heating steps, right?

7 A. Yes, that's correct.

8 Q. And the examples do not disclose the dopant
9 concentration in the polysilicon emitter region, right?

10 A. In the polysilicon emitter region, that's
11 correct.

12 Q. And the exact temperatures that were used are
13 also not reported. Instead, the examples report either
14 above 900 degrees celsius or below 900 degrees celsius,
15 correct?

16 A. Yes, that's correct.

17 Q. You have a helpful annotation in your
18 declaration, so if we could look at paragraph 40 of
19 Exhibit 2021. And I'm looking at the graph on page 24.

20 A. Okay. The graph on -- this is paragraph 40, but
21 you're looking at the graph that occurs on -- down below
22 it, okay. Yes, I see it.

1 Q. Yes. So top of page 24?

2 A. Yes.

3 Q. And here you've annotated the four examples that
4 are disclosed in the '315 Patent, correct?

5 A. Yes.

6 Q. And you affixed the -- what everybody agrees is
7 a typo with respect to example C and D to show that
8 those examples used a temperature above 900 degrees
9 celsius, right?

10 A. Yes, that's right.

11 Q. Okay. And this graph shows that in both
12 instances in which the solar cell was heated above
13 900 degrees celsius, gettering of metal impurities from
14 the silicon substrate and into the polysilicon was
15 recorded, right?

16 A. So in this particular case, what this is showing
17 you is that the lifetime increased.

18 Q. The column that says "gettering location"?

19 A. Yes.

20 Q. Are you with me?

21 A. Yes.

22 Q. For both of the examples in which a temperature

1 above 900 degrees was utilized, the gettering location
2 is listed as poly, right?

3 A. That's exactly right, yes.

4 Q. And that referred to gettering of metal
5 impurities into the polysilicon emitter region --

6 A. That's correct, yes.

7 Q. So in both instances in which the temperature
8 above 900 degrees was utilized, the inventors reported
9 gettering of metal impurities into the polysilicon
10 emitter, right?

11 A. Into the polysilicon, yes, in this case, yes.

12 Q. Okay. And they observed gettering into the
13 polysilicon emitter regardless of the dopant
14 concentration that was used on the front surface of the
15 solar cell, correct?

16 A. That's correct, for the two cases that you have
17 here.

18 MR. PETERSON: Now might be a good time
19 for a break. Can we go off the record?

20 THE COURT REPORTER: We're off the record
21 at 12:26.

22 (Recess.)

1 THE COURT REPORTER: We're back on the
2 record at 1:00.

3 BY MR. PETERSON:

4 Q. Welcome back, Dr. Carroll.

5 A. Thank you very much. I appreciate it.

6 Q. So --

7 MR. PETERSON: Dr. Carroll, you may be on
8 mute. Are you on mute?

9 THE WITNESS: No, I'm not on mute. Can
10 you hear me?

11 MR. SNODGRASS: My fault.

12 BY MR. PETERSON:

13 Q. Okay. Dr. Carroll, in your declaration you
14 discuss silicon substrates that are pure or near pure of
15 metal impurities. Do you recall that?

16 A. Pure or near pure, yes.

17 Q. And if you want to look at paragraph 38 of your
18 declaration, Exhibit 2021, that's where I was getting
19 the phrase "pure or near pure" from.

20 A. Yes.

21 Q. And you cite to a paper by Neuhaus?

22 A. Neuhaus.

1 Q. Yes?

2 A. Yes.

3 Q. And that paper refers to -- you can see in the
4 quote -- sorry. Let me strike that.

5 You have a quote here to Exhibit 1011 that says,
6 "The IBC solar cell design requires extraordinarily high
7 lifetime silicon starting material."

8 Do you see that?

9 A. Yes.

10 Q. That's a quote from Neuhaus, correct?

11 A. Yes, that's right.

12 Q. What does "extraordinarily high" mean to you?

13 A. Well, it would be -- extraordinarily high would
14 be, obviously, above the lifetimes that you would
15 typically measure for sil- -- the -- the
16 electronics-grade silicon. That's what I'm trying to
17 think of. Sorry.

18 Q. And does electronics-grade silicon encompass
19 solar-grade silicon?

20 A. Generally, yes. And if you see the --
21 anything -- any -- lifetimes that are above something on
22 the order of milliseconds or so, I think, would be --

1 hold on a moment. Yeah, milliseconds. So milliseconds
2 is one over -- one over hundreds of hertz or something
3 like that, so -- yeah.

4 Q. How would the type of extraordinarily high
5 lifetime silicon starting material that you describe
6 here be manufactured?

7 A. Well, usually that's done through some sort of
8 float of -- the float zone growth and then using
9 subsequent zone refining. So this is exactly what we
10 use, for instance, for the materials that are -- make --
11 that we use to make our very best silicon chips today.

12 Q. Is that a more costly process than is typically
13 undertaken for solar-grade silicon -- silicon
14 substrates?

15 A. Yes, it is. It's significantly more costly.

16 Q. What about in terms of time? Is it a more
17 time-consuming process than is typically used for
18 solar-grade silicon?

19 A. Yes, it is. It's quite a bit more time
20 consuming.

21 Q. I believe we mentioned before the lunch break
22 that the '315 Patent doesn't specify the type of silicon

1 substrate that was utilized, correct?

2 A. It doesn't specify the type of silicon substrate
3 that is -- that is -- is used; that is, in terms of its
4 claims, it does not say it must be this or that. But
5 what it does show you, of course, is a silicon that
6 is -- that has a very specific efficiency associated
7 with it and has a very specific lifetime associated with
8 it. So they are starting from one performance level and
9 going to another performance level, and we read into
10 that what we have learned from the references that we
11 discussed, that that's associated with concentration of
12 impurities.

13 Q. And you may recall in the '315 Patent the
14 silicon substrate was referred to -- was described as
15 either being single-crystalline or multicrystalline,
16 right?

17 A. That's correct, yes.

18 I did say -- if I can just make sure and make
19 one -- one small clarification. So there are times in
20 which I used polycrystalline and multicrystalline as
21 being the same thing, and there are times in which I --
22 I use those two phrases to refer to something slightly

1 different. Polycrystalline usually is referred to in
2 terms of films, and the film has small crystallites.
3 The multicrystalline stuff usually refers to stuff that
4 is larger in crystal structure and can be obtained in
5 boule form. So they are -- they are the same thing, as
6 I've stated, but just know that they -- that they are
7 delivered to you in different -- in different
8 morphologies.

9 Q. In terms of their band gap, would
10 multicrystalline silicon have the same band gap as
11 polycrystalline silicon?

12 A. Generally speaking, yes.

13 Q. I'm going to put in the chat Exhibit 1005, which
14 is the Li patent publication.

15 A. Sure. I think we have that already, don't we,
16 in the chat?

17 Q. We have certainly mentioned it. I don't know if
18 it's been in the chat, but for the record, I just want
19 to put it in.

20 A. Okay. I have it.

21 Q. And in Li, on page 3, paragraph 42, the end of
22 paragraph 42 --

1 A. Page 3 has figures.

2 Q. Sorry. At the very top of the page, there are
3 -- in the specification, there are page numbers, and I'm
4 looking at page number 3.

5 A. Oh, I'm sorry. I'm sorry. Yes, indeed there
6 are page numbers.

7 Q. And paragraph 42 is at the bottom of column 1
8 and then it continues on to column 2 of page number 3.

9 A. Yes, it does.

10 Q. And in the very last sentence it says, "In
11 another alternative embodiment, instead of using a
12 single-crystalline substrate, a multicrystalline
13 substrate is used in its place."

14 Do you see that?

15 A. Yes.

16 Q. So is it fair to say that Li contemplates use of
17 either single-crystalline or multicrystalline silicon
18 substrates?

19 A. Yes, it is fair to say that.

20 Q. So it's the same as the '315 Patent in that
21 regard, correct?

22 A. With respect to the multicrystalline substrate,

1 yes.

2 Q. And the -- Li does not describe the method that
3 is used to manufacture the silicon substrate, correct?

4 A. That's correct; it does not.

5 Q. And Li also doesn't disclose the manufacturer of
6 the silicon substrate, right?

7 A. That's correct; it does not.

8 Q. And so that's another way in which Li and the
9 '315 Patent are similar; neither of them describe the
10 manufacturer of the substrate, right?

11 A. That's correct. There is a similarity in that.

12 Q. So you can't tell from their disclosures whether
13 Li and the '315 Patent use the same type of silicon
14 substrate, right?

15 A. That's correct, because Li does not provide any
16 performance data either.

17 Q. And we know that Li and the '315 Patent are both
18 assigned to SunPower, right?

19 A. That's correct.

20 Q. And they share David Smith as an inventor,
21 correct?

22 A. Yes, that's correct.

1 Q. So you can't rule out the possibility that Li
2 and the '315 Patent used the same type of silicon
3 substrate, right?

4 A. Yes, that's correct; you can't rule that out.

5 Q. And there's nothing in Li that would preclude
6 the use of a typical solar-grade multicrystalline
7 silicon substrate, right?

8 A. Say that one more time. There's nothing in Li
9 that would preclude the use of a typical...

10 Q. Solar-grade silicon substrate.

11 A. Solar-grade silicon substrate.

12 MR. SNODGRASS: Objection to form.

13 Dr. Carroll, you can answer.

14 THE WITNESS: Okay. Yes, there is
15 nothing that would preclude that.

16 BY MR. PETERSON:

17 Q. And the '315 Patent also does not preclude the
18 use of a standard multicrystalline solar-grade silicon
19 substrate, correct?

20 MR. SNODGRASS: Objection to form.

21 You can answer.

22 THE WITNESS: Yes, that's correct.

1 BY MR. PETERSON:

2 Q. If you could look in your declaration, paragraph
3 53. This is on page 30 -- sorry. It begins on page 29
4 and then spans to page 30.

5 A. Yes, I've read it.

6 Q. Okay. You -- you state that for the
7 extraordinarily high lifetime silicon starting material
8 from SunPower, the impurity concentration could be,
9 quote, "as low as 10 to the 12th," right?

10 A. Yes, that's right. That's at the bottom.

11 Q. In your declaration, you haven't identified any
12 silicon substrate with an impurity concentration lower
13 than 10 to the 12th, correct?

14 A. That's correct. In this, I have not
15 identified -- in this declaration, I have not identified
16 a reference that says that.

17 Q. You have not identified a reference that
18 describes a silicon substrate that was completely free
19 of metal impurities as of 2014, correct?

20 A. That's correct. I'm not sure that one could
21 make such a statement because you would have to have
22 detectability that would've -- that would be uncommon at

1 that time.

2 Q. What would it take to prepare a completely pure
3 silicon substrate as of 2014?

4 A. Well, that would take me into the realms of
5 speculation because, again, it's impossible to know
6 exactly. But we do know what the sources of most of
7 these impurities are. And so what we would have done --
8 if you ask me to do that in a laboratory, what I would
9 have done would be to construct growth apparatus that
10 did not contain very specific elements. Iron is a
11 problem, so I would've made sure that both the feed
12 stock for the silicon and the growth chambers and the
13 growth hearth did not have iron in them, and so on.

14 So you would have done it that way, which would
15 have made it extraordinarily expensive to do. But
16 that's only speculation on my part right now, uh-huh.

17 Q. The opinions in your report are not premised on
18 the assumption that Li would utilize a completely pure
19 silicon substrate with no metal impurities, correct?

20 A. That's -- it's -- they're not predicated upon
21 that, no.

22 Q. You would agree that in 2014 at least some

1 silicon substrates were known to contain a substantial
2 concentration of metal impurities, right?

3 A. Yes, in 2014, some were known to contain a
4 substantial amount of metal impurities.

5 Q. And do you know approximately what percentage of
6 silicon substrates would have what you would consider to
7 be a substantial concentration of metal impurities as of
8 2014?

9 A. I do not know of 2014, what percentage of the
10 silicon market was dedicated to the production of impure
11 silicon. But at that time, the largest production of
12 silicon that was out there was really not semiconductor
13 industry, but it was, in fact, materials used for things
14 like solar. So it would have been a large percentage
15 that would have had some impurities.

16 Q. Do you think it would have been more than half?

17 A. I honestly do not know, not in 2014.

18 Q. Do you have a sense for what that percentage
19 would be today?

20 A. Today I understand that the largest
21 production -- the largest amount of production is for
22 the -- the chip industry, so it would be over half. But

1 that is just my understanding. I have not seen a recent
2 reference.

3 Q. Is determining the amount of metal impurities
4 that are present in the silicon substrate something that
5 you would do when conducting your research on various
6 solar cell structures?

7 A. At the time when I was working with silicon,
8 then yes. And we would do that on an atomic basis and
9 on an effectual basis. So I would have looked at
10 lifetimes and I would have correlated that with the
11 total concentration that we measure atomically. Unlike
12 many of the references that we see here, I would have
13 typically done both.

14 Q. And just to orient ourselves, the work that you
15 were describing, that -- with silicon, that was, I
16 believe, in the 2000s and early 2010s, right?

17 A. With silicon in the 2010s to the 2015s, in that
18 period of time. Before that, it was organics.

19 Q. Understood.

20 A. We did some amorphous silicon, but that's a
21 different thing than we are talking about here.

22 Q. Do you have a recollection of what the highest

1 level of concentration on an atomic basis was that you
2 observed in that 2010-to-2015 time frame?

3 A. I do not remember exactly. I know that it was
4 over 10 to the 15, but that -- beyond that, I don't
5 remember exactly what the number was in front of the 10
6 to the 15.

7 Q. Would you say that that is what you observed --
8 sorry, let me strike that.

9 For the average silicon semiconductor that you
10 were using, is that -- is that 10 to the 15th like
11 approximately what you would expect?

12 A. Yes, because we bought silicon that could be
13 used for either the electronic applications or for
14 applications in solar or whatever else, so we bought
15 pretty good stuff. The reason for that, of course, is
16 as experimentalists, we want to control what we have.

17 Q. In your declaration, at page 60 -- or, sorry,
18 paragraph 60, page 33 -- again, this is Exhibit 2021.
19 Could you least turn there?

20 A. I am here. I am there, Ramappa.

21 Q. Yes. This is where you performed your
22 hypothetical calculation of the pileup effect using

1 Ramappa, right?

2 A. Uh-huh.

3 Q. Okay. And one of the assumptions that you used
4 in that calculation was a beginning impurity
5 concentration in Li's substrate of 1 times 10 to the 11,
6 right?

7 A. Uh-huh.

8 Q. You didn't perform any of your calculations
9 regarding the pileup effect of silicon oxides using a
10 higher impurity concentration of the silicon substrate
11 than 1 times 10 to the 11th, correct?

12 A. No. That's -- that's just to give a lower
13 bound.

14 Q. You didn't calculate what would be an upper
15 bound using a higher concentration, right?

16 A. No.

17 Q. Do you recall that Dr. Banerjee cited a source
18 that reported metal impurities in multicrystalline
19 silicon substrates of between 10 to the 14th and 10 to
20 the 16th?

21 A. Yes, indeed.

22 Q. You didn't perform a calculation of what the

1 pileup effect would believe for a silicon substrate with
2 a concentration of 10 to the 14th and 10 to the 16th,
3 right?

4 A. No. The -- the reason for that, of course, is
5 simple: The pileup gets worse as it gets bigger. So
6 the lower bound is supposed to give you an idea, only a
7 guidance, of what to expect even as you go vanishingly
8 small. So you expect the effect to get worse. So
9 that's the reason that we only did the one estimate.

10 Q. So is it your testimony that if the starting
11 substrate had a higher concentration of metal
12 impurities, the end result of your calculation would be
13 lower in terms of the concentration of atoms -- of metal
14 impurity atoms present in the polysilicon?

15 A. The pileup at the interface would be higher.
16 That is my testimony.

17 Q. And would the amount of metal impurities that
18 getter through the silicon oxide and into the
19 polysilicon, notwithstanding the pileup effect, be
20 higher if the starting concentration was higher?

21 A. The answer to that's contextual, right, because
22 it depends very much on exactly what kind of oxide

1 you're dealing with and how the pileup occurred. If the
2 oxide is not commensurate, if I don't have complete
3 registry of the atoms, then the pileup can be greater
4 than expected and the actual amount of atoms that make
5 it through the silicon dioxide will go down. That's a
6 surprising result because you would think since I
7 started with more on one side, I would end up with more
8 on the other side. The reason it's counterintuitive is
9 because the pileup has a charge associated with it and
10 that charge prevents the motion of the atoms across the
11 boundary.

12 On the other hand, there are many cases in which
13 you can find a greater number in the polysilicon,
14 starting with a greater number in the silicon, even with
15 the pileup. So it depends on exactly what the structure
16 of the thin film -- the -- the silicon dioxide thin film
17 is.

18 Q. Okay. Let's talk about the front surface --

19 A. Okay.

20 Q. -- of the solar cell. You mentioned, I believe,
21 that recombination at the front surface of a solar cell
22 is a concern in the solar cell industry, correct?

1 A. That is correct.

2 Q. And passivation and doping were two known
3 techniques in 2014 to reduce surface recombination,
4 right?

5 A. That's correct.

6 Q. Okay. And it was known in 2014 that if you
7 reduce the recombination at the surface, that can result
8 in an increased efficiency of the solar cell overall,
9 right?

10 A. That's correct.

11 Q. And it was known before 2014 that doping of the
12 front surface of the silicon solar cell was a way to
13 increase solar cell efficiency and reduce surface
14 recombination, correct?

15 A. I would say it was known that dopant within
16 certain parameters was known to do it. Not -- not every
17 dopant scheme works, so you had to do it a certain way.
18 But then, yes, I --

19 Q. Techniques for doping the front surface were
20 known as a way to reduce surface recombination, correct?

21 A. Yes.

22 Q. And those techniques for reducing -- for

1 reducing surface recombination through doping were known
2 to be applicable to back-contact solar cells as of 2014,
3 correct?

4 A. Yes. They would have -- they would have applied
5 to any type of solar cell.

6 Q. As of 2014, what --

7 A. Let me make sure that I add a caveat to that.
8 The question was whether or not it reduced
9 recombination, right? Just reducing recombination does
10 not always increase the efficiency. But in so much as
11 it reduces recombination, then it applies to all forms
12 of the solar cells.

13 Q. Do you recall the techniques that were available
14 in 2014 for doping the front surface of the solar cell?

15 A. I recall -- yes, there were multiple different
16 kinds, and I know that the industrial standard was the
17 addition of the -- the compounds -- the liquid -- liquid
18 dopant that you put on top and dried in.

19 Q. And were gaseous -- were gaseous dopant --
20 sorry, let me strike that.

21 Were there also known techniques for doping the
22 front surface using gaseous dopant sources?

1 A. Yes, there were.

2 Q. And was ion implantation also a known technique
3 for doping the front surface of the solar cell?

4 A. Yes. To my recollection, in 2014 that one was
5 more rare for commercial vendors to do.

6 Q. I think we discussed a moment ago that another
7 known technique for reducing surface recombination was
8 through passivation, correct?

9 A. Yes, that's correct.

10 Q. And were there known methods of growing
11 passivation layers on the front surface of a
12 back-contact solar cell in 2014?

13 A. Yes, there were.

14 Q. Sorry. Before I move on to the passivation
15 layers, the techniques that we discussed for doping the
16 front surface of the back-contact solar cell, would
17 those have been techniques that a skilled artisan would
18 have known how to implement?

19 A. A skilled artisan defined as has been defined in
20 my declaration, yes.

21 Q. Okay. And then turning back to passivation.
22 Can you describe the types of passivation techniques

1 that were available in 2014 for a back-contact solar
2 cell?

3 A. So, generally speaking, there were multiple.
4 The most popular ones were to grow a thin film of
5 something that would take up the dangling bonds of the
6 silicon surface. So the silicon surface has silicon.
7 You could have recombination -- you could have -- the
8 bonds can hybridize and form -- and form a zero dipole
9 layer on top, right, so there is no dipole layer, so
10 they reform. And when those bonds form, they create a
11 state in the band gap of the material, and that causes
12 the problems. What you want to do is you want to take
13 those bonds up and make those bonds feel like they are
14 in silicon. So you can do that with silicon dioxide,
15 silicon nitride, or in some cases alumina.

16 And so the idea would be to grow one of those
17 films on top. Sometimes you could add something that
18 helps to catalyze the formation of the bond properly.
19 So lithium, for instance, can be used. And that gives
20 you then the bonds at the interface thinking like they
21 are coordinated in exactly the same way that they would
22 be inside the silicon. And so in that sense, you get

1 rid of the state that occurs in the band gaps. So that
2 passive -- so that passivates the surface. Very typical
3 to use, again, silicon dioxide, silicon nitride,
4 aluminium oxide, so.

5 Q. And would those types of techniques that you
6 just described have been something that a skilled
7 artisan as of 2014 would have been able to implement for
8 a back-contact solar cell?

9 A. They would have been able to implement in 2014
10 silicon dioxide fairly easily. The other ones, the use
11 of -- the effective use of alumina and some of the
12 others didn't come about until later.

13 Q. Okay. Passivation with an aluminum oxide or a
14 silicon nitride layer is something that had been
15 disclosed in the art at least as of 2014, correct?

16 A. Yes, that's correct.

17 Q. Okay. You mentioned that the -- that, at least
18 in some cases, the -- it was popular to grow a thin film
19 to act as a passivation layer. Do I have that right?

20 A. Yes, that's correct.

21 Q. When you say "thin," how -- what -- what types
22 of, you know, measurements are we talking about?

1 A. Okay. So it depends a little bit on exactly
2 what you're doing, but normally you would have to go by
3 the different functionalities that you want that
4 passivation layer to take onto itself. So it wants to
5 passivate. That, you need to have happen. But you may
6 also want it to block certain types of radiation. And
7 so usually between 100 and 200 nanometers, that tends to
8 be a sweet spot for doing exactly what you want,
9 although there were some manufacturers that made that as
10 much as half a micron.

11 Q. And what you just described, would that have
12 been true as of 2014?

13 A. Oh, yes, absolutely.

14 Q. Okay. Why would some manufacturers have made
15 it, the passivation layer, as much as a half micron?

16 A. The conceived application of the device.
17 Because in some cases you are applying this device at
18 different places on the surface of the planet. It may
19 have to withstand a hail strike or it may simply be in a
20 place where you are going to have to have so much UV
21 radiation that you feel like you have more absorption --
22 you need more absorption. So it could be simply where

1 you're going to place it. We do manufacture solar
2 cells, generally speaking now, to cover most of the
3 planet. But if you buy high-performance solar cells,
4 they will be made slightly differently for higher
5 latitudes.

6 Q. You mentioned that one reason you may use a
7 thicker oxide would be if you're having a -- in a higher
8 UV radiation environment; is that right?

9 A. Yes, that -- that might be a reason that you
10 would do it.

11 Q. If you were constructing a solar cell for space
12 applications, is that a reason why these silicon oxide
13 layer may be thicker than otherwise -- than you would
14 otherwise use?

15 A. So, again, this is a little bit outside of '315,
16 but, yes, in solar cells, you would not use a thicker
17 layer because it adds to the aerial density of the
18 device. The aerial density is how much it costs to
19 launch it, and so you do not want to add anything.
20 One -- simply adding an extra 100 nanometers across the
21 size of something like a solar cell is going to cost you
22 a million dollars more to lift it into space.

1 Q. Of the front surface --

2 A. I was on the panel for the NASA -- the Gossamer
3 project, so I am familiar with how much launch costs
4 are.

5 Q. You know, I'd like to have a separate
6 conversation with you about that, but probably off the
7 record.

8 So, Dr. Carroll, of the front surface
9 passivation techniques that were available in 2014,
10 would you say that silicon oxidation passivation was the
11 most popular?

12 A. In 2014, yes, I would say so.

13 Q. And would you say that passivating with a
14 silicon oxide layer on the front surface was quite
15 common for back-contact solar cells?

16 A. Yes, for all the manufacturers that I knew in
17 2014. I didn't know anyone that used anything other
18 than silicon dioxide.

19 Q. Are you aware of any manufacturers as of 2014
20 that didn't utilize any passivation layer on the front
21 surface?

22 A. I am not aware of anyone that -- that did not

1 use anything, no.

2 Q. And is there a reason why that would be a bad
3 idea -- sorry. Let me clarify. Let me strike that and
4 restart.

5 Is there a reason why not utilizing any
6 passivation layer on the front surface of a back-contact
7 solar cell would be a bad idea?

8 A. Yes. The primary function of preventing
9 oxidation of the silicon. You need to do something that
10 stops the silicon from sort of etching itself away in
11 the oxygen that we live, and specific to that is the
12 need to protect the contact areas, those emitter regions
13 and so forth. So there is -- the oxygen will attack
14 there and the silicon will -- the silicon device will
15 simply fail. So you need something to protect it.

16 Q. And would a skilled artisan in 2014 have
17 understood that?

18 A. Yes, they would have. I'm not sure that a
19 skilled artisan would have known all of the choices to
20 have been made, but they certainly would have known you
21 had to protect it.

22 Q. If you were -- sorry, let me -- let me strike

1 that.

2 In 2014, if you wanted to form an oxide layer on
3 the front surface of a back-contact solar cell, what
4 would be the manufacturing process for creating that
5 layer?

6 A. Some people use CVD, which is the best one that
7 you can do. Others used a slight modification of CVD
8 known as hot-wire CVD, and that's what most people did.
9 You can grow the film over the top of everything in a
10 line. Since you want to produce the panel using line
11 types of production methods, then the hot-wire CVD
12 method allows you to move the panel into and out of the
13 growth region without having to break the vacuum. So
14 that's usually the way that people did it.

15 However, you can use thermal growth methods
16 where the panel is heated. And that normally would be
17 heated in a -- in a -- a semi-vacuum that contained a
18 small amount of water vapor. And so both of those would
19 have been used.

20 Q. Would you -- let me strike that.

21 Would you qualify -- would you -- sorry. Would
22 you classify either of those methods as particularly

1 complicated to implement?

2 A. The CVD is not complicated, but you do know --
3 you have to know what you're doing. The other one, a
4 monkey can do.

5 Q. How about in terms of cost? How costly is it to
6 implement a silicon oxide passivation layer using the
7 techniques you just described?

8 A. So that's a good question. The actual
9 implementation is not very costly in either case.
10 However, the thermal oxide fails earlier. And so if you
11 have warranties that you are applying to your solar --
12 your solar panels, then the thermal one ends up being
13 more costly because you're likely to have to repair more
14 panels.

15 Q. In terms of time added in the manufacturing
16 process, how time consuming is it to add the thermal
17 oxide layer?

18 A. The thermal oxide layer?

19 Q. I'm sorry. Let me strike that. I didn't mean
20 to provide a qualification there. So let me restart.

21 In terms of time added to the manufacturing
22 process, how time consuming was it to add an oxide

1 passivation layer?

2 A. It's not very -- it's not very time consuming.
3 It is literally less than 10 percent of the time it
4 takes to make the cell.

5 Q. We also discussed silicon nitride as a
6 passivation layer. Do you recall that?

7 A. Yes.

8 Q. How difficult is it to implement a silicon
9 nitride passivation layer in 20-- as of 2014?

10 A. It was well known at that time how to do that.

11 Q. And in terms of cost, how costly would it be to
12 implement a silicon nitride passivation?

13 A. So it's not very costly to do that. You have --
14 however, you do have to use a mixture of silane and
15 ammonia for the creation of the silicon nitride film,
16 which means that the manufacturing plant itself has to
17 have additional safety precautions, which drives the
18 infrastructure cost up a little bit.

19 Q. And in terms of time added to the manufacturing
20 process, how -- how long would it take to implement a
21 silicon nitride passivation layer?

22 A. A little bit longer than the other two.

1 Q. A little bit longer than silicon oxide and
2 aluminum oxide?

3 A. No, a little bit longer than the silicon oxide,
4 the two methods of silicon oxide.

5 Q. Okay. I think you said that the silicon oxide
6 would be less than 10 percent of the overall
7 manufacturing process. Do you have a ballpark of how
8 much time in the overall manufacturing process would be
9 taken up by the aluminum oxide passivation layer?

10 A. I haven't grown the aluminum oxide passivation
11 layers myself, so I really don't know exactly how long
12 that takes. It -- it wouldn't be significantly longer,
13 but I can't tell you exactly.

14 Q. Okay. And in terms of the silicon nitride, do
15 you have a sense for how much longer that would take to
16 grow relative to the silicon oxide?

17 A. No. But from my experience, I can tell you that
18 in the laboratory scale experiments, it really is only
19 10 percent longer or so to grow it. It grows more
20 slowly and so -- and for safety's sake, you need to grow
21 it more slowly -- more slowly. But I can't tell you
22 what it would -- what that converts into on an

1 industrial scale.

2 Q. And I jumped the gun a little bit on aluminum
3 oxide. But in terms of forming an aluminum oxide
4 passivation layer, how difficult would that be to
5 implement as of 2014?

6 A. It wasn't very difficult to implement then. The
7 aluminum oxide technology had progressed and matured due
8 to the advent of high temperature from conductors. We
9 used aluminum oxide to grow all those films on top of,
10 and so people knew how to do it, how to manipulate it.

11 Q. And do you have a sense for what the cost of
12 implementing an aluminum oxide passivation layer would
13 be?

14 A. Not on an industrial scale, no. The -- what we
15 pay for it in a laboratory is different.

16 Q. Okay. Do you -- strike that.

17 Let's look at Li, Exhibit 1005.

18 A. Okay, I have it here.

19 Q. And on the front page, in the abstract, Li
20 describes a method of fabricating the back-contact solar
21 cell, right?

22 A. Yes.

1 Q. And the phrase "back-contact solar cell" also
2 appears in the title of Li, right?

3 A. Yes, it does.

4 Q. And in the figure that appears on the front
5 page, that's a back-contact solar cell, correct?

6 A. In the figure that appears on the front page,
7 yes, I believe it is. I hesitate only because the
8 stippling under 228 and 232 is the same, but, of course,
9 they would be -- they would be serving different
10 functions if it's a back-contact system.

11 Q. Li -- sorry. Let me restart.

12 Informing your opinions, you reviewed Li,
13 correct?

14 A. Yes, that's correct.

15 Q. I assume you reviewed it cover to cover,
16 correct?

17 A. Yes, I did.

18 Q. Li does not state that its solar cell is
19 directed to a particular radiation environment, correct?

20 A. Yes, that's correct.

21 Q. So Li does not state that the solar --
22 back-contact solar cell that's described therein is

1 directed only to terrestrial environments, right?

2 A. Yes, that's correct; it does not.

3 Q. And Li does not state that it is directed only
4 to one-sun environments, right?

5 A. Yes, that's correct; it does not.

6 Q. And Li does not state that it is directed to
7 non-space environments, right?

8 A. Yes, that's correct; it does not state that.

9 Q. In paragraph 38 of Li --

10 A. Yes.

11 Q. -- Li describes doping of the back-contact solar
12 cell at or near surfaces of the substrate that are not
13 covered by a material layer, correct?

14 A. It describes what again? Not covered by
15 material layer? Yes, that's right, uh-huh.

16 Q. Right.

17 And so Li discloses that the front portion of
18 the silicon substrate should be doped, but it doesn't
19 specify what the concentration of that dopant would be,
20 right?

21 A. That's right; it does not.

22 Q. And Li mentions that the front portion could be

1 doped with n-type dopants, right?

2 A. It mentions that it can be n-type dopants at or
3 near the surface of the substrate, yes.

4 Q. And if the -- if the substrate itself is n-type
5 doped and you apply n-type dopant to the front surface,
6 that would form what's called a front surface field,
7 correct?

8 A. Doping the front surface relative to anything in
9 the silicon would form a front surface field. The
10 question is really to what extent does that field extend
11 in a useful manner into the substrate. But what --
12 what's referred to as a front surface field in silicon
13 technology for solar usually means a field which can --
14 can address high-energy electrons being created by UV.

15 So -- so, yeah. So it -- just -- a front
16 surface field would, of course, be the result of any
17 dopant you put on the front of the -- of the system.

18 Q. If the dopant that you apply to the front
19 surface was opposite of the dopant that is in the
20 substrate itself, would you still call that a front
21 surface field?

22 A. Well, you wouldn't call the dopant itself a

1 field of any sort. The question might better be
2 phrased, does it create a field. Is that what you mean?

3 Q. Sure. So if you had a front portion of the
4 silicon substrate that is p-type doped on an -- on a
5 substrate that is n-type doped, what would you call
6 that -- the -- the structure that is formed at the front
7 portion?

8 A. Well, I haven't really thought about what you
9 would call that. But let me -- let me add context to
10 my -- to my answer, because when we say "front surface
11 field" in a solar cell, what we mean is a field which is
12 being created that prevents certain carriers from
13 getting to the surface of -- or the interface to the
14 surface, to the front of the device. So, for instance,
15 if I have a negative carrier and that negative carrier
16 is moving around in the material and it -- it wanders
17 around to the front of the device, it may recombine with
18 positive carriers that are up there and cause a problem.
19 So what I want to do is I want to put charge -- by using
20 dopant, put charge there to prevent that negative
21 carrier from getting there.

22 So while combinations of positive and negative

1 near the front of this device can be imagined, the only
2 combinations of any real use to you and, thus, the only
3 ones that you would call a front surface field by a
4 solar cell person are the ones that actually filter out
5 one or the other of the charges. So let's say that I
6 have done as you suggest, but I've set that device up so
7 that only negative electrons -- that is, negative
8 charges -- are going towards the front surface. It will
9 have a field at the front surface due to that charge,
10 but we would not refer to it as a front surface field
11 device because it is not serving the purpose of
12 filtering out the right kind of charge.

13 Does that make sense?

14 So it really depends very much on what you mean
15 and how the rest of the device is built. I'm sorry for
16 not being more precise, but...

17 I feel bad sometimes because I feel -- I feel
18 like I've disappointed people in my answer, but that's
19 just kind of the reality.

20 Q. One of the references that you discuss in your
21 declaration is the Muller reference. Do you recall
22 that?

1 A. Yeah, uh-huh.

2 Q. And Muller discusses a -- what is called a front
3 surface field and a front floating emitter. Do you
4 recall that?

5 A. Yes, indeed.

6 Q. Okay. What is your understanding of the
7 difference between a front floating emitter and a front
8 surface field?

9 A. Well, a front floating emitter simply means that
10 the emitter is being tied to the affinity level of the
11 material or the electron affinity of the material at the
12 front. Right. So it floats around. It is not being
13 tied to ground anywhere.

14 And so what happens is as the field is being
15 formed -- as any field is being formed on the front of
16 it, then the energy to enter that emitter simply floats
17 up with the field that is being applied, and that field
18 is being applied by the addition of the dopants. The
19 front surface field is due to the field which is built
20 into the material by the addition of dopants, but it
21 does not refer to the field which comes from the contact
22 with the emitter.

1 Q. Does the -- does the type of dopant, either
2 p-type or n-type, factor in to your analysis of whether
3 a particular structure on the front surface of the solar
4 cell is considered a front floating emitter or a front
5 surface field?

6 A. Only insofar as I know what the rest of the
7 device looks like. So I have to have the context of the
8 device to know whether or not the designer has built a
9 front surface field in there. There can be a field, but
10 this is parsing language now, because a front surface
11 field is referring to something which has functional
12 use. It does not necessarily mean there isn't a field
13 there if there's no front surface field. There can be a
14 field, and that field may do certain things. But when
15 we talk about a front surface field, we have a very
16 definite function in mind.

17 Q. Okay. In the context of a back-contact solar
18 cell, does the type of dopant that you use on the front
19 surface impact whether you are forming a front surface
20 field or a front floating emitter?

21 A. The type of dopant that you use in the
22 substrate? Is that what you're saying? Repeat your

1 question one more time.

2 Q. Yeah.

3 So in the context of a back-contact solar cell
4 -- let's assume that the substrate is n-type doped,
5 okay?

6 A. Uh-huh. Yes, okay.

7 Q. Would the type of dopant that you use at the
8 front surface of the substrate impact whether you are
9 forming a front surface field or, instead, a front
10 floating emitter?

11 A. I would say within the context for front surface
12 field that I just gave, yes, it would make some
13 difference as to whether I called it that or not. It
14 would, however, make no difference as to whether or not
15 a field exists there.

16 Q. Okay. And what type of dopant would need to be
17 used at the front surface on an n-type substrate to form
18 a front floating emitter?

19 A. For a back-contact device?

20 Q. Yes.

21 A. So I would say that you need to have something
22 which is relatively more positive, I think, than the

1 negative dopant. Am I right? For front surface
2 emitter -- no. You would want it more negative. I'm
3 sorry. So you would want to go more negative, I believe
4 it is. And so if you had an n-type, then you would have
5 to have, you know, double the n dopant and so forth. I
6 believe that's correct.

7 I'm sorry. I -- when I say "I believe that's
8 correct," keep in mind that normally if I answer such a
9 question, I sit here with my -- my pen and my pencil and
10 I draw down what -- where the pluses and where the
11 minuses are, and I'm not doing that. But I think I'm
12 right. I think it's that. I think you have to go more
13 negative, and then in the other case you go more
14 positive.

15 Q. And just for clarity, too, you're saying with an
16 n-type substrate, you would add more n-type in order to
17 form an emitter -- a front floating emitter; is that
18 right?

19 A. For the front floating emitter, I believe that's
20 right, yeah. I think that's more -- I think that's more
21 n-type, so...

22 Again, you know, I'm doing that off of the top

1 of my head, so please realize it is -- it is either --
2 for the emitter or for the front surface field, it is
3 either more negative or more positive. You have to
4 choose one of those two; and I think for the emitter
5 it's more negative. I believe that's true, but I would
6 have to sit here and play with the -- the energy
7 diagrams which I'm not doing currently.

8 Q. Let's take a look at Li, paragraph 5. This is
9 Exhibit 1005.

10 A. Li, paragraph 5.

11 Q. Yes.

12 A. Li, I've got that. And it is paragraph number
13 5?

14 Q. Yes.

15 A. Oh, okay, "Efficiency is an important
16 characteristic of a solar cell," is that what you're
17 saying?

18 Q. Yes, that's right.

19 A. Okay. I have it.

20 Q. So -- so in paragraph 5, Li states that,
21 "Efficiency is an important characteristic of a solar
22 cell," right?

1 A. Yes.

2 Q. And it states that it discloses embodiments --
3 "embodiments of the present invention allow for
4 increased solar cell efficiency," right?

5 A. "Embodiment of the present invention allow for
6 increased solar cell efficiency by providing processes
7 for" -- yes.

8 Q. Yeah, I'll just read the whole sentence for the
9 record. It says, "Embodiments of the present invention
10 allow for increased solar cell efficiency by providing
11 processes for fabricating novel solar cell structures,"
12 right?

13 A. That's correct, yes.

14 Q. Okay. Now if we could look at paragraph 24.
15 That's at the bottom of page 1 and continues on to page
16 2.

17 A. "In accordance with at least some
18 embodiments" -- yes.

19 Q. Yes, that's the right paragraph.

20 A. Uh-huh.

21 Q. And starting at the third line of paragraph 24,
22 it reads, "In some embodiments, a reduction in the sheer

1 number of process operations is achieved by using
2 process flows described herein, as compared with
3 conventional process flows."

4 Do you see that?

5 A. Yes.

6 Q. What does "in some embodiments" mean to you?

7 A. You mean in context of this thing here? It
8 simply means the different structures of the cell that
9 you're going to build, right?

10 Q. Right.

11 So it means sometimes Li will result in a
12 reduction in the number of process steps, right?

13 A. Yeah. I mean, I suppose that you could state it
14 that way. I mean, in some of the -- using Li -- yes, I
15 guess that's right. Yeah, you could say it like that,
16 yes.

17 Q. It's not a requirement of Li that in all cases
18 there is a reduction in the number of process steps,
19 right?

20 A. Exactly, yes. Exactly. Exactly.

21 Q. And, in fact, in the next sentence, Li says, "In
22 some embodiments, using process flows such as those

1 described in detail herein may be preferable over
2 conventional flows even though some of the process flows
3 described herein include an additional heating or anneal
4 operation," right?

5 A. That's correct.

6 Q. So in some embodiments, Li may actually result
7 in more process steps than a conventional process flow,
8 right?

9 A. Yes, uh-huh.

10 Q. Taking a look at paragraph 37, which is on page
11 3 of Li.

12 A. 37. 37. Got you. Yes, I'm here.

13 Q. And here Li describes a material layer of a
14 back-contact solar cell that is polycrystalline -- that
15 is a polycrystalline silicone layer and that is applied
16 onto a silicon substrate, correct?

17 A. "The present invention, material layer of
18 back-contact solar cell is a polycrystalline silicon
19 layer substrate." Yes, that's correct.

20 Q. And at the bottom of that paragraph, Li notes
21 that the silicon substrate could be single-crystalline
22 or multicrystalline, right?

1 A. Yes.

2 Q. And in paragraph 39 of Li, it refers to a
3 dielectric film, right?

4 A. Yes, it does.

5 Q. And that dielectric film is between the material
6 layer and the substrate, right?

7 A. Between the material layer of polycrystalline
8 and the substrate, yes.

9 Q. And so that dielectric layer is in the same
10 position between the substrate and the poly- -- the
11 polycrystalline, as in the '315 Patent, correct?

12 A. As in the '31 -- as in the '315, yes.

13 Q. And Li paragraph 39 states that the dielectric
14 can be silicon dioxide and has a thickness in the range
15 of 1 to 2 nanometers, right?

16 A. Yes, it does.

17 Q. And it -- it describes that that dielectric film
18 can be a tunnel oxide barrier layer film, right?

19 A. Yes, it does.

20 Q. Li doesn't require that the 1-to-2-nanometer
21 dielectric layer is formed in any particular way, right?

22 A. Li doesn't require that. But in the statement

1 where the embodiment is a tunnel oxide barrier layer,
2 then there is an additional requirement that it be
3 contiguous; otherwise it is not a tunneling oxide.

4 Q. Okay. But in terms of the methodology that's
5 used to form that layer, Li doesn't require one method
6 over other potential methods for forming that layer,
7 right?

8 A. Li does not.

9 Q. In paragraph 45 of Li --

10 A. Yes.

11 Q. -- Li describes driving dopants into the
12 polysilicon layer by heating the cell to a temperature
13 of approximately 950 degrees celsius, right?

14 A. Li does describe that in paragraph 45.

15 Q. And 950 degrees celsius is 50 degrees higher
16 than the 900-degree threshold that is set in the
17 examples of the '315 Patent, correct?

18 A. That is correct.

19 Q. Li doesn't state how long the heating process
20 takes place, right?

21 A. Li does not state how long.

22 Q. And Li also doesn't describe the target dopant

1 concentration of the polycrystalline after the heating
2 process is completed, right?

3 A. Li does not describe the target dopant
4 concentration after the heating.

5 Q. In your declaration, I believe you pointed out
6 that in Li the heating process to dope the
7 polycrystalline layer -- polycrystalline layers would
8 take place before the doping of Li's front surface of
9 the substrate; is that correct?

10 A. It can do, yes.

11 Q. It can be, but it's not required that the
12 heating of the -- the heating to drive in dopants to the
13 polycrystalline takes place before the front surface,
14 right?

15 A. Yes, that's correct.

16 Q. If the heating to dope the polycrystalline
17 layers takes place before the doping of the front
18 surface -- sorry. Let me strike that.

19 So at least in some embodiments, Li permits the
20 heating step at 950 degrees to diffuse dopants into the
21 polysilicon to occur before any other heating steps take
22 place with respect to the silicon -- the silicon

1 substrate, right?

2 A. Yes. That's my understanding, yes.

3 Q. If you'd take a look at your declaration,
4 paragraph 45 [sic], which is on page 78.

5 A. I have it.

6 Q. Okay. And in this sentence you state, "A person
7 of ordinary skill in the art would have chosen a dopant
8 concentration that was appropriate for the particular
9 application."

10 A. No, that -- what I'm talking about --

11 Q. Do you see that? Paragraph 145.

12 A. 145. I thought it was 45. Sorry.

13 Q. Oh, apologies.

14 A. 145.

15 Q. Sure.

16 A. I was confused there for a moment.

17 Yes, I've read that, uh-huh.

18 Q. Okay. And so you -- you state your opinion that
19 a person of ordinary skill in the art would have chosen
20 a dopant concentration that was appropriate for the
21 particular application, right?

22 A. That's correct, yes.

1 Q. And that's the particular application to which
2 the solar cell is going to be put, right?

3 A. Yes, but involved in that application that
4 you're going to use is the structure of the solar cell
5 itself. So for different applications, the structure of
6 the cell may be different, and you have to take into
7 account the balance of charge within the solar cell and,
8 of course, the spectral content of the solar -- the
9 solar spectrum.

10 Q. And it would have been within the capability of
11 a person of ordinary skill in the art to take all of
12 that into account and determine what the front dopant
13 concentration would be for a particular solar cell,
14 right?

15 A. Yes. They would have been able to have
16 determined what that should be.

17 Q. In your declaration you do not dispute that
18 King, Swanson-352, Marvin and Muller all disclose
19 examples in which solar cells were constructed with a
20 front portion of the substrate that was doped to a
21 concentration of approximately 2 times 10^{18}
22 per cubic centimeter or less, right?

1 A. That's right. I do not dispute that they
2 disclose that particular dopant for a very specific
3 region of their cells.

4 Q. Instead, one of the opinions you provided is
5 that King, Swanson-352 and Marvin are, quote,
6 "outdated," right?

7 A. Yes. I don't mean to be derogatory.

8 Q. And in paragraph 137 of your declaration -- do
9 you want to turn to that? It's on page 73. Please let
10 me know when you're there.

11 A. I will.

12 I am there.

13 Q. Okay. And in the sentence that starts paragraph
14 137 and goes on to the next page, you say that King,
15 Swanson-352 and Marvin disclose solar cell structures
16 that were no longer in use, right?

17 A. Yes.

18 Q. And that's -- by that, you mean no longer in use
19 as of 2014, I take it?

20 A. Yes, that's correct. We had adjusted them,
21 uh-huh.

22 Q. What did you do to confirm that the designs of

1 King, Swanson-352 and Marvin were no longer in use as of
2 2014?

3 A. So the parameters that are used for dopants and
4 so forth in solar cells in all of these can be found
5 primarily in the modern literature, particularly
6 literature which is describing what the overall
7 performance metrics are for the dopant concentrations,
8 the thicknesses and so forth. So if you look at the --
9 for -- for an example, if you look at the solar cells
10 that we currently float in space, you'll see that they
11 are not -- those parameters are no longer the same as
12 the ones that are described in Marvin and so on.

13 So what I did was I looked at current literature
14 and the current literature of manufacturing --
15 manufacturing processes as it can be found, and in both
16 of those cases we see deviations from King, Swanson and
17 Marvin. So that's what I used as my standard.

18 Q. You can't rule out the possibility that
19 somewhere in the world in 2014 a solar cell meeting the
20 parameters of King, Swanson-352 or Marvin was still in
21 use, right?

22 A. No. They may very well have been in use. The

1 question is whether or not a major manufacturer was
2 making those any longer.

3 Q. And can you rule out the possibility that a
4 major manufacturer was still manufacturing at least some
5 solar cells that would have met King, Swanson-352 or
6 Marvin's specifications as of 2014?

7 A. I cannot rule that out, no.

8 Q. In your declaration you point to four other
9 references that you say teach to use a higher dopant
10 concentration on the front portion of the solar cell.
11 Do you recall that?

12 A. Yes.

13 Q. And those references are called Granek, Lamers,
14 Desa and Procel, right?

15 A. Yes.

16 Q. And I think you characterized those as more
17 recent than King, Swanson and Marvin, right?

18 A. I believe I did, yes.

19 Q. Okay. Do you believe that a person of ordinary
20 skill in the art would have been more likely to consult
21 and rely on the statements in those more recent
22 references when attempting to determine the

1 concentration that should be used in Li's front portion
2 of the silicon substrate?

3 A. I believe that they would have, yes. But,
4 again, of course, it would've depended a little bit on
5 what they were trying to design the cell to do. Don't
6 forget that part.

7 Q. And one of your opinions is that Li is, quote,
8 "incompatible with King, Swanson-352 and Marvin because
9 those three references include a thick silicon oxide
10 passivation layer on the front side of the silicon
11 substrate," correct?

12 A. Yes.

13 Q. Okay. And you say that Li does not disclose
14 using a passivation oxide layer at all on the front side
15 of its substrate, right?

16 A. Yes, that's right. We just -- we just mentioned
17 that.

18 Q. Right.

19 And I assume you say that because Li is silent
20 regarding whether there's a passivation layer applied to
21 the front surface, right?

22 A. Yes, that's right. That's what we had -- had

1 just said previously.

2 Q. There is no statement in Li that says, Do not
3 apply a silicon oxide passivation layer to the front
4 surface, right?

5 A. No, there is no statement that says that.

6 Q. And, in fact, as of 2014 it would've been
7 unusual to construct a silicon -- a back-contact solar
8 cell without some form of passivation on the front
9 surface, right?

10 A. It would've been unusual, yes.

11 Q. It would've been a bad idea, I believe you said,
12 right?

13 A. Yeah. Well, yeah, it, generally speaking, would
14 not protect it against -- protect it against oxidation.
15 But in 2014, don't forget that people were beginning to
16 use the urea-based polymers, and so the -- in terms of
17 adding a passivation layer, it didn't necessarily need
18 to be silicon dioxide. It could've been a spray-on
19 polymer.

20 Q. What you just described as a spray-on polymer,
21 that would still serve as a -- as a form of passivation,
22 right?

1 A. So the polymer itself would not necessarily have
2 formed a passivation layer. It would've formed a
3 protective layer for oxidation. So if you chose to,
4 let's say, really heavily dope the front and you decide
5 that in that heavy doping that you're not going to drive
6 the dopant deep into -- into the system so that much of
7 the dopant remains at the front, then the only thing you
8 really need to do is to protect it against oxidation,
9 and so you could've done that.

10 Anyone, I think, skilled in the art would know
11 that, because we just talked about, for instance,
12 gettering and how gettering can mean not to get rid of
13 the -- the metal impurities, but to instead make them
14 not affect the electronics. Well, the same thing holds
15 true for the defects that exist on the surface. Adding
16 a passivation layer is a very nice way to do it, but, of
17 course, you could passivate by using very specific types
18 of dopants that interacted with those defects, and then
19 you simply need to protect against oxidation. And there
20 are references to those out in the literature.

21 Q. Li doesn't contain any statement that suggests
22 to use a spray-on polymer on the front surface, correct?

1 A. No, he does not. No.

2 Q. If you could take a look at paragraph 133 of
3 your declaration, Exhibit 2021.

4 A. 133. Granek. Yes, I'm there.

5 Q. Okay. So in this paragraph you discuss a
6 reference that has been called Granek, right?

7 A. Uh-huh.

8 Q. Okay. And you said that Granek shows a
9 correlation between the thickness of the silicon oxide
10 passivation layer and the dopant concentration on the
11 front side of the substrate, right?

12 A. Yes.

13 Q. Can you explain what you meant by Granek showing
14 a correlation between oxide thickness and dopant
15 concentration?

16 A. Sure. Simply that as the oxide is increased in
17 thickness, then the concentration at the very front that
18 is at the interface between where the oxide is and where
19 the dopant is in the -- in the silicon, that -- that
20 beginning concentration changes. Now, the reason for
21 that is discussed in Granek as to why that can be, and
22 so that's what we're talking about. As you make the

1 front thickness of the oxide thicker and thicker and
2 thicker, then the distribution of the charge -- that is,
3 the dopants that are adding charge to the system -- that
4 distribution as you go in -- following the normal to the
5 surface as you go in, that changes, right, after you've
6 applied certain heating steps.

7 Now, of course, you can see clearly why that
8 would happen, because you are taking up a very specific
9 amount of the heat capacity of the substrate by silicon
10 dioxide in the front, and so that's what's happening.
11 But, clearly, as -- we know why this happens. But the
12 thickness of the film that you put in the front is going
13 to determine how those dopants distribute themselves
14 beneath that film.

15 Q. You present some of Granek's results on page 71
16 of your declaration, right?

17 A. Yes.

18 Q. And these figures are annotated. Those are your
19 annotations that you added, right?

20 A. That's right. We -- we -- yeah, I did.

21 Q. And --

22 A. It's a draw of the eye, we say.

1 Q. And you note four examples in Granek Table 2
2 that you classify as thin oxides, right?

3 A. Yes, uh-huh.

4 Q. And one of those is in blue at the very bottom.
5 It has a diffusion number of 353, right?

6 A. Yes, that's correct. Yes.

7 Q. And of the -- of the thin oxides, that one
8 you've highlighted in blue appears to be the highest
9 performing; is that correct?

10 A. Yes.

11 Q. Okay. And then in the red -- highlighted in
12 red, you have what you called thick oxide, and you say
13 "e.g., King, Swanson-352 and Marvin," right?

14 A. That's right.

15 Q. And so you're representing that the
16 red-highlighted example is similar to the solar cell
17 that's described in King, Swanson-352 and Marvin, right?

18 A. For instance, yes.

19 Q. Okay. Can you explain what the difference is,
20 in terms of performance, that's observed between the
21 blue- and the red-highlighted examples?

22 A. Sure.

1 So the -- the things that you've got -- the
2 numbers that are being given down there are numbers that
3 tell you what the power rectangle of the device is.
4 That is the open circuit -- the open circuit voltage and
5 the short circuit current. So when you put those two
6 things together, that represents the maximum amount of
7 power that the system can give you.

8 And so what you want is the open circuit voltage
9 to be fairly large and you want the short circuit
10 current -- I'm sorry, the -- the -- yeah, the -- the
11 open circuit voltage and the short circuit current to be
12 large. But what you have to do is you have to recognize
13 that if I make one too big, the other one goes down.
14 And so the thing that makes these things perform better
15 is what's known as the power -- this power rectangle.
16 So it is the multiplication of the two times power
17 factor.

18 And so in this particular case, the 31 times the
19 -- the 710, that's -- that's going to represent sort of
20 the best number that I can get in the power rectangle
21 for a certain amount of -- of -- of photons that are
22 hitting the device. So that's what you've got to be

1 able to do. So you're balancing those two things. So,
2 in other words, the little grayish strip there is
3 showing you a device that gives you the best overall
4 power output.

5 Q. Okay. And among these -- these options that are
6 reported in Table 2, is the solar cell that's
7 highlighted in red the second-best in terms of power
8 output?

9 A. Let me see. Yes, it looks like it is the
10 second-best for these particular examples, yes.

11 Now, keep in mind that the JOS is referring to
12 how much leakage that you're getting for -- due to -- to
13 the recombination, right. So it's not showing you the
14 actual short circuit current.

15 Q. And so it appears that the red -- the
16 red-highlighted deep diffusion example is resulting in
17 better performance than the three thin oxide examples
18 that are not highlighted, correct?

19 A. Yes. In this example, that's exactly right for
20 these particular front surface field diffusions.

21 Q. Okay. If we could turn to the next page. I'd
22 like to look at paragraph 135.

1 A. Uh-huh, 135.

2 Q. Sorry. Before we go there, I just have one more
3 question about Table 2.

4 A. Sure.

5 Q. In terms of the difference between -- in power
6 output between the blue-highlighted example and the
7 red-highlighted example --

8 A. Uh-huh.

9 Q. -- what is the magnitude of the -- of the
10 difference?

11 A. The magnitude of the difference between what?

12 Q. Sorry. I -- as between the blue-highlighted
13 example and the red-highlighted example, in terms of
14 performance, are those -- would you consider those to be
15 relatively close in -- in terms of efficiency?

16 A. They are close relative to the numbers that you
17 see here, but they are not close, no. The reason I say
18 that is you notice that the units that are being used
19 are millivolts and inverse square centimeters. Solar
20 cells are built to cover meters. So when we talk about
21 the amount of leakage current that you're getting per
22 square centimeter, it looks like, wow, gee, that

1 number's almost the same thing. But when you multiply
2 that over the thousands of square centimeters it takes
3 to make up a square meter, then that panel is leaking
4 far more current than the -- the panel in blue. So in
5 actual fact, the numbers can look deceiving because they
6 are scaled by square centimeters.

7 Q. Okay. Now turning to paragraph 135.

8 A. Sure.

9 Q. On page 72.

10 A. 135; accordingly, Granek.

11 Q. Yes. You say, "At a minimum, Granek proves that
12 front-surface dopant concentration is dependent on the
13 thickness of the front-side oxide passivation layer and
14 that it was not settled in 1990," right?

15 A. Yes.

16 Q. In other words, a skilled artisan would
17 recognize that you could use a low dopant concentration
18 in a thick oxide or a high dopant concentration and a
19 thinner oxide, right?

20 A. Well, I would say it a little bit differently:
21 A skilled artisan wouldn't have known which one of those
22 to chose.

1 Q. As of 1990?

2 A. As of 1990.

3 Q. Okay. How about as of 2014? Would you agree
4 that a skilled artisan would have known that you could
5 either use a low dopant concentration and a thick oxide
6 or a higher dopant concentration and a thin oxide?

7 A. I would say that they would be more likely to
8 have known, yes. There was still a lot of debate in the
9 literature, but, yes, they would have been more likely
10 to have known.

11 Q. And would you say that a skilled artisan would
12 have been able to implement either of those options?

13 A. Oh, yes, I think so.

14 Q. Okay. Let's talk for a moment about the
15 Li-Muller combination.

16 A. Okay.

17 Q. Is it your understanding that in the petition
18 there's a discussion of replacing Li's front-surface
19 doping with Muller's ion-implanted boron floating
20 emitter?

21 A. Please say that one more time. I'm sorry.

22 Q. Yeah. In the petition and in Dr. Banerjee's

1 declaration, is it your understanding that the
2 combination that's being contemplated is replacing Li's
3 front-surface dopant -- doping via gaseous doping with
4 Muller's ion-implanted boron floating emitter?

5 A. Yes, I believe that is what they're thinking. I
6 think that's what -- I believe that is what Dr. Banerjee
7 intended to convey.

8 Q. And Dr. Banerjee did not suggest changing Li's
9 back-side doping process based on Muller, right?

10 A. Yes, that's right. I don't believe that he did,
11 uh-huh.

12 Q. So in terms of the dopant drive-in step on the
13 back side of Li's solar cell, that would be the same in
14 the Li-Muller combination as in the Li-King combination,
15 for example?

16 A. Yes, for example, if one were to do that.

17 Q. Okay. Can you take a look at paragraph 150 --

18 A. Sure.

19 Q. -- of your declaration?

20 A. Uh-huh.

21 Q. That's on page 80.

22 A. I'm there. "When Muller used an n-type dopant

1 source."

2 Q. Right.

3 So do you agree that Muller reported better
4 results for the boron-diffused ion-implanted emitter
5 than for the phosphorous-diffused surface field?

6 A. Let me remind myself of that, because that's a
7 very specific question, when you're asking better
8 results. So the Muller --

9 Q. Sure. Muller is Exhibit Number 1008, I believe.
10 And I'll put it in the chat just so we all have it.

11 A. Oh, okay. That would be great. Make it very
12 easy.

13 Q. It should be in your printed materials, but just
14 so we all have it.

15 A. 1000 -- oh, I have it up here. Let me just get
16 this here.

17 Q. Okay.

18 A. Oh, yes, that's right. It's the lovely work
19 from the Fraunhofer.

20 And so your question was specifically whether or
21 not -- your question was, what did you believe was
22 better in Muller?

1 Q. Sure. Let me restate the question.

2 Do you agree that Muller reported better results
3 for a boron-diffused ion-implemented emitter than for a
4 phosphor-diffused front surface field?

5 A. Just a moment. I have to remind myself, I'm
6 sorry. The reason I remind myself on this is simply
7 that different passivation layers were used, and so it's
8 hard to say that something was better, because it is not
9 the same. However, in terms of the J_0 values, which
10 would be the current that's leaking due to
11 recombination, those that he describes -- that Muller
12 describes are better than the ones that you see for the
13 front surface passivation -- or for the front surface
14 field. I apologize.

15 And so, yes, that is true. And if you look at
16 the filling factors for these things then the filling
17 factors on the front surface -- the front surface field
18 versus the front -- the front of the floating emitter,
19 you'll notice that the filling factor itself is better
20 for the front surface field. In that case, I would say
21 no, in -- the front surface field system is -- is
22 operating better.

1 So a filling factor is the thing that tells you
2 how close to its ideal function it is coming, so how
3 close to what it can do is it getting. And in that
4 case, the front surface field device is working better
5 than the floating emitter device. However, the leakage
6 current, the JO, is telling you how well you're
7 passivating things and how well that's functioning, and
8 that is better in Muller's floating emitter.

9 So the reason we say that is that you always
10 have to compare the best device to the best device. You
11 don't necessarily compare apples to apples. We like to
12 think, oh, compare apples to apples, but if you're
13 building solar cells, you have to -- you have to design
14 the best device you can using a principle, and then
15 compare it to the comparative principle and build the
16 best device in that way that you can. Those are the
17 things that you must compare.

18 And so I would say that in one way Muller's
19 device is better; in another way it is not better.

20 I'm sorry, that's not as definitive maybe as you
21 wanted, but it is -- it is a frequently seen thing in
22 literature.

1 Q. Have you ever performed ion implantation to dope
2 the front surface of a silicon substrate?

3 A. Oh, Lordy, yes. It's -- it's a pain.

4 Q. Is that a hard process to implement?

5 A. It is not, no.

6 Q. Are there advantages to using ion implantation
7 over other methods of doping the front surface?

8 A. The advantage is generally conceded to be better
9 positioning of the concentration as you go in normal to
10 the surface. So you have better control over that.
11 That's typically the advantage.

12 Q. And in terms of time, how does the time required
13 to implement ion implantation compare to other methods
14 of doping front surface?

15 A. The actual dopant process itself, ion is faster.
16 The preparation of everything for ion is slower. So
17 they end up being about the same.

18 Q. And in terms of cost, how would ion implantation
19 compare to other methodologies for doping the front
20 surface?

21 A. The other methodologies are generally cheaper.

22 Q. Is it a lot cheaper or -- what's the magnitude?

1 A. No, no, it's not a lot cheaper, but it does take
2 a lot of power to do ion implantation, and you have to
3 have very pure gases to do -- put into the implanters.
4 So, generally, yeah, it's a little bit more expensive.

5 MR. PETERSON: Let's go off the record.

6 THE COURT REPORTER: Off the record at
7 2:38.

8 (Recess.)

9 THE COURT REPORTER: Back on the record
10 at 2:45.

11 MR. PETERSON: Thank you for your time,
12 Dr. Carroll.

13 I'll pass the witness.

14 MR. SNODGRASS: I have no questions, so I
15 think we can go off the record.

16 THE COURT REPORTER: Off the record at
17 2:45.

18 (The deposition was concluded at 2:45
19 p.m.)

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DISCLOSURE

Pursuant to Article 10.B of the Rules and Regulations of the Board of Court Reporting of the Judicial Council of Georgia which states: Each court reporter shall tender a disclosure form at the time of the taking of the deposition stating the arrangements made for the reporting services of the certified court reporter, by the certified court reporter, the court reporter's employer or the referral source for the deposition, with any party to the litigation, counsel to the parties, or other entity. Such form shall be attached to the deposition transcript, I make the following disclosure: I am a Georgia Certified Court Reporter. I am here as a representative of Planet Depos.

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10 *Susan DiFilippantonio*

11 Susan DiFilippantonio, Notary Public
12 and Registered Professional Reporter
Commission Expires 11-22-2030
Georgia Certificate Number 2125

1 STATE OF GEORGIA:

2 COUNTY OF FULTON:

3 I hereby certify that the foregoing transcript was
4 reported, as stated in the caption, and the questions
5 and answers thereto were reduced to typewriting under my
6 direction; that the foregoing pages represent a true,
7 complete, and correct transcript of the evidence given
8 upon said hearing, and I further certify that I am not
9 of kin or counsel to the parties in the case; am not in
10 the employ of counsel for any of said parties; nor am I
11 in any way interested in the result of said case.

12

13

14 *Susan DiFilippantonio*

15 Susan DiFilippantonio, Notary Public
16 and Registered Professional Reporter
Commission Expires 10-22-2028
Georgia Certificate Number 2125

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CAPTION

The Deposition of DAVID L. CARROLL, PH.D., taken in the matter, on the date, and at the time and place set out on the title page hereof.

It was requested that the deposition be taken by the reporter and that same be reduced to typewritten form.

It was agreed by and between counsel and the parties that the Deponent will read and sign the transcript of said deposition.

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CERTIFICATE OF REPORTER

STATE OF GEORGIA

COUNTY OF FULTON

Before me, this day, personally appeared, DAVID L. CARROLL, PH.D., who, being duly sworn, states that the foregoing transcript of his deposition, taken in the matter, on the date, and at the time and place set out on the title page hereof, constitutes a true and accurate transcript of said deposition.

If no changes need to be made on the following two pages, place a check here ____, and return only this signed page.

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DEPOSITION ERRATA SHEET

Assignment No: 587647

Case Caption: CANADIAN SOLAR, INC. -vs- MAXEON SOLAR
PTE, LTD.

Witness: DAVID L. CARROLL, PH.D.

DECLARATION UNDER PENALTY OF PERJURY I declare
under penalty of perjury that I have read the entire
transcript of my deposition taken in the captioned
matter or the same has been read to me, and the same is
true and accurate, save and except for changes and/or
corrections, if any, as indicated by me on the
DEPOSITION ERRATA SHEET hereof, with the understanding
that I offer these changes as if still under oath.

_____ There are no changes noted.

_____ The following changes are noted:

Page No.____ Line No.____
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6 Should read: _____

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8 Page No. ____ Line No. ____
9 Should read: _____

10 Reason for Change: _____

11 SIGNATURE OF DEPONENT

12 DAVID L. CARROLL, PH.D. _____

13 Sworn to and subscribed before me
14 this ____ day of _____, ____.

15

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1 CERTIFICATE OF SHORTHAND REPORTER - NOTARY PUBLIC

2 I, Mary Susan DiFilippantonio, RPR, RMR, CRR, Court
3 Reporter and Notary Public within and for the State of
4 Georgia, do hereby certify:

5 That DAVID L. CARROLL, PH.D., the witness whose
6 deposition is hereinbefore set forth, was duly sworn by
7 me before the commencement of such deposition and that
8 such deposition was taken before me and is a true record
9 of the testimony given by such witness.

10 I further certify that the adverse party, Canadian
11 Solar, was represented by counsel at the deposition.

12 I further certify that the deposition of DAVID L.
13 CARROLL, PH.D., occurred remotely, on June 18, 2025,
14 commencing at 8:59 a.m., to 2:45 p.m.

15 I further certify that I am not related to any of
16 the parties to this action by blood or marriage, I am
17 not employed by or an attorney to any of the parties to
18 this action, and that I am in no way interested,
19 financially or otherwise, in the outcome of this matter.

20 IN WITNESS WHEREOF, I have hereunto set my hand on this
21 June 18, 2025.

22 My commission expires:

1 October 22, 2028

2
3 *Susan DeFilippantonio*

4 _____
5 NOTARY PUBLIC IN AND FOR THE STATE OF GEORGIA.

A			
ability	202:14, 207:17	90:12, 115:9,	additional
22:15, 31:10,	above	182:1	9:8, 11:5,
61:9	98:11, 115:18,	achievement	12:6, 168:17,
able	127:18, 134:12,	25:1	183:3, 185:2
24:19, 86:17,	134:20, 138:14,	across	address
86:19, 103:20,	139:8, 139:12,	54:11, 54:21,	173:14
103:21, 112:18,	140:1, 140:8,	73:2, 96:12,	adds
112:19, 161:7,	142:14, 142:21	120:20, 122:6,	163:17
161:9, 188:15,	absolutely	130:14, 156:10,	adhesive
199:1, 202:12	14:17, 16:7,	163:20	43:11
about	64:2, 71:3,	act	adjusted
11:18, 11:19,	82:17, 118:19,	161:19	189:20
12:3, 14:6,	162:13	acted	advantage
16:10, 17:20,	absorber	12:15	207:8, 207:11
19:9, 22:22,	39:14	acting	advantageous
23:16, 23:17,	absorption	116:22	28:17, 47:19,
25:10, 28:4,	20:9, 46:15,	action	126:1
28:18, 34:21,	162:21, 162:22	216:16, 216:18	advantages
35:6, 36:1,	abstract	actions	207:6
36:2, 39:11,	170:19	35:2	advent
42:16, 42:19,	academia	active	52:9, 70:17,
44:13, 45:9,	40:6	114:8	170:8
46:17, 48:18,	academic	actual	adverse
48:19, 49:3,	24:2, 24:3,	85:1, 85:7,	216:10
49:14, 50:5,	38:18, 38:20,	120:21, 135:9,	aerial
50:10, 54:3,	38:21	156:4, 167:8,	163:17, 163:18
62:15, 62:17,	accessible	199:14, 201:5,	affect
67:4, 67:19,	103:1	207:15	115:3, 121:1,
69:20, 70:1,	accidental	actually	194:14
70:14, 72:3,	28:14	38:9, 72:11,	affected
72:5, 72:12,	accommodate	75:3, 79:17,	22:6
74:22, 75:6,	25:13	126:5, 175:4,	affects
75:18, 77:8,	accordance	183:6	22:3, 113:19
80:10, 86:21,	181:17	add	affinity
87:10, 112:2,	according	76:19, 97:9,	176:10, 176:11
113:6, 113:7,	78:10, 128:9	158:7, 160:17,	affixed
123:6, 127:1,	accordingly	163:19, 167:16,	139:6
129:8, 130:16,	201:10	167:22, 174:9,	after
136:7, 143:16,	account	179:16	8:13, 11:6,
152:21, 156:18,	80:18, 91:1,	added	11:15, 11:16,
161:12, 161:22,	188:7, 188:12	167:15, 167:21,	19:8, 21:11,
164:6, 167:5,	accurate	168:19, 196:19	32:19, 45:8,
174:8, 177:15,	213:9, 214:10	adding	76:20, 99:3,
187:10, 194:11,	achieve	163:20, 193:17,	101:14, 101:16,
195:22, 200:3,	24:17, 61:4,	194:15, 196:3	101:20, 102:12,
200:20, 202:3,	89:5, 89:22,	addition	108:7, 108:9,
	90:3, 106:7	158:17, 176:18,	109:9, 111:9,
	achieved	176:20	111:20, 116:8,
	78:4, 90:3,		

136:4, 186:1, 186:4, 196:5 afterwards 62:20 again 8:21, 48:17, 66:10, 94:4, 94:5, 95:22, 118:4, 122:19, 150:5, 153:18, 161:3, 163:15, 172:14, 179:22, 192:4 against 193:14, 194:8, 194:19 agency 210:2 ago 33:17, 34:13, 39:11, 47:13, 131:7, 159:6 agree 66:11, 78:21, 81:17, 89:10, 89:11, 89:16, 89:18, 90:21, 101:2, 104:16, 104:17, 112:21, 117:2, 150:22, 202:3, 204:3, 205:2 agreed 212:8 agreement 209:22 agreements 13:15 agrees 139:6 ah 91:18, 94:14 ahead 112:16, 117:18 all 6:8, 6:21, 11:1, 15:8, 16:8, 16:10,	17:4, 29:11, 32:8, 35:7, 41:5, 41:10, 42:2, 42:9, 44:12, 45:3, 45:21, 47:16, 48:22, 52:16, 57:18, 69:11, 76:5, 77:9, 78:20, 79:6, 79:9, 79:10, 79:13, 90:1, 94:3, 106:15, 107:11, 108:15, 109:6, 117:6, 118:1, 118:9, 118:17, 123:11, 123:18, 123:19, 136:1, 158:11, 164:16, 165:19, 170:9, 182:17, 188:11, 188:18, 190:4, 192:14, 204:10, 204:14, 210:5 allow 40:2, 46:3, 181:3, 181:5, 181:10 allowed 13:13, 13:17 allowing 132:22 allows 166:12 almost 27:4, 36:2, 47:2, 69:10, 77:9, 201:1 along 33:4 alpha 40:10, 70:20 already 6:10, 7:21, 58:18, 60:10, 69:14, 145:15 also 7:12, 23:12,	30:12, 31:1, 31:2, 36:4, 38:14, 40:5, 45:11, 50:6, 55:16, 58:1, 59:4, 62:9, 65:3, 65:7, 74:1, 74:12, 75:22, 77:10, 77:20, 80:22, 82:9, 94:20, 98:14, 107:3, 124:17, 124:21, 131:16, 132:16, 132:20, 137:14, 138:13, 147:5, 148:17, 158:21, 159:2, 162:6, 168:5, 171:1, 185:22 altered 10:19 alternative 146:11 although 40:3, 132:1, 162:9 alumina 160:15, 161:11 aluminium 161:4 aluminum 43:10, 161:13, 169:2, 169:9, 169:10, 170:2, 170:3, 170:7, 170:9, 170:12 always 27:4, 47:2, 67:15, 68:4, 79:10, 158:10, 206:9 ammonia 168:15 among 106:20, 127:16, 135:14, 135:20, 199:5	amorphous 40:10, 43:6, 152:20 amount 17:16, 53:6, 62:18, 78:3, 78:19, 80:12, 85:19, 88:2, 98:10, 98:14, 98:15, 101:21, 103:13, 114:15, 127:22, 151:4, 151:21, 152:3, 155:17, 156:4, 166:18, 196:9, 198:6, 198:21, 200:21 analysis 58:20, 177:2 angeles 2:6 angstroms 83:4 anneal 107:13, 183:3 anneals 105:13 annotated 139:3, 196:18 annotation 138:17 annotations 196:19 another 5:8, 27:20, 30:16, 73:13, 79:18, 113:14, 114:11, 144:9, 146:11, 147:8, 159:6, 206:19 answer 19:15, 23:14, 29:15, 35:22, 44:1, 44:6, 73:7, 73:22, 76:10, 102:21, 117:20, 117:21, 148:13, 148:21,
--	---	--	---

155:21, 174:10, 175:18, 179:8 answered 8:13 answering 52:22 answers 7:22, 53:2, 211:5 any 5:14, 5:21, 8:11, 9:8, 9:22, 10:13, 10:22, 13:19, 14:7, 16:12, 16:16, 16:17, 16:18, 17:19, 31:16, 32:1, 33:3, 33:4, 49:12, 49:14, 58:8, 60:6, 61:21, 63:14, 63:15, 75:14, 77:16, 78:11, 80:1, 84:11, 85:21, 87:5, 90:18, 93:21, 121:19, 124:17, 126:8, 126:18, 132:5, 132:7, 132:16, 133:13, 138:2, 142:21, 147:15, 149:11, 154:8, 158:5, 164:19, 164:20, 165:5, 173:16, 174:1, 175:2, 176:15, 184:21, 186:21, 191:2, 194:21, 209:10, 209:20, 210:1, 210:2, 210:6, 211:10, 211:11, 214:11, 216:15, 216:17 anybody 8:22, 23:17, 51:14 anymore 37:16	anyone 5:17, 5:20, 8:15, 51:10, 51:12, 100:5, 164:17, 164:22, 194:10 anything 6:6, 6:14, 6:15, 14:12, 23:4, 23:17, 23:22, 34:20, 36:7, 58:16, 68:3, 133:7, 142:21, 163:19, 164:17, 165:1, 173:8 anyway 104:8 anywhere 114:11, 176:13 apologies 187:13 apologize 7:4, 18:14, 92:22, 113:1, 118:6, 126:15, 205:14 apparatus 150:9 appeal 1:2 appearances 2:1 appeared 213:4 appears 15:21, 15:22, 16:3, 92:4, 93:8, 94:15, 104:21, 131:17, 171:2, 171:4, 171:6, 197:8, 199:15 apples 206:11, 206:12 applicable 158:2 applicant 64:20, 66:5	application 162:16, 187:9, 187:21, 188:1, 188:3 applications 153:13, 153:14, 163:12, 188:5 applied 25:8, 158:4, 176:17, 176:18, 183:15, 192:20, 196:6 applies 26:13, 132:16, 158:11 apply 28:3, 132:16, 132:20, 173:5, 173:18, 193:3 applying 162:17, 167:11 appreciate 141:5 approach 79:18, 89:15 approaches 88:21 appropriate 11:18, 132:7, 187:8, 187:20 approximate 73:19 approximately 51:5, 56:6, 83:18, 83:20, 102:1, 102:13, 102:16, 102:18, 109:18, 111:7, 130:10, 151:5, 153:11, 185:13, 188:21 approximation 73:15 april 16:3 architecture 20:7, 39:7, 47:19, 74:2	area 40:18, 103:22 areas 18:20, 18:21, 165:12 aren't 16:12, 16:13, 119:15 argument 56:12 around 19:19, 41:13, 52:17, 76:2, 92:10, 128:22, 129:16, 131:2, 174:16, 174:17, 176:12 arrangements 209:7 art 56:21, 57:6, 63:22, 64:8, 65:4, 80:8, 100:5, 161:15, 187:7, 187:19, 188:11, 191:20, 194:10 article 209:2 articulate 85:12 artisan 159:17, 159:19, 161:7, 165:16, 165:19, 201:16, 201:21, 202:4, 202:11 asked 8:6, 16:11, 17:17, 18:5, 19:10, 34:13, 50:19, 50:20, 58:7 asking 56:10, 56:18, 57:3, 78:6, 123:6, 204:7 aspects 79:4
--	--	--	---

asserted 57:13 assessing 55:2, 63:21 assigned 147:18 assignee 65:7, 65:9, 65:15, 66:4 assignment 214:2 associated 144:6, 144:7, 144:11, 156:9 assume 8:9, 171:15, 178:4, 192:19 assuming 94:10 assumption 150:18 assumptions 85:8, 85:12, 154:3 atmosphere 46:4 atmospheric-pres- sure 133:12 atom 31:10, 116:10, 116:21, 116:22, 118:13, 120:21, 121:11, 137:1 atomic 152:8, 153:1 atomically 152:11 atoms 30:20, 35:1, 35:7, 85:14, 119:21, 122:2, 125:8, 135:10, 155:13, 155:14, 156:3, 156:4, 156:10 attached 209:12	attack 165:13 attempting 191:22 attorney 216:17 attorneys 17:3, 19:9, 50:18 austin 2:3, 4:10 australia 96:7 australian 100:9 author 51:17 authored 13:8 authors 101:3, 103:20 available 7:17, 86:6, 87:1, 87:6, 158:13, 160:1, 164:9 avenue 2:5, 2:14 average 153:9 aware 16:16, 16:17, 18:21, 20:10, 23:16, 27:13, 30:19, 32:12, 52:5, 77:19, 164:19, 164:22 away 6:2, 47:9, 68:5, 69:8, 73:10, 87:16, 165:10 axis 95:16, 108:6 B b2 1:10	back 19:8, 20:15, 20:18, 42:9, 47:14, 47:16, 48:22, 50:22, 59:21, 60:2, 123:1, 128:15, 128:20, 141:1, 141:4, 159:21, 203:13, 208:9 back-contact 42:6, 42:8, 66:12, 66:16, 158:2, 159:12, 159:16, 160:1, 161:8, 164:15, 165:6, 166:3, 170:20, 171:1, 171:5, 171:10, 171:22, 172:11, 177:17, 178:3, 178:19, 183:14, 183:18, 193:7 back-side 203:9 backscattering 96:9, 103:5 bad 71:7, 78:15, 78:16, 78:17, 78:19, 165:2, 165:7, 175:17, 193:11 balance 68:5, 74:6, 74:7, 74:13, 188:7 balanced 74:1, 74:10 balancing 199:1 ballpark 169:7 band 27:20, 27:21, 73:11, 77:13, 113:17, 113:18, 145:9, 145:10, 160:11, 161:1 banerjee 49:6, 50:2, 50:4, 50:6, 154:17, 203:6, 203:8 banerjee's 49:21, 202:22 bankrupt 37:16 bar 101:18, 102:5, 102:12, 106:19, 107:11, 108:5, 108:16, 109:18, 110:3, 111:12 barrier 184:18, 185:1 barriers 20:21, 72:14 bars 101:12, 108:14, 110:2, 111:2 based 39:6, 40:9, 49:13, 52:10, 59:11, 64:12, 67:16, 67:17, 68:9, 68:12, 93:14, 125:10, 203:9 basic 52:9, 104:18, 104:22, 105:8 basically 130:19 basis 152:8, 152:9, 153:1 because 7:1, 8:1, 10:7, 13:14, 14:10, 17:5, 17:15, 17:17, 18:17, 19:11, 21:1, 21:5, 23:14, 26:5, 27:12, 27:15, 31:19,
---	--	--

33:5, 35:22, 37:7, 42:3, 42:21, 43:11, 44:7, 44:22, 45:22, 46:9, 47:11, 48:5, 52:9, 52:20, 53:4, 53:8, 53:13, 54:5, 55:6, 58:12, 59:2, 59:6, 61:17, 65:18, 68:1, 69:3, 70:2, 70:15, 70:16, 73:13, 75:8, 76:15, 76:22, 77:8, 77:12, 79:17, 79:22, 80:5, 82:11, 85:7, 90:22, 97:13, 98:7, 99:5, 104:4, 109:13, 109:20, 113:20, 114:22, 115:6, 118:13, 122:2, 125:4, 147:15, 149:21, 150:5, 153:12, 155:21, 156:6, 156:9, 162:17, 163:17, 167:13, 171:7, 174:10, 175:11, 175:17, 177:10, 192:8, 192:19, 194:11, 196:8, 201:5, 204:6, 205:8 become 23:2 becomes 68:2, 77:15, 115:5 becoming 33:17, 70:18 been 5:8, 7:20, 10:14, 11:5,	11:9, 12:3, 12:18, 13:6, 13:22, 23:21, 26:15, 30:3, 40:20, 45:9, 48:4, 48:14, 48:16, 49:2, 49:3, 51:6, 52:14, 53:9, 53:14, 55:19, 56:20, 57:1, 57:6, 57:8, 64:12, 67:15, 69:4, 69:7, 69:13, 70:22, 72:13, 75:6, 75:12, 84:13, 86:19, 86:20, 87:8, 90:11, 90:19, 97:13, 104:1, 115:12, 115:13, 115:21, 120:22, 121:18, 122:8, 126:12, 136:5, 145:18, 151:14, 151:16, 159:17, 159:19, 161:6, 161:7, 161:9, 161:14, 162:12, 165:20, 166:19, 188:10, 188:15, 190:22, 191:20, 193:6, 193:10, 193:11, 193:18, 195:6, 202:9, 202:12, 210:3, 214:9 before 1:2, 12:16, 13:1, 14:1, 14:4, 16:6, 28:8, 46:10, 48:12, 50:15, 64:13, 71:17, 77:20, 137:15, 143:21, 152:18, 157:11, 159:14, 186:8, 186:13,	186:17, 186:21, 200:2, 213:4, 215:22, 216:7, 216:8 began 26:1, 62:19, 76:20 begin 24:9, 26:4, 28:6, 43:20, 76:7 beginning 85:9, 122:14, 154:4, 193:15, 195:20 begins 149:3 behalf 2:2, 2:10, 4:10, 4:12 behavior 35:4 behind 6:20, 24:14 being 4:7, 18:7, 18:18, 19:1, 19:18, 35:1, 35:7, 37:3, 47:8, 47:9, 61:7, 61:8, 61:13, 79:6, 79:9, 79:13, 82:4, 90:14, 92:22, 100:21, 126:11, 130:14, 132:3, 135:17, 144:15, 144:21, 167:12, 173:14, 174:12, 175:16, 176:10, 176:12, 176:14, 176:15, 176:17, 176:18, 198:2, 200:18, 203:2, 207:17, 213:5 believe 7:11, 15:11,	26:20, 27:7, 34:12, 39:10, 47:22, 54:17, 55:11, 55:12, 56:13, 56:19, 57:7, 57:14, 60:10, 65:5, 65:6, 65:21, 67:19, 74:20, 75:5, 84:8, 96:18, 107:11, 116:11, 126:4, 137:17, 143:21, 152:16, 155:1, 156:20, 171:7, 179:3, 179:6, 179:7, 179:19, 180:5, 186:5, 191:18, 191:19, 192:3, 193:11, 203:5, 203:6, 203:10, 204:9, 204:21 believes 53:12 below 24:18, 24:22, 45:21, 70:6, 80:1, 106:14, 115:8, 135:2, 138:14, 138:21 beneath 196:14 best 87:17, 143:11, 166:6, 198:20, 199:3, 206:10, 206:14, 206:16 better 25:16, 34:10, 43:12, 174:1, 198:14, 199:17, 204:3, 204:7, 204:22, 205:2, 205:8, 205:12, 205:19, 205:22, 206:4, 206:8, 206:19, 207:8,
--	--	---	--

207:10 between 34:14, 68:6, 72:18, 75:12, 81:9, 81:20, 83:12, 83:13, 84:2, 92:6, 93:12, 93:15, 93:17, 93:18, 94:16, 96:14, 97:14, 109:12, 154:19, 162:7, 176:7, 184:5, 184:7, 184:10, 195:9, 195:14, 195:18, 197:20, 200:5, 200:6, 200:11, 200:12, 212:8 beyond 153:4 big 38:7, 77:11, 198:13 bigger 155:5 bit 31:20, 47:13, 62:13, 78:17, 95:22, 107:21, 130:17, 143:19, 162:1, 163:15, 168:18, 168:22, 169:1, 169:3, 170:2, 192:4, 201:20, 208:4 block 44:17, 162:6 blocking 47:7 blood 216:16 blue 101:13, 101:18, 102:12, 107:17, 107:21, 111:19, 197:4, 197:8, 197:21, 201:4	blue-highlighted 200:6, 200:12 board 1:2, 209:3 bond 160:18 bonds 30:22, 160:5, 160:8, 160:10, 160:13, 160:20 boron 22:20, 23:15, 23:16, 31:3, 103:8, 105:3, 105:10, 107:20, 111:11, 111:14, 112:3, 121:1, 202:19, 203:4 boron-diffused 100:21, 101:15, 101:21, 102:13, 104:1, 104:14, 111:15, 204:4, 205:3 boron-doped 92:5 borons 34:21 both 23:11, 27:17, 28:12, 28:14, 39:1, 40:16, 47:17, 48:1, 48:8, 66:4, 66:7, 77:18, 78:19, 79:3, 94:1, 94:9, 95:2, 95:19, 103:5, 108:2, 108:5, 112:1, 135:5, 139:11, 139:22, 140:7, 147:17, 150:11, 152:13, 166:18, 190:15 bottom 6:21, 83:3, 85:17, 146:7,	149:10, 181:15, 183:20, 197:4 bought 14:10, 153:12, 153:14 boule 26:5, 145:5 bounce 41:7 bound 154:13, 154:15, 155:6 boundary 156:11 box 6:4, 7:10 break 8:11, 8:13, 59:14, 60:3, 60:7, 64:14, 140:19, 143:21, 166:13 bridge 72:17, 72:21 bring 6:6 brings 125:19 broadly 23:2 build 40:3, 62:19, 182:9, 206:15 building 206:13 built 20:7, 40:16, 175:15, 176:19, 177:8, 200:20 bulk 33:1, 33:7, 72:15, 92:1, 106:2, 106:15 buy 26:3, 163:3 C ca 2:6	calculate 85:13, 137:9, 154:14 calculation 84:19, 84:20, 153:22, 154:4, 154:22, 155:12 calculations 154:8 california 1:28 call 19:10, 35:5, 54:6, 103:10, 173:20, 173:22, 174:5, 174:9, 175:3 called 4:6, 20:4, 20:6, 37:10, 173:6, 176:2, 178:13, 191:13, 195:6, 197:12 calling 54:19, 69:16 came 50:22, 62:22, 97:18, 97:22, 117:22 camel 20:4, 21:14, 37:10, 37:12, 37:22, 38:10, 38:17, 48:18 can't 5:14, 29:1, 70:14, 100:15, 117:9, 121:12, 121:16, 122:1, 122:2, 122:7, 147:12, 148:1, 148:4, 169:13, 169:21, 190:18 canadian 1:5, 2:2, 14:18, 53:16, 214:3, 216:10 cannot 74:18, 109:20,
---	--	---	--

117:9, 117:11, 191:7 capabilities 20:9 capability 188:10 capacity 14:4, 14:7, 196:9 caption 211:4, 212:1, 214:3 captioned 214:8 capture 41:10 capturing 40:14 carbon-based 39:22 careful 54:16, 92:22, 115:11, 121:5 carefully 53:13 carried 76:19 carrier 69:19, 113:19, 116:16, 174:15, 174:21 carriers 33:1, 33:3, 114:7, 114:20, 115:3, 115:14, 126:22, 174:12, 174:18 carroll 1:17, 3:4, 3:12, 4:5, 4:16, 5:5, 5:7, 5:14, 6:13, 7:6, 12:12, 14:22, 15:6, 15:16, 15:17, 49:5, 53:15, 60:2, 60:14, 117:18, 141:4, 141:7,	141:13, 148:13, 164:8, 208:12, 212:2, 213:5, 214:5, 215:20, 216:5, 216:13 case 7:2, 10:19, 12:13, 13:5, 14:1, 14:4, 16:9, 20:20, 22:2, 33:12, 35:12, 51:17, 51:22, 53:13, 60:7, 60:15, 61:6, 72:10, 74:9, 75:11, 76:16, 96:11, 97:8, 98:6, 113:16, 114:3, 118:9, 119:17, 122:12, 135:9, 139:16, 140:11, 167:9, 179:13, 198:18, 205:20, 206:4, 210:1, 210:2, 210:5, 211:9, 211:11, 214:3 cases 13:1, 18:5, 18:12, 18:15, 48:8, 72:6, 86:15, 87:13, 118:9, 120:6, 120:17, 140:16, 156:12, 160:15, 161:18, 162:17, 182:17, 190:16 catalyze 160:18 causal 90:5, 99:13 cause 31:2, 31:3, 33:1, 71:1, 75:8, 75:10, 174:18 causes 160:11	causing 21:4 caution 82:3 caveat 68:1, 104:9, 158:7 caveats 28:3 cbd 12:8 cells 21:10, 27:12, 36:2, 38:5, 38:22, 39:1, 39:2, 39:3, 39:12, 40:6, 40:9, 41:6, 41:17, 52:2, 52:9, 58:14, 64:15, 67:21, 70:13, 72:6, 72:7, 88:22, 89:17, 106:1, 158:2, 158:12, 163:2, 163:3, 163:16, 164:15, 188:19, 189:3, 190:4, 190:9, 191:5, 200:20, 206:13 celsius 107:16, 107:17, 107:18, 107:22, 111:18, 127:18, 134:20, 138:14, 139:9, 139:13, 185:13, 185:15 center 9:19 centers 106:1 centimeter 92:2, 106:16, 188:22, 200:22 centimeters 56:7, 200:19, 201:2, 201:6	certain 53:6, 62:5, 62:18, 89:4, 89:21, 114:15, 115:8, 121:12, 121:16, 157:16, 157:17, 162:6, 174:12, 177:14, 196:6, 198:21 certainly 31:21, 52:7, 67:18, 71:18, 97:13, 145:17, 165:20 certainty 87:14 certificate 3:8, 210:14, 211:18, 213:1, 216:1 certified 209:8, 209:14 certify 211:3, 211:8, 216:4, 216:10, 216:12, 216:15 challenged 60:19, 63:15 chambers 150:12 change 14:10, 22:7, 76:4, 76:9, 97:19 change: _ 214:19, 214:24, 215:1, 215:6, 215:10 change: __ 215:15 changed 23:6, 25:22, 104:7 changes 44:8, 73:3, 195:20, 196:5, 213:11, 214:10, 214:13, 214:14,
--	---	--	---

214:15 changing 45:3, 73:10, 203:8 characteristic 180:16, 180:21 characterized 191:16 charge 72:5, 72:7, 72:8, 72:9, 72:14, 72:16, 72:18, 72:19, 156:9, 156:10, 174:19, 174:20, 175:9, 175:12, 188:7, 196:2, 196:3, 210:4 charged 36:18 charges 175:5, 175:8 chart 108:15, 110:3 charts 107:11, 108:2, 108:5 chat 5:20, 7:13, 14:22, 60:10, 80:22, 88:7, 145:13, 145:16, 145:18, 204:10 cheaper 69:18, 207:21, 207:22, 208:1 check 213:12 chem 108:17, 110:7, 110:9 chemical 107:6, 109:1, 111:15, 132:13, 133:8, 133:11 chemical-oxide-g- rown 110:17	chemically 107:4, 111:6 chemists 54:13 chief 38:4 chip 151:22 chips 143:11 chloride 97:9 choices 165:19 choose 180:4 chose 47:4, 194:3, 201:22 chosen 187:7, 187:19 chromium 31:5, 35:6, 43:9, 43:13, 135:14 circuit 198:4, 198:5, 198:8, 198:9, 198:11, 199:14 cite 91:2, 126:5, 141:21 cited 11:2, 11:5, 12:3, 132:6, 154:17 citing 10:22 city 20:4, 21:14, 37:11, 37:12, 37:22, 38:10, 38:17, 48:19 claim 55:5, 55:7, 55:15, 55:19, 57:16, 57:18, 57:20, 58:16,	58:17, 58:22, 59:12, 61:19, 62:4, 62:9, 62:14, 63:9, 63:10, 63:14, 63:17, 66:17, 66:19, 97:1, 122:22, 123:1, 123:2, 123:5, 123:6, 123:7, 123:10, 124:7, 135:20 claimed 62:10, 98:7 claiming 82:19, 91:9, 95:9, 98:5, 102:3, 130:4 claims 57:13, 58:3, 58:4, 59:3, 59:5, 59:7, 59:11, 60:19, 61:18, 63:16, 92:17, 144:4 clarification 8:6, 8:8, 144:19 clarify 50:12, 112:13, 126:19, 165:3 clarity 110:6, 179:15 classify 166:22, 197:2 cleaned 137:15 clear 19:6, 27:15, 33:18, 50:3 clearing 18:13 clearly 97:14, 196:7, 196:11 clemson 48:12 click 15:9, 15:11	close 6:11, 99:21, 200:15, 200:16, 200:17, 206:2, 206:3 closed 6:19, 6:22 closest 118:16 closing 6:22 cobalt 29:12, 30:13, 32:4 coefficient 31:12 coffee 60:5 column 66:20, 67:1, 67:2, 67:3, 89:2, 92:9, 102:7, 106:5, 123:15, 123:16, 123:20, 127:6, 127:14, 129:1, 129:2, 131:21, 133:10, 134:1, 134:9, 136:8, 136:9, 136:10, 139:18, 146:7, 146:8 columns 135:12 com 2:8, 2:18 combination 202:15, 203:2, 203:14 combinations 174:22, 175:2 come 22:21, 68:1, 69:20, 74:21, 80:3, 98:7, 99:12, 100:7, 161:12 comes 59:7, 89:17,
--	--	--	---

176:21 coming 82:6, 206:2 commencement 216:7 commencing 216:14 commensurate 156:2 comment 18:5, 51:3 commercial 25:3, 25:6, 25:7, 37:13, 159:5 commercialization 20:4, 20:5 commercialize 38:11, 52:11 commercially 27:8, 52:13, 87:1, 87:6 commission 210:13, 211:17, 216:22 common 27:5, 27:7, 27:8, 30:18, 31:17, 88:20, 89:15, 164:15 commonly 105:22, 106:6 companies 14:10, 14:11, 27:13 company 20:4, 37:9, 38:16 comparative 206:15 compare 18:10, 18:11, 25:2, 30:20, 206:10, 206:11, 206:12, 206:15, 206:17, 207:13, 207:19 compared 42:4, 99:18,	182:2 compares 32:3, 107:6 comparing 101:18 compensation 72:9 complete 156:2, 211:7 completed 186:2 completely 44:15, 87:5, 149:18, 150:2, 150:18 complicated 167:1, 167:2 complying 66:22, 106:12 compound 73:13, 118:17 compounded 120:22 compounds 120:19, 158:17 computer 5:20, 6:16, 11:15, 17:17 computers 50:7 concede conceded 100:4 207:8 conceived 162:16 concentration 24:15, 29:5, 32:1, 32:2, 32:3, 32:13, 43:22, 44:3, 44:7, 44:21, 45:2, 45:3, 45:5, 45:8, 47:21, 55:18, 56:6, 56:17, 57:11, 58:18, 58:22, 59:4,	59:8, 62:18, 73:2, 73:3, 73:5, 73:16, 73:20, 73:21, 78:12, 78:15, 82:11, 82:17, 85:9, 85:21, 90:5, 95:5, 96:21, 98:21, 99:16, 99:17, 100:1, 101:13, 101:14, 106:16, 112:5, 114:14, 114:17, 118:3, 118:4, 118:11, 124:18, 124:22, 125:7, 125:18, 125:20, 134:7, 136:20, 136:22, 137:4, 137:5, 138:9, 140:14, 144:11, 149:8, 149:12, 151:2, 151:7, 152:11, 153:1, 154:5, 154:10, 154:15, 155:2, 155:11, 155:13, 155:20, 172:19, 186:1, 186:4, 187:8, 187:20, 188:13, 188:21, 191:10, 192:1, 195:10, 195:15, 195:17, 195:20, 201:12, 201:17, 201:18, 202:5, 202:6, 207:9 concentration-de- pendent 78:11 concentrations 23:21, 24:17, 24:21, 29:8, 29:10, 70:1, 70:5, 74:4, 79:18, 80:5, 104:7, 190:7	concentrators 25:8 concept 34:6, 71:19 concern 22:17, 32:13, 76:7, 76:22, 156:22 concerned 22:18, 23:15, 75:18, 113:6 concerning 60:7, 74:16 concerns 75:6, 76:18, 76:19 concluded 136:5, 208:18 conclusion 125:1 condensed 35:8 conditions 131:16 conduct 85:1 conducted 1:21, 106:20 conducting 152:5 conduction 113:18 conductors 170:8 confidence 87:12 configuration 120:4, 121:19 configurations 119:8, 119:11, 121:6 confirm 85:2, 117:9, 117:11, 117:12, 189:22 confused 187:16 confusing 50:2
--	---	--	---

connections 39:3 consider 42:2, 151:6, 200:14 considerably 20:15 considered 11:6, 11:8, 35:1, 35:16, 35:19, 37:1, 41:22, 47:17, 92:19, 177:4 considering 48:3 consistent 36:22, 78:2, 133:5 consolidated 5:8, 15:18 constant 73:2 constitutes 213:8 constituting 93:10 construct 62:10, 150:9, 193:7 constructed 188:19 constructing 91:16, 163:11 construction 63:15, 63:17 consult 191:20 consuming 143:20, 167:16, 167:22, 168:2 contact 5:20, 42:9, 46:3, 47:14, 47:15, 47:16, 48:22, 54:8, 72:11, 72:15, 89:5, 89:7, 90:15, 90:17,	100:22, 101:15, 101:21, 102:13, 104:2, 165:12, 176:21 contacted 51:7, 209:18 contacts 43:5, 46:1, 46:2, 46:6, 88:21, 89:4, 89:21 contain 16:8, 124:11, 124:17, 150:10, 151:1, 151:3, 194:21 contained 17:10, 43:2, 166:17 contains 16:10 contaminants 12:9 contaminated 96:16, 97:21 contamination 92:1, 100:3, 105:19 contemplated 203:2 contemplates 146:16 contending 99:7 content 188:8 contention 99:7, 99:8 context 35:22, 36:8, 38:19, 38:20, 38:21, 49:9, 49:20, 49:22, 71:22, 72:2, 79:11, 92:21, 93:2, 174:9, 177:7, 177:17, 178:3, 178:11,	182:7 contextual 54:12, 155:21 contextually 54:5 contiguous 94:11, 185:3 continue 39:18 continues 146:8, 181:15 contract 209:20, 209:22 control 96:15, 97:8, 98:11, 98:12, 105:19, 153:16, 207:10 convenient 7:18 conventional 132:4, 182:3, 183:2, 183:7 conversation 9:7, 122:14, 164:6 converts 169:22 convey 203:7 coordinated 160:21 copy 7:16, 7:17, 15:3 corporation 64:20 corrections 16:18, 214:11 correctly 23:11, 31:15, 32:15, 43:9 correlated 152:10 correlates 114:6 correlation 195:9, 195:14	corresponding 97:19 cost 25:18, 52:11, 67:5, 67:8, 67:20, 68:4, 122:15, 163:21, 167:5, 168:11, 168:18, 170:11, 207:18 costly 143:12, 143:15, 167:5, 167:9, 167:13, 168:11, 168:13 costs 47:11, 69:12, 163:18, 164:3 could 21:1, 22:21, 23:8, 23:20, 27:2, 29:11, 30:12, 32:14, 33:19, 65:10, 69:14, 77:10, 77:17, 80:14, 100:1, 101:8, 128:10, 128:14, 128:18, 132:13, 133:18, 133:21, 138:18, 149:2, 149:8, 149:20, 153:12, 153:19, 160:7, 160:17, 162:22, 172:22, 181:14, 182:13, 182:15, 183:21, 194:17, 195:2, 199:21, 201:17, 202:4 could've 193:18, 194:9 council 209:4 counsel 8:15, 8:17, 8:20, 9:7, 9:10, 17:9, 17:20,
---	--	---	--

209:11, 210:1, 211:9, 211:10, 212:8, 216:11 count 10:8 counterintuitive 156:8 counts 103:17 county 211:2, 213:3 couple 19:16, 31:20, 51:16, 126:22 course 6:9, 10:7, 18:16, 19:12, 29:10, 33:14, 46:16, 48:5, 49:8, 51:19, 61:7, 62:19, 68:8, 72:9, 94:10, 137:1, 144:5, 153:15, 155:4, 171:8, 173:16, 188:8, 192:4, 194:17, 196:7 court 4:2, 8:2, 13:3, 59:19, 59:21, 140:20, 141:1, 208:6, 208:9, 208:16, 209:3, 209:5, 209:8, 209:9, 209:14, 209:18, 216:2 cover 64:17, 163:2, 171:15, 200:20, 210:3 covered 172:13, 172:14 craft 17:4 create 24:19, 35:4, 41:8, 46:15,	76:21, 160:10, 174:2 created 24:20, 72:19, 173:14, 174:12 creates 27:20 creating 52:21, 53:4, 61:12, 76:16, 76:17, 106:1, 166:4 creation 168:15 crosses 82:5 crr 216:2 crystal 24:10, 24:14, 24:20, 145:4 crystalline 40:11 crystallinity 105:17 crystallites 145:2 crystals 24:22 csi 14:18 csi's 49:5 csr 1:28 cubic 56:7, 92:2, 106:16, 188:22 cup 60:5 curious 50:13 current 190:13, 190:14, 198:5, 198:10, 198:11, 199:14, 200:21, 201:4, 205:10, 206:6	currently 34:3, 54:3, 54:19, 180:7, 190:10 customary 210:5 cut 70:17 cutoff 46:17 cv 50:20 cvd 43:15, 69:5, 133:11, 133:12, 166:6, 166:7, 166:8, 166:11, 167:2 D damage 33:20, 68:3, 75:8, 75:10, 75:12 damaged 46:20 dangerous 69:22 dangling 160:5 data 95:22, 96:10, 125:15, 147:16 date 11:16, 212:3, 213:7 dated 16:2 david 1:17, 3:4, 3:11, 4:5, 15:5, 15:17, 65:1, 65:3, 66:7, 147:20, 212:2, 213:4, 214:5, 215:20, 216:5, 216:12 day 213:4, 215:23	dc 2:16 dealing 156:1 dealt 13:20 debate 202:8 decay 116:20 deceiving 201:5 december 64:1 decide 194:4 declaration 3:11, 10:21, 11:2, 11:6, 12:4, 15:1, 15:5, 15:17, 16:6, 16:8, 16:16, 16:17, 16:19, 16:21, 17:11, 17:14, 17:21, 36:11, 56:22, 65:6, 65:11, 65:12, 65:13, 81:4, 84:15, 87:19, 119:5, 137:7, 138:18, 141:13, 141:18, 149:2, 149:11, 149:15, 153:17, 159:20, 175:21, 186:5, 187:3, 188:17, 189:8, 191:8, 195:3, 196:16, 203:1, 203:19, 214:6 declarations 4:21, 12:16, 12:22, 13:4, 13:6, 13:9, 13:12, 13:20 declare 214:6
--	---	---	---

decrease 44:20, 71:5, 98:1 decreasing 33:6 dedicated 151:10 deep 194:6, 199:16 deeper 76:12, 76:13 defeated 73:14 defect-induced 21:11 defects 21:4, 21:9, 22:4, 22:8, 22:14, 46:15, 69:20, 82:10, 194:15, 194:18 deferent 52:20, 53:3, 53:5 defined 23:2, 56:21, 79:1, 159:19 definite 177:16 definition 23:5, 37:3, 54:1, 115:20 definitionally 14:14 definitions 56:21, 68:22 definitive 206:20 definitively 121:20 degenerate 44:15 degree 74:7, 111:3, 120:18, 121:8, 185:16 degrees 107:16, 107:17,	107:18, 107:22, 111:5, 111:18, 127:18, 134:20, 138:14, 139:8, 139:13, 140:1, 140:8, 185:13, 185:15, 186:20 delay 113:2, 113:5 deleterious 27:21 delivered 145:7 demonstrate 53:17, 55:17, 56:5 dense 21:2, 46:8 denser 76:21 density 163:17, 163:18 depend 29:17, 31:20 depended 192:4 dependent 58:3, 58:17, 59:3, 59:5, 59:7, 59:10, 201:12 depending 29:12 depends 36:8, 62:13, 69:3, 79:4, 90:10, 90:17, 90:20, 127:22, 155:22, 156:15, 162:1, 175:14 depiction 93:9 depicts 66:11, 91:15 deponent 3:9, 212:9, 215:17 depos 209:16, 209:17,	209:19, 209:21, 210:4 deposed 4:7, 10:12, 12:18, 13:6 deposited 132:4 deposition 1:16, 6:7, 7:12, 8:16, 8:19, 9:4, 10:1, 11:9, 132:4, 132:5, 133:11, 208:18, 209:6, 209:10, 209:13, 209:19, 209:20, 210:4, 212:2, 212:5, 212:10, 213:6, 213:9, 214:1, 214:8, 214:12, 216:6, 216:7, 216:8, 216:11, 216:12 derogatory 189:7 desa 191:14 describe 17:21, 19:22, 20:17, 24:7, 38:2, 38:21, 45:17, 60:22, 64:13, 143:5, 147:2, 147:9, 159:22, 185:14, 185:22, 186:3 described 25:2, 33:17, 55:14, 85:4, 91:17, 91:22, 92:14, 132:3, 132:6, 133:14, 136:8, 144:14, 161:6, 162:11, 167:7, 171:22, 182:2, 183:1, 183:3, 190:12, 193:20, 197:17	describes 61:3, 91:18, 127:14, 129:6, 129:11, 134:2, 136:11, 149:18, 170:20, 172:11, 172:14, 183:13, 184:17, 185:11, 205:11, 205:12 describing 58:13, 152:15, 190:6 description 124:11, 134:6 design 64:14, 142:6, 192:5, 206:13 designer 177:8 designing 38:5 designs 189:22 desired 133:13 despite 81:9, 81:19, 117:14 destroy 87:6 destructive 86:13 detail 135:2, 183:1 detailed 44:6 detect 86:16, 87:7, 87:9, 87:11 detectability 25:1, 70:6, 80:1, 87:13, 87:17, 149:22 detected 85:21, 87:15 detection 85:22, 86:4, 86:10
---	--	---	---

deteriorate 46:5 determine 114:12, 188:12, 191:22, 196:13 determined 125:12, 125:14, 126:3, 126:12, 188:16 determines 44:9 determining 152:3 developed 40:14, 41:12 developing 39:6, 41:18, 41:20 deviations 190:16 device 45:4, 61:8, 61:10, 61:13, 74:2, 74:10, 74:14, 106:2, 121:2, 121:4, 162:16, 162:17, 163:18, 165:14, 174:14, 174:17, 175:1, 175:6, 175:11, 175:15, 177:7, 177:8, 178:19, 198:3, 198:22, 199:3, 206:4, 206:5, 206:10, 206:14, 206:16, 206:19 device's 27:21 devices 93:3, 126:1 diagrams 180:7 dielectric 62:20, 129:6, 129:11, 129:15, 129:19, 129:22, 132:2, 132:10,	134:22, 135:18, 137:15, 137:20, 138:2, 184:3, 184:5, 184:9, 184:13, 184:17, 184:21 differ 54:15, 99:5 difference 48:4, 78:11, 96:14, 97:14, 114:21, 176:7, 178:13, 178:14, 197:19, 200:5, 200:10, 200:11 different 22:17, 25:9, 25:11, 29:14, 37:8, 46:20, 54:21, 69:6, 105:18, 106:21, 107:21, 113:9, 115:20, 130:5, 145:1, 145:7, 152:21, 158:15, 162:3, 162:18, 170:15, 171:9, 182:8, 188:5, 188:6, 205:7 differently 163:4, 201:20 difficult 23:14, 44:22, 82:12, 82:13, 87:7, 87:8, 87:11, 109:13, 168:8, 170:4, 170:6 difficulty 75:17 diffuse 30:21, 186:20 diffused 98:15 diffusion 21:5, 22:6, 22:7, 27:6, 28:10, 77:5,	99:3, 107:12, 107:20, 108:15, 110:4, 120:11, 120:13, 120:14, 121:8, 197:5, 199:16 diffusions 106:6, 199:20 diffusivity 30:20, 31:8, 31:9, 31:13, 31:18 difilippantonio 1:28, 210:11, 211:15, 216:2 dioxide 21:10, 21:12, 76:1, 76:2, 76:9, 76:12, 82:2, 129:19, 156:5, 156:16, 160:14, 161:3, 161:10, 164:18, 184:14, 193:18, 196:10 dipole 160:8, 160:9 direct 9:7, 29:7, 73:1 directed 61:1, 171:19, 172:1, 172:3, 172:6 direction 69:11, 211:6 directly 125:7 disadvantages 75:14 disagree 62:13 disappear 116:14 disappointed 175:18 disclose 54:4, 55:12, 136:15, 136:19,	137:10, 137:14, 137:19, 138:1, 138:5, 138:8, 147:5, 188:18, 189:2, 189:15, 192:13 disclosed 16:13, 17:22, 61:11, 83:19, 119:16, 121:19, 139:4, 161:15 discloses 53:21, 55:2, 55:4, 57:12, 83:21, 119:8, 119:10, 172:17, 181:2 disclosing 120:3 disclosure 3:7, 124:18, 209:1, 209:5, 209:14 disclosures 147:12 discount 210:6 discovery 17:1 discuss 7:11, 81:3, 141:14, 175:20, 195:5 discussed 54:9, 64:13, 69:1, 93:10, 134:12, 135:1, 137:20, 144:11, 159:6, 159:15, 168:5, 195:21 discusses 110:3, 176:2 discussing 23:8, 26:8, 28:9, 40:13, 48:14, 48:16, 54:18, 71:19, 122:17
--	--	---	--

discussion 134:5, 202:18 discussions 17:20, 60:6 disposal 87:17 dispute 53:21, 57:12, 57:21, 58:1, 59:3, 59:4, 59:6, 70:11, 188:17, 189:1 disputed 59:10 disputing 55:3, 56:13, 58:5 distance 118:13, 118:14 distinct 82:7 distinction 34:14, 37:6, 68:6 distribute 196:13 distribution 196:2, 196:4 dlts 82:8 doc 7:10 doctor 101:10 document 119:19 documents 6:4, 6:6, 7:10, 7:13 doing 5:19, 7:21, 20:10, 27:9, 32:11, 37:22, 39:5, 48:9, 51:1, 52:12, 80:19, 87:1, 114:4, 114:5, 115:2, 117:5,	162:2, 162:8, 167:3, 179:11, 179:22, 180:7 dollars 25:20, 163:22 dominant 33:2 done 12:20, 13:10, 14:12, 19:18, 43:19, 43:20, 50:17, 89:18, 91:18, 122:18, 128:18, 135:21, 143:7, 150:7, 150:9, 150:14, 152:13, 175:6, 194:9 dopant 27:6, 27:20, 28:10, 35:2, 35:3, 35:19, 36:3, 36:4, 37:1, 43:1, 43:2, 43:7, 44:11, 47:21, 55:18, 56:6, 56:16, 57:10, 58:22, 62:17, 73:1, 73:2, 73:3, 73:21, 74:13, 77:11, 89:14, 97:10, 113:15, 117:1, 118:4, 118:8, 118:10, 118:11, 118:13, 118:18, 127:10, 133:3, 133:6, 133:18, 134:6, 138:8, 140:13, 157:15, 157:17, 158:18, 158:19, 158:22, 172:19, 173:5, 173:17, 173:18, 173:19, 173:22, 174:20, 177:1, 177:18, 177:21,	178:7, 178:16, 179:1, 179:5, 185:22, 186:3, 187:7, 187:20, 188:12, 189:2, 190:7, 191:9, 194:6, 194:7, 195:10, 195:14, 195:19, 201:12, 201:17, 201:18, 202:5, 202:6, 203:3, 203:12, 203:22, 207:15 dopants 22:19, 23:11, 27:19, 32:17, 35:15, 43:21, 44:4, 46:12, 58:13, 120:16, 127:9, 128:17, 173:1, 173:2, 176:18, 176:20, 185:11, 186:12, 186:20, 190:3, 194:18, 196:3, 196:13 dope 42:12, 133:6, 186:6, 186:16, 194:4, 207:1 doped 54:7, 72:13, 73:8, 73:10, 73:12, 74:12, 74:16, 78:7, 84:13, 88:18, 132:21, 132:22, 133:18, 172:18, 173:1, 173:5, 174:4, 174:5, 178:4, 188:20 doping 36:18, 44:13, 78:3, 128:15, 133:21, 157:2, 157:11, 157:19, 158:1, 158:14, 158:21, 159:3,	159:15, 172:11, 173:8, 186:8, 186:17, 194:5, 202:19, 203:3, 203:9, 207:7, 207:14, 207:19 dots 82:6 double 179:5 doubts 49:14 down 6:20, 8:3, 31:4, 43:12, 43:20, 46:1, 46:10, 79:19, 122:5, 129:14, 130:16, 130:21, 138:21, 156:5, 179:10, 198:2, 198:13 download 15:11 dr 4:16, 5:5, 5:7, 5:14, 6:13, 7:6, 12:12, 14:22, 15:16, 49:5, 49:6, 49:21, 50:4, 53:4, 53:15, 60:2, 60:14, 117:18, 141:4, 141:7, 141:13, 148:13, 154:17, 164:8, 202:22, 203:6, 203:8, 208:12 drag 60:9 dramatically 33:6 drastically 22:7 draw 179:10, 196:22 dried 158:18
---	--	--	---

drive 24:12, 48:6, 76:12, 127:9, 133:4, 186:12, 194:5 drive-in 133:18, 203:12 driven 27:1, 43:3, 45:8 driver 25:19 drives 168:17 driving 43:21, 185:11 drop 14:22, 88:7 dropping 80:22 drops 130:16 due 10:9, 46:15, 69:20, 170:7, 175:9, 176:19, 199:12, 205:10 duly 4:7, 213:5, 216:6 during 7:11, 20:12, 47:17, 60:7, 89:5, 128:11	26:14, 77:2, 152:16 earned 53:8 easily 161:10 easy 28:16, 204:12 eclipsed 39:11 edge 103:11 effect 22:14, 74:21, 84:12, 84:16, 90:5, 113:11, 115:17, 153:22, 154:9, 155:1, 155:8, 155:19 effective 33:6, 88:20, 89:5, 89:15, 89:22, 90:14, 90:19, 104:12, 106:7, 116:16, 161:11 effectively 113:20 effects 21:22, 33:3, 114:20 effectual 152:9 efficiencies 62:1, 106:2 efficiency 32:14, 61:6, 61:8, 61:9, 61:22, 67:9, 71:5, 122:16, 144:6, 157:8, 157:13, 158:10, 180:15, 180:21, 181:4, 181:6, 181:10, 200:15 efficient 78:7 either 73:1, 78:13,	92:4, 103:3, 104:22, 105:3, 105:9, 105:10, 106:22, 107:3, 114:1, 116:18, 138:13, 144:15, 146:17, 147:16, 153:13, 166:22, 167:9, 177:1, 180:1, 180:3, 202:5, 202:12 electrically 114:8 electron 21:11, 176:11 electron-dispers- ive 86:8 electronic 5:21, 7:17, 153:13 electronically 7:13, 114:2, 114:19, 115:14, 116:1 electronics 194:14 electronics-grade 142:16, 142:18 electrons 115:7, 117:7, 125:17, 173:14, 175:7 element 114:17 elements 32:3, 150:10 else 6:6, 6:14, 6:16, 23:17, 23:22, 45:13, 79:6, 79:9, 79:10, 79:13, 100:3, 100:7, 153:14 elsewhere 74:13, 103:14 embodies 61:14	embodiment 124:1, 127:8, 128:3, 128:5, 129:18, 129:21, 134:19, 146:11, 181:5, 185:1 embodiments 181:2, 181:3, 181:9, 181:18, 181:22, 182:6, 182:22, 183:6, 186:19 emitter 35:16, 53:18, 53:21, 54:6, 54:14, 54:15, 54:19, 55:4, 55:13, 56:14, 57:12, 71:20, 72:1, 72:4, 72:10, 72:11, 72:17, 72:20, 73:6, 73:8, 73:16, 73:21, 74:1, 74:8, 74:11, 74:17, 105:4, 105:11, 107:8, 111:16, 123:3, 123:8, 127:10, 132:2, 132:18, 134:2, 134:5, 134:10, 134:14, 135:1, 138:9, 138:10, 140:5, 140:10, 140:13, 165:12, 176:3, 176:7, 176:9, 176:10, 176:16, 176:22, 177:4, 177:20, 178:10, 178:18, 179:2, 179:17, 179:19, 180:2, 180:4, 202:20, 203:4, 204:4, 205:3, 205:18, 206:5, 206:8 emitters 54:2
E			
e 197:13 each 110:11, 118:13, 132:6, 209:4 earlier 67:20, 71:19, 75:5, 96:20, 124:6, 124:14, 137:21, 167:10 early 20:20, 25:22,			

employ 211:10 employed 51:13, 216:17 employer 209:9 encompass 142:18 end 29:13, 31:18, 31:21, 49:2, 72:18, 145:21, 155:12, 156:7, 207:17 ended 99:22 ending 94:4, 124:21 ends 47:8, 167:12 energy 75:20, 113:16, 176:16, 180:6 engineers 54:13 enhance 44:19 enhanced 61:5, 62:5 enormous 99:18 enough 8:10, 52:10, 68:2, 75:19, 75:20, 99:14, 122:8 entail 135:4 entails 24:7 enter 134:22, 176:16 enters 73:4 entire 41:21, 125:9, 214:7 entirety 16:5	entity 14:11, 14:12, 209:12 environment 163:8, 171:19 environments 105:18, 172:1, 172:4, 172:7 epi 70:17 equal 56:7, 79:6, 79:9, 79:10, 79:13 equalized 80:5 equates 79:7 errata 214:1, 214:12 errors 16:16, 16:17 essentially 76:16, 86:14 established 96:20 estimate 114:7, 155:9 estimated 97:12 etches 43:18 etching 43:16, 43:18, 165:10 evaporate 86:14 even 29:15, 70:4, 76:20, 77:15, 79:20, 81:9, 81:19, 87:16, 98:16, 120:15, 120:17, 155:7, 156:14, 183:2 eventually 20:22, 21:14, 39:11, 46:5	ever 12:18, 13:22, 14:3, 14:6, 21:8, 24:20, 49:5, 51:10, 51:12, 51:14, 207:1 every 102:5, 113:3, 117:3, 157:16 everybody 139:6 everyone 22:9, 22:20, 44:13 everything 6:18, 6:19, 6:22, 7:11, 8:3, 12:2, 32:9, 43:15, 44:15, 45:9, 45:13, 47:10, 59:16, 99:19, 103:18, 166:9, 207:16 evidence 211:7 exact 17:15, 131:3, 138:12 exactly 13:7, 17:12, 21:3, 29:12, 29:16, 29:17, 38:12, 40:8, 45:15, 48:7, 62:13, 70:16, 92:3, 96:2, 98:13, 105:12, 105:13, 115:19, 122:13, 129:13, 133:16, 140:3, 143:9, 150:6, 153:3, 153:5, 155:22, 156:15, 160:21, 162:1, 162:8, 169:11, 169:13, 182:20, 199:19	exam 137:6 examination 3:2, 3:5, 4:14 examined 4:7 example 77:4, 80:5, 119:1, 133:9, 133:10, 136:12, 139:7, 190:9, 197:16, 199:16, 199:19, 200:6, 200:7, 200:13, 203:15, 203:16 examples 102:5, 112:1, 131:18, 136:7, 136:12, 136:15, 137:7, 137:10, 137:14, 137:19, 138:2, 138:5, 138:8, 138:13, 139:3, 139:8, 139:22, 185:17, 188:19, 197:1, 197:21, 199:10, 199:17 excellent 89:6, 90:14, 104:12 except 39:14, 214:10 exception 6:9, 58:18 exhibit 3:11, 10:14, 15:1, 15:5, 15:16, 16:5, 16:13, 18:1, 30:5, 36:11, 55:9, 57:17, 60:13, 60:14, 65:11, 65:21, 80:20, 88:15, 91:4, 92:15, 104:11, 119:7, 122:20, 138:19,
--	--	--	--

141:18, 142:5, 145:13, 153:18, 170:17, 180:9, 195:3, 204:9 exhibits 5:11, 10:3, 11:10, 88:7, 88:11 exist 194:15 exists 63:1, 99:12, 178:15 expect 58:15, 68:19, 68:20, 103:13, 126:18, 153:11, 155:7, 155:8 expected 156:4 expensive 25:21, 28:6, 52:17, 68:10, 70:19, 150:15, 208:4 experience 20:14, 20:17, 38:22, 39:1, 40:6, 64:7, 64:9, 64:11, 67:16, 67:17, 68:9, 68:12, 70:3, 169:17 experienced 74:15, 109:16 experiment 84:6, 85:1, 85:7, 98:8, 100:2, 108:21, 109:6, 117:3, 118:1 experimental 91:7, 91:15 experimentalists 153:16 experiments 27:10, 106:20, 107:15, 110:11,	117:16, 119:15, 121:13, 136:16, 169:18 expert 12:13, 12:15, 13:22, 49:5, 49:14 expertise 18:19 expires 210:13, 211:17, 216:22 explain 19:11, 34:16, 34:18, 41:3, 195:13, 197:19 explicitly 136:3 exponentially 79:20 expressing 16:12 expulsion 23:3 extend 173:10 extensive 40:17 extent 38:2, 94:6, 173:10 extra 163:20 extraordinarily 23:21, 82:12, 87:8, 142:6, 142:12, 142:13, 143:4, 149:7, 150:15 extremely 52:7, 52:8 eye 196:22 eyes 116:14 F fabricating 88:21, 89:16,	170:20, 181:11 fabrication 27:3, 38:18, 106:8, 128:4, 128:6 face 41:7, 53:10, 81:22 facing 62:15 fact 5:22, 21:7, 40:12, 69:18, 88:1, 90:6, 125:9, 136:3, 151:13, 182:21, 193:6, 201:5 factor 71:4, 177:2, 198:17, 205:19, 206:1 factors 205:16, 205:17 fail 165:15 failed 53:16, 55:17 fails 56:5, 167:10 fair 6:17, 8:10, 17:8, 146:16, 146:19 fairly 161:10, 198:9 fall 44:18, 59:5, 66:16, 66:19 familiar 68:6, 100:9, 164:3 far 24:22, 28:5, 87:16, 115:8, 131:1, 201:4 fast 55:6, 78:17, 98:18	faster 30:22, 31:7, 78:7, 79:3, 207:15 father 52:4 fault 141:11 fe 95:13, 95:15 feed 150:11 feel 7:16, 160:13, 162:21, 175:17 few 7:20, 34:13 fiber 20:6, 47:19 fick's 31:13, 78:10 fiddle 110:22 field 10:7, 19:5, 19:18, 20:1, 49:13, 52:1, 57:3, 74:3, 74:5, 74:7, 87:15, 116:2, 173:6, 173:9, 173:10, 173:12, 173:13, 173:16, 173:21, 174:1, 174:2, 174:11, 175:3, 175:9, 175:10, 176:3, 176:8, 176:14, 176:15, 176:17, 176:19, 176:21, 177:5, 177:9, 177:11, 177:12, 177:13, 177:14, 177:15, 177:20, 178:9, 178:12, 178:15, 180:2, 199:20, 204:5, 205:4, 205:14,
--	--	--	---

205:17, 205:20, 205:21, 206:4 fields 27:16, 54:21 figure 21:3, 66:11, 66:13, 81:15, 82:20, 83:8, 91:3, 91:9, 91:15, 93:5, 94:12, 94:15, 94:22, 95:18, 100:16, 100:20, 101:8, 104:16, 104:21, 106:10, 106:14, 115:18, 117:3, 119:16, 125:4, 125:6, 131:18, 131:20, 135:2, 136:7, 171:4, 171:6 figured 52:17 figures 62:3, 146:1, 196:18 filed 15:1, 15:22, 19:1 filling 205:16, 205:19, 206:1 film 88:19, 89:14, 145:2, 156:16, 160:4, 161:18, 166:9, 168:15, 184:3, 184:5, 184:17, 184:18, 196:12, 196:14 films 12:8, 12:11, 21:12, 76:21, 90:8, 120:15, 122:5, 145:2, 160:17, 170:9 filter 175:4	filtering 175:12 finally 8:11, 129:21 financial 210:6 financially 216:19 find 11:11, 77:17, 156:13 fine 6:12, 6:13, 59:15, 68:4 finest 96:8 first 4:7, 12:19, 21:8, 42:7, 45:21, 63:1, 66:22, 89:13, 90:1, 105:14, 105:15 flexibility 132:15 flexible 40:15 float 143:8, 190:10 floating 176:3, 176:7, 176:9, 177:4, 177:20, 178:10, 178:18, 179:17, 179:19, 202:19, 203:4, 205:18, 206:5, 206:8 floats 176:12, 176:16 flow 183:7 flowchart 91:6 flowing 23:12, 23:13 flows 182:2, 182:3, 182:22, 183:2	flux 34:1 focus 41:18, 107:10, 108:14 focused 42:1, 52:12 focuses 58:20 focusing 66:10, 82:20 follow 21:16, 126:20 follow-ups 19:16 following 196:4, 209:13, 213:11, 214:15 follows 4:8 foregoing 211:3, 211:6, 213:6 foreign 17:6 forest 38:15, 48:10, 48:11, 87:2 forget 192:6, 193:15 forgotten 65:17 form 17:22, 18:2, 35:8, 57:2, 62:22, 63:9, 73:16, 73:20, 76:5, 117:17, 131:17, 145:5, 148:12, 148:20, 160:8, 160:10, 166:2, 173:6, 173:9, 178:17, 179:17, 185:5, 193:8, 193:21, 209:5, 209:12, 212:7 formation 89:6, 104:1,	129:6, 129:8, 132:5, 133:14, 134:2, 160:18 formed 62:20, 92:4, 105:3, 129:11, 129:22, 131:8, 132:7, 137:16, 137:20, 174:6, 176:15, 184:21, 194:2 forming 20:21, 31:1, 101:14, 101:20, 102:12, 131:12, 170:3, 177:19, 178:9, 185:6 forms 30:22, 105:7, 118:17, 158:11 forth 14:11, 20:21, 21:2, 21:6, 27:17, 29:12, 39:4, 62:16, 86:9, 165:13, 179:5, 190:4, 190:8, 216:6 forward 18:7 found 21:1, 49:17, 105:22, 122:5, 122:21, 190:4, 190:15 four 39:11, 136:11, 139:3, 191:8, 197:1 fraction 116:7, 116:9 frame 21:17, 22:10, 22:12, 22:16, 23:7, 23:10, 27:5, 28:8, 28:11, 33:8, 40:19, 48:17,
---	---	--	---

51:5, 153:2 fraunhofer 204:19 free 7:16, 149:18 frequently 27:18, 206:21 fresh 60:5 front-side 201:13 front-surface 74:3, 201:12, 202:18, 203:3 full 19:14 fully 52:22 fulton 211:2, 213:3 function 7:13, 27:21, 44:10, 45:18, 78:21, 80:8, 113:11, 121:1, 121:4, 130:19, 165:8, 177:16, 206:2 functional 61:7, 177:11 functionalities 162:3 functioning 206:7 functions 130:21, 171:10 furnace 127:16 further 20:15, 45:22, 129:14, 129:18, 211:8, 216:10, 216:12, 216:15 G gap 72:18, 77:13, 145:9, 145:10,	160:11 gaps 161:1 gas 86:15 gaseous 133:21, 158:19, 158:22, 203:3 gases 12:10, 208:3 gather 85:14 gathered 21:6 gathering 39:7 gave 21:1, 21:8, 28:3, 50:21, 88:10, 178:12 gee 200:22 general 42:20, 42:22, 69:2, 70:1, 80:8 generally 12:5, 13:11, 23:18, 43:5, 46:11, 67:12, 67:22, 68:10, 68:14, 68:19, 72:3, 73:9, 128:1, 130:11, 142:20, 145:12, 160:3, 163:2, 193:13, 207:8, 207:21, 208:4 generate 44:13, 115:6 georgia 209:4, 209:14, 210:14, 211:1, 211:18, 213:2, 216:4, 217:5 getter 22:15, 33:10, 33:19, 68:3, 75:21, 77:16,	77:21, 78:14, 85:19, 87:20, 88:3, 113:9, 155:18 gettered 76:8, 77:3, 101:4, 112:5, 112:7, 112:8, 112:9, 113:8, 114:18, 121:13, 121:21, 135:17 gettering 22:1, 22:3, 22:4, 22:5, 22:13, 22:18, 23:1, 23:8, 23:11, 26:7, 26:21, 26:22, 27:6, 28:9, 33:13, 33:15, 34:2, 34:7, 71:8, 71:10, 71:12, 71:14, 75:7, 75:15, 76:14, 77:10, 78:4, 78:6, 78:13, 78:21, 79:1, 79:4, 79:7, 79:14, 79:19, 79:21, 80:4, 80:8, 80:11, 80:13, 80:17, 81:4, 89:5, 89:22, 90:3, 90:12, 94:7, 104:13, 106:7, 108:22, 113:19, 114:4, 114:5, 115:17, 115:19, 116:3, 119:2, 119:11, 119:17, 120:4, 120:7, 120:8, 120:9, 121:7, 121:10, 122:9, 122:11, 122:12, 123:4, 123:9, 123:10, 134:13,	134:21, 135:4, 135:22, 136:5, 139:13, 139:18, 140:1, 140:4, 140:9, 140:12, 194:12 getting 13:18, 17:19, 38:6, 38:7, 60:5, 96:10, 141:18, 174:13, 174:21, 199:12, 200:21, 206:3 give 7:1, 12:22, 15:20, 17:15, 55:10, 82:3, 87:11, 90:21, 103:13, 112:21, 112:22, 125:4, 130:13, 154:12, 155:6, 198:7 given 12:16, 198:2, 210:6, 211:7, 216:9 gives 44:11, 114:7, 125:5, 136:22, 137:3, 160:19, 199:3 giving 41:10 glass 46:10, 46:17 glaucoma 113:2 go 12:16, 24:4, 26:1, 26:3, 44:8, 44:15, 46:9, 55:11, 59:18, 72:14, 78:17, 78:19, 90:7, 94:1, 108:10, 112:16, 114:10, 116:15, 116:16, 117:18,
---	---	--	--

118:15, 120:20, 123:22, 130:13, 130:16, 130:20, 131:1, 140:19, 155:7, 156:5, 162:2, 179:3, 179:12, 179:13, 196:4, 196:5, 200:2, 207:9, 208:5, 208:15 goal 67:7 goals 67:5, 67:13, 67:16, 67:18 gobbled 25:12 goes 78:18, 79:3, 189:14, 198:13 going 5:5, 6:1, 6:19, 10:11, 14:22, 24:12, 41:13, 44:10, 46:2, 46:13, 46:18, 56:19, 59:16, 60:9, 76:15, 79:22, 95:5, 95:9, 99:20, 115:6, 115:7, 118:20, 120:8, 120:18, 130:15, 144:9, 145:13, 162:20, 163:1, 163:21, 175:8, 182:9, 188:2, 188:4, 194:5, 196:12, 198:19 gone 39:18, 113:20 good 4:16, 4:17, 7:21, 28:6, 28:14, 33:14, 52:10, 57:7, 59:14, 96:10, 100:11, 118:8,	134:11, 140:18, 153:15, 167:8 gossamer 164:2 gotten 99:15 governed 61:7, 61:8 grabbed 121:18 grade 25:6, 25:7, 25:15 gradient 24:6, 24:12, 44:19, 73:4, 90:4 graduate 39:17 grand 2:5 granek 191:13, 195:4, 195:6, 195:8, 195:13, 195:21, 197:1, 201:10, 201:11 granek's 196:15 graph 82:1, 82:22, 94:22, 96:1, 96:14, 96:19, 97:3, 99:6, 99:9, 100:14, 100:19, 114:13, 118:21, 137:2, 137:17, 138:19, 138:20, 138:21, 139:11 graphs 106:19, 111:12, 112:7, 116:4 gray 101:12, 101:18, 102:5 grayish 199:2	great 204:11 greater 29:8, 61:6, 156:3, 156:13, 156:14 green 107:18, 109:18, 111:2 grew 21:13, 90:20, 104:4, 122:4 ground 7:20, 176:13 group 96:6 groups 19:5, 35:1, 96:9 grow 69:4, 160:4, 160:16, 161:18, 166:9, 169:16, 169:19, 169:20, 170:9 growing 159:10 grown 21:10, 21:12, 32:19, 43:15, 69:4, 107:4, 110:13, 111:6, 129:22, 132:3, 169:10 grows 169:19 growth 29:13, 32:7, 32:20, 132:5, 133:13, 143:8, 150:9, 150:12, 150:13, 166:13, 166:15 guess 13:2, 21:7, 49:4, 50:18, 61:15, 182:15 guidance 155:7	gun 170:2 guys 17:5 H habit 35:12 hail 162:19 half 91:1, 151:16, 151:22, 162:10, 162:15 hand 81:2, 156:12, 216:20 happen 27:15, 162:5, 196:8 happened 28:12, 100:1 happening 22:19, 77:18, 196:10 happens 118:17, 120:22, 176:14, 196:11 happy 8:12 hard 17:7, 48:7, 205:8, 207:4 harder 35:21 head 7:22, 8:1, 118:5, 180:1 hear 141:10 heard 51:21 hearing 211:8 heart 79:11 hearth 150:13
--	---	---	---

heat 22:21, 24:6, 27:17, 76:4, 76:7, 115:5, 196:9 heated 31:11, 111:5, 139:12, 166:16, 166:17 heating 27:1, 27:2, 34:6, 71:16, 79:13, 79:14, 80:15, 108:8, 108:9, 109:9, 111:3, 111:9, 111:21, 115:5, 116:8, 127:9, 127:15, 128:3, 128:5, 128:10, 128:11, 128:14, 128:19, 134:20, 138:6, 183:3, 185:12, 185:19, 186:1, 186:4, 186:6, 186:12, 186:16, 186:20, 186:21, 196:6 heats 127:21 heavily 20:3, 54:7, 72:13, 73:8, 73:10, 73:12, 194:4 heavy 43:7, 118:12, 120:16, 194:5 held 39:10, 62:2 help 65:10 helped 17:4 helpful 138:17 helps 20:8, 160:18	here 4:20, 6:20, 8:2, 32:16, 36:12, 37:4, 37:16, 48:12, 50:5, 61:13, 62:14, 70:3, 82:11, 87:2, 90:2, 91:12, 91:21, 101:3, 109:21, 113:1, 113:4, 114:13, 116:1, 118:7, 119:18, 120:8, 120:9, 123:5, 123:22, 129:5, 131:19, 139:3, 140:17, 142:5, 143:6, 152:12, 152:21, 153:20, 170:18, 179:9, 180:6, 182:7, 183:12, 183:13, 200:17, 204:15, 204:16, 209:15, 213:12 hereby 211:3, 216:4 herein 132:6, 182:2, 183:1, 183:3 hereinbefore 216:6 hereof 212:4, 213:8, 214:12 hereunto 216:20 hertz 143:2 hesitate 171:7 heterogenous 43:18 heterostructures 40:4 high 17:19, 26:4,	43:4, 60:22, 61:2, 75:20, 142:6, 142:12, 142:13, 143:4, 149:7, 170:8, 201:18 high-energy 173:14 high-performance 163:3 high-purity 12:9 high-quality 25:12, 26:5 high-resolution 82:14 high-temperature 104:6 higher 32:6, 68:15, 68:20, 79:3, 79:6, 98:21, 99:2, 154:10, 154:15, 155:11, 155:15, 155:20, 163:4, 163:7, 185:15, 191:9, 202:6 higher-quality 25:18 highest 152:22, 197:8 highest-performance 39:9 highlighted 197:8, 197:11, 199:7, 199:18 highly 74:12 historical 17:2 hitting 198:22 hold 143:1 holds 194:14	home 25:10 honestly 49:22, 151:17 hot-wire 43:15, 166:8, 166:11 hotter 24:13 hours 9:5, 9:7, 9:11, 17:18 however 11:15, 29:9, 33:1, 33:14, 36:6, 67:22, 72:10, 77:6, 82:18, 86:13, 86:18, 99:8, 103:16, 115:4, 166:15, 167:10, 168:14, 178:14, 205:9, 206:5 hundreds 72:22, 143:2 hybridize 160:8 hydrides 40:10 hydrogen 34:20 hydroxide 70:21 hydroxyls 70:21 hyperbole 90:13 hypothetical 84:20, 153:22 I ibc 142:6 idea 22:16, 36:3, 73:19, 130:14, 137:3, 155:6, 160:16, 165:3,
--	---	---	---

165:7, 193:11 ideal 206:2 identification 15:7 identified 149:11, 149:15, 149:17 identify 21:9 ieees 37:8 imagine 76:6 imagined 175:1 immediately 100:7, 103:15 impact 32:14, 32:22, 177:19, 178:8 implantation 133:19, 159:2, 207:1, 207:6, 207:13, 207:18, 208:2 implanters 208:3 implanting 22:20 implement 159:18, 161:7, 161:9, 167:1, 167:6, 168:8, 168:12, 168:20, 170:5, 170:6, 202:12, 207:4, 207:13 implementation 47:18, 167:9 implementing 55:17, 55:21, 56:5, 57:22, 170:12 implied 63:3, 63:12, 125:18 implies 74:4, 102:17	important 52:21, 79:11, 82:8, 93:1, 114:21, 180:15, 180:21 impossible 150:5 improve 20:8 improvement 137:2 improving 134:15 impure 151:10 impurities 22:13, 23:3, 23:12, 24:13, 24:15, 24:18, 27:18, 29:11, 30:11, 30:18, 31:16, 32:16, 32:22, 33:4, 33:9, 33:10, 33:22, 34:7, 34:14, 34:15, 36:2, 36:5, 53:17, 56:14, 57:11, 58:19, 58:21, 68:13, 68:18, 69:1, 69:21, 71:1, 71:9, 71:15, 75:7, 75:16, 77:3, 77:21, 80:13, 81:7, 81:18, 87:19, 88:3, 93:21, 105:1, 105:21, 121:13, 121:20, 123:2, 123:7, 124:19, 124:22, 125:12, 125:16, 126:3, 134:12, 134:14, 134:21, 135:5, 135:13, 135:16, 136:1, 136:4, 136:20,	137:6, 139:13, 140:5, 140:9, 141:15, 144:12, 149:19, 150:7, 150:19, 151:2, 151:4, 151:7, 151:15, 152:3, 154:18, 155:12, 155:17, 194:13 impurity 29:5, 31:15, 35:20, 36:3, 36:7, 36:19, 37:1, 37:8, 85:9, 85:14, 89:5, 89:22, 90:3, 104:12, 106:7, 113:10, 113:14, 113:15, 113:17, 117:1, 125:7, 149:8, 149:12, 154:4, 154:10, 155:14 ims 50:17 inc 1:5, 2:2, 214:3 include 26:20, 29:11, 30:12, 36:3, 127:15, 134:6, 134:21, 183:3, 192:9 includes 54:7 including 52:14, 82:10, 85:9, 87:2 incompatible 192:8 increase 67:9, 78:3, 80:12, 80:14, 97:16, 157:13, 158:10 increased 139:17, 157:8, 181:4, 181:6,	181:10, 195:16 increasing 80:4 indeed 127:13, 146:5, 154:21, 176:5 indicate 99:1 indicated 30:7, 214:11 indication 29:20 individual 11:13 industrial 105:16, 158:16, 170:1, 170:14 industries 116:18 industry 22:13, 25:13, 25:14, 25:19, 26:13, 28:19, 52:21, 53:5, 67:13, 67:16, 69:7, 151:13, 151:22, 156:22 inflection 70:16, 70:22 inform 11:22 informed 12:2 informing 171:12 infrastructure 168:18 inherently 53:17 initial 50:10, 101:13, 106:15, 112:4 initially 84:10, 99:1, 102:10, 102:14, 102:18, 103:22, 108:3, 108:6, 109:8, 111:8
---	--	---	---

inorganic 39:2, 40:6, 40:9 inside 160:22 insofar 136:22, 177:6 instance 4:6, 37:7, 132:14, 143:10, 160:19, 174:14, 194:11, 197:18 instances 139:12, 140:7 instead 138:13, 146:11, 178:9, 189:4, 194:13 instrument 80:2 integrated 42:2 intended 82:1, 82:18, 100:4, 101:3, 101:7, 203:7 intending 38:11, 101:3 intentionally 34:16 interact 27:19, 113:14, 117:7, 118:14 interacted 194:18 interacting 125:17 interaction 27:20, 77:10 interactions 31:3 interacts 31:2 interest 10:6, 10:10, 10:17, 11:21, 12:10, 22:9, 62:2	interested 10:8, 12:7, 21:21, 50:22, 211:11, 216:18 interesting 79:16, 79:17 interface 75:12, 81:9, 81:20, 83:13, 83:16, 84:12, 93:17, 93:18, 99:21, 101:5, 103:15, 118:15, 120:21, 155:15, 160:20, 174:13, 195:18 interfaces 69:19, 84:17, 85:3, 85:20, 93:15, 94:1, 94:9, 94:11, 95:2, 95:20, 96:13, 97:5, 135:6 interlayer 88:20, 89:14, 93:15 interpretation 17:1, 17:2 interrupt 69:19 intervening 106:21 interviewed 50:19 intimate 46:3 introduce 69:9 introduced 35:15, 123:8 introduction 36:18 invented 71:12, 71:14 invention 181:3, 181:5, 181:9, 183:17	inventor 51:17, 65:4, 66:7, 147:20 inventors 64:22, 140:8 inverse 200:19 involve 73:1, 73:3 involved 20:3, 37:21, 38:9, 43:6, 188:3 involvement 19:18, 20:1, 38:3 involves 39:1, 44:6 ion 103:4, 133:18, 159:2, 207:1, 207:6, 207:13, 207:15, 207:16, 207:18, 208:2 ion-implanted 202:19, 203:4, 204:4 ion-implemented 205:3 ionic 77:13 ipr 1:8, 5:2, 5:3, 5:11, 15:19, 50:14, 50:16 iron 29:11, 30:12, 30:20, 30:22, 31:2, 31:4, 31:6, 31:7, 31:15, 32:3, 32:5, 32:7, 35:6, 69:9, 69:11, 76:13, 76:16, 81:4, 81:18, 82:1, 82:11, 82:17, 85:13, 87:4,	88:2, 92:1, 94:7, 94:8, 94:22, 95:4, 95:8, 95:18, 96:3, 96:4, 96:5, 96:12, 96:15, 96:17, 96:19, 96:21, 97:3, 97:8, 97:9, 97:10, 97:16, 97:18, 97:20, 97:21, 98:2, 98:7, 98:10, 98:21, 99:1, 99:12, 99:16, 99:21, 100:7, 101:4, 101:13, 101:21, 102:9, 102:14, 102:18, 103:9, 103:13, 103:22, 105:1, 106:15, 108:4, 108:6, 108:21, 109:8, 111:8, 111:20, 112:4, 116:7, 116:9, 116:13, 117:4, 117:5, 117:6, 117:10, 117:14, 118:1, 118:14, 119:2, 120:10, 120:20, 120:21, 122:2, 135:13, 150:10, 150:13 irons 87:3 isolated 114:19, 115:14, 116:1 issue 51:16, 60:15, 65:22 issued 65:15 itself 65:18, 73:5, 74:11, 75:19,
--	--	--	--

76:3, 162:4, 165:10, 168:16, 173:4, 173:20, 173:22, 188:5, 194:1, 205:19, 207:15	130:22, 155:22, 175:12, 175:19 kinds 130:7, 158:16 king 188:18, 189:5, 189:14, 190:1, 190:16, 190:20, 191:5, 191:17, 192:8, 197:13, 197:17 knew 10:11, 19:4, 19:5, 22:4, 164:16, 170:10 know 5:21, 6:16, 8:12, 10:8, 12:17, 13:13, 13:16, 18:9, 19:17, 23:18, 27:8, 27:11, 31:19, 35:11, 37:18, 41:6, 45:1, 49:7, 49:9, 50:5, 51:18, 52:6, 52:20, 52:22, 54:10, 70:2, 70:15, 75:2, 80:14, 84:2, 85:6, 95:22, 100:8, 109:16, 126:10, 145:6, 145:17, 147:17, 150:5, 150:6, 151:5, 151:9, 151:17, 153:3, 158:16, 161:22, 164:5, 164:17, 167:2, 167:3, 169:11, 177:6, 177:8, 179:5, 179:22, 189:10, 194:10, 196:11 knowledge 14:9, 18:11, 18:17, 29:4,	32:2, 64:4, 64:7, 64:9, 64:10, 82:15 known 32:21, 33:8, 52:1, 52:7, 52:8, 65:17, 69:14, 71:1, 71:8, 71:17, 80:8, 80:10, 96:8, 151:1, 151:3, 157:2, 157:6, 157:11, 157:15, 157:16, 157:20, 158:1, 158:21, 159:2, 159:7, 159:10, 159:18, 165:19, 165:20, 166:8, 168:10, 198:15, 201:21, 202:4, 202:8, 202:10 knows 44:13 konarka 39:4	large 78:15, 151:14, 198:9, 198:12 larger 39:13, 86:11, 98:5, 145:4 largest 151:11, 151:20, 151:21 last 13:10, 16:2, 48:18, 51:8, 89:3, 105:15, 106:14, 128:3, 146:10 lasted 70:19 lasts 43:13 latching 99:10 later 23:2, 33:2, 34:11, 161:12 latitudes 163:5 launch 163:19, 164:3 law 31:13, 78:10 lawyer 61:17 lawyers 54:13 layer 43:12, 45:12, 45:19, 46:8, 47:1, 75:19, 76:14, 81:8, 81:19, 82:2, 83:6, 87:21, 88:4, 92:6, 93:10, 93:11, 95:9, 105:2, 105:9, 109:1, 110:14, 120:4, 122:6, 129:7, 129:16, 132:6,
J			
jacob 2:13, 2:18, 4:11, 8:20 jargon 19:11, 19:12, 19:13 jo 205:9, 206:6 job 1:25, 7:21, 41:22, 42:2, 117:6 jos 199:11 judge 12:16 judgments 11:18 judicial 209:4 jump 128:22 jumped 170:2 june 1:20, 4:1, 4:2, 216:13, 216:21 justify 11:1			
K			
keep 6:13, 9:12, 17:17, 76:4, 179:8, 199:11 kin 211:9 kind 22:8, 22:17, 76:2, 96:10,			
		L	
		l-i 30:3 lab 127:4, 127:5 label 36:16 laboratories 27:9, 86:6, 87:1 laboratory 70:4, 150:8, 169:18, 170:15 lamers 191:13 language 17:5, 54:11, 93:1, 177:10 languages 17:6 laptop 6:8	

132:16, 135:6, 137:16, 137:20, 138:2, 160:9, 161:14, 161:19, 162:4, 162:15, 163:13, 163:17, 164:14, 164:20, 165:6, 166:2, 166:5, 167:6, 167:17, 167:18, 168:1, 168:6, 168:9, 168:21, 169:9, 170:4, 170:12, 172:13, 172:15, 183:13, 183:15, 183:17, 183:19, 184:6, 184:7, 184:9, 184:18, 184:21, 185:1, 185:5, 185:6, 185:12, 186:7, 192:10, 192:14, 192:20, 193:3, 193:17, 194:2, 194:3, 194:16, 195:10, 201:13 layers 27:16, 63:5, 93:9, 106:21, 119:11, 120:5, 120:7, 121:7, 159:11, 159:15, 169:11, 186:7, 186:17, 205:7 layman's 31:10, 31:12 lead 77:10 leading 19:5, 30:4 leads 125:22 leakage 199:12, 200:21, 206:5 leaking 201:3, 205:10	learned 144:10 least 64:3, 64:6, 64:9, 64:12, 103:19, 107:7, 125:20, 136:8, 150:22, 153:19, 161:15, 161:17, 181:17, 186:19, 191:4 leave 59:16, 118:21 leaving 24:14 led 28:14, 28:16, 39:7 left 64:19, 82:22, 90:18, 95:14, 95:16, 103:8, 103:9, 107:11, 110:16, 114:14, 114:17 legal 17:5, 17:9, 61:16, 63:19 leif 2:4, 4:9, 4:18 less 56:6, 68:10, 85:21, 101:22, 102:14, 103:6, 109:8, 109:11, 109:22, 111:8, 111:19, 117:3, 117:5, 130:17, 168:3, 169:6, 188:22 let's 21:21, 35:9, 44:10, 59:3, 59:18, 88:1, 88:6, 100:16, 104:10, 106:10, 111:11, 122:19, 122:22, 123:14,	156:18, 170:17, 175:5, 178:4, 180:8, 194:4, 202:14, 208:5 level 17:19, 44:11, 60:22, 61:2, 64:4, 64:6, 68:13, 68:18, 75:3, 81:17, 82:1, 85:2, 87:3, 91:12, 96:2, 96:3, 98:11, 113:16, 115:8, 115:9, 144:8, 144:9, 153:1, 176:10 levels 86:16, 86:17, 105:17 li 30:3, 30:4, 30:5, 30:7, 53:18, 53:21, 54:3, 54:18, 55:2, 55:4, 55:12, 55:17, 56:5, 56:19, 56:20, 57:12, 57:21, 65:4, 65:7, 65:14, 65:15, 65:18, 66:4, 66:8, 83:19, 83:21, 85:4, 92:14, 92:16, 145:14, 145:21, 146:16, 147:2, 147:5, 147:8, 147:13, 147:15, 147:17, 148:1, 148:5, 148:8, 150:18, 170:17, 170:19, 171:2, 171:11, 171:12, 171:18, 171:21, 172:3, 172:6, 172:9, 172:11, 172:17,	172:22, 180:8, 180:10, 180:12, 180:20, 182:11, 182:14, 182:17, 182:21, 183:6, 183:11, 183:13, 183:20, 184:2, 184:13, 184:20, 184:22, 185:5, 185:8, 185:9, 185:11, 185:14, 185:19, 185:21, 185:22, 186:3, 186:6, 186:19, 192:7, 192:13, 192:19, 193:2, 194:21 li's 154:5, 186:8, 192:1, 202:18, 203:2, 203:8, 203:13 li-king 203:14 li-muller 202:15, 203:14 lifetime 46:6, 61:5, 61:6, 61:7, 62:6, 62:8, 114:6, 116:17, 125:6, 125:22, 126:14, 126:22, 134:16, 139:17, 142:7, 143:5, 144:7, 149:7 lifetimes 69:19, 126:11, 126:12, 137:3, 142:14, 142:21, 152:10 lift 163:22 light 39:7, 40:14, 44:17, 47:7, 109:21, 118:10 likelihood 121:17
--	---	--	---

likely 88:5, 94:21, 104:7, 118:16, 118:20, 122:2, 167:13, 191:20, 202:7, 202:9 limit 31:8, 73:12 limitation 61:21 limitations 55:3, 57:13, 57:15, 58:6, 58:8, 58:16, 58:21, 59:11 limiting 132:10 limits 25:1, 80:1, 86:10 line 38:6, 38:7, 83:12, 94:15, 95:6, 95:8, 95:13, 95:15, 96:4, 97:19, 123:20, 123:22, 127:8, 127:14, 129:3, 129:6, 129:10, 129:16, 132:1, 134:1, 134:10, 134:19, 166:10, 181:21 lines 67:4, 82:3 links 22:6, 103:5 liquid 43:3, 158:17 list 66:4 listed 30:13, 64:20, 65:9, 65:18, 66:7, 140:2 lists 133:8 literally 168:3	literature 17:2, 18:10, 18:11, 28:9, 28:11, 36:1, 37:7, 54:17, 77:2, 77:19, 190:5, 190:6, 190:13, 190:14, 194:20, 202:9, 206:22 lithium 35:10, 160:19 litigation 12:14, 209:11, 210:7 little 31:20, 33:17, 39:8, 54:16, 62:13, 78:17, 95:22, 107:21, 109:13, 115:11, 130:17, 162:1, 163:15, 168:18, 168:22, 169:1, 169:3, 170:2, 192:4, 199:2, 201:20, 208:4 liu 88:6, 88:9, 88:10, 88:14, 91:7, 91:10, 91:22, 92:9, 93:22, 94:6, 96:21, 98:14, 103:20, 104:10, 104:12, 104:17, 104:18, 104:19, 104:22, 105:14, 106:5, 107:3, 107:15, 109:7, 111:7, 111:14, 111:19, 112:3, 112:18, 112:19, 115:16, 116:4, 117:2, 119:1, 119:8, 119:10, 119:16, 120:3, 120:11, 120:13,	121:19, 125:9, 125:13, 125:15, 127:2 liu's 127:4 live 165:11 llp 2:3, 4:10 located 94:18 location 139:18, 140:1 locked 120:19 locking 76:13 logarithmic 108:12, 109:14, 109:17 long 9:12, 37:20, 37:21, 127:3, 168:20, 169:11, 185:19, 185:21 longer 43:13, 68:4, 70:19, 72:16, 79:13, 80:19, 102:19, 112:10, 112:15, 112:17, 113:19, 130:21, 168:22, 169:1, 169:3, 169:12, 169:15, 169:19, 189:16, 189:18, 190:1, 190:11, 191:2 look 6:19, 11:14, 16:2, 36:1, 36:10, 51:2, 53:13, 55:6, 57:16, 58:7, 58:12, 61:19, 64:17, 65:11, 66:20, 80:20, 86:15, 88:1,	88:6, 90:16, 93:5, 94:12, 99:11, 100:16, 101:8, 104:10, 106:10, 110:1, 110:6, 111:2, 111:11, 119:4, 122:19, 122:22, 123:15, 123:20, 128:2, 128:22, 131:15, 131:21, 135:11, 138:18, 141:17, 149:2, 170:17, 180:8, 181:14, 183:10, 187:3, 190:8, 190:9, 195:2, 199:22, 201:5, 203:17, 205:15 looked 19:3, 124:7, 152:9, 190:13 looking 11:16, 61:18, 67:3, 81:15, 88:18, 89:2, 91:3, 95:6, 104:16, 104:21, 106:13, 107:10, 109:6, 134:1, 134:9, 138:19, 138:21, 146:4 looks 7:4, 177:7, 199:9, 200:22 lordy 207:3 los 2:6 lot 19:12, 37:7, 39:16, 50:6, 52:13, 53:9, 53:14, 76:3, 126:15, 202:8, 207:22, 208:1, 208:2 lovely 204:18
---	---	--	--

low 23:21, 24:22, 28:20, 68:2, 149:9, 201:17, 202:5 low-pressure 133:11 low-quality 28:20, 29:6 low-temperature 120:11, 120:13, 120:14 lower 24:15, 25:14, 26:1, 26:12, 31:8, 31:18, 31:21, 68:4, 69:17, 73:4, 79:7, 86:16, 122:15, 149:12, 154:12, 155:6, 155:13 lower-quality 26:18, 28:22, 67:21 lowering 106:2 lowest 31:19 lpeterson@sidley 2:8 lunch 143:21	200:9, 200:11, 207:22 main 38:6 mainly 48:13, 120:18 maintain 120:17 maintaining 89:6, 90:14 major 99:9, 191:1, 191:4 majority 70:12, 70:15 make 6:18, 6:19, 6:21, 19:2, 19:6, 21:2, 25:16, 25:20, 26:18, 32:8, 35:3, 35:11, 35:12, 37:6, 39:12, 46:8, 46:13, 52:13, 55:1, 69:3, 69:6, 70:1, 70:4, 73:9, 74:6, 74:12, 78:11, 78:17, 82:2, 85:8, 96:18, 100:15, 112:21, 116:13, 143:10, 143:11, 144:18, 149:21, 156:4, 158:7, 160:13, 168:4, 175:13, 178:12, 178:14, 194:13, 195:22, 198:13, 201:3, 204:11, 209:13 makes 38:7, 43:13, 44:11, 69:18, 72:13, 76:9, 94:3, 96:12, 198:14	making 11:18, 12:10, 27:14, 46:2, 61:14, 82:16, 126:21, 191:2 manipulate 170:10 mankind 24:20 manner 173:11 manufacture 64:14, 89:17, 147:3, 163:1 manufactured 124:12, 124:15, 143:6 manufacturer 147:5, 147:10, 191:1, 191:4 manufacturers 162:9, 162:14, 164:16, 164:19 manufacturing 34:4, 38:10, 63:7, 63:11, 67:6, 67:8, 125:1, 128:11, 166:4, 167:15, 167:21, 168:16, 168:19, 169:7, 169:8, 190:14, 190:15, 191:4 many 13:8, 18:5, 18:17, 30:21, 34:19, 39:16, 69:6, 69:7, 117:15, 152:12, 156:12 marked 10:14, 11:9, 15:7 market 70:15, 151:10 marriage 216:16 marvin 188:18, 189:5,	189:15, 190:1, 190:12, 190:17, 190:20, 191:17, 192:8, 197:13, 197:17 marvin's 191:6 mary 216:2 mass 103:4 material 11:4, 41:9, 72:13, 73:11, 75:21, 76:6, 76:8, 78:8, 82:10, 113:10, 113:14, 114:8, 114:10, 120:20, 122:3, 142:7, 143:5, 149:7, 160:11, 172:13, 172:15, 174:16, 176:11, 176:20, 183:13, 183:17, 184:5, 184:7 materials 10:1, 10:13, 10:18, 10:22, 11:1, 11:5, 11:8, 11:21, 15:3, 21:6, 25:6, 25:16, 28:5, 29:14, 51:3, 60:6, 80:22, 88:8, 143:10, 151:13, 204:13 matrix 35:3 matter 29:2, 45:3, 50:9, 116:14, 212:3, 213:7, 214:9, 216:19 matters 78:14 matured 170:7
---	--	--	--

maxeon 1:11, 2:10, 4:12, 10:5, 14:1, 14:3, 14:12, 14:14, 51:10, 51:11, 52:3, 214:3 maximum 198:6 maybe 206:20 mean 23:3, 29:1, 33:15, 34:1, 34:3, 34:17, 36:20, 45:1, 45:2, 45:17, 53:5, 53:6, 54:11, 62:14, 72:9, 86:4, 100:14, 103:17, 114:9, 114:16, 114:18, 118:19, 122:10, 126:19, 142:12, 167:19, 174:2, 174:11, 175:14, 177:12, 182:6, 182:7, 182:13, 182:14, 189:7, 189:18, 194:12 meaning 32:16, 57:15, 61:9, 62:18, 116:1 means 5:21, 33:13, 62:21, 63:18, 74:11, 85:22, 86:4, 86:5, 86:13, 87:5, 87:6, 102:17, 168:16, 173:13, 176:9, 182:8, 182:11 meant 19:13, 23:4, 23:9, 36:4, 41:3, 61:16, 96:12, 195:13 measure 82:13, 97:13, 103:21, 112:18, 112:19, 142:15, 152:11 measured 98:1, 116:17, 126:12 measurement 113:21, 113:22, 114:2, 114:11, 118:2, 126:14, 126:21 measurements 82:7, 161:22 measuring 137:1 mechanics 36:7 mechanism 40:14, 41:2 mechanisms 29:13 medicine 113:2 meet 8:22 meeting 9:9, 51:14, 190:19 melt 24:10 memorized 55:7 memory 19:2, 19:6, 29:7, 50:6 mental 29:5, 29:10 mentioned 7:8, 9:13, 21:17, 30:11, 34:14, 37:9, 40:5, 40:22, 45:11, 47:13, 73:7, 75:5, 107:13, 131:7, 143:21, 145:17, 156:20, 161:17, 163:6, 192:16 mentions 172:22, 173:2 met 49:5, 191:5 metal 22:13, 23:12, 30:11, 30:18, 30:20, 31:15, 31:16, 32:12, 32:16, 32:18, 33:9, 34:14, 34:15, 34:21, 43:12, 44:16, 53:17, 56:14, 57:11, 58:19, 58:21, 68:18, 69:1, 71:1, 71:9, 71:15, 72:18, 75:7, 75:15, 77:3, 77:11, 77:21, 80:13, 81:7, 81:17, 87:19, 93:21, 121:13, 121:20, 123:2, 123:7, 124:18, 124:22, 125:11, 125:16, 126:3, 134:12, 134:13, 134:21, 135:4, 135:10, 135:13, 135:16, 136:20, 137:6, 139:13, 140:4, 140:9, 141:15, 149:19, 150:19, 151:2, 151:4, 151:7, 152:3, 154:18, 155:11, 155:13, 155:17, 194:13 metallic 35:4, 44:12, 68:13, 69:21 metals 27:18, 30:12, 35:1, 35:5, 35:8, 35:10, 35:17, 70:2, 70:5, 90:18, 105:22, 115:1 meter 201:3 meters 200:20 method 131:11, 137:19, 147:2, 166:12, 170:20, 185:5 methodologies 207:19, 207:21 methodology 185:4 methods 159:10, 166:11, 166:15, 166:22, 169:4, 185:6, 207:7, 207:13 metrics 190:7 micron 162:10, 162:15 microscopic 93:8 mid 26:14 middle 94:17 might 27:19, 59:14, 73:1, 76:9, 76:19, 79:21, 80:19, 117:6, 140:18, 163:9, 174:1, 210:3 million 163:22 milliseconds 142:22, 143:1 millivolts 200:19 mind 62:21, 126:8, 177:16, 179:8,			
--	--	--	--

199:11 mine 86:7 minimum 47:9, 125:20, 201:11 minority 116:16 minuses 179:11 minute 122:4 missing 59:12 mistake 100:15 mixture 168:14 mm-hmm 133:16 mobile 76:6 mobility 31:21, 32:22 mocvd 69:5 modern 80:1, 190:5 modification 166:7 modify 21:5 moly 29:12, 35:6 moment 7:1, 15:20, 17:15, 55:10, 102:2, 112:21, 113:3, 118:3, 131:7, 131:19, 143:1, 159:6, 187:16, 202:14, 205:5 monatomic 36:8 money 47:12 monkey 167:4	monocrystalline 68:11 more 7:1, 21:2, 23:2, 25:18, 26:2, 28:5, 33:6, 41:11, 47:2, 47:11, 50:1, 55:21, 67:7, 68:16, 70:19, 78:7, 79:7, 79:14, 80:4, 81:11, 109:16, 113:3, 115:4, 115:6, 143:12, 143:15, 143:16, 143:19, 148:8, 151:16, 156:7, 159:5, 162:21, 162:22, 163:22, 167:13, 169:19, 169:21, 175:16, 178:1, 178:22, 179:2, 179:3, 179:12, 179:13, 179:16, 179:20, 180:3, 180:5, 183:7, 191:16, 191:20, 191:21, 200:2, 201:4, 202:7, 202:9, 202:21, 208:4 moreover 98:4 morning 4:16, 4:17 morphologies 145:8 morphology 75:18, 76:4 most 22:18, 23:16, 24:12, 24:19, 25:12, 28:13, 46:19, 47:18, 52:12, 75:17, 82:8, 86:6,	88:20, 89:15, 94:21, 104:6, 118:16, 150:6, 160:4, 163:2, 164:11, 166:8 motion 72:16, 135:9, 156:10 move 31:11, 69:8, 98:18, 99:20, 99:21, 159:14, 166:12 moved 48:12, 121:14, 135:21 movement 23:4 moves 31:16, 76:2 moving 174:16 much 9:3, 17:13, 20:10, 30:21, 31:7, 34:10, 42:21, 52:11, 90:17, 90:20, 100:13, 103:8, 103:16, 114:7, 115:1, 121:3, 141:5, 155:22, 158:10, 162:10, 162:15, 162:20, 163:18, 164:3, 169:8, 169:15, 175:14, 194:6, 199:12 muller 175:21, 176:2, 188:18, 203:9, 203:22, 204:3, 204:8, 204:9, 204:22, 205:2, 205:11 muller's 202:19, 203:4, 206:8, 206:18	multicrystalline 68:7, 68:10, 68:14, 68:19, 69:4, 69:10, 69:16, 70:9, 70:12, 124:3, 124:8, 137:11, 144:15, 144:20, 145:3, 145:10, 146:12, 146:17, 146:22, 148:6, 148:18, 154:18, 183:22 multiple 30:22, 42:17, 77:8, 128:10, 158:15, 160:3 multiplication 198:16 multiply 201:1 must 74:10, 99:12, 144:4, 206:17 must've 97:12 mute 141:8, 141:9 myself 52:14, 84:8, 113:4, 169:11, 204:6, 205:5, 205:6 N n-type 35:15, 58:13, 173:1, 173:2, 173:4, 173:5, 174:5, 177:2, 178:4, 178:17, 179:4, 179:16, 179:21, 203:22 n2 108:17 name 4:18 named 51:17, 65:3
--	---	---	--

names 11:12, 11:13, 14:10 nanoamp 130:15, 130:17, 130:18 nanometer 105:2, 107:6, 107:7, 108:17, 110:7, 110:9, 110:12, 111:14, 112:2, 112:3 nanometer-thick 81:8, 81:19, 83:17, 108:22 nanometers 47:3, 47:4, 72:22, 83:4, 83:5, 92:11, 92:13, 103:6, 105:9, 105:10, 106:22, 107:1, 130:13, 130:20, 131:2, 162:7, 163:20, 184:15 nasa 164:2 national 96:8, 100:10 native 43:14, 75:13 naturally 21:13 nature 20:11, 24:16, 24:18, 34:22, 53:11 near 141:14, 141:16, 141:19, 172:12, 173:3, 175:1 nearest 103:12 necessarily 35:9, 44:14, 57:8, 69:19, 76:3, 85:8, 112:8, 114:9,	114:11, 177:12, 193:17, 194:1, 206:11 necessary 25:15 need 7:21, 8:11, 53:7, 74:6, 86:11, 92:17, 94:1, 133:6, 162:5, 162:22, 165:9, 165:12, 165:15, 169:20, 178:16, 178:21, 193:17, 194:8, 194:19, 213:11 needed 57:1, 80:12 needs 74:8, 74:11, 92:21, 125:3, 131:12 negative 174:15, 174:20, 174:22, 175:7, 179:1, 179:2, 179:3, 179:13, 180:3, 180:5 neighborhood 130:12 neither 122:18, 147:9 neuhaus 141:21, 141:22, 142:10 never 13:6, 14:12, 36:3, 76:11 nevertheless 53:12, 105:16, 126:17 new 10:21, 12:9, 39:6 next 89:2, 93:6, 94:13, 106:5, 110:8, 128:2,	182:21, 189:14, 199:21 nice 46:8, 194:16 nickel 29:11, 30:16, 32:4, 35:7, 135:13 nitride 160:15, 161:3, 161:14, 168:5, 168:9, 168:12, 168:15, 168:21, 169:14 nitrogen 105:12, 105:13, 107:12 nod 8:1 noise 96:1, 96:2, 96:3 non-space 172:7 nondestructive 86:7 nondisclosure 13:15 none 60:8, 98:3 nonequilibrium 24:16 nontechnical 61:16 normal 196:4, 207:9 normally 24:16, 34:22, 72:5, 162:2, 166:16, 179:8 notary 210:11, 211:15, 216:1, 216:3, 217:5 note 96:6, 197:1 noted 59:11, 124:6,	214:14, 214:15 notes 183:20 nothing 97:15, 148:5, 148:8, 148:15 notice 62:16, 82:8, 96:14, 116:15, 200:18, 205:19 notwithstanding 155:19 novel 181:11 novice's 63:19 number 10:2, 29:10, 29:16, 33:9, 54:8, 58:10, 60:20, 61:19, 64:19, 65:1, 85:13, 86:9, 87:12, 116:10, 118:8, 125:16, 146:4, 146:8, 153:5, 156:13, 156:14, 180:12, 182:1, 182:12, 182:18, 197:5, 198:20, 204:9, 210:14, 211:18 number's 201:1 numbers 29:7, 48:5, 55:7, 60:19, 82:4, 82:6, 120:11, 120:14, 146:3, 146:6, 198:2, 200:16, 201:5 O oath 214:13 objection 117:17, 148:12,
--	---	---	--

148:20 observed 85:3, 108:22, 140:12, 153:2, 153:7, 197:20 obtain 24:4 obtained 145:4 obvious 27:22, 28:1, 55:19, 56:20, 57:1, 57:6, 57:9 obviously 5:19, 8:21, 142:14 obviousness 56:12, 58:5, 59:10 occur 22:5, 24:16, 118:16, 119:12, 120:5, 121:8, 186:21 occurred 21:4, 33:4, 98:2, 99:15, 156:1, 216:13 occurring 18:9, 120:15 occurs 97:17, 138:21, 161:1 october 217:1 offer 214:13 offered 63:14 office 1:1 officer 38:4 often 113:3 oh 8:7, 10:15, 36:12, 41:4,	42:13, 44:10, 51:8, 51:11, 53:2, 53:6, 55:11, 65:12, 71:3, 85:18, 91:5, 100:11, 100:13, 112:20, 113:1, 117:21, 118:7, 120:12, 123:1, 123:16, 124:13, 125:14, 129:10, 131:15, 146:5, 162:13, 180:15, 187:13, 202:13, 204:11, 204:15, 204:18, 206:12, 207:3 once 48:5 one's 17:7, 36:12 one-sun 172:4 ones 32:6, 39:14, 40:15, 57:20, 120:16, 135:20, 160:4, 161:10, 175:3, 175:4, 190:12, 205:12 ongoing 7:3 only 6:11, 13:2, 19:3, 23:15, 28:3, 30:22, 90:22, 98:8, 100:1, 103:16, 115:1, 115:7, 128:5, 128:10, 150:16, 155:6, 155:9, 169:18, 171:7, 172:1, 172:3, 175:1, 175:2, 175:7, 177:6, 194:7, 213:12 open 6:13, 6:15,	15:13, 15:15, 198:4, 198:8, 198:11 open-ended 89:11 opened 6:5, 6:9, 6:10 opening 6:14 operating 205:22 operation 183:4 operations 182:1 opinion 12:3, 55:16, 56:4, 57:5, 57:8, 58:5, 87:18, 187:18 opinions 10:19, 11:22, 16:9, 16:10, 16:12, 17:10, 17:22, 18:3, 19:9, 53:15, 63:14, 63:21, 150:17, 171:12, 189:4, 192:7 opposite 95:12, 173:19 options 199:5, 202:12 orbit 28:5 order 21:2, 25:13, 25:16, 30:21, 32:5, 62:10, 63:8, 74:8, 130:15, 142:22, 179:16 ordering 63:4, 63:5 orders 98:4 ordinary 63:22, 64:7,	80:7, 187:7, 187:19, 188:11, 191:19 organic 39:2, 39:3, 39:6, 39:9, 39:21 organics 48:13, 152:18 orient 152:14 originally 50:17, 51:7 other 5:21, 6:5, 6:15, 8:15, 8:17, 8:22, 9:22, 12:12, 14:4, 14:11, 17:6, 29:8, 30:12, 32:3, 32:6, 32:16, 53:9, 53:13, 57:10, 57:13, 57:15, 60:5, 63:4, 72:17, 75:14, 77:17, 78:16, 78:18, 80:18, 82:9, 106:20, 112:9, 121:13, 122:9, 128:14, 132:5, 132:16, 133:13, 156:8, 156:12, 161:10, 164:17, 167:3, 168:22, 175:5, 179:13, 185:6, 186:21, 191:8, 198:13, 199:2, 201:16, 207:7, 207:13, 207:19, 207:21, 209:12 others 30:13, 40:15, 127:17, 135:14, 161:12, 166:7 otherwise 5:12, 163:13,
---	--	---	---

163:14, 185:3, 216:19 ourselves 152:14 out 11:21, 13:3, 21:3, 22:21, 24:10, 33:11, 33:19, 52:17, 65:6, 65:10, 68:3, 70:21, 74:21, 75:7, 112:5, 112:8, 113:8, 121:21, 122:13, 131:1, 148:1, 148:4, 151:12, 166:12, 175:4, 175:12, 186:5, 190:18, 191:3, 191:7, 194:20, 212:4, 213:7 outcome 216:19 outcomes 28:14, 28:15, 28:17 outdated 189:6 outer 25:9 outlined 64:10 output 199:4, 199:8, 200:6 outside 38:18, 38:20, 163:15 oven 127:16, 127:20, 128:1 over 5:19, 33:7, 43:6, 62:21, 62:22, 63:6, 76:19, 112:20, 114:14, 125:6,	125:22, 143:2, 151:22, 153:4, 166:9, 183:1, 185:6, 201:2, 207:7, 207:10 overall 29:9, 73:11, 74:2, 134:16, 157:8, 169:6, 169:8, 190:6, 199:3 own 10:6, 17:11, 18:16, 39:18, 70:3 owner 1:13, 2:10, 4:12, 14:15 owner's 3:13, 15:2, 15:6, 15:18 ox 129:19 oxidant 21:9 oxidate 46:1 oxidation 45:22, 76:13, 101:16, 164:10, 165:9, 193:14, 194:3, 194:8, 194:19 oxides 20:14, 20:18, 20:19, 20:21, 20:22, 21:2, 21:4, 21:22, 22:14, 31:1, 32:12, 48:6, 90:18, 92:17, 107:3, 130:7, 154:9, 197:2, 197:7 oxidize 46:1 oxygen 22:4, 46:4,	46:5, 76:11, 76:22, 165:11, 165:13 P p-type 35:15, 58:13, 174:4, 177:2 pack 99:19 page 3:2, 16:2, 36:14, 66:3, 66:22, 70:7, 81:16, 85:17, 88:17, 91:3, 92:9, 93:6, 94:13, 100:16, 101:9, 104:17, 105:14, 105:15, 106:11, 108:16, 138:19, 139:1, 145:21, 146:1, 146:2, 146:3, 146:4, 146:6, 146:8, 149:3, 149:4, 153:17, 153:18, 170:19, 171:5, 171:6, 181:15, 183:10, 187:4, 189:9, 189:14, 196:15, 199:21, 201:9, 203:21, 212:4, 213:8, 213:13, 214:16, 214:20, 214:25, 215:2, 215:7, 215:11 pages 1:26, 211:6, 213:12 pain 207:3 painted 39:16 panel 42:3, 42:5, 164:2, 166:10,	166:12, 166:16, 201:3, 201:4 panels 26:18, 38:7, 39:13, 167:12, 167:14 paper 7:16, 15:3, 91:19, 118:12, 141:21, 142:3 papers 49:11, 126:15 paragraph 36:10, 36:13, 65:11, 65:12, 84:15, 84:20, 85:7, 85:13, 85:17, 87:4, 88:18, 89:3, 105:16, 119:4, 128:2, 129:14, 134:2, 138:18, 138:20, 141:17, 145:21, 145:22, 146:7, 149:2, 153:18, 172:9, 180:8, 180:10, 180:12, 180:20, 181:14, 181:19, 181:21, 183:10, 183:20, 184:2, 184:13, 185:9, 185:14, 187:4, 187:11, 189:8, 189:13, 195:2, 195:5, 199:22, 201:7, 203:17 paragraphs 36:16 parameters 157:16, 190:3, 190:11, 190:20 parse 34:19 parsing 54:10, 75:3, 177:10 part 26:7, 27:2,
---	---	--	--

27:6, 32:20, 33:2, 48:11, 64:12, 64:16, 83:8, 97:20, 103:11, 150:16, 192:6 particular 10:6, 18:12, 18:15, 22:2, 41:11, 41:12, 59:7, 72:6, 77:12, 96:11, 114:3, 118:12, 119:17, 126:8, 131:11, 139:16, 171:19, 177:3, 184:21, 187:8, 187:21, 188:1, 188:13, 189:2, 198:18, 199:10, 199:20 particularly 49:16, 166:22, 190:5 parties 13:19, 209:11, 210:5, 211:9, 211:10, 212:9, 216:16, 216:17 parts 16:22, 17:4, 52:17, 62:14 party 209:11, 210:1, 210:6, 216:10 pass 81:8, 81:18, 93:21, 94:8, 208:13 passed 94:22, 97:4 passes 95:18, 96:19 passivate 42:12, 162:5, 194:17 passivates 161:2	passivating 88:21, 89:4, 89:6, 89:21, 90:2, 90:8, 90:15, 90:17, 164:13, 206:7 passivation 45:12, 61:5, 125:5, 157:2, 159:8, 159:11, 159:14, 159:21, 159:22, 161:13, 161:19, 162:4, 162:15, 164:9, 164:10, 164:20, 165:6, 167:6, 168:1, 168:6, 168:9, 168:12, 168:21, 169:9, 169:10, 170:4, 170:12, 192:10, 192:14, 192:20, 193:3, 193:8, 193:17, 193:21, 194:2, 194:16, 195:10, 201:13, 205:7, 205:13 passive 161:2 past 25:11, 46:1 patent 1:1, 1:2, 1:9, 1:13, 2:10, 3:13, 4:12, 4:22, 6:10, 6:13, 8:21, 9:14, 9:16, 9:17, 9:19, 9:22, 12:1, 12:3, 12:13, 13:1, 14:15, 15:2, 15:6, 15:18, 29:20, 30:2, 41:2, 55:3, 55:5, 55:8, 60:10, 60:15, 61:1,	61:2, 61:3, 61:19, 62:1, 63:21, 64:17, 65:7, 65:9, 65:15, 65:18, 65:22, 66:4, 66:8, 66:10, 66:11, 66:17, 66:21, 67:4, 71:11, 71:17, 72:1, 72:2, 92:14, 92:16, 122:19, 123:14, 124:11, 124:17, 125:12, 126:2, 127:6, 128:9, 129:10, 131:3, 131:16, 132:10, 132:22, 134:6, 134:9, 135:22, 136:8, 136:11, 139:4, 143:22, 144:13, 145:14, 146:20, 147:9, 147:13, 147:17, 148:2, 148:17, 184:11, 185:17 patentability 11:22 patented 42:21, 61:13 patents 11:17, 13:19, 18:22, 40:13 pay 53:6, 170:15 pecdd 21:1 pecvd 69:5, 76:21, 104:5 pedantic 54:20 pen 179:9 penalty 214:6, 214:7 pencil 179:9	pending 8:13 penetration 103:5 people 10:5, 13:15, 19:5, 23:16, 27:9, 35:5, 39:4, 42:1, 52:19, 53:3, 54:2, 54:6, 69:12, 75:18, 90:11, 166:6, 166:8, 166:14, 170:10, 175:18, 193:15 perceived 75:14 percent 102:1, 102:6, 102:9, 102:14, 102:18, 103:22, 108:11, 109:8, 109:11, 109:12, 109:13, 109:22, 111:8, 111:19, 112:4, 117:4, 117:5, 117:10, 117:12, 117:13, 117:15, 168:3, 169:6, 169:19 percentage 108:3, 108:6, 109:19, 137:1, 151:5, 151:9, 151:14, 151:18 percentages 108:10 perfect 24:19, 135:22 perform 25:16, 26:5, 154:8, 154:22, 198:14 performance 33:7, 44:20, 69:17, 144:8, 144:9, 147:16,
--	--	---	---

190:7, 197:20, 199:17, 200:14 performed 127:9, 153:21, 207:1 performing 128:15, 128:17, 130:19, 197:9 performs 45:4 perhaps 103:14 period 19:20, 20:2, 40:21, 49:1, 64:8, 74:20, 152:18 perjury 214:6, 214:7 permanently 76:15 permits 186:19 person 63:22, 64:7, 80:7, 80:12, 175:4, 187:6, 187:19, 188:11, 191:19 personal 19:18 personally 51:19, 74:15, 213:4 perspective 63:22 peterson 2:4, 3:6, 4:9, 4:15, 4:18, 15:10, 59:18, 60:1, 117:19, 140:18, 141:3, 141:7, 141:12, 148:16, 149:1, 208:5, 208:11 petition 53:16, 55:17, 202:17, 202:22	petitioner 1:7, 2:2, 4:6, 4:10, 4:19, 14:19, 56:5 petitioner's 56:12 ph 1:17, 3:4, 3:12, 4:5, 15:6, 15:17, 212:2, 213:5, 214:5, 215:20, 216:5, 216:13 phenomenon 26:10, 71:15 phone 5:21, 6:1 phonons 115:6 phosphor 104:13, 120:22, 121:18 phosphor-diffused 205:4 phosphorous 104:13, 107:12, 110:4 phosphorous-diff- used 105:3, 105:11, 107:8, 110:13, 204:5 phosphors 34:21 phosphorus 77:5, 98:15, 98:18, 99:3, 106:6, 108:15, 112:2 phosphorus-doped 92:5, 95:3 photoconductance 116:19, 116:20 photoelectron 86:8 photons 46:16, 46:19, 198:21	phrase 59:5, 113:7, 141:19, 171:1 phrased 174:2 phrases 144:22 physical 114:17, 116:10, 120:10, 122:8, 122:10, 122:12, 123:3, 123:9, 135:9 physically 114:1, 115:22 physicist 37:5 physics 34:19 picking 72:7 piece 23:19, 24:14, 44:16, 46:10, 72:12, 127:3 pieces 18:10, 42:3, 54:12 pileup 81:9, 81:20, 84:12, 84:16, 85:2, 153:22, 154:9, 155:1, 155:5, 155:15, 155:19, 156:1, 156:3, 156:9, 156:15 pinholes 76:5 place 27:2, 61:21, 63:8, 113:18, 127:20, 146:13, 162:20, 163:1, 185:20, 186:8, 186:13, 186:17, 186:22, 212:3, 213:7, 213:12	placed 43:3, 43:7, 45:12, 130:14 places 162:18 placing 127:15 planet 162:18, 163:3, 209:15, 209:17, 209:19, 209:21, 210:4 plant 168:16 plasma 69:5 plasma-coupled 69:5 plasma-enhanced 12:8, 133:12 play 180:6 please 6:16, 7:1, 8:6, 8:12, 14:9, 15:14, 40:2, 55:6, 55:10, 55:21, 57:14, 66:20, 68:16, 81:11, 112:16, 112:22, 113:3, 180:1, 189:9, 202:21 pluses 179:10 poc13 110:7, 110:9 point 8:11, 36:6, 65:6, 68:1, 70:22, 71:18, 79:20, 80:3, 86:17, 86:20, 191:8 pointed 122:13, 186:5 points 18:18, 95:14
---	--	---	--

poly 101:5, 140:2, 184:10 poly-si 94:17, 94:20, 108:17, 110:7, 110:8 polycrystalline 69:3, 69:15, 70:2, 70:4, 70:8, 88:19, 90:6, 144:20, 145:1, 145:11, 183:14, 183:15, 183:18, 184:7, 184:11, 186:1, 186:7, 186:13, 186:16 polymer 39:15, 40:1, 40:4, 193:19, 193:20, 194:1, 194:22 polymers 193:16 polysilicon 74:17, 77:21, 78:3, 78:5, 85:15, 87:21, 89:4, 89:14, 89:21, 90:2, 92:5, 93:11, 93:16, 93:19, 93:22, 94:8, 95:2, 95:3, 95:10, 95:20, 97:6, 97:17, 97:21, 98:11, 98:16, 98:22, 99:3, 99:12, 99:16, 99:17, 100:22, 101:6, 101:15, 101:21, 102:13, 104:2, 104:5, 105:4, 105:11, 109:1, 110:14, 111:15, 119:11, 120:4,	120:7, 121:7, 121:15, 121:22, 122:6, 132:17, 132:18, 134:11, 135:1, 135:7, 135:18, 138:9, 138:10, 139:14, 140:5, 140:9, 140:11, 140:13, 155:14, 155:19, 156:13, 185:12, 186:21 poor 28:14, 29:1 popular 70:14, 70:18, 160:4, 161:18, 164:11 portion 56:8, 82:22, 91:22, 103:19, 110:3, 112:12, 112:14, 112:17, 112:19, 132:21, 133:4, 133:17, 172:17, 172:22, 174:3, 174:7, 188:20, 191:10, 192:1 portions 56:12 position 19:14, 28:2, 184:10 positioning 93:14, 207:9 positions 11:2, 94:4 positive 174:18, 174:22, 178:22, 179:14, 180:3 possibility 148:1, 190:18, 191:3 possible 52:15, 52:18 post 25:15, 26:2,	26:6, 26:19 post-diffusion 101:16 post-docs 39:17 potassium 35:10 potential 72:14, 185:6 power 41:10, 61:10, 198:3, 198:7, 198:15, 198:16, 198:20, 199:4, 199:7, 200:5, 208:2 precautions 168:17 precise 35:13, 113:6, 175:16 precisely 59:13, 67:8, 74:19, 80:6 preclude 148:5, 148:9, 148:15, 148:17 predicated 150:20 predict 28:16 prefactor 29:16 prefer 6:11, 131:1 preferable 183:1 premised 150:17 preparation 10:1, 10:9, 11:9, 207:16 prepare 8:18, 16:21, 150:2 preparing 8:16, 9:3, 17:13, 17:16	presence 57:11, 125:11, 126:2 present 53:18, 68:14, 99:1, 99:2, 102:10, 102:18, 103:22, 108:3, 108:7, 109:8, 111:8, 112:10, 112:15, 112:17, 152:4, 155:14, 181:3, 181:5, 181:9, 183:17, 196:15 presumably 97:9 presume 97:17 pretty 40:17, 153:15 prevent 77:17, 174:20 preventing 165:8 prevents 41:9, 156:10, 174:12 previously 12:14, 13:5, 52:3, 193:1 primarily 20:20, 41:18, 190:5 primary 25:19, 165:8 principle 206:14, 206:15 printed 80:21, 88:8, 204:13 printout 109:21 prior 13:20, 38:17, 51:21, 65:4, 74:15, 74:19 priori 28:2
--	--	---	--

priority 11:16 probably 31:15, 52:19, 58:12, 122:5, 164:6 problem 31:2, 31:3, 57:21, 60:4, 77:12, 98:13, 99:9, 111:1, 114:22, 115:6, 150:11, 174:18 problems 77:1, 160:12 procedures 91:7, 91:16 proceeding 14:20, 50:14 proceedings 4:19, 4:22, 5:2, 5:8, 9:20, 10:9, 10:14, 11:10, 14:16, 15:18, 16:13, 26:8 procel 191:14 process 12:19, 12:20, 17:21, 18:2, 18:15, 24:4, 24:7, 24:17, 25:2, 25:3, 27:3, 27:6, 28:10, 32:20, 34:4, 34:10, 38:10, 43:17, 61:14, 75:15, 76:22, 77:1, 77:10, 77:17, 78:12, 79:21, 80:15, 80:17, 91:10, 104:6, 108:8, 108:9, 109:9, 111:21, 115:1, 115:2, 116:8, 122:16,	122:17, 125:2, 127:9, 128:4, 128:6, 128:10, 128:19, 130:1, 132:3, 132:6, 132:7, 133:11, 133:18, 134:13, 136:5, 143:12, 143:17, 166:4, 167:16, 167:22, 168:20, 169:7, 169:8, 182:1, 182:2, 182:3, 182:12, 182:18, 182:22, 183:2, 183:7, 185:19, 186:2, 186:6, 203:9, 207:4, 207:15 processes 25:5, 33:22, 63:8, 63:11, 69:9, 76:20, 77:5, 128:11, 128:18, 136:11, 181:6, 181:11, 190:15 processing 25:15, 26:2, 26:6, 26:19, 53:2 produce 61:10, 69:10, 69:15, 166:10 produced 29:17, 29:21, 39:17 product 37:13, 42:7, 42:8 production 38:6, 43:6, 151:10, 151:11, 151:21, 166:11 professional 210:12, 211:16 professor 38:14	progressed 170:7 prohibited 209:21 project 164:3 prompted 10:16 properly 160:18 protect 43:15, 45:16, 45:18, 45:21, 47:10, 165:12, 165:15, 165:21, 193:14, 194:8, 194:19 protective 27:16, 194:3 prove 79:22, 118:22 proves 201:11 provide 7:12, 53:16, 58:4, 75:19, 147:15, 167:20, 209:18, 209:22 provided 10:4, 10:5, 16:18, 19:3, 189:4 provides 55:16, 56:4 providing 87:18, 181:6, 181:10 psg 95:9, 98:16 pte 1:11, 2:10, 214:4 public 210:11, 211:15, 216:1, 216:3, 217:5 publication 30:2, 49:10,	74:22, 80:21, 145:14 publications 11:13, 49:13, 74:16, 74:18, 74:21, 91:1 published 18:20, 49:17, 75:3 pull 24:10 pun 34:1 pure 23:19, 24:5, 36:7, 69:15, 69:17, 127:3, 141:14, 141:16, 141:19, 150:2, 150:18, 208:3 purely 80:17, 99:10 purer 24:14 purity 105:17 purport 71:11 purpose 73:14, 96:16, 175:11 purposes 24:5, 28:19, 46:21, 55:2, 63:20 pursuant 209:2 put 6:1, 18:7, 32:17, 34:16, 43:8, 43:12, 47:11, 48:6, 98:5, 98:8, 112:20, 113:2, 122:4, 145:13, 145:19, 158:18, 173:17, 174:19, 174:20, 188:2,
---	--	---	--

196:12, 198:5, 204:10, 208:3 putting 22:19, 43:20, 46:12 pvlaw 2:12, 4:12 pyramidal 20:7 pyramids 43:18	204:21, 205:1 questions 16:11, 19:9, 34:13, 208:14, 211:4 quite 25:1, 52:20, 59:6, 100:20, 109:21, 143:19, 164:14 quote 85:20, 115:17, 142:4, 142:5, 142:10, 149:9, 189:5, 192:7	read 8:21, 10:3, 10:10, 15:22, 49:11, 49:19, 49:21, 51:19, 52:6, 54:16, 54:18, 100:6, 125:9, 144:9, 149:5, 181:8, 187:17, 212:9, 214:7, 214:9, 214:17, 214:21, 214:26, 215:3, 215:8, 215:12 reading 9:11, 10:9, 109:17 reads 181:22 real 55:6, 115:5, 175:2 reality 175:19 realize 112:20, 180:1 realized 33:2 really 11:17, 22:22, 25:12, 25:21, 28:6, 29:1, 36:8, 52:10, 79:11, 81:13, 82:14, 93:1, 109:20, 113:6, 116:14, 131:1, 151:12, 169:11, 169:18, 173:10, 174:8, 175:14, 194:4, 194:8 realms 150:4 reason 5:14, 5:16, 32:6, 50:1, 73:22, 90:15, 108:10, 114:21,	114:22, 122:1, 153:15, 155:4, 155:9, 156:8, 163:6, 163:9, 163:12, 165:2, 165:5, 195:20, 200:17, 205:6, 206:9, 214:19, 214:24, 215:1, 215:6, 215:10, 215:15 reasonable 85:22, 86:3, 99:8 reasons 57:7 recall 11:4, 11:8, 11:13, 12:5, 13:11, 28:8, 28:21, 28:22, 30:2, 30:7, 30:9, 30:10, 42:10, 42:11, 42:13, 43:22, 44:3, 45:5, 45:10, 46:22, 47:4, 49:20, 49:22, 50:8, 50:13, 51:5, 51:12, 51:14, 53:18, 65:3, 71:20, 74:19, 75:4, 84:17, 141:15, 144:13, 154:17, 158:13, 158:15, 168:6, 175:21, 176:4, 191:11 recent 152:1, 191:17, 191:21 recently 89:3, 89:20 recess 59:20, 140:22, 208:8 recited 55:18, 63:9,
Q qualification 125:4, 167:20 qualifications 49:14 qualified 51:4, 90:21, 90:22, 122:8 qualify 14:9, 95:21, 102:21, 122:10, 166:21 quality 26:1, 26:4, 26:12, 68:2, 89:7, 90:15, 90:17 quantum 50:7 quasi-steady-sta- te 116:19 question 8:5, 8:9, 8:13, 19:15, 23:14, 29:15, 32:15, 34:13, 44:1, 44:22, 53:1, 56:10, 77:15, 79:17, 81:14, 89:11, 113:7, 158:8, 167:8, 173:10, 174:1, 178:1, 179:9, 191:1, 200:3, 204:7, 204:20,	R radiation 46:14, 46:18, 162:6, 162:21, 163:8, 171:19 raise 113:16, 122:15, 122:16 raising 127:17 raman 21:8 ramappa 80:21, 81:2, 81:3, 81:7, 81:15, 81:17, 82:19, 84:11, 84:16, 84:21, 86:18, 153:20, 154:1 ramappa's 84:6 range 92:13, 92:14, 131:4, 184:14 rare 159:5 rates 210:5 raw 46:4 reactive 104:6		

63:10 recites 124:7 recognize 15:16, 88:2, 198:12, 201:17 recognized 39:8, 67:13 recollection 28:13, 28:15, 48:2, 152:22, 159:4 recombination 33:1, 33:5, 71:2, 71:4, 106:1, 134:15, 156:21, 157:3, 157:7, 157:14, 157:20, 158:1, 158:9, 158:11, 159:7, 160:7, 199:13, 205:11 recombine 174:17 record 4:4, 5:10, 30:5, 49:10, 55:8, 59:18, 59:19, 59:21, 60:9, 140:19, 140:20, 141:2, 145:18, 164:7, 181:9, 208:5, 208:6, 208:9, 208:15, 208:16, 216:8 recorded 139:15 recorder 8:2 rectangle 198:3, 198:15, 198:20 red 95:6, 95:8, 96:4, 101:15, 107:17, 197:11, 197:12, 199:7,	199:15 red-highlighted 197:16, 197:21, 199:16, 200:7, 200:13 reduce 33:9, 67:5, 67:8, 67:20, 69:12, 76:11, 157:3, 157:7, 157:13, 157:20 reduced 46:7, 158:8, 211:5, 212:6 reduces 158:11 reducing 134:14, 157:22, 158:1, 158:9, 159:7 reduction 181:22, 182:12, 182:18 refer 5:5, 9:16, 14:14, 14:18, 24:1, 31:9, 34:20, 54:14, 54:15, 70:8, 70:10, 72:20, 116:2, 144:22, 175:10, 176:21 reference 30:8, 65:4, 65:21, 84:14, 90:10, 91:17, 125:8, 125:9, 126:8, 126:11, 149:16, 149:17, 152:2, 175:21, 195:6 references 10:2, 10:6, 12:6, 19:3, 19:4, 50:21, 51:16, 51:20, 77:7, 77:8, 81:3, 88:10,	126:5, 126:14, 144:10, 152:12, 175:20, 191:9, 191:13, 191:22, 192:9, 194:20 referral 209:10, 210:3 referred 19:17, 23:8, 23:11, 26:20, 30:3, 52:3, 93:4, 140:4, 144:14, 145:1, 173:12 referring 5:11, 9:17, 14:15, 14:19, 19:19, 32:18, 36:5, 39:21, 41:14, 50:4, 54:2, 86:3, 91:11, 119:15, 119:18, 120:3, 120:6, 120:10, 121:6, 135:17, 177:11, 199:11 refers 119:20, 130:9, 135:13, 142:3, 145:3, 184:2 refined 86:20 refinement 24:6, 24:9 refining 24:21, 26:9, 143:9 reflections 72:16 reflective 20:9 reflectivity 41:9 reform 160:10 refrain 6:14 regard 146:21	regarding 4:21, 11:22, 32:2, 154:9, 192:20 regardless 111:6, 140:13 region 46:13, 53:18, 53:22, 54:4, 54:6, 54:14, 54:15, 54:18, 54:19, 55:4, 55:13, 56:14, 57:12, 62:20, 71:20, 72:1, 72:10, 72:15, 72:21, 73:6, 73:8, 73:17, 73:21, 74:1, 74:8, 74:11, 90:13, 92:5, 94:16, 94:17, 123:3, 123:8, 127:10, 129:22, 132:2, 132:11, 132:17, 132:18, 132:22, 134:2, 134:5, 134:7, 134:22, 135:1, 135:7, 138:9, 138:10, 140:5, 166:13, 189:3 regions 72:17, 72:20, 78:13, 78:14, 132:17, 134:10, 134:11, 134:14, 165:12 registered 210:12, 211:16 registry 156:3 regulations 209:3 related 4:22, 18:8, 81:4, 125:7, 216:15
--	---	--	--

relative 63:4, 78:4, 169:16, 173:8, 200:16 relatively 31:4, 34:1, 42:4, 127:3, 178:22, 200:15 release 38:15 reliable 49:18 relied 17:9 relieve 46:2 rely 191:21 relying 18:16 remain 94:11, 136:4 remaining 101:22, 102:15, 102:16, 108:7, 108:9, 109:9, 111:9, 111:20, 116:7, 117:4, 117:10, 117:14, 117:15 remains 116:10, 194:7 remember 29:16, 30:4, 42:3, 43:8, 49:7, 104:4, 126:13, 126:16, 153:3, 153:5 remind 48:17, 84:8, 118:3, 204:6, 205:5, 205:6 reminded 5:22 reminding 113:4 remotely 1:21, 216:13	removal 23:17, 33:22, 79:1, 119:21, 120:10, 121:10 remove 33:13, 34:7, 71:8, 75:15, 75:21, 76:8, 113:9, 115:2 removed 71:16, 104:1, 114:1, 114:10, 115:9, 115:13, 115:22, 120:19 removing 33:14, 90:19, 114:19 repair 167:13 repeat 177:22 replacing 202:18, 203:2 report 53:15, 55:16, 56:4, 58:4, 84:11, 87:4, 117:15, 138:13, 150:17 reported 1:27, 77:18, 89:3, 89:20, 90:11, 98:10, 98:12, 98:22, 100:20, 100:21, 102:6, 106:19, 117:3, 119:2, 125:12, 138:13, 140:8, 154:18, 199:6, 204:3, 205:2, 211:4 reporter 3:8, 4:2, 8:2, 59:19, 59:21, 140:20, 141:1, 208:6, 208:9, 208:16, 209:5, 209:8, 209:9,	209:15, 210:2, 210:12, 211:16, 212:6, 213:1, 216:1, 216:3 reporter's 209:9 reporting 77:3, 84:11, 101:12, 103:21, 108:21, 111:7, 112:4, 115:17, 209:3, 209:7, 209:18, 209:22, 210:2 reports 77:20, 92:10, 94:6, 98:14, 98:15, 107:15, 108:3, 108:6, 109:7, 111:19, 115:16, 116:4, 117:2 represent 4:18, 31:8, 107:12, 198:19, 211:6 representative 209:15 represented 216:11 representing 107:22, 197:15 represents 31:18, 198:6 requested 212:5 require 62:9, 135:22, 184:20, 184:22, 185:5 required 63:8, 186:11, 207:12 requirement 62:5, 62:8, 182:17, 185:2 requires 142:6	requiring 64:11, 133:3 research 19:4, 152:5 reside 76:15 respect 20:18, 20:19, 21:22, 22:3, 53:7, 57:10, 58:3, 58:22, 63:15, 74:13, 139:7, 146:22, 186:22 respected 100:12 respectively 132:4 respond 7:22 response 3:13, 15:2, 15:7, 15:18 responsible 38:5, 38:6 rest 46:10, 91:17, 119:19, 175:15, 177:6 restart 73:18, 165:4, 167:20, 171:11 restate 205:1 result 79:14, 80:4, 155:12, 156:6, 157:7, 173:16, 182:11, 183:6, 211:11 resulting 199:16 results 84:11, 196:15, 204:4, 204:8, 205:2 retained 13:22, 50:8,
--	--	---	---

50:13, 50:15 return 213:12 review 7:16, 9:22, 10:13, 10:18, 16:5, 60:6 reviewed 9:13, 11:21, 12:6, 60:21, 75:1, 171:12, 171:15 reviewing 30:2, 60:18 richard 51:17, 51:21 rid 46:18, 161:1, 194:12 ringer 6:1 rmr 1:28, 216:2 rooftops 25:7, 52:15 room 5:17, 5:18 rough 48:5, 49:4 roughly 17:18, 47:7, 48:8, 51:8 round 82:5 rpr 1:28, 216:2 rule 148:1, 148:4, 190:18, 191:3, 191:7 rules 7:20, 209:2 running 38:8 rust 76:17 rutherford 96:9, 103:4	S s 20:20 safety 168:17 safety's 169:20 said 26:13, 26:20, 36:13, 47:15, 47:22, 50:22, 51:2, 53:3, 56:9, 85:19, 88:9, 96:19, 100:6, 100:7, 100:9, 100:12, 115:21, 121:3, 122:14, 137:5, 169:5, 193:1, 193:11, 195:8, 211:8, 211:10, 211:11, 212:10, 213:9 sake 169:20 same 28:12, 31:5, 38:14, 39:4, 48:1, 66:3, 70:7, 70:8, 77:16, 78:18, 96:3, 104:18, 108:16, 116:2, 116:13, 125:13, 125:15, 129:14, 144:21, 145:5, 145:10, 146:20, 147:13, 148:2, 160:21, 171:8, 184:9, 190:11, 194:14, 201:1, 203:13, 205:9, 207:17, 212:6, 214:9 sample 104:22 samples 106:15, 111:5,	116:17 sanjay 50:4 save 214:10 saved 70:18 saying 35:18, 52:6, 87:3, 88:5, 95:11, 95:13, 97:7, 113:7, 113:22, 116:13, 120:8, 125:11, 125:14, 125:15, 177:22, 179:15, 180:17 says 53:8, 62:20, 67:7, 82:22, 83:9, 89:3, 94:16, 94:17, 95:13, 95:15, 96:3, 97:21, 102:4, 102:7, 102:22, 104:3, 105:21, 106:6, 106:15, 108:16, 110:8, 123:5, 124:1, 127:8, 128:2, 129:14, 129:18, 129:21, 132:1, 132:15, 133:9, 133:10, 134:9, 134:19, 136:3, 139:18, 142:5, 146:10, 149:16, 181:9, 182:21, 193:2, 193:5 scale 108:2, 108:12, 109:14, 169:18, 170:1, 170:14 scaled 201:6 scales 109:17	scatter 115:7 scatterers 116:11 scattering 116:9 scheme 157:17 science 53:11, 71:7 scientific 16:22, 17:1, 17:2, 17:10 scientists 54:13 scope 66:17, 66:19 second 42:8, 46:11, 56:16, 88:18, 89:20, 92:9, 108:14, 110:2, 112:22, 113:13, 115:1 second-best 199:7, 199:10 secondarily 62:22 secondary 103:4 secret 42:22 see 6:20, 15:9, 36:10, 36:16, 40:15, 47:18, 64:19, 64:21, 65:1, 65:9, 66:15, 67:4, 68:15, 68:19, 68:20, 81:1, 81:16, 86:1, 86:17, 88:12, 89:8, 89:9, 90:16, 91:21, 95:14, 105:15, 106:17, 108:18, 115:18, 118:7,
---	---	--	---

119:13, 124:4, 127:12, 129:5, 129:7, 131:19, 132:8, 134:3, 134:17, 134:18, 135:3, 138:22, 142:3, 142:8, 142:20, 146:14, 152:12, 182:4, 187:11, 190:10, 190:16, 196:7, 199:9, 200:17, 205:12 seems 104:3, 104:4 seen 74:16, 74:18, 152:1, 206:21 self 103:11 semi-vacuum 166:17 semiconducting 40:1 semiconductor 25:13, 151:12, 153:9 semiconductors 71:2, 71:9 send 28:5, 103:3 sense 25:20, 34:3, 61:12, 79:5, 151:18, 160:22, 169:15, 170:11, 175:13 sensitive 46:14, 82:9, 115:4 sent 6:4, 7:10, 15:3, 17:3, 51:3 sentence 90:1, 105:15, 106:14, 135:11, 146:10, 181:8, 182:21, 187:6,	189:13 separate 164:5 separately 27:15, 128:18 seriously 100:14 serve 193:21 service 50:18 services 209:7, 209:18, 210:1 serving 46:20, 171:9, 175:11 set 62:9, 63:2, 63:7, 63:11, 91:12, 108:14, 110:2, 111:12, 175:6, 185:16, 212:3, 213:7, 216:6, 216:20 sets 108:5 settled 13:3, 201:14 several 9:11, 10:10, 13:1, 41:13, 45:20 shake 8:1 shall 209:5, 209:12 share 147:20 sheer 181:22 sheet 214:1, 214:12 shifting 69:7 shifts 69:8 shock 8:1	short 59:14, 198:5, 198:9, 198:11, 199:14 shorter 79:15, 118:14 shorthand 216:1 should 15:2, 34:18, 80:21, 88:8, 100:13, 118:5, 121:17, 121:18, 172:18, 188:16, 192:1, 204:13, 214:17, 214:21, 214:26, 215:3, 215:8, 215:12 shoved 50:16 show 6:15, 82:1, 82:18, 84:16, 96:4, 96:5, 96:12, 101:3, 137:2, 139:7, 144:5 showed 77:9, 118:1 showing 93:8, 95:4, 96:1, 114:3, 114:6, 121:7, 139:16, 195:13, 199:3, 199:13 shown 111:18, 125:8, 131:18 shows 81:7, 81:17, 91:6, 94:22, 95:18, 96:14, 96:19, 97:3, 97:14, 98:16, 101:20, 102:12, 114:13, 115:12, 115:13, 125:19, 137:2, 139:11,	195:8 si 83:9, 94:16 sic 116:18, 187:4 side 78:13, 78:16, 78:18, 97:19, 108:2, 108:5, 116:5, 156:7, 156:8, 192:10, 192:14, 195:11, 203:13 sides 78:19, 128:15 sidley 2:3, 4:10 sigma 87:12, 87:14, 87:15 sign 13:14, 212:9 signature 3:9, 16:3, 16:4, 215:17 signature-b7fzp 211:13 signature-mig2k 210:9 signature-plkal 217:3 signed 213:13 significant 22:8 significantly 21:5, 86:10, 143:15, 169:12 signing 16:6 sil 142:15 silane 168:14 silent 192:19 silicide 31:1
---	--	--	--

silicides 31:1	183:21	slowest 31:16	62:14, 68:1,
silicone 183:15	sink 134:11	slowly 24:10, 78:18,	72:5, 72:22,
siloxane 12:10	sinton 116:18	169:20, 169:21	74:6, 81:7,
similar 26:6, 26:8,	sio2 83:1	slows 79:19	81:9, 81:17,
31:6, 39:13,	siox 108:17, 110:7,	slurry 43:2	82:1, 85:8,
40:12, 40:13,	110:8	small 42:4, 85:13,	86:13, 87:1,
41:1, 41:2,	sir 5:1, 37:19	86:18, 88:2,	88:2, 90:12,
55:13, 55:14,	sit 46:4, 75:13,	144:19, 145:2,	98:1, 98:16,
100:20, 147:9,	179:9, 180:6	155:8, 166:18	103:13, 118:20,
197:16	sits 77:13	smith 65:1, 65:3,	120:15, 120:17,
similarity 147:11	situation 18:21	66:7, 147:20	122:2, 130:13,
similarly 62:4	six 87:15	smoother 72:15	136:3, 137:3,
simple 50:1, 155:5	size 42:4, 79:18,	snodgrass 2:13, 4:11,	143:7, 150:22,
simply 13:16, 32:7,	163:21	8:20, 9:1,	151:3, 151:15,
33:13, 53:6,	skepticism 99:11	117:17, 141:11,	152:20, 160:15,
58:13, 162:19,	skill 63:22, 64:7,	148:12, 148:20,	161:11, 161:18,
162:22, 163:20,	187:19, 188:11,	208:14	162:9, 162:14,
165:15, 176:9,	191:20	snodgrass@pvuslaw 2:18	162:17, 166:6,
176:16, 182:8,	skilled 56:20, 57:6,	so-called 26:7	178:12, 181:17,
194:19, 195:16,	100:5, 159:17,	solar's 53:16	181:22, 182:6,
205:6	159:19, 161:6,	solar-grade 25:3, 142:19,	182:14, 182:22,
sims 103:1	165:16, 165:19,	143:13, 143:18,	183:2, 183:6,
simultaneous 28:9	194:10, 201:16,	148:6, 148:10,	186:19, 191:4,
simultaneously 77:4, 128:16	201:21, 202:4,	148:11, 148:18	193:8, 196:15
since 16:19, 25:19,	202:11	sold 37:17, 37:18	somebody 117:22
156:6, 166:10	slight 48:7, 166:7	some 10:3, 10:5,	somehow 97:18, 99:8
single 119:1	slightly 22:17, 86:16,	14:3, 18:6,	someone 52:16, 56:20,
single-crystal 68:7, 68:11,	144:22, 163:4	26:6, 26:9,	57:6
68:15, 68:21	slow 31:4	27:1, 30:13,	someone's 36:1, 53:10
single-crystalline 124:2, 124:9,	slower 207:16	31:6, 31:7,	someplace 100:7
137:12, 144:15,		35:4, 39:10,	something 12:10, 18:7,
146:12, 146:17,		40:3, 40:12,	18:8, 29:8,
		42:21, 50:20,	47:2, 48:19,
		60:18, 61:14,	62:22, 65:16,
			72:4, 72:8,
			87:11, 97:16,
			113:4, 114:6,
			126:13, 126:18,
			130:15, 142:21,
			143:2, 144:22,
			152:4, 160:5,
			160:17, 161:6,

161:14, 163:21, 165:9, 165:15, 177:11, 178:21, 205:8 sometime 25:22, 26:14 sometimes 14:10, 34:19, 35:5, 35:14, 37:1, 50:2, 54:6, 54:8, 160:17, 175:17, 182:11 somewhat 52:20, 53:3, 69:13 somewhere 49:3, 70:21, 84:2, 100:3, 109:12, 130:12, 190:19 sorry 5:6, 7:8, 11:7, 13:17, 18:12, 18:13, 23:9, 26:10, 33:4, 34:18, 40:2, 42:18, 45:10, 48:15, 49:22, 53:2, 55:22, 56:2, 64:4, 66:2, 83:4, 88:1, 91:11, 92:22, 94:3, 101:11, 103:8, 108:4, 110:22, 112:12, 112:20, 113:5, 118:4, 120:1, 123:18, 126:6, 128:22, 129:10, 129:15, 131:15, 133:9, 134:10, 142:4, 142:17, 146:2, 146:5, 149:3, 153:8, 153:17, 158:20, 159:14, 165:3, 165:22,	166:21, 167:19, 171:11, 175:15, 179:3, 179:7, 186:18, 187:12, 198:10, 200:2, 200:12, 202:21, 205:6, 206:20 sort 47:9, 53:8, 72:5, 72:22, 95:21, 102:21, 143:7, 165:10, 174:1, 198:19 sorts 6:8, 76:5 sound 5:3, 56:9 sounds 22:12, 26:15, 54:10, 59:15 source 72:5, 72:8, 154:17, 204:1, 209:10 sources 18:10, 18:11, 150:6, 158:22 south 2:5 space 25:9, 163:11, 163:22, 190:10 spaces 39:19 spans 135:12, 149:4 speak 8:15, 17:6, 17:7 speaking 23:19, 46:12, 51:12, 67:22, 72:3, 73:9, 130:11, 145:12, 160:3, 163:2, 193:13 speaks 31:10	species 77:12, 77:13 specific 61:3, 62:8, 62:9, 63:7, 63:10, 74:5, 103:3, 125:16, 133:3, 144:6, 144:7, 150:10, 165:11, 189:2, 194:17, 196:8, 204:7 specifically 18:20, 19:10, 22:3, 23:3, 38:22, 58:7, 72:21, 81:18, 119:20, 120:9, 135:11, 135:12, 204:20 specification 67:1, 129:5, 135:12, 146:3 specifications 123:17, 191:6 specifics 13:18 specified 126:14 specify 124:21, 126:2, 126:17, 131:3, 131:11, 131:16, 143:22, 144:2, 172:19 spectral 188:8 spectroscopy 21:9, 86:8, 86:9, 103:4 spectrum 61:10, 188:9 speculation 150:5, 150:16 spend 9:8, 17:13 spent 9:3, 9:11,	17:16 spoke 8:20 spoken 51:10 spot 162:8 spray-on 193:18, 193:20, 194:22 sputtering 133:13 square 130:16, 130:17, 130:18, 200:19, 200:22, 201:2, 201:3, 201:6 squared 82:5 squares 82:6 stacking 93:9 stainless 32:8, 40:16 standard 87:15, 148:18, 158:16, 190:17 start 44:10, 88:14, 106:13, 129:3 started 26:14, 96:21, 97:4, 156:7 starting 28:20, 34:8, 94:4, 95:8, 105:14, 111:20, 124:18, 129:10, 132:1, 136:9, 136:19, 137:5, 142:7, 143:5, 144:8, 149:7, 155:10, 155:20, 156:14, 181:21 starts 189:13 state 5:12, 65:14,
--	---	--	---

149:6, 160:11, 161:1, 171:18, 171:21, 172:3, 172:6, 172:8, 182:13, 185:19, 185:21, 187:6, 187:18, 211:1, 213:2, 216:3, 217:5 stated 58:18, 58:19, 63:11, 63:13, 145:6, 211:4 statement 18:6, 61:17, 69:2, 70:1, 82:16, 89:13, 89:16, 112:22, 125:3, 149:21, 184:22, 193:2, 193:5, 194:21 statements 89:10, 89:12, 191:21 states 1:1, 52:4, 67:5, 88:17, 180:20, 181:2, 184:13, 209:4, 213:5 stating 90:7, 209:6 statistical 36:7 stay 59:16, 123:14 staying 131:21, 133:10 steel 32:9 stems 39:2 stenographically 1:27 step 26:21, 26:22, 128:4, 128:5, 128:14, 186:20,	203:12 steps 42:11, 42:17, 43:20, 62:10, 63:2, 138:6, 182:12, 182:18, 183:7, 186:21, 196:6 sticks 43:12 still 28:1, 29:17, 33:22, 42:21, 47:10, 48:13, 76:21, 87:16, 120:21, 130:19, 173:20, 190:20, 191:4, 193:21, 202:8, 214:13 stippling 171:8 stock 150:12 stop 45:22 stops 165:10 strength 74:5, 74:7 stretch 20:15 stretches 20:18 strike 5:6, 7:9, 11:7, 23:9, 26:10, 29:19, 37:20, 42:10, 45:10, 48:15, 49:12, 56:2, 58:2, 64:4, 73:17, 108:4, 120:1, 126:6, 133:9, 142:4, 153:8, 158:20, 162:19, 165:3, 165:22, 166:20, 167:19, 170:16, 186:18	strip 199:2 strong 24:11 strongly 29:17, 90:10 structure 24:11, 41:12, 61:3, 61:4, 61:5, 73:11, 75:10, 90:1, 104:18, 104:22, 105:8, 113:17, 145:4, 156:15, 174:6, 177:3, 188:4, 188:5 structured 43:16 structures 20:7, 61:12, 152:6, 181:11, 182:8, 189:15 structuring 41:4, 41:5 struggling 20:12 students 39:17 studies 23:20, 24:1, 24:2, 24:3, 24:5 study 29:22 studying 21:22, 22:14, 32:12, 47:13 stuff 20:14, 25:18, 49:19, 62:19, 78:16, 78:17, 78:19, 145:3, 153:15 sub 112:12 sub-picoamps 130:21 subjected 105:18	subjecting 75:22 subjective 90:15 submitted 4:21, 10:21, 13:4, 13:5, 75:2 submitting 16:19 subscribed 215:22 subsequent 22:21, 143:9 substance 132:7, 132:16 substantial 151:1, 151:4, 151:7 substrates 25:4, 28:20, 29:1, 29:6, 30:19, 31:17, 77:4, 92:1, 141:14, 143:14, 146:18, 151:1, 151:6, 154:19 successful 69:13 suggest 100:5, 175:6, 203:8 suggests 194:21 suite 2:15 summary 61:15 sun 41:7, 62:16 sunpower 14:6, 14:7, 14:12, 51:13, 51:15, 64:20, 65:7, 65:16, 66:4, 147:18, 149:8 super-high-energy 46:19
--	---	--	---

supplied 30:7 support 3:12, 15:2, 15:6, 15:17 suppose 13:1, 182:13 supposed 83:15, 155:6 sure 6:18, 6:19, 6:21, 19:2, 19:6, 21:20, 22:11, 24:8, 29:3, 35:11, 35:12, 54:22, 55:1, 56:1, 59:9, 61:20, 65:10, 67:11, 68:17, 70:20, 71:3, 74:6, 79:12, 81:12, 81:15, 91:13, 96:18, 100:18, 109:22, 112:21, 113:22, 120:2, 126:20, 130:8, 144:18, 145:15, 149:20, 150:11, 158:7, 165:18, 174:3, 187:15, 195:16, 197:22, 200:4, 201:8, 203:18, 204:9, 205:1 surface 27:16, 33:5, 41:4, 41:5, 41:8, 41:15, 41:19, 42:1, 42:11, 42:12, 44:4, 45:6, 45:7, 45:13, 47:21, 55:18, 57:2, 57:3, 103:12, 104:8, 122:3, 140:14, 156:18, 156:21,	157:3, 157:7, 157:12, 157:13, 157:19, 157:20, 158:1, 158:14, 158:22, 159:3, 159:7, 159:11, 159:16, 160:6, 161:2, 162:18, 164:1, 164:8, 164:14, 164:21, 165:6, 166:3, 173:3, 173:5, 173:6, 173:8, 173:9, 173:12, 173:16, 173:19, 173:21, 174:10, 174:13, 174:14, 175:3, 175:8, 175:9, 175:10, 176:3, 176:8, 176:19, 177:3, 177:5, 177:9, 177:10, 177:13, 177:15, 177:19, 178:8, 178:9, 178:11, 178:17, 179:1, 180:2, 186:8, 186:13, 186:18, 192:21, 193:4, 193:9, 194:15, 194:22, 196:5, 199:20, 204:5, 205:4, 205:13, 205:17, 205:20, 205:21, 206:4, 207:2, 207:7, 207:10, 207:14, 207:20 surfaces 20:11, 33:5, 172:12 surprise 118:10 surprised 117:22 surprising 117:13, 156:6 susan 1:28, 210:11,	211:15, 216:2 swanson 51:18, 51:21, 53:4, 188:18, 189:5, 189:15, 190:1, 190:16, 190:20, 191:5, 191:17, 192:8, 197:13, 197:17 sweet 162:8 sworn 4:7, 213:5, 215:22, 216:6 system 42:8, 43:3, 43:4, 44:16, 69:9, 74:6, 86:14, 103:11, 171:10, 173:17, 194:6, 196:3, 198:7, 205:21 systems 21:1, 28:4, 40:11, 41:1, 69:17 T table 197:1, 199:6, 200:3 take 8:12, 27:2, 36:10, 53:10, 57:16, 63:8, 65:10, 66:20, 76:3, 79:10, 80:20, 86:14, 100:14, 100:16, 101:8, 104:10, 106:10, 111:2, 115:1, 119:4, 122:19, 122:22, 123:15, 150:2, 150:4, 160:5, 160:12, 162:4, 168:20, 169:15, 180:8, 186:8,	186:21, 187:3, 188:6, 188:11, 189:19, 195:2, 203:17, 208:1 taken 42:12, 45:2, 54:5, 62:10, 81:22, 90:22, 169:9, 212:2, 212:5, 213:6, 214:8, 216:8 takes 36:6, 168:4, 169:12, 185:20, 186:13, 186:17, 201:2 taking 8:3, 80:18, 183:10, 196:8, 209:6, 209:19 talk 21:8, 28:4, 34:21, 36:2, 37:5, 72:3, 74:22, 87:10, 136:7, 156:18, 177:15, 200:20, 202:14 talked 67:19, 112:2, 124:14, 127:1, 194:11 talking 22:22, 23:16, 23:17, 25:10, 28:18, 35:6, 36:1, 48:18, 50:5, 50:10, 54:3, 54:13, 54:21, 72:4, 72:12, 77:7, 129:8, 152:21, 161:22, 187:10, 195:22 talks 62:15, 62:17 target 185:22, 186:3
--	---	---	--

teach 191:9 technical 19:11, 19:12, 19:13, 38:4, 71:6 technique 133:14, 159:2, 159:7 techniques 33:16, 82:15, 86:19, 103:1, 103:2, 157:3, 157:19, 157:22, 158:13, 158:21, 159:15, 159:17, 159:22, 161:5, 164:9, 167:7 technology 13:20, 20:1, 20:5, 37:17, 49:15, 52:4, 52:15, 170:7, 173:13 tell 13:14, 42:16, 42:19, 42:20, 57:14, 71:22, 87:12, 109:13, 109:18, 112:8, 147:12, 169:13, 169:17, 169:21, 198:3 telling 11:12, 116:21, 116:22, 206:6 tells 206:1 temperature 24:12, 43:4, 75:20, 76:1, 78:22, 79:2, 79:3, 79:6, 79:7, 80:9, 80:15, 90:4, 127:17, 139:8, 139:22, 140:7, 170:8, 185:12	temperatures 107:16, 107:21, 109:7, 121:9, 134:20, 138:12 ten 13:10, 17:18 tend 31:4, 32:9, 86:7 tendency 26:12 tender 209:5 tends 31:7, 162:7 term 23:1, 23:5, 35:12, 36:9, 63:19, 71:6, 119:18, 119:20 terms 11:12, 31:10, 31:12, 32:1, 34:19, 39:20, 42:20, 42:22, 54:10, 55:4, 73:21, 105:18, 109:18, 143:16, 144:3, 145:2, 145:9, 155:13, 167:5, 167:15, 167:21, 168:11, 168:19, 169:14, 170:3, 185:4, 193:16, 197:20, 199:7, 200:5, 200:13, 200:15, 203:12, 205:9, 207:12, 207:18 terrestrial 28:19, 172:1 terrestrial-based 25:10, 28:4 tested 109:7, 111:14 testified 12:13 testify 4:20, 5:15	testimony 31:14, 36:22, 155:10, 155:16, 216:9 tests 107:3, 110:17 text 67:3, 106:14, 108:16 texture 41:8, 41:9 texturing 41:14 th 47:22, 56:7, 98:8, 98:9, 106:16, 130:18, 149:9, 149:13, 153:10, 154:11, 154:19, 154:20, 155:2, 188:21 thank 5:13, 6:3, 7:6, 60:3, 88:13, 104:15, 141:5, 208:11 themselves 35:16, 91:1, 196:13 theoretical 82:4 theoretically 79:21 therefore 72:15, 106:2 therein 12:9, 62:12, 119:8, 171:22 thereto 211:5 thermal 20:21, 20:22, 32:12, 33:15, 71:10, 75:15, 107:7, 110:19, 127:16, 127:17, 130:1, 130:3, 130:4, 130:7, 131:8, 131:12, 131:17, 132:3, 132:11, 133:12, 166:15, 167:10, 167:12, 167:16, 167:18 thermally 107:4, 111:7 thesis 21:11 thick 72:22, 105:10, 130:10, 130:13, 192:9, 197:12, 201:18, 202:5 thicker 83:18, 84:3, 120:15, 163:7, 163:13, 163:16, 196:1, 196:2 thickness 46:22, 47:5, 83:6, 92:10, 93:3, 106:22, 130:6, 131:4, 138:1, 184:14, 195:9, 195:14, 195:17, 196:1, 196:12, 201:13 thicknesses 131:4, 190:8 thin 12:8, 12:11, 21:12, 88:19, 89:14, 90:7, 156:16, 160:4, 161:18, 161:21, 197:2, 197:7, 199:17, 202:6 thing 15:22, 41:21, 46:4, 46:11, 54:6, 62:15, 63:1, 69:18, 76:8, 78:12, 86:12, 86:15, 89:13, 89:20, 99:13, 113:6,
--	---	---

113:13, 116:2, 116:13, 118:15, 118:16, 123:19, 144:21, 145:5, 152:21, 182:7, 194:7, 194:14, 198:14, 201:1, 206:1, 206:21 things 6:8, 6:21, 7:2, 10:2, 10:10, 11:15, 13:1, 18:17, 20:11, 27:14, 27:17, 28:12, 31:20, 33:16, 34:22, 36:5, 45:20, 50:21, 52:11, 52:12, 52:18, 53:7, 53:8, 67:10, 76:5, 77:18, 80:18, 82:9, 106:20, 151:13, 177:14, 198:1, 198:6, 198:14, 199:1, 205:16, 206:7, 206:17 think 11:18, 13:10, 19:16, 21:17, 21:19, 30:9, 30:13, 34:22, 35:9, 35:21, 37:10, 40:5, 43:8, 43:9, 47:15, 51:8, 52:14, 52:19, 62:3, 73:7, 83:20, 86:22, 96:20, 99:4, 109:4, 109:5, 124:6, 124:14, 137:20, 142:17, 142:22, 145:15, 151:16, 156:6, 159:6, 169:5, 178:22, 179:11,	179:12, 179:20, 180:4, 191:16, 194:10, 202:13, 203:6, 206:12, 208:15 thinking 160:20, 203:5 thinner 201:19 thinness 92:13 thiophene 39:15 third 110:2, 181:21 thought 28:16, 51:4, 174:8, 187:12 thousands 201:2 three 9:5, 9:7, 13:10, 13:12, 13:20, 38:1, 107:16, 109:7, 192:9, 199:17 threshold 185:16 throat 18:13 through 8:21, 20:4, 21:6, 22:5, 22:13, 23:4, 23:5, 23:12, 23:13, 24:4, 24:20, 33:15, 34:7, 43:4, 46:9, 58:4, 58:8, 58:10, 60:19, 81:4, 81:8, 81:18, 82:2, 84:19, 85:14, 85:20, 87:20, 88:3, 90:4, 90:7, 90:12, 93:21, 94:1, 94:8,	95:1, 95:9, 95:19, 97:4, 101:4, 104:1, 119:19, 123:3, 123:8, 129:22, 132:4, 134:21, 135:5, 135:18, 137:7, 143:7, 155:18, 156:5, 158:1, 159:8 tied 79:2, 176:10, 176:13 time-consuming 143:17 times 13:8, 22:7, 34:20, 37:7, 48:4, 53:9, 56:7, 57:2, 83:18, 84:2, 144:19, 144:21, 154:5, 154:11, 188:21, 198:16, 198:18 title 115:18, 171:2, 212:4, 213:8 to--nanometer 46:17, 92:19 today 4:2, 5:10, 5:15, 5:17, 6:7, 7:12, 8:16, 25:11, 25:12, 25:19, 26:3, 26:14, 70:4, 71:19, 86:16, 143:11, 151:19, 151:20 today's 8:18, 9:4 tofu 76:2 together 28:2, 44:12, 67:10, 79:2, 198:6	told 56:22 tool 116:17, 127:16, 127:17 top 20:8, 43:6, 43:8, 43:10, 43:14, 45:12, 46:9, 64:19, 91:21, 94:20, 105:2, 106:5, 112:20, 118:5, 123:19, 139:1, 146:2, 158:18, 160:9, 160:17, 166:9, 170:9, 179:22 topic 12:5, 12:7, 13:11 topics 10:11 total 98:2, 152:11 touch 10:10 toward 49:2 towards 26:12, 175:8 track 9:12, 17:17 trade 42:22 trademark 1:1 traditionally 58:14 traipsing 120:20 transcript 209:13, 211:3, 211:7, 212:10, 213:6, 213:9, 214:8 transient 116:19
--	--	---	--

transistors 93:2 transition 105:21 transitioned 47:15, 48:21 trap 134:12, 134:13 trapping 21:12 treat 34:4 treating 22:21 treatment 45:8 trial 1:2 tried 97:9 trouble 77:14, 82:16 true 18:7, 18:8, 26:15, 31:5, 48:3, 90:9, 105:20, 121:16, 126:18, 127:4, 162:12, 180:5, 194:15, 205:15, 211:6, 213:8, 214:10, 216:8 truthfully 5:15 try 27:17 trying 27:14, 56:11, 68:3, 69:12, 75:21, 91:14, 122:13, 122:15, 142:16, 192:5 tunnel 92:20, 93:1, 93:4, 129:16, 130:9, 130:10, 130:12, 130:14, 130:19, 131:5,	134:22, 184:18, 185:1 tunneling 93:2, 130:22, 185:3 turn 5:22, 73:13, 153:19, 189:9, 199:21 turning 159:21, 201:7 two 4:21, 5:2, 5:7, 27:14, 40:8, 46:20, 50:16, 56:13, 58:20, 59:11, 75:1, 79:18, 82:6, 87:14, 88:10, 93:15, 110:6, 110:13, 110:16, 113:9, 140:16, 144:22, 157:2, 168:22, 169:4, 180:4, 198:5, 198:16, 199:1, 213:11 type 13:5, 35:19, 39:15, 41:11, 41:12, 118:2, 123:18, 133:3, 136:15, 143:4, 143:22, 144:2, 147:13, 148:2, 158:5, 177:1, 177:18, 177:21, 178:7, 178:16 types 29:14, 40:9, 64:14, 89:4, 89:21, 106:21, 159:22, 161:5, 161:21, 162:6, 166:11, 194:17 typewriting 211:5 typewritten 212:6	typical 29:4, 32:2, 148:6, 148:9, 161:2 typically 18:16, 25:14, 26:22, 28:19, 32:5, 73:16, 73:20, 93:4, 142:15, 143:12, 143:17, 152:13, 207:11 typo 139:7 U uh-huh 7:7, 30:6, 56:9, 66:15, 67:22, 71:10, 80:6, 82:21, 83:7, 84:4, 91:5, 93:7, 95:21, 107:14, 109:5, 111:13, 116:6, 123:13, 124:10, 127:19, 128:8, 129:13, 129:17, 131:22, 132:19, 133:2, 150:16, 154:2, 154:7, 172:15, 176:1, 178:6, 181:20, 183:9, 187:17, 189:21, 195:7, 197:3, 200:1, 200:8, 203:11, 203:20 ultimately 37:15 uncommon 149:22 under 22:21, 64:19, 85:12, 104:8, 116:16, 171:8, 209:20, 211:5, 214:6, 214:7,	214:13 underneath 54:7, 64:22, 108:16 understand 4:20, 5:7, 6:5, 7:19, 8:4, 8:5, 8:14, 9:17, 13:4, 14:15, 14:19, 32:15, 34:5, 35:7, 55:1, 56:11, 56:18, 60:14, 63:20, 80:6, 81:13, 87:10, 91:14, 96:18, 121:10, 151:20 understanding 5:4, 5:9, 11:20, 19:14, 23:10, 31:14, 33:21, 35:14, 63:17, 63:18, 63:19, 77:7, 78:2, 84:5, 84:9, 91:15, 92:18, 108:20, 110:12, 152:1, 176:6, 187:2, 202:17, 203:1, 214:12 understandings 17:10 understood 8:9, 33:18, 34:2, 34:8, 34:11, 152:19, 165:17 undertaken 143:13 undertaking 75:15 undertook 17:22, 18:2 undetectable 87:5 undoped 77:21, 78:5,
---	---	---	--

78:8, 84:7, 84:10, 109:1, 109:4, 109:5 unique 61:11 united 1:1, 52:4 units 25:10, 200:18 university 96:7, 96:8, 100:10 unless 5:11 unlike 152:11 until 39:10, 161:12 unusual 193:7, 193:10 upper 154:14 urea-based 193:16 use 6:11, 11:1, 11:18, 12:9, 17:5, 18:16, 21:10, 24:21, 25:10, 25:17, 25:20, 27:17, 28:6, 29:1, 32:7, 33:15, 36:9, 37:8, 40:13, 41:11, 42:4, 42:22, 43:4, 43:13, 56:19, 56:22, 57:1, 67:21, 71:6, 74:16, 78:4, 86:5, 95:16, 103:1, 103:2, 103:3, 119:18, 119:20, 123:10, 126:1, 133:21, 143:10, 143:11, 144:22, 146:16, 147:13,	148:6, 148:9, 148:18, 161:3, 161:10, 161:11, 163:6, 163:14, 163:16, 165:1, 166:6, 166:15, 168:14, 175:2, 177:12, 177:18, 177:21, 178:7, 188:4, 189:16, 189:18, 190:1, 190:21, 190:22, 191:9, 193:16, 194:22, 201:17, 202:5 useful 76:10, 173:11 uses 25:14, 104:17 using 21:8, 26:2, 32:16, 33:12, 43:16, 47:20, 54:2, 68:22, 69:5, 74:3, 76:20, 77:20, 82:14, 84:20, 87:5, 87:16, 104:5, 115:21, 116:18, 120:9, 121:5, 132:7, 133:18, 143:8, 146:11, 153:10, 153:22, 154:9, 154:15, 158:22, 166:10, 167:6, 174:19, 182:1, 182:14, 182:22, 192:14, 194:17, 206:14, 207:6 usual 210:4 usually 54:20, 68:12, 72:22, 73:8, 143:7, 145:1, 145:3, 162:7, 166:14, 173:13	utilize 150:18, 164:20 utilized 84:6, 91:22, 104:22, 140:1, 140:8, 144:1 utilizing 165:5 uv 46:14, 162:20, 163:8, 173:14 v vacuum 77:1, 166:13 value 53:10, 81:22 values 205:9 vanishingly 155:7 vapor 133:8, 133:11, 166:18 variation 48:7 varies 54:11 various 27:13, 64:14, 131:8, 133:1, 133:2, 152:5 varying 105:17 vendors 159:5 verbally 7:22 versions 48:1 versus 1:9, 78:8, 205:18 very-high-energy 46:16 vessels 32:7 via 5:20, 203:3	viable 52:13 video 8:2 view 36:6 volt 130:14 voltage 198:4, 198:8, 198:11 volume 102:22, 118:21 vs 214:3 w wafer 106:2 wafers 21:10, 105:16, 105:22 wait 118:7 wake 38:15, 48:9, 48:11, 87:2 walk 84:19 wanders 174:16 want 15:13, 36:6, 36:10, 41:7, 41:10, 43:21, 44:14, 44:16, 45:22, 46:15, 47:10, 55:1, 66:13, 67:10, 69:8, 73:9, 80:20, 81:16, 88:9, 95:4, 95:15, 96:18, 106:13, 107:10, 108:14, 110:1, 110:6, 111:2, 115:11, 121:4, 123:20, 129:3,
---	--	--	---

130:11, 136:7, 141:17, 145:18, 153:16, 160:12, 162:3, 162:6, 162:8, 163:19, 166:10, 174:19, 179:2, 179:3, 189:9, 198:8, 198:9 wanted 21:16, 35:11, 166:2, 206:21 wants 99:6, 162:4 warrantees 167:11 washington 2:16 water 166:18 watt 25:20 wavelength 47:6 way 20:21, 21:1, 24:11, 27:1, 33:9, 33:19, 34:3, 37:4, 37:8, 43:19, 44:8, 44:19, 54:3, 59:2, 59:6, 61:4, 61:11, 61:14, 61:16, 67:20, 71:8, 72:17, 76:9, 76:11, 77:16, 79:22, 94:3, 100:1, 119:19, 122:6, 125:13, 125:15, 147:8, 150:14, 157:12, 157:17, 157:20, 160:21, 166:14, 182:14, 184:21, 194:16, 206:16, 206:18, 206:19, 211:11,	216:18 ways 26:6, 26:9, 52:17, 54:9, 69:6, 69:7, 110:13, 113:9, 126:22, 131:8, 133:1, 133:2 wct 116:17 we'll 7:11, 8:12 we're 5:19, 24:19, 26:8, 40:13, 48:18, 50:3, 50:5, 54:2, 54:3, 54:21, 66:3, 70:7, 108:15, 122:13, 122:15, 122:17, 140:20, 141:1, 195:22 we've 48:14, 48:16, 58:18, 67:19 wednesday 4:1 welcome 60:2, 141:4 went 37:16, 42:8, 47:2, 70:21 weren't 9:9 whatever 74:13, 76:14, 153:14 whatsoever 60:8, 87:19 whereas 35:8 whereof 216:20 whether 13:19, 18:6, 18:8, 30:7, 51:4, 54:12,	55:2, 56:18, 56:22, 78:6, 90:9, 90:17, 90:19, 111:6, 116:22, 137:10, 137:14, 147:12, 158:8, 177:2, 177:8, 177:19, 178:8, 178:13, 178:14, 191:1, 192:20, 204:20 whichever 7:17 whole 15:22, 41:20, 86:14, 127:21, 181:8 wholly 28:1 window 6:20 wisconsin 2:14 wish 78:14 within 35:2, 35:3, 66:16, 66:19, 87:13, 92:14, 114:8, 134:15, 157:15, 178:11, 188:7, 188:10, 216:3 without 13:18, 17:19, 73:10, 105:1, 166:13, 193:8 withstand 162:19 witness 3:2, 4:6, 4:13, 12:15, 15:8, 141:9, 148:14, 148:22, 208:13, 214:5, 216:5, 216:9, 216:20 word 23:1, 33:12,	53:10, 61:9, 69:1, 120:9, 120:10, 123:10 words 53:9, 112:9, 121:14, 122:9, 128:14, 199:2, 201:16 work 7:2, 10:7, 21:14, 32:11, 37:9, 37:21, 38:15, 38:17, 39:3, 39:5, 39:7, 39:18, 40:17, 41:18, 46:6, 48:9, 48:21, 49:10, 49:17, 49:21, 50:7, 52:12, 53:4, 64:13, 70:3, 152:14, 204:18 worked 14:3, 14:6, 18:18, 27:12, 38:18 working 41:1, 152:7, 206:4 works 47:7, 115:8, 133:7, 157:17 world 39:9, 96:9, 190:19 worse 155:5, 155:8 would've 49:2, 49:3, 49:20, 51:6, 56:20, 57:1, 149:22, 150:11, 192:4, 193:6, 193:10, 193:11, 194:2 wouldn't 87:6, 98:19,
---	--	--	---

169:12, 173:22, 201:21 wow 200:22 write 19:8 written 6:12 wrong 90:2 wrote 17:3	zone 24:6, 24:9, 24:13, 24:21, 26:9, 143:8, 143:9 zones 24:13, 24:14 zoom 7:14	112:2, 112:3, 120:16 1.4 92:11, 92:12, 92:13, 92:19 10 29:9, 44:13, 45:9, 47:22, 48:8, 55:5, 55:15, 55:19, 56:7, 57:2, 57:16, 57:18, 57:20, 58:17, 58:22, 59:12, 59:19, 59:22, 60:19, 61:19, 62:4, 62:9, 62:15, 63:3, 63:9, 63:10, 66:17, 66:19, 74:4, 74:9, 81:1, 82:12, 92:1, 96:2, 96:22, 97:11, 98:4, 98:8, 98:9, 99:22, 106:16, 108:11, 109:12, 122:22, 123:1, 123:2, 123:5, 123:7, 123:10, 124:7, 130:16, 130:17, 130:18, 131:20, 134:10, 149:9, 149:13, 153:4, 153:5, 153:10, 154:5, 154:11, 154:19, 155:2, 168:3, 169:6, 169:19, 188:21, 209:2, 211:17 100 83:3, 83:18, 84:2, 102:6, 102:9, 103:6, 109:8, 109:11, 109:13, 109:22, 117:4, 117:5,	117:10, 117:12, 117:13, 130:20, 162:7, 163:20 1000 204:15 1001 55:9, 60:13, 60:14, 122:20, 122:21 1005 30:5, 92:15, 145:13, 170:17, 180:9 1008 204:9 101 36:15 1011 142:5 1025 80:20, 81:1 1028 88:7, 88:11, 88:15, 91:4 1029 88:7, 88:11, 104:11 106 135:2 11 58:4, 58:8, 58:10, 82:12, 131:18, 131:20, 136:7, 154:5, 154:11, 209:21, 210:13 11,251,315 1:10, 4:22, 9:16 12 140:21, 149:9, 149:13 120 81:8, 81:19, 83:4, 83:5, 83:17, 116:17 1200 83:4
x-ray 86:8	zoom 7:14 . .6600 2:7 .6861 2:17 0		
x			
y	0.1 102:1, 102:14, 102:16, 111:8, 111:19, 117:15 00 141:2 01038 1:8, 5:2, 5:11, 15:19 01194 5:3, 15:19 1		
yeah 42:14, 44:5, 48:20, 55:10, 62:7, 66:1, 84:1, 94:6, 104:20, 109:11, 109:15, 112:14, 117:8, 117:11, 123:1, 124:16, 128:8, 129:3, 143:1, 143:3, 173:15, 176:1, 178:2, 179:20, 181:8, 182:13, 182:15, 193:13, 196:20, 198:10, 202:22, 208:4 year 75:1 year-ish 51:8 years 13:10, 23:2, 34:11, 38:1, 39:11 yep 15:13 yourself 9:9, 16:21	1 141:2 1-to-2-nanometer 184:20 1-to-2-nanometer- -thick 83:21 1-to-2-nanometer 87:20 1.3 92:10, 92:12, 92:13, 92:19, 105:2, 105:5, 105:9, 106:22, 107:6, 107:7, 108:17, 108:22, 110:7, 110:8, 110:12, 111:14,		
zero 160:8			
z			

13 106:16, 134:10 133 195:2, 195:4 135 199:22, 200:1, 201:7, 201:10 136 105:15 137 104:17, 189:8, 189:14 139 106:11 14 28:18, 92:2, 96:22, 97:11, 98:8, 99:22, 154:19, 155:2, 168:9 14383 1:28 145 187:11, 187:12, 187:14 15 3:11, 29:9, 58:9, 153:4, 153:6, 153:10 150 203:17 16 58:4, 58:10, 60:19, 96:2, 154:20, 155:2 17 98:4, 98:9, 99:22 18 1:20, 4:1, 4:2, 44:14, 45:9, 47:22, 48:4, 48:8, 56:7, 57:2, 59:19, 74:4, 74:9, 188:21, 216:13, 216:21 180 46:17	19 58:4, 58:10, 58:11, 60:20 1980 20:16, 20:18, 20:19, 21:21, 23:7, 23:10, 32:11, 34:6, 75:6 1984 21:17, 21:19 1990 201:14, 202:1, 202:2 1999 82:13, 82:15 2 2 208:7, 208:10, 208:17, 208:18, 216:14 20 28:18, 36:14, 48:12, 65:21, 108:11, 168:9 200 46:17, 47:3, 47:4, 162:7 2000 25:22, 26:1, 26:14, 26:15, 75:6, 76:20, 152:16 20015 2:16 2003 48:13 2010 40:20, 48:19, 77:2, 152:16, 152:17, 153:2 2012 75:2 2014 19:19, 20:2, 26:16, 26:17, 27:5, 27:7,	28:8, 28:11, 28:18, 34:10, 40:20, 48:19, 49:3, 64:1, 67:13, 69:14, 70:11, 70:16, 71:2, 71:8, 74:15, 74:19, 75:1, 75:2, 77:20, 80:7, 80:10, 86:21, 86:22, 87:17, 149:19, 150:3, 150:22, 151:3, 151:8, 151:9, 151:17, 157:3, 157:6, 157:11, 158:2, 158:6, 158:14, 159:4, 159:12, 160:1, 161:7, 161:9, 161:15, 162:12, 164:9, 164:12, 164:17, 164:19, 165:16, 166:2, 168:9, 170:5, 189:19, 190:2, 190:19, 191:6, 193:6, 193:15, 202:3 2015 40:21, 48:19, 49:3, 75:3, 152:17, 153:2 2018 89:18 202.371 2:17 2021 3:11, 15:1, 15:5, 15:16, 16:5, 16:13, 18:1, 36:11, 65:11, 119:7, 138:19, 141:18, 153:18, 195:3 2024 1:8, 5:2, 5:3,	5:11, 15:19 2025 1:20, 4:1, 4:3, 16:3, 216:13, 216:21 2027 65:22, 66:2 2028 211:17, 217:1 2030 210:13 2052 2:16 209 3:7 21 134:19 2125 210:14, 211:18 213 3:8 213.896 2:7 215 3:9 216 1:26 22 210:13, 211:17, 217:1 220 134:12 2275 88:17 2276 91:3 2277 93:6 2278 94:13 2279 100:17 228 171:8 2280 101:9 232 171:8
--	--	---	--

24 138:19, 139:1, 181:14, 181:21 25 34:11, 81:1 26 140:21 28 59:22, 209:21 29 149:3 3 30 108:11, 149:3, 149:4 31 129:3, 129:8, 129:10, 184:12, 198:18 315 5:1, 9:17, 11:19, 12:1, 12:3, 29:20, 41:2, 55:3, 55:5, 60:9, 60:15, 60:22, 61:2, 61:18, 63:21, 64:17, 66:3, 66:8, 66:10, 66:11, 66:13, 66:17, 66:20, 66:22, 67:4, 71:11, 71:17, 72:1, 72:2, 122:19, 123:14, 124:11, 124:17, 125:12, 126:2, 126:6, 127:6, 128:9, 131:3, 131:16, 132:10, 132:22, 134:5, 134:9, 136:11, 139:4, 143:22, 144:13, 146:20, 147:9, 147:13, 147:17, 148:2, 148:17,	163:15, 184:11, 184:12, 185:17 33 85:17, 153:18 35 67:4, 123:21, 123:22 350 2:5 352 188:18, 189:5, 189:15, 190:1, 190:20, 191:5, 192:8, 197:13, 197:17 353 197:5 37 36:11, 36:13, 183:10, 183:12 3776 81:16 38 129:6, 129:9, 129:16, 141:17, 172:9, 208:7 39 184:2, 184:13 4 40 67:4, 127:14, 138:18, 138:20 410 2:15 42 134:1, 145:21, 145:22, 146:7 45 185:9, 185:14, 187:4, 187:12, 208:10, 208:17, 208:18, 216:14 5 5 184:12 50 84:2, 185:15	53 65:11, 65:12, 65:13, 149:3 5335 2:14 56 132:1 587647 1:25, 214:2 59 1:19, 4:1, 4:3, 216:14 6 60 84:15, 84:20, 85:7, 85:13, 85:17, 87:4, 153:17, 153:18 7 70 119:4 71 64:19, 196:15 710 198:19 72 65:1, 201:9 73 189:9 78 187:4 780 107:16, 120:17, 120:18, 121:8 8 8 1:19, 4:1, 4:3, 216:14 80 203:21 820 107:17, 120:18, 121:8 84 21:7	890 107:18, 111:3, 111:5 9 9-- (c 209:21 90 20:20 900 134:20, 138:14, 139:8, 139:13, 140:1, 140:8, 185:16 90071 2:6 930 107:22, 111:18 950 185:13, 185:15, 186:20 970 127:18 99.9 102:18, 103:22, 112:4
---	---	--	---