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

CIRRUS LOGIC, INCORPORATED,
OMNIVISION TECHNOLOGIES, INCORPORATED,
and TEXAS INSTRUMENTS, INCORPORATED,
Petitioners,
v.
GREENTHREAD, LLC,
Patent Owner.

IPR2024-00001
U.S. Patent No. 10,734,481

ORAL AND VIDEOTAPED DEPOSITION OF
SANJAY BANERJEE, PH.D.
DECEMBER 6, 2024

ORAL AND VIDEOTAPED DEPOSITION OF SANJAY BANERJEE, PH.D., produced as a witness at the instance of the Patent Owner, and duly sworn, was taken in the above-styled and numbered cause on December 6, 2024, from 9:13 a.m. to 6:31 p.m., before Donna Wright, CSR in and for the State of Texas, reported by machine shorthand and remotely via Zoom, pursuant to the Federal Rules of Civil Procedure and any stipulations or agreements stated on the record or attached hereto.

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3 SANJAY BANERJEE, PH.D.

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1 THE VIDEOGRAPHER: We're on the
2 record. This is the remote video
3 deposition of Dr. Sanjay Banerjee in
4 the matter of Cirrus Logic
5 Incorporated, et al., versus
6 Greenthread, LLC, filed in the United
7 States Patent and Trademark Office.
8 My name is Billy Fahnert. I am
9 the video technician today. The court
10 reporter is Donna Marie Smith. We
11 both represent Digital Evidence Group.
12 Today's date is December 6th, 2024.
13 The time is 9:14 a.m. Central Daylight
14 Time. All parties have stipulated to
15 the witness being sworn in remotely.
16 Will counsel please identify
17 yourselves for the record and then the
18 witness will be sworn.
19 MR. WHITEHURST: Good morning,
20 everybody. This is Alan Whitehurst
21 with McKool Smith for the patent
22 owner, Greenthread.

1 MR. PAUL: This is Raj Paul of
2 Covington & Burling on behalf of
3 petitioners. Also with me is Anupam
4 Sharma, also with Covington & Burling,
5 on behalf of petitioners. And also
6 with me is Emre Yuzak of
7 GlobalFoundries and Kent Cooper of
8 GlobalFoundries.
9 MR. BLUESTONE: And also
10 present is David Bluestone with
11 Benesch on behalf of co-petitioner
12 Omnivision.
13 SANJAY BANERJEE, PH.D.,
14 having been first duly sworn, testified as
15 follows:
16 EXAMINATION
17 BY MR. WHITEHURST:
18 Q. Good morning, Dr. Banerjee.
19 A. Good morning.
20 Q. Happy Friday. I certainly
21 appreciate your time today. I know it's a
22 busy time of the year.

1 I don't believe we've ever met
2 before, have we?
3 A. No, I don't think so.
4 Q. But I do understand you have
5 testified in a deposition before; is that
6 correct?
7 A. Yes.
8 Q. Do you know roughly how many
9 times you have testified in a deposition?
10 A. I'm guessing probably a couple
11 of dozen times.
12 Q. So you know how the procedure
13 works. I'm not going to go over all of that
14 now. But you know that under the rules for
15 these IPR proceedings, you're not allowed to
16 talk to anybody during the breaks about your
17 testimony.
18 Do you understand that rule?
19 A. Yes.
20 Q. And do you intend to comply
21 with that rule today?
22 A. Yes.

1 Q. Now, like I said, I don't
2 believe we have ever met before, but I have
3 certainly seen your name before. It's nice
4 to finally meet you, at least via Zoom.
5 I want to go over a little bit,
6 just at a real high level, your educational
7 background. Can you tell me when you got
8 your Ph.D.?
9 A. 1983.
10 Q. And where did you get your
11 Ph.D. from?
12 A. University of Illinois at
13 Urbana-Champaign.
14 Q. And what did you do after you
15 got your Ph.D.?
16 A. I started working at Texas
17 Instruments Dallas where I was part of the
18 team that made the world's first 4 MegaBit
19 DRAM.
20 THE REPORTER: I'm sorry.
21 THE WITNESS: The world's first
22 4 MegaBit DRAM, D-R-A-M.

1 Q. (BY MR. WHITEHURST) And just
2 to help our court reporter out, Dr. Banerjee,
3 I believe you said 4 MegaBit; is that
4 correct?
5 A. Yes, yes.
6 Q. That would be the number four
7 followed by a capital M, capital B?
8 A. That's correct.
9 Q. DRAM would be capital D-R-A-M.
10 Dr. Banerjee, is there a
11 particular reason why you decided to work for
12 TI?
13 A. TI is a leading company for
14 semiconductors and I had offers from other
15 companies also, but I felt the TI offer
16 allowed me to do R&D.
17 Q. And I assume TI was a very
18 prestigious company to work for?
19 A. Yes, it was.
20 Q. And can you tell me a little
21 bit about your work on the DRAMs at TI, just
22 at a high level?

A. Sure. So I was the device physicist on the team. In a DRAM, you have what are called pass transistors that connect to a storage capacitor, which is an MOS capacitor. The gate of the pass transistor is connected to a word line and the drain is connected to a bit line and you have one memory cell at each intersection of the word line and the bit line. So my job was to study the physics of the pass transistor. In this case, it was a vertical pass transistor in a trench.

I also worked on other devices, including things like polysilicon thin film transistors, which are used in other kinds of memories.

Q. Now, you will need to help me and our court reporter out today. You referred to a particular type of transistor and I'm not sure that came across on the transcript.

What type of transistor did you

1 mention?
2 A. For the DRAM I worked on
3 something called a trench transistor where
4 you dig a hole, etch a hole in silicon, you
5 draw the gate dielectrics on the side walls
6 of the trench and you put in a polysilicon
7 gate electrode into the trench, and then you
8 have the source on the top and the drain on
9 the bottom.
10 So unlike a plainer MOSFET
11 where the current goes laterally, on the
12 trench transistor the current goes up and
13 down the side walls of the trench.
14 I also worked on other types of
15 transistors such as polysilicon, P-O-L-Y,
16 silicon thin transistors, which are --
17 THE REPORTER: Silicon --
18 THE WITNESS: Thin.
19 THE REPORTER: Tin?
20 THE WITNESS: Thin, T-H-I-N,
21 which are cleaner transistors where
22 the current goes laterally on the

1 surface.
2 Q. (BY MR. WHITEHURST)
3 Dr. Banerjee, I don't know if you've ever
4 seen a realtime transcript before, but I'm
5 just trying to help our court reporter out.
6 As we go along today and the words get
7 entered into the transcript, it will become
8 easier and easier because it populates using
9 a known dictionary.
10 Just to help our court reporter
11 out, could you please spell poly -- excuse
12 me -- polysilicon?
13 A. P-O-L-Y-S-I-L-I-C-O-N.
14 Q. When did you first learn about
15 DRAMs?
16 A. Back when I was in graduate
17 school, between 1979 and 1983, you have to
18 take graduate school courses also, so I
19 learned about DRAMs in that context. And
20 prior to that, when I was at -- in my
21 undergrad program at the Indian Institute of
22 Technology --

1 THE REPORTER: At where?
2 THE WITNESS: At the Indian
3 Institute of Technology, we also had
4 to take courses on devices and
5 circuits to learn about semiconductor
6 memories and DRAMs in a broad sense,
7 even then.
8 Q. (BY MR. WHITEHURST) And when
9 you were at TI would you say that DRAMs were
10 important technology to TI?
11 MR. PAUL: Objection to form.
12 Q. (BY MR. WHITEHURST) I'm sorry,
13 I think we had an objection. But,
14 Dr. Banerjee, I hope you heard my question.
15 I will repeat it.
16 When you were at TI, would you
17 say that DRAM was an important technology to
18 TI?
19 MR. PAUL: Objection to form.
20 THE WITNESS: I guess it
21 depends on what exactly you mean by
22 "objection," but TI did do a lot of

1 work on DRAMs. So in that sense, it
2 was important.
3 Q. (BY MR. WHITEHURST) Were you
4 proud of your work on the DRAMs?
5 A. Yes. In fact, we won a best
6 paper award at the ISSCC, along with my
7 colleagues of that work.
8 Q. So you were building actual
9 products while you were at TI?
10 A. I was in the R&D group where
11 you don't make commercial products, but I was
12 involved in the design and the fabrication of
13 memory cells primarily. I got a chance to
14 see a little bit of both circuit design
15 aspects, as well as the device application
16 aspect in the clean room, but I was not on
17 the production team.
18 Q. So did you write a lot of
19 papers while you were at TI?
20 A. Yes.
21 Q. And you helped with the design
22 of products?

1 A. I had quite a few patents also
2 when I was at TI. It depends on what exactly
3 you mean by "design of products." I was on
4 the R&D team. These are not commercial
5 products in that sense.
6 Q. Who worked on the commercial
7 products?
8 A. Other teams at TI.
9 Q. And you mentioned production
10 team. What is a production team?
11 A. Production team would take our
12 design that was commercially viable and then
13 manufacture the chips at scale in a foundry
14 or a clean room. It's a large volume, it's
15 very important. When in R&D, you're not
16 trying to make things at scale. You're
17 trying to demonstrate the viability of the
18 technology.
19 Q. As part of the research group,
20 did you ever work with any of the production
21 teams?
22 A. Indirectly, we would have --

1 these teams are quite big, as you probably
2 know, and you have meetings all the time with
3 various R&D groups, as well as, on occasion,
4 production groups. But my interactions were
5 primarily within the R&D team.
6 Q. So it's fair to say you did not
7 work directly with the production teams?
8 A. That's probably a fair
9 assessment. Not extensively, at least.
10 Q. Did you know any of the people
11 on the production teams?
12 A. Yes, I do. I did.
13 Q. Do you remember the names of
14 any of the people on the DRAM production
15 teams?
16 A. I remember one name because
17 after I left TI and I started working at the
18 university, I was asked to write
19 recommendation letters for, you know, several
20 TI employees for different awards. And I
21 believe I wrote letters for a gentleman,
22 Lionel Wright, who used to work in Houston.

1 He passed away.
2 Q. Do you remember the names of
3 any of the other team members?
4 A. Not offhand.
5 Q. Do you recognize the name
6 Dr. Mohan Rao?
7 A. Yes.
8 Q. Did you ever interact with
9 Dr. Rao while you were at TI?
10 A. Not directly. I heard him give
11 a talk once, but that was the only time.
12 THE REPORTER: What?
13 THE WITNESS: I heard him give
14 a talk at TI once.
15 Q. (BY MR. WHITEHURST) When did
16 you hear him give a talk?
17 A. When?
18 Q. Yes, sir. I'm sorry, I'll
19 speak up. Let me re-ask the question. I
20 apologize. I'll try to do a better job.
21 When did you hear Dr. Rao give
22 a talk?

1 A. I don't remember exactly, but I
2 worked at TI between 1983 and '87, so it
3 would be sometime in that timeframe.
4 Q. Do you remember why Dr. Rao
5 gave the talk?
6 A. No. It was just a company
7 talk. It wasn't a conference talk.
8 Q. Was it about DRAMs?
9 A. I do not think so. I do
10 remember one thing. Even though TI was a
11 semiconductor company, I think he started
12 talking about particle physics issues and all
13 of that, just as a preamble.
14 THE REPORTER: Just as what?
15 THE WITNESS: Started talking
16 about particle physics as a preamble
17 to the talk. It wasn't directly
18 relevant to TI, but I remember that
19 because it was kind of entertaining at
20 the time.
21 Q. (BY MR. WHITEHURST) Was
22 Dr. Rao part of a production team?

A. He was not part of the corporate R&D group when I was there. He was in what was called the semiconductor group.

Q. Did Dr. Rao work on commercial products?

A. I couldn't tell you.

Q. Do you know what Dr. Rao worked on?

A. I think he worked on memories, but I'm not sure. TI is a big company.

Q. Have you ever met Dr. Rao personally?

A. Like I said, I have heard him give a talk, but just in a group of several hundred people. I did not go up to him and speak to him. But I think, many years later, he -- and I cannot remember exactly. Many years later, when I was at the University of Texas, I believe he and I were on a litigation where we were on the same team and I may have met him briefly. That was also many, many years ago. I'm not 100 percent

1 certain.
2 Q. What do you mean when you say
3 you were on a litigation team?
4 A. I view these proceedings as an
5 example of a litigation. So I was an expert
6 witness and I believe he was the consulting
7 witness. So they did not have him testify or
8 be deposed or anything like that. I was the
9 main witness, but I think he provided some
10 behind-the-scenes input for the team, I
11 think. And I may have met him once in that
12 context, but I can't remember 100 percent.
13 Q. What do you mean when you said
14 you were on the same team?
15 A. So in many cases, I think
16 lawyers will hire a primary expert who
17 gets deposed and maybe testifies at the IPC,
18 or whatever, but they sometimes also hire, I
19 believe, consulting experts that they consult
20 with to get additional input, but they don't
21 go out in front of the lawyers and testify.
22 Q. And do you remember if Dr. Rao

1 provided consultant help to you on that
2 litigation?
3 A. I don't think so, but I -- I'm
4 trying to think. It was probably 30 years
5 ago. So it was a very limited interaction so
6 I don't think he did, but I can't remember.
7 Q. Do you know why he was hired as
8 a consultant?
9 A. I do not.
10 Q. I want to go back to the talk
11 that you attended. Was it common for TI
12 employees to give talks?
13 A. Depends on what you mean by
14 "common." I mean, I have given talks also
15 when I was at TI, internal talks, on
16 technical matters.
17 Q. And why were you asked to give
18 talks?
19 A. As I remember, I told you I was
20 working on polysilicon thin film transistors
21 and I found some interesting results on the
22 reliability of these devices and TI wanted me

1 to present those results. That was one
2 example.
3 And then, of course, you know,
4 you have meetings on a weekly basis, group
5 meetings, and you typically present at those
6 meetings. I remember presenting to our chief
7 technology officer. It's quite common.
8 Q. And when you gave these talks,
9 were you helping other people at TI learn
10 about stuff?
11 A. Hopefully.
12 Q. And when Dr. Rao gave this
13 talk, was he explaining stuff to people at
14 TI?
15 A. Like I said, I do not remember
16 the details of the talk, except I remember
17 that he started out talking about something
18 completely different from semiconductors or
19 particle physics, which wasn't relevant, but
20 I found it interesting because I'm also
21 interested in physics.
22 I believe he has -- I think he

1 has two Ph.D.s, if I remember right. The
2 first one may have been in physics, so maybe
3 that's why he was trying to educate the
4 crowd.
5 Q. Do you know many people that
6 have two Ph.D.s?
7 A. No, I do not.
8 Q. Have you ever met anyone
9 besides Dr. Rao that has two Ph.D.s?
10 A. I can't remember.
11 Q. Would you say that Dr. Rao was
12 highly regarded at TI?
13 MR. PAUL: Objection to form.
14 THE WITNESS: I couldn't tell
15 you. I was a junior engineer. He was
16 more senior than me.
17 Q. (BY MR. WHITEHURST) So when
18 you were at TI, Dr. Rao was a more senior
19 engineer than you?
20 A. Yes.
21 Q. And Dr. Rao worked on
22 commercial products?

1 A. I think so, but I don't know.
2 I don't exactly know what he did. I do think
3 he did work on memories, but I don't know any
4 detailed knowledge other than that.
5 Q. And as a junior engineer, you
6 were involved in research; is that correct?
7 A. Research and development.
8 Q. And as part of the research and
9 development group, you did not directly work
10 on commercial products?
11 MR. PAUL: Objection, form.
12 THE WITNESS: I mean, it
13 depends on what you mean by
14 "directly." In R&D, you develop
15 technologies and the more promising
16 ones involve the products. In that
17 sense, there is an indirect
18 connection.
19 Q. (BY MR. WHITEHURST) But you
20 did not directly work on the commercial
21 products, correct?
22 A. No. I was not in a production

team in that sense.

Q. What is a doped semiconductor?

A. If you use silicon as a four-particle semiconductor, it's the most common semiconductor that's used. Silicon has four electrons in the outermost shell, which is called the valence shell.

THE REPORTER: Called the what?

THE WITNESS: Valence, V-A-L-E-N-C-E, valence shell. And because atoms like to have an outermost shell with eight electrons, silicon forms four covalent bonds with four neighboring silicon atoms, but then it can replace some of the silicon atoms. Silicon is in column 4 of the periodic table. You can replace a silicon atom of column 5, impurity, such as phosphorous or arsenic --

THE REPORTER: Phosphorous or --

1 THE WITNESS: Or arsenic,
2 sorry, or arsenic, which has five
3 electrons, skin and shell. When you
4 replace a silicon atom in the crystal
5 with an arsenic atom, for example,
6 four of the arsenic valence electrons
7 satisfy the four covalent bonds, but
8 then the fifth electron is donated to
9 the crystal, making it an n-type
10 semiconductor. So that's an example
11 of doping.
12 Conversely, you could replace
13 silicon with a column 3 impurity, such
14 as boron, and now if you have -- since
15 you have a deficit of one electron
16 compared to silicon, you create a
17 missing state in the valence band and
18 that --
19 THE REPORTER: In the what?
20 THE WITNESS: In the valence,
21 V-A-L-E-N-C-E, band which leads to a
22 positively charged carrier for the

1 pole, making it a p-type doped
2 semiconductor.
3 THE REPORTER: I had a hard
4 time understanding.
5 MR. WHITEHURST: Yeah, miss
6 court reporter, I'll try to help you
7 out.
8 Q. (BY MR. WHITEHURST)
9 Dr. Banerjee, you can hopefully help me out
10 as well. Could you please spell covalent?
11 A. C-O-V-A-L-E-N-T.
12 Q. And I believe you said p-type;
13 is that correct?
14 A. Yes, I did talk about p-type.
15 So p, hyphen, type, T-Y-P-E.
16 Q. And what does p-type mean?
17 A. P-type would be our dope
18 silicon doped with column 3 impurities, such
19 as boron, which are known as acceptor
20 impurities because they accept electrons from
21 neighboring silicon atoms. And by doing so,
22 it creates an empty state in the valence

band, and this empty state behaves like positively charged carriers, which are known as poles.

Q. I should have asked, Dr. Banerjee, what did you do after your time at TI?

A. I joined the University of Texas in 1987. I have been there ever since.

Q. And when you joined in 1987, what were your roles at the university?

A. Well, as you probably know, professors wear multiple hats. We teach classes. So I have been teaching an undergrad course on semiconductor device physics where we talk about the subject matter for probably over 40 years.

I also teach a course on device fabrication where I talk about the theory of how devices are made, including transistors. I have students actually make transistors in the lab and test them.

I have also taught, in the

1 past, an advanced graduate course on
2 semiconductor physics. That's on the
3 teaching side.
4 The main role of a professor in
5 a research university, as you probably know,
6 is research, actually bringing in research
7 funding. The graduate students do the hard
8 work. And I have worked on different kinds
9 of semiconductor devices, transistors,
10 different kinds of memories, including flash
11 memory, for example, other kinds of memory,
12 CMOS, C-M-O-S. I believe I have over 1,200
13 papers and 30 patents on these topics.
14 Q. Very impressive. And I know
15 how much work it can be, or at least I've
16 heard how much work it can be bringing in
17 research funding.
18 When did you -- when did it
19 become part of your job to secure research
20 funding?
21 A. From day one. I mean, if you
22 do not bring in research funding, you do not

1 get tenure at research universities. They
2 kick you out in six years. So that's
3 probably more important than being a good
4 teacher.
5 Q. That's exactly what I've been
6 told and I know it's part of the reality in
7 the world we live in.
8 And I assume you're a tenured
9 professor there at University of Texas?
10 A. I'm a tenured chair professor.
11 I hold a doctoral chair in electrical
12 engineering and I'm also director of the
13 Microelectronics Research Center.
14 Q. What is the Microelectronics
15 Research Center?
16 A. This is a center where over a
17 dozen faculty members who work on all kinds
18 of semiconductor devices, such as
19 transistors, electronic devices such as
20 light-emitting diodes, lasers, detectors,
21 MEMS, M-E-M-S.
22 These are made in a clean room,

1 which is kind of like a production foundry,
2 except on a much smaller scale, where you
3 have -- it's -- I mean, these are very
4 expensive facilities. They cost over $100
5 million. We have probably 100 tools, each
6 costing several million dollars. So I
7 supervise the technicians and the engineers
8 who run and maintain the tools, in addition
9 to my professorial work.
10 It's also part of a national
11 facility, one of a dozen or so across the
12 country funded by the National Science
13 Foundation. This is a network including
14 Harvard, Stanford, Cornell. It's a pretty
15 serious network, so I'm the director of that
16 also, where outside companies can come in and
17 do R&D. So they make not full production
18 chips, but devices which hopefully will then
19 lead to production.
20 Q. You mentioned NSF. What is
21 NSF?
22 A. The National Science

1 Foundation. This is the main federal agency
2 which funds basic research and R&D.
3 Q. Is the Microelectronics Center
4 also privately funded?
5 A. Yes.
6 Q. Who are some of --
7 A. So we -- so we bring in funds
8 from companies or consortia, which are made
9 up of companies.
10 In my case, for example, over
11 the years, I have had a lot of funding from
12 the Semiconductor Research Corporation, which
13 is a consortium of the leading semiconductor
14 companies in the US, and now, in fact,
15 globally. Companies such as Intel, Texas
16 Instruments used to be part of it. I think
17 they are still part of segments of it.
18 I also have funding directly
19 from companies, including TI and many other
20 companies, Intel, Samsung. I have had
21 funding from the Department of Defense,
22 DARPA. Not just me. Most active faculty

1 have to bring in funding from sources.
2 Q. You mentioned a consortium.
3 Does the consortium have a name?
4 A. This particular consortium is
5 actually located where you went to school in
6 North Carolina, the Semiconductor Research
7 Corporation.
8 Q. That's interesting. How did
9 you learn about me?
10 A. I looked you up and you have
11 very impressive credentials.
12 THE REPORTER: Pardon? I
13 didn't hear. Something, credentials.
14 THE WITNESS: I said he has
15 impressive credentials. I mean, Duke
16 is a top-notch school.
17 Q. (BY MR. WHITEHURST) Do you
18 know any of the professors at Duke?
19 A. Yes.
20 Q. Any names in particular come to
21 mind?
22 A. I have interacted with Hisham

1 Massoud, who is a Stanford Ph.D. I don't
2 know if you know him. He used to be funded
3 by the Semiconductor Research Consortium also
4 and we would interact.
5 Q. Anybody else?
6 A. I think there is a guy called
7 Aaron Franklin who joined more recently.
8 Q. Going back to the consortium,
9 who are some of the other companies that are
10 in the consortium?
11 A. The SRC, the Semiconductor
12 Research Corporation, was founded, I think in
13 the 1980s, about the time I joined the
14 university, and membership has changed and
15 evolved over the years. So I believe you
16 have all of the leading players, Intel --
17 initially, it was all US companies only, but
18 now it's Global. I believe Samsung and TSMC
19 are also part of it. I can't tell you
20 exactly what the current membership is, but I
21 know Intel is, I think Applied Materials is,
22 Micron. All of the big players.

1 Q. Is GlobalFoundries a member?
2 A. I think so, but I'm not one
3 100 percent certain.
4 Q. Do you remember who you got
5 your first funding from when you joined the
6 University of Texas-Austin?
7 A. I believe it was from the NSF.
8 I was awarded the Presidential
9 Young Investigator Award. It's a fairly
10 prestigious award for young scientists and
11 engineers. Ronald Reagan was in the White
12 House.
13 THE REPORTER: Pardon? What
14 was the last thing?
15 THE WITNESS: I got it when
16 Ronald Reagan was in the White House.
17 I have a certificate signed by him.
18 Q. (BY MR. WHITEHURST) After NSF,
19 do you remember who else you got funding
20 from?
21 A. You don't get funding
22 sequentially, so at any time you try to get

1 funding from many sources. So I believe I
2 also got funding from the State of Texas when
3 I first started. We had a program called the
4 Texas Advanced Technology Program and Texas
5 Advanced Research Program. This is only for
6 Texas-based universities. I remember getting
7 funding from them.
8 You probably have a copy of my
9 CV and that lists the various funding
10 sources. I have to look at my CV to give you
11 a more detailed answer.
12 Q. Do you think your CV has a
13 complete list of all of the funding that you
14 have received?
15 A. I believe so.
16 Q. Who have you received private
17 funding from?
18 A. Will you repeat that question,
19 please?
20 Q. Who have you received private
21 funding from?
22 A. Depends on how you define

1 "private" because the Semiconductor Research
2 Corporation is a corporation -- is a
3 consortium of private companies. In that
4 sense, that is also private funding. And I
5 have had a lot of funding from SRC over the
6 years, but I have also been funded directly
7 by several companies, such as AMD, which was
8 a precursor to GlobalFoundries where I worked
9 on flash memories.
10 I got funding from Texas
11 Instruments. In fact, I have funding from
12 them now. I probably got funding from
13 Samsung. In the past, I had funding from
14 Micron, Intel. I'm trying to think. I think
15 those are some of the immediate ones.
16 Q. Can you think of any others?
17 A. So I was also director of
18 another consortium called the Nanoelectronics
19 Research Initiative. So they had established
20 three major centers in the US, and I directed
21 one of them called the Southwest Academy of
22 Nanoelectronics.

1 That's kind of ironic because
2 the goal of this consortium was to try to
3 invent a new type of transistor which would
4 displace the MOSFET. So in some sense, I was
5 trying to undo the work that I had done in
6 the first part of my career.
7 Anyway, that was also a
8 consortium of private companies, including
9 Intel, TI -- I'm trying to think -- AMD may
10 have been part of it, but I can't remember.
11 It was a different subset of companies than
12 the main SRC.
13 So this consortium, NRI, was
14 also managed by SRC, but it was a separate
15 consortium.
16 Q. To go back, you mentioned AMD,
17 TI, some of the companies that have funded
18 you over the years. Can you think of any
19 other companies that have funded you directly
20 or indirectly?
21 A. I would have to look at my CV
22 to give you an accurate answer.

1 Q. Are you currently receiving any
2 funding directly or indirectly from
3 GlobalFoundries?
4 A. No, I'm not. I'm trying to
5 think. No, I'm not.
6 Q. Have you received any funding
7 from GlobalFoundries directly or indirectly
8 in the past?
9 A. I have not received funding
10 directly from them. But, as I told you, I
11 have received funding from this SRC
12 consortium. I do not remember if -- I don't
13 have any funding from SRC right now. I do
14 not recall if during the years I had SRC
15 funding if Global was a member of the
16 consortium. I couldn't tell you that.
17 Q. When did you receive funding
18 from SRC?
19 A. I have had multiple grants from
20 SRC over the years. Once again, I would have
21 to look at my CV. It's all listed in my CV.
22 Q. How much funding have you

1 received from SRC?
2 A. I couldn't tell you without
3 looking at my CV, but I'm guessing tens of
4 millions of dollars.
5 Q. Is that a lot?
6 MR. PAUL: Objection to form.
7 THE WITNESS: Depends on what
8 you mean by "a lot." I think I have
9 been quite successful among faculty
10 when it comes to raising money in our
11 field. That's why I got this endowed
12 chair and they promoted me to be the
13 director.
14 But, you know, if you look at a
15 person who works at a company like
16 nuclear fusion, there the expenses are
17 so high that they most likely probably
18 receive a lot more money. So it's all
19 independent, but in our area I think I
20 have been quite successful.
21 Q. (BY MR. WHITEHURST) And you
22 being successful in raising funding is part

1 of why you're an endowed chair at UT?
2 A. Well, the funding is the
3 precursor. The output is the research that
4 we do and the papers. So they look at how
5 much money you're bringing in, what papers
6 you publish and then how much professional
7 recognition you have gotten.
8 So over the years, I have been
9 fortunate to have received several awards,
10 including, interestingly, the Andrew Grove
11 Award. I know the Grove textbook was cited
12 in the proceedings. Grove was, I think, one
13 of the co-founders or an early employee of
14 Intel. So I got the Andrew Grove Award from
15 IEEE, I-E-E-E. It's the leading award for
16 semiconductor device research. So I was
17 fortunate enough to get that.
18 So the university looks at
19 things like that when they decide who to give
20 these endowed chairs to.
21 Q. And that's very impressive.
22 And one of the things that the

1 University of Texas looks at when it's making
2 an endowed chair is the amount of funding
3 that's been raised?
4 A. I suppose.
5 Q. And you've been very successful
6 at raising funding?
7 A. I think so. I mean, it depends
8 on your definition of "very."
9 Q. And you have raised tens of
10 millions of dollars from SRC?
11 A. Like I said, I'm just guessing.
12 Probably, yeah.
13 Q. And that's part of why you're
14 now an endowed chair?
15 MR. PAUL: Objection, asked and
16 answered.
17 MR. WHITEHURST: That's not a
18 proper objection, my friend. Look at
19 the rules.
20 Q. (BY MR. WHITEHURST)
21 Dr. Banerjee, and that's part of why you are
22 now an endowed chair?

1 A. When universities decide who to
2 give these endowments to, they look at
3 multiple aspects of a person's record, right,
4 teaching, research publications, and I'm sure
5 funding is also part of the equation.
6 Q. When was the most recent that
7 you received SRC funding?
8 A. I think I -- the last one, I
9 think, ended a couple of years ago. So now
10 SRC also has a mechanism where these member
11 companies can direct a portion of their
12 contribution to the consortium for specific
13 research projects.
14 In this case, Intel chose to
15 fund me through SRC. I think that project
16 ended maybe last year or the year before. It
17 was fairly recently.
18 Q. What other companies have
19 funded you through SRC?
20 A. So the bulk of the funding has
21 been the regular consortium. So all of these
22 companies bring money into a common pot and

1 then SRC gives grants. So in that sense,
2 every consortium member funded my research
3 through the consortium.
4 But, as I told you, they also
5 have a mechanism where a portion of the -- a
6 portion of the contribution can be directed
7 funding. So the latest example of that was
8 this funding that I got from Intel, and I
9 believe in the past also, many years ago, I
10 had directed funding also from Intel through
11 the SRC. The vast majority of my SRC funding
12 has been as part of the overall consortium.
13 Q. What other companies besides
14 Intel have you received directed funding
15 from?
16 A. I currently have direct funding
17 from Texas Instruments, Samsung. I think
18 currently those are the only two that are
19 active.
20 Q. How much funding have you
21 received from Samsung?
22 A. So let me tell you, in many

1 cases you have also called principal
2 investigator of a grant, and, in this case,
3 Samsung wanted me to be the principal
4 investigator of TI. And over a three-year
5 period, I believe they are giving us close to
6 $3 million, but I also have three other
7 faculty members as part of my grant. So my
8 share of the $3 million is probably roughly
9 half of that, maybe, approximately.
10 Q. Approximately $1.5 million?
11 A. Over three years,
12 approximately, yes.
13 Q. So you've received at least
14 1.5 million in funding from TI?
15 A. No, no, this is from Samsung.
16 Q. My apologies.
17 You have received at least
18 1.5 million in funding from Samsung?
19 A. Approximately.
20 Q. Have you received additional
21 funding from Samsung at other times?
22 A. I don't recall receiving

research funding from them. If you can get a copy of my CV, I can give you more detailed answers if you want.

Q. We can check that later.

You also mentioned Texas Instruments. When have you received funding directly or indirectly from Texas Instruments?

A. Indirectly from SRC for many years and directly I have funding from them.

Q. So you are currently receiving funding from Texas Instruments?

A. That's correct.

Q. And what is Texas Instruments' funding you to do?

A. Work on transistors, thin film transistors, the modeling of them.

THE REPORTER: What transistors?

THE WITNESS: Thin film transistors.

Q. (BY MR. WHITEHURST) When did

1 Texas Instruments begin funding you?
2 A. This latest financial funding
3 started, I think, in April of this year.
4 Q. And how much have they paid you
5 since April of this year?
6 A. It's a small amount, something
7 like $90,000; 80-, 90,000.
8 Q. Going back before April of this
9 year, when has TI funded you?
10 A. They funded me through SRC
11 right from the outset. I don't think I got
12 direct funding from TI, but I could be wrong.
13 Q. And when you say "from the
14 outset," I'm trying to remember, was
15 that 1987?
16 A. Yes.
17 Q. So TI has been funding you
18 since 1987?
19 A. Not continuously, but over the
20 years I've had multiple grants from SRC or
21 this Nanoelectronics Research Initiative that
22 I mentioned that I directed one of the

1 centers, and TI was part of that, along with
2 Micron, Intel.
3 These grants typically last for
4 three years and sometimes you may get
5 overlapping grants or multiple grants,
6 sometimes you have gaps in funding. But I
7 need to look at my CV to give you a more
8 detailed answer. It's all in my CV.
9 Q. You mentioned Micron and Intel.
10 Can you recall any other companies?
11 A. Well, AMD gave me some funding
12 way back. I'm trying to think. Again,
13 without my CV, I can't remember offhand.
14 Q. Since 1987, has TI ever
15 directly funded you through SRC?
16 A. If it's funding through SRC, I
17 don't consider that to be direct funding
18 unless it's one of those directed grants like
19 Intel did. TI did not do one of those
20 directed grants through SRC. But, as I told
21 you, I currently have direct funding from TI,
22 not through SRC.

1 Q. Let me see if I can understand
2 this a little better.
3 Since 1987, how much has TI
4 funded you directly?
5 A. I think it's only the most
6 recent grant, which is about 80-, $90,000. I
7 don't recall receiving direct funding from
8 them.
9 Q. And the grant that you are
10 currently working on for TI, they typically
11 last for three years; is that correct?
12 A. Not this one. This is a
13 shorter grant, a year. In fact, the money is
14 kind of almost gone.
15 Q. Are you hoping to get future
16 funding from TI?
17 A. I'm always hoping to get
18 funding from everybody.
19 Q. And why are you hoping to get
20 funding from everybody?
21 A. That's how you pay your
22 graduate students, your postdoctoral fellows.

1 Your lab collapses if you don't have money.
2 THE REPORTER: You what? I
3 didn't -- I'm sorry.
4 THE WITNESS: Your lab
5 collapses if you don't have funding.
6 Q. (BY MR. WHITEHURST) And you
7 don't want your lab to collapse?
8 A. No.
9 Q. And that's why it's important
10 to get funding?
11 A. That's true of all
12 research-active faculty.
13 Q. When did you first receive
14 funding from GlobalFoundries?
15 A. As I told you, I do not think I
16 have ever received funding from them
17 directly. I have received funding from SRC
18 over the years. I do not recall if Global
19 was a member of SRC during the years I got
20 money from SRC. This membership changes over
21 time. You can actually look at the SRC
22 history and see if there is an overlap, but I

1 have not received direct funding from Global.
2 Q. Do you ever interact directly
3 with GlobalFoundries?
4 MR. PAUL: Objection to form.
5 THE WITNESS: Depends on what
6 you mean by direct interactions. So
7 when you get these grants from SRC,
8 for example, you have to go to these
9 annual review meetings where the
10 company representatives are present.
11 Assuming Global was a
12 consortium member during this time, I
13 may have spoken to the Global
14 engineers at those reviews.
15 We also go to conferences,
16 technical conferences where you have
17 engineers from many companies,
18 including Global. I'm sure I have
19 interacted with them in that context.
20 Some of my students work at Global.
21 Q. (BY MR. WHITEHURST) How many
22 of your students work at GlobalFoundries?

1 A. I can't recall. Not a whole
2 lot. The vast majority recently have ended
3 up at Intel. I think there are a couple who
4 entered Global.
5 Q. Do you remember going to an
6 annual review meeting and a GlobalFoundries
7 person being present?
8 A. I couldn't tell you. I don't
9 recall.
10 Q. Have you ever communicated with
11 GlobalFoundries about funding?
12 A. No, I don't think I have.
13 Q. Have you ever sought funding
14 from GlobalFoundries?
15 A. No.
16 Q. Does GlobalFoundries -- strike
17 that.
18 Does GlobalFoundries fund any
19 professors or universities?
20 A. I do not know.
21 Q. Do you recall what years
22 GlobalFoundries was part of the consortium?

1 A. I do not know.
2 Q. How would you find that
3 information?
4 A. I don't know, but I suppose I
5 could go to the SRC website, maybe, and they
6 probably have a list of the members, but I
7 have not done that research.
8 Q. When was the last time you went
9 to an annual review meeting?
10 A. Any annual review or SRC annual
11 review?
12 Q. Let start with any. When was
13 the last time you went to an annual review
14 meeting?
15 A. It was during the summer. I
16 went to Korea for the first annual review at
17 Samsung.
18 Q. Going back, when was the second
19 most recent annual review meeting?
20 A. That probably was the one with
21 this SRC Intel directed funding. That was
22 last year.

1 Q. How many annual review meetings
2 did you go to in 2024?
3 A. It's only been the one for the
4 Samsung grant. I went to Korea. I think
5 that was the only one.
6 Q. How many annual review meetings
7 did you go to in 2023?
8 A. I don't recall. I think the
9 last year of the SRC grant was in 2023. I
10 remember that.
11 Q. Do you remember who was present
12 at the SRC annual review meeting?
13 A. No.
14 Q. Do you remember any of the
15 companies?
16 A. The Intel guys were definitely
17 there because they were the ones funding me.
18 I'm trying to think. I can't remember.
19 Q. You can't remember anybody
20 other than Intel?
21 MR. PAUL: Objection to form.
22 THE WITNESS: I'm trying to

1 think. I think the Samsung guys were
2 also there, if I remember right.
3 Yeah, I think the Samsung guys were
4 there also.
5 Q. (BY MR. WHITEHURST) Other than
6 Samsung and Intel, can you remember anybody
7 else that was at the annual review meeting?
8 MR. PAUL: Objection, asked and
9 answered.
10 MR. WHITEHURST: That's not a
11 proper objection. Please go read the
12 rules.
13 MR. PAUL: I disagree.
14 MR. WHITEHURST: Well, we will
15 talk about it offline.
16 Q. (BY MR. WHITEHURST) And I did
17 not --
18 A. I --
19 Q. I'm sorry, Dr. Banerjee. My
20 apologies. I got interrupted there. Let me
21 re-ask the question.
22 Other than Samsung and Intel,

1 can you remember anybody else that was at the
2 annual review meeting?
3 MR. PAUL: Same objection.
4 THE WITNESS: I do not recall.
5 Q. (BY MR. WHITEHURST) How would
6 you find that information?
7 A. You could probably contact SRC.
8 They would probably have an attendance list.
9 They could probably tell you.
10 Q. And do they keep those
11 attendance lists on a website?
12 A. I don't know, but I don't think
13 so.
14 Q. Where do they keep the
15 attendance list?
16 A. I have no idea.
17 Q. We have been going for about an
18 hour. Would you like to take a break?
19 A. Yes, please.
20 Q. Let's go off the record.
21 THE VIDEOGRAPHER: Going off
22 the record, the time is 10:13.

1 (Recess from 10:13 a.m. to
2 10:26 a.m.)
3 THE VIDEOGRAPHER: We're back
4 on the record, the time is 10:26.
5 Q. (BY MR. WHITEHURST)
6 Dr. Banerjee, welcome back.
7 A. Thank you.
8 Q. I want to ask you about some of
9 the work you did once you were at the
10 University of Texas. I believe you have
11 worked on some textbooks in the past?
12 A. Yes.
13 Q. When did you begin work on your
14 first textbook? Do you recall?
15 A. So I'm co-author on a
16 textbook --
17 THE REPORTER: Pardon? I'm
18 sorry, I couldn't hear.
19 THE WITNESS: I'm co-author on
20 a textbook with Ben Streetman, who was
21 my Ph.D. advisor back at Illinois. He
22 wrote the original version, I believe,

in 1972, but then -- and then he wrote several editions.

In 1999, he invited me to be a co-author, and so I have been a co-author from, I think, the fourth, fifth, sixth and seventh editions, I believe, or maybe fifth, sixth, seventh. I have been co-author with Dr. Streetman on current editions, I believe starting in 1999, because by that time Streetman had become the dean of engineering in 1999.

Most of the updates and changes have been made by me, but the original version, first edition was written by Dr. Streetman. So that's one book.

But I'm also authors or co-authors on book chapters, and those, I think, are also listed on my CV. I think I have about ten of those. I can't remember when I wrote the first of those. I have to look at

1 my CV.
2 Q. (BY MR. WHITEHURST) And why do
3 you make updates and changes to the
4 textbooks?
5 A. Because technology evolves.
6 The basic physics doesn't change that
7 rapidly, but details of engineering and
8 technology change more rapidly. That's why
9 engineering textbooks need to be updated.
10 Otherwise, it's not relevant to the students.
11 Q. What did you mean when you said
12 "the basic physics doesn't change that
13 rapidly"?
14 A. By "basic physics," I mean, for
15 example -- I know you're an electrical
16 engineer, I think, so you will appreciate
17 this. You know, Maxwell's equations have
18 been known since the mid-19th century --
19 THE REPORTER: The what?
20 THE WITNESS: Maxwell's
21 equations have been known since the
22 mid-19th century, and they haven't

1 changed. Of course, everything in
2 physics might be overturned if new
3 discoveries are made, but Maxwell's
4 equations are probably here to stay.
5 The rules of quantum mechanics,
6 which were first developed in the
7 1920s, haven't changed in a
8 fundamental way, though there have
9 been modifications. So those are the
10 things that have a longer time span.
11 On the other hand, details of
12 how you make a transistor or works of
13 a transistor, those things change more
14 rapidly and those are the aspects that
15 need more updating.
16 Q. (BY MR. WHITEHURST) What are
17 Maxwell's equations?
18 A. What are Maxwell's equations?
19 Q. I'm just going to help our
20 court reporter out real quick and then I'll
21 re-ask my question.
22 Dr. Banerjee, how do you spell

1 Maxwell?
2 THE REPORTER: No, I know. It
3 might not have come up on there yet.
4 Q. (BY MR. WHITEHURST) Can you
5 please spell Maxwell?
6 A. M-A-X-W-E-L-L.
7 Q. And do you normally write
8 Maxwell, apostrophe, S?
9 A. When you write Maxwell's
10 equations, yes.
11 Q. And what are Maxwell's
12 equations?
13 A. There are four of these that
14 determine the connection between electric and
15 magnetic fields, and then also how these
16 electric fields relate to charges and the
17 magnetic fields relate to currents.
18 Q. You said four. What did you
19 mean when you said four?
20 A. There's four partial
21 differential equations that are known as the
22 Maxwell equations.

1 Q. And when did you first learn
2 about Maxwell's equations?
3 A. When I was in undergrad. This
4 would be between 1974 to 1979, sometime in
5 that timeframe.
6 Q. You also mentioned quantum
7 mechanics. What did you mean by quantum
8 mechanics?
9 A. So quantum mechanics is the
10 extension of classical mechanics developed by
11 Isaac Newton and others for macroscopic
12 objects.
13 When people started studying
14 atomic physics, people realized that
15 classical mechanics rules don't seem to be
16 applicable, and that's why quantum mechanics
17 was developed.
18 Q. Do you write about Maxwell's
19 equations in any of your textbooks?
20 A. In our textbook we focus on one
21 of the four that's particularly relevant for
22 devices, and that's also known as a Poisson

1 equation.
2 THE REPORTER: As a what?
3 THE WITNESS: Poisson equation,
4 P-O-I-S-S-O-N.
5 Q. (BY MR. WHITEHURST) Is that
6 something you used while you were at TI?
7 A. Yes.
8 Q. When you mentioned basic
9 physics, are there any other rules or laws or
10 equations that you use?
11 MR. PAUL: Objection to form.
12 THE WITNESS: I'm not sure
13 exactly what you mean by that.
14 Q. (BY MR. WHITEHURST) Other than
15 Maxwell's equations, are there any other
16 equations that are useful for understanding
17 physics?
18 MR. PAUL: Objection to form.
19 THE WITNESS: Yes.
20 Q. (BY MR. WHITEHURST) What other
21 equations are helpful?
22 A. As I mentioned, quantum

1 mechanics and the main partial differential
2 equation is known as the Schrodinger
3 equation. I use that extensively both in
4 teachings in our textbook, as well as in my
5 research.
6 Q. What classes are you currently
7 teaching at the University of Texas?
8 A. I'm teaching two courses. One
9 is a course out of our textbook. It's an
10 undergraduate senior-level textbook on device
11 physics.
12 And the other one is a combined
13 graduate/undergraduate course on device
14 application where I teach students how to
15 make devices, such as transistors. That also
16 includes a lab where they make the devices
17 and test them.
18 Q. When you teach your device
19 physics class, what do you typically cover in
20 the first week or so?
21 A. In the first week, we cover
22 chapter 1 in our textbook, which is crystals

1 and crystal structure.
2 Q. Anything else?
3 A. In the first week, that's
4 generally all that we have time for.
5 THE REPORTER: Pardon? I
6 couldn't hear.
7 THE WITNESS: And then maybe
8 towards the end of the first week or
9 definitely by the second week, we
10 start talking about quantum mechanics.
11 Q. (BY MR. WHITEHURST) I know you
12 have an impressive resume.
13 When did you first study
14 physics?
15 A. Well, I studied physics in high
16 school, the equivalent of AP physics in this
17 country.
18 Q. Do you remember --
19 A. And then -- and then in
20 undergrad and grad.
21 Q. And you currently teach about
22 physics?

A. So device physics is applications of physics principles, semiconductor devices. In that sense, yes.

Q. What do you mean when you say "physics principles"?

A. The applications of the rules of physics, for example, as embodied in the Schrodinger equation or the Maxwell's equations, in this case, applied to semiconductor devices.

Q. What do you mean by "rules of physics"?

MR. PAUL: Objection to form.

THE WITNESS: In a semiconductor device, when you look at the motion of electrons and holes, you cannot really understand that based on classical physics, Newtonian physics. You really have to invoke quantum mechanics to understand those aspects. Those are the things that I talk about.

1 Q. (BY MR. WHITEHURST) Let's go
2 back to when you were first studying physics.
3 Do you remember learning about
4 Newton's laws of motion?
5 A. Yes.
6 Q. What are Newton's laws of
7 motion?
8 A. I don't see how it's relevant
9 to this, but you have the three laws. A body
10 at rest stays at rest, a body in motion stays
11 in a state of constant velocity unless there
12 are external forces, indirect external
13 forces, mass times acceleration equals
14 applied force, and then the third law is a
15 reaction --
16 THE REPORTER: Pardon, wait.
17 And then the external forces --
18 THE WITNESS: The mass times
19 accelerations equals applied force.
20 And the third law is every action has
21 an equal and opposite reaction.
22 Q. (BY MR. WHITEHURST) Let's help

1 our court reporter, or maybe help me.
2 Sometimes I say for the court reporter and
3 I'm really asking to help me. But,
4 Dr. Banerjee, let's break this down a little
5 bit, and I appreciate your patience. You
6 have been very helpful today and I certainly
7 appreciate your time.
8 How many Newton laws are there?
9 A. There are three laws.
10 Q. What is the first law?
11 A. That is the law of inertia,
12 which is if the body is at rest, it can stay
13 at rest forever, or if it's moving at a
14 certain velocity, continuing with that
15 velocity forever unless there are external
16 forces.
17 Q. What is the second Newton law?
18 A. That's the mass of an object
19 times the acceleration equals the applied
20 force.
21 Q. Is that sometimes written as
22 "F = ma"?

1 A. Yes. In fact, the first law is
2 really a subset of the second law. If F
3 becomes zero, A becomes zero.
4 Q. Do you use the second law of
5 physics in your work at all?
6 A. Yes.
7 Q. How do you use it in your work?
8 A. Not to be facetious, but every
9 time I move something, I'm using Newton's
10 second law. But in my research, you -- you
11 know, these are fundamental laws that, of
12 course, you are using.
13 Q. What do you mean when you say
14 "fundamental law"?
15 A. Rules of quantum mechanics
16 would be an example.
17 THE REPORTER: Pardon?
18 THE WITNESS: Rules of quantum
19 mechanics would be an example of such
20 a fundamental law.
21 Q. (BY MR. WHITEHURST) Do you
22 think Newton's second law is still true

1 today?
2 A. Yes, with caveats, with
3 caveats. So classical mechanics is only
4 applicable through macroscopic objects
5 traveling at slow speeds. If we approach
6 speeds comparable to the speed of light, then
7 Einstein modified those equations in the
8 section of the general theories of
9 relativity.
10 Q. What is something that would be
11 moving at the speed of light?
12 A. In particle accelerators, you
13 can accelerate subatomic particles close to
14 the speed of light. You cannot move any
15 object with a nonzero mass at the speed of
16 light, but it can actually totally approach
17 that.
18 Q. What is something that has a
19 nonzero mass?
20 A. Things like electrons, protons.
21 Q. So when you talk about
22 electrons, it has a nonzero mass?

1 A. It has a nonzero rest mass,
2 yes.
3 Q. So I believe you said that
4 Newton's second law applies to things with a
5 nonzero mass.
6 Did I get that right?
7 A. Newton's laws would apply to
8 particles with a nonzero mass, provided they
9 are not traveling at speeds comparable to the
10 speed of light. And, furthermore, if those
11 objects are tiny, you sometimes have to
12 modify those rules of Newton according to the
13 rules of quantum mechanics.
14 Q. Would Newton's second law apply
15 to electrons?
16 A. In what scenario?
17 Q. Well, let me ask the question a
18 different way.
19 When would Newton's second law
20 apply to electrons?
21 A. Newton's second law would apply
22 to electrons, for example, moving in free

1 space at speeds much slower than the speed of
2 light where it can ignore relativistic
3 corrections.
4 THE REPORTER: Ignore --
5 THE WITNESS: Relativistic
6 R-E-L-A -- I feel like I'm at a
7 spelling bee -- relativistic
8 corrections, R-E-L-A-T-I-V-I-S-T-I-C.
9 Q. (BY MR. WHITEHURST) Have you
10 ever mentioned Newton's second law in your
11 textbook?
12 A. I don't think so.
13 Q. Have you ever mentioned F = ma
14 in your textbook?
15 A. I do not recall using that law
16 in that particular form, but I think I did
17 have that in another form. I could look at
18 my textbook.
19 So ma is also sometimes written
20 as the momentum, P. And I believe in one of
21 the chapters, we do talk about dP/dt. This
22 is dP divided by dt. That is the time rate

of change of momentum equals the force. I think I did have that in the textbook somewhere.

Q. So let me see if I got this correctly. In your textbook, you mentioned F = P multiplied by dP divided by dt.

Did I get that right?

A. No, no. F = dP/dt.

Q. I'm sorry, can you repeat that, please?

A. F = dP divided by dt; dP is a change of momentum in a time interval dt. That would be the time derivative of momentum.

Q. Let's get the entire equation for the record. What would the entire equation be?

A. F = dP divided by dt.

Q. What is dP?

A. dP is the change of momentum in a time interval dt.

Q. Is this related or not related

1 to Newton's second law?
2 A. It is Newton's second law.
3 Q. It is Newton's --
4 A. It is.
5 Q. Okay. How is F = dP divided
6 by dt the same as Newton's second law?
7 A. Newton's second law, as stated
8 earlier, is F = ma; ma, a is the
9 acceleration, which is given by dV/dt where V
10 is the velocity. Mass times velocity is the
11 momentum, P.
12 So if you are in the classical
13 regime where mass does not depend on
14 velocity, you can move mass inside the time
15 derivative. So an alternative form of
16 Newton's second law would be F = dm times V
17 over dt or dP/dt.
18 THE REPORTER: Vpd?
19 THE WITNESS: T as in time. D,
20 P as in Peter -- D as in dog, P as in
21 Peter, divided by D as in dog, T as in
22 time.

Q. (BY MR. WHITEHURST) So one way to write Newton's second law is F = m times a.

Did I get that correct?

A. Yes.

Q. Another way to write Newton's second law is F = dP divided by dt.

Did I get that correct?

A. Yes.

Q. And in your textbook, you mention Newton's second law when you mention F = dP divided by dt?

A. I have to refresh my memory, but I believe I have that equation somewhere.

Q. And do you recall why you included that equation in your textbook?

A. I believe that was in the context of how electrons are holes who move in a semiconductor.

Q. And does the equation S = dP divided by dt describe how electrons move in a semiconductor?

1 MR. PAUL: Object to form.
2 (Discussion off the record).
3 MR. WHITEHURST: Dr. Banerjee,
4 we're going to go off the record.
5 THE VIDEOGRAPHER: Going off
6 the record. The time is 10:51.
7 (Recess from 10:51 a.m. to
8 11:00 a.m.)
9 THE VIDEOGRAPHER: We're back
10 on the record. The time is 11:00 a.m.
11 Q. (BY MR. WHITEHURST)
12 Dr. Banerjee, welcome back. Sorry about the
13 fire alarm, but I'm glad everything is okay
14 now. Before the break, we were talking about
15 Newton's second law.
16 Do you recall that?
17 A. Yes.
18 Q. And you were explaining that
19 one way to write Newton's second law is
20 F = dP divided by dt.
21 Do you recall that?
22 A. Yes.

Q. And you testified that you mentioned Newton's second law, F = dP divided by dt, in your textbook.

Do you recall that?

A. Yes.

Q. And do you recall explaining how electrons move in a semiconductor?

A. I didn't explain it, but I think we start talking about it.

Q. Okay. Let's -- let's resume there. How do electrons move in a semiconductor?

A. So in a semiconductor, you have not just one electron, but a huge number, which are constantly moving around in all random directions at room temperature. That's known as Brownian motion, B-R-O-W-N-I-A-N, motion.

One breaks down the problem or the movement of electrons or holes in a semiconductor into three parts to make the problem manageable. The first part is you

1 take into account the subatomic nature of the
2 electrons and you describe the electron
3 quantum mechanically using what is called a
4 wave function. And the first part of the
5 problem is the motion of electron in the
6 periodic crystal potential --
7 THE REPORTER: In the what?
8 Wait, I'm sorry, I was on mute.
9 Motion of electron in the --
10 THE WITNESS: The periodic,
11 P-E-R-I-O-D-I-C.
12 THE REPORTER: Oh, periodic.
13 THE WITNESS: Periodic, yeah.
14 Crystal potential.
15 Did you get that?
16 THE REPORTER: Yes.
17 THE WITNESS: So that part of
18 the motion is handled quantum
19 mechanically. That leads to something
20 called the band structure. And, in a
21 nutshell, the important result of that
22 part of the force is you change the

1 actual mass of the electron into what
2 is called an effective mass.
3 Once you do that, you can sort
4 of forget about the periodic crystal
5 forces and now you can see how these
6 electrons or holes with a modified
7 effective mass respond to the external
8 forces. I believe that's the form of
9 Newton's law we wrote in the textbook.
10 But there is a third component
11 to the force, which is when electrons
12 or holes are moving in the crystal
13 with this effective mass and
14 responding to externally applied
15 forces or built-in forces, like the
16 built-in electric fields, which is the
17 subject matter of this patent.
18 They can also undergo random
19 collisions or scattering where the
20 scattering is not caused by the
21 periodic crystalline potential, but
22 deviations from periodic potential,

1 such as lattice vibrations or defects
2 or these dopant impurities that you're
3 talking about.
4 THE REPORTER: What impurities?
5 THE WITNESS: Dopant
6 impurities, D-O-P-A-N-T.
7 THE REPORTER: Okay, thank you.
8 Q. (BY MR. WHITEHURST) Sounds
9 pretty complicated.
10 A. It is.
11 Q. And I apologize, but I'm going
12 to try to break down everything you said and
13 hopefully you can be patient with me. And
14 I'll try to do the best job I can, but
15 obviously I don't understand it as well as
16 you do. But, like you said, it's
17 complicated.
18 So it sounds like to determine
19 movement of an electron in a semiconductor,
20 you have to look at a number of factors,
21 correct?
22 A. Yes.

1 MR. PAUL: Objection to form.
2 Q. (BY MR. WHITEHURST) What are
3 some of the factors you have to look at?
4 A. Well, as I mentioned, there's
5 three broad categories of forces. The
6 periodic crystalline potential forces.
7 Q. Okay. And I apologize, we're
8 going to take these one by one. You said
9 there are three broad categories of forces.
10 And, Dr. Banerjee, I apologize for
11 interrupting you. I'm just trying to help
12 our court reporter.
13 Before we get the three broad
14 categories of forces, can you please spell
15 what the first broad category of force is?
16 A. I believe I used the term
17 periodic crystalline potential.
18 THE REPORTER: Periodic
19 crystalline --
20 THE WITNESS: Crystalline
21 potential, P-O-T-E-N-T-I-A-L.
22 THE REPORTER: Yes, potential,

1 okay.
2 Q. (BY MR. WHITEHURST) So you
3 said that -- strike that.
4 In order to understand the
5 movement of an electron in a semiconductor,
6 you have to look at three categories of
7 forces, correct?
8 A. Yes.
9 Q. And the first category of force
10 that you have to look at is the periodic
11 crystalline potential; is that right?
12 A. Yes.
13 Q. What is the second category of
14 force that you have to look at in order to
15 understand the movement of an electron in a
16 semiconductor?
17 A. Generally --
18 MR. PAUL: Objection to form.
19 THE WITNESS: Generally, the
20 second category -- in order to be
21 considered the first, second or third
22 category, that's a matter of

1 convention.
2 The second category, in my
3 opinion, would be the externally
4 applied forces or forces that would
5 develop due to these built-in electric
6 fields, such as this doping profile
7 gradient at the --
8 THE REPORTER: Such as the --
9 okay.
10 THE WITNESS: Doping gradient.
11 THE REPORTER: Okay.
12 Q. (BY MR. WHITEHURST) So thank
13 you. So in order to understand the movement
14 of an electron in a semiconductor, you have
15 to look at three categories of forces, and
16 one category of forces would be the periodic
17 crystalline potential, correct?
18 A. Yes.
19 Q. The second category of force
20 that you would have to look at is externally
21 applied forces or a built-in electric field.
22 Did I get that correct?

A. Yes.

Q. And then what is the third category of force that you would have to look at in order to understand the movement of an electron in a semiconductor?

MR. PAUL: Objection to form.

THE WITNESS: The third category of forces are these random forces, which can be time dependent, such as lattice vibrations or static random forces due to structural defects in the crystal, including dopant impurities that we are talking about.

Q. (BY MR. WHITEHURST) So the third category of force are random forces, which can be time dependent, such as lattice vibrations or static random forces due to structural defects in the crystal.

Did I get that correct?

A. Yes.

Q. Let's go --

1 A. I think -- I think I also added
2 the phrase "such as the dopant." I think I
3 said something like that.
4 Q. Let's get that on the record
5 that the third -- strike that.
6 The third category of force
7 that you would need to look at in order to
8 understand movement of an electron in a
9 semiconductor would involve dopants; is that
10 right?
11 MR. PAUL: Objection to form.
12 THE WITNESS: The dopants would
13 introduce these random static forces
14 because the dopants do not follow a
15 periodic arrangement.
16 Q. (BY MR. WHITEHURST) And why
17 would these dopants introduce static forces?
18 A. As we were discussing, the two
19 types of dopants are donors, which donate
20 electrons to the crystal, a negatively
21 charged electron, or acceptors, which accept
22 electrons, and thereby create what is

1 tantamount to a positively charged carrier in
2 the valence band, which is known as a hole --
3 THE REPORTER: Which would --
4 okay. When you talk more slowly, it's
5 easier for me.
6 THE WITNESS: Yeah, sorry.
7 THE REPORTER: Create this
8 tantamount --
9 THE WITNESS: Tantamount.
10 MR. WHITEHURST: Tantamount.
11 THE REPORTER: I have that, but
12 I lost it after that.
13 THE WITNESS: To a positively
14 charged carrier known as a hole,
15 H-O-L-E.
16 Q. (BY MR. WHITEHURST) And why
17 would the static forces created by the
18 dopants affect the movement of an electron in
19 a semiconductor?
20 MR. PAUL: Objection to form.
21 THE WITNESS: So let's look at
22 donors as an example. The phosphorous

1 or arsenic donor atom itself is a
2 neutral object because the positive
3 charge in the nucleus is
4 counterbalanced by the various
5 electrons in various energy levels.
6 The lowest energy levels are
7 the core electrons, but then you have
8 the outermost shell, which is the
9 valence shell. When I put it into a
10 silicon crystal and I replace one of
11 the silicon atoms with this
12 phosphorous donor, the fifth electron
13 in the valence shell is donated to the
14 crystal that creates an electron in
15 the conduction band, which can then
16 move around in this periodic
17 crystalline potential, almost like a
18 free particle, like a free electron,
19 but with a modified effective mass
20 because the electron is seeing the
21 periodic crystalline forces.
22 Now, once the phosphorous or

1 the arsenic has donated an electron,
2 which can move around, it leaves
3 behind a positively charged donor
4 impurity, which cannot move around.
5 These are the fixed dopants, which
6 once you have created them in the
7 solid, they do not move around at room
8 temperature. And that's what's
9 responsible for the built-in electric
10 field.
11 Now, in regards to scattering,
12 these donors are acceptors. When you
13 put them into the crystal through a
14 technique, such as ion implantation,
15 they will occupy --
16 THE REPORTER: Such as ion --
17 THE WITNESS: Implantation.
18 THE REPORTER: Implantation,
19 okay.
20 THE WITNESS: They will occupy
21 random sites in the crystal and
22 anything that's at randomness, either

in time or space, is what starts the scattering.

Contrary to classical physics, people used to think that electrons could be scattered from the periodic arrangement of the atoms themselves, and then people realized that the periodic arrangement of atoms do not cause scattering. All that they do is to modify the actual mass into this effective mass.

And once you have accounted for that, you can kind of forget about these periodic crystalline forces. You can just focus on the external forces. Now the electrons are moving with an effective mass, but every now and then they are getting scattered by these random forces and that is what determines the mobility and ultimately the resistivity of the solid.

THE REPORTER: Mobility and

what?

THE WITNESS: Or the resistivity, R-E-S-I-S-T --

THE REPORTER: Oh, I know that, yes. When you talk slow, I can figure it out.

The mobility or the resistivity --

THE WITNESS: Of the solid.

THE REPORTER: Okay, thanks.

Q. (BY MR. WHITEHURST) So let's go back and try to unpack all of these forces that you mentioned.

Going back to the first category, which I believe you referred to as a periodic crystalline potential, why does this first category of periodic crystalline potential forces affect the movement of an electron in a semiconductor?

MR. PAUL: Objection to form.

THE WITNESS: So to answer that, one needs to distinguish between

the electrons, which are in these lowest energy levels. These are called core electrons. And here I'm trying to correct the wrong statements made by your expert.

These core electrons are attracted to the positive nucleus and they are held like springlike forces. They do not move.

THE REPORTER: The what?

THE WITNESS: They are held to the positive nucleus by springlike forces and they cannot move in the crystal.

On the other hand, the electrons that are donated by the donor and are now in the conduction band can move. Although, with this modified effective mass, they are not held to the nuclei, the positive nuclei, with the springlike forces that have to be overcome before they

1 move. That's an error in the
2 declaration made by Dr. Glew.
3 Q. (BY MR. WHITEHURST) I'm just
4 trying to understand this better,
5 Dr. Banerjee, and I certainly appreciate your
6 help.
7 So let's talk about this first
8 category of forces, which you've referred to
9 as periodic crystalline potential. First of
10 all, what do you mean by "periodic"?
11 A. A crystal has a periodic
12 arrangement of atoms in space. In the case
13 of silicon, we talk about that in chapter 1
14 of our textbook, you have atoms in what is
15 called a face-centered cubic lattice, and
16 then you put a second atom associated with
17 these lattice points at a certain location.
18 And once you do that, you end
19 up with a different structure, which happens
20 to be the same structure as diamond. That's
21 why it's sometimes also called diamond
22 structure. Colloquially, people would call

1 that a diamond lattice, but if you want to be
2 accurate, it's a face-centered lattice at the
3 bases of two atoms.
4 Q. And what do you mean by
5 "crystalline"?
6 A. So crystalline structure is
7 periodic in space over long distances.
8 Q. And what --
9 A. In this case -- in this case,
10 over the entire dimensions of the silicon
11 wafer, for example.
12 Q. And what do you mean by
13 "potential"?
14 A. By "potential," I mean the
15 silicon atoms or all atoms have a positive
16 nucleus because they have the heavy protons
17 and the neutral neutrons, which make up the
18 nucleus. And, as I'm sure you know, unlike
19 charges tend to attract to each other, so
20 they create these potential wells, which will
21 draw the negative electrons toward the
22 nucleus.

However, as I told you a few minutes back, you have to categorize electrons into two groups. One are the core electrons, the lower energy level electrons, which are bound to the positive nucleus through coulombic forces.

THE REPORTER: Which are bound to the --

THE WITNESS: Positive nucleus by coulombic, C-O-U-L-O-M-B-I-C, coulombic forces.

But the highest energy electrons, in this case, the free electrons in the conduction band, are not bound to any particular nucleus. They can move around almost like free electrons, except that it gets slightly modified. And these are known as Bloch waves, B-L-O-C-H.

So unlike what Dr. Glew said, these electrons are not -- I'm talking about the highest flying electrons in

the conduction band or the holes in the valence band are not tied to any nuclei where you have to break those bonds before they can start moving.

THE REPORTER: You do not have to take those bonds?

THE WITNESS: You do not have to break those bonds before they start moving.

Q. (BY MR. WHITEHURST) When do these periodic crystalline potential forces affect the movement of an electron in a semiconductor?

MR. PAUL: Objection to form.

THE WITNESS: They affect the movement of electrons in the semiconductor only by -- by modifying the actual mass of the electron that an electron would have in a vacuum, for example, and converting that into the effective mass. Different semiconductors are different effective

1 masses because they have different
2 periodic crystalline potentials.
3 THE REPORTER: Different
4 periodic --
5 THE WITNESS: Periodic
6 crystalline potentials.
7 Q. (BY MR. WHITEHURST) So let me
8 see if I got this correct. In order to
9 understand the movement of an electron in a
10 semiconductor, you would first need to look
11 at the periodic crystalline potential forces
12 in order to determine the effective mass of
13 the electron.
14 Did I get that right?
15 MR. PAUL: Objection to form.
16 THE WITNESS: You do that for
17 the electrons, especially in the
18 highest line energy levels, in this
19 case, for example, the conduction band
20 in silicon or the holes in the valence
21 band. These are --
22 THE REPORTER: Or the holes --

1 THE WITNESS: Holes in the
2 valence band, V-A-L-E-N-C-E.
3 THE REPORTER: Right.
4 THE WITNESS: These carriers
5 are not tied to any specific crystal
6 location -- lattice location. They
7 move around. But the crystal does
8 matter in the sense that it modifies
9 the masses into effective masses. But
10 once you have an effective mass, they
11 are free to move around.
12 In fact, as I told you, at room
13 temperature these electrons are not
14 going to be static. They are bouncing
15 around in all kinds of random
16 directions and that's known as this
17 random Brownian motion.
18 THE REPORTER: Random grounding
19 motion?
20 THE WITNESS: Brownian.
21 My Zoom screen disappeared.
22 THE REPORTER: Yes, you froze

on our end.

THE WITNESS: Brownian is B-R-O-W-N-I-A-N.

MR. WHITEHURST: Let's take a quick break and see if we can fix Dr. Banerjee's video feed.

THE VIDEOGRAPHER: Going off the record, the time is 11:24.

(Recess from 11:24 a.m. to 11:34 a.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 11:34.

Q. (BY MR. WHITEHURST) So before the break, Dr. Banerjee, we were talking about the first category of forces that affect the movement of an electron in a semiconductor, and I believe we were referring to those as the periodic crystalline potential forces.

Do you recall that?

A. Yes.

Q. And you also mentioned the

1 effective mass of the electron.
2 Do you recall that?
3 A. Yes.
4 Q. What is the effective mass of
5 the electron?
6 A. So the spacing between the
7 atoms and the crystal is generally quite
8 small on the order of angstroms,
9 A-N-G-S-T-R-O-M-S, which is comparable to the
10 quantum mechanical de Broglie wavelength
11 electrons, D-E-B-R-O-G-L-I-E.
12 When that's the case, you
13 cannot feed these electrons using Newton's
14 laws. You have to invoke quantum mechanics.
15 Specifically, you have to solve the
16 Schrodinger equation, S-C-H-R-O-D-I-N-G-E-R,
17 equation, and that solution leads to a
18 modification of the actual mass into the
19 effective mass.
20 So the effective mass is a nice
21 compact way of feeding these periodic
22 crystalline forces. And since the periodic

1 crystalline structure does not change, once
2 you solve that problem, you're done and then
3 you can just focus on the second and the
4 third category of force.
5 Q. So by calculating the effective
6 mass of the electron, it becomes easier to
7 look at the other two categories of forces;
8 is that correct?
9 A. That is correct, especially for
10 these highest line electrons in the
11 conduction band or the holes in the valence
12 band. The lower line core electrons are
13 still tied to the nuclei because unlike
14 charges affect each other, so they are
15 connected by springlike forces.
16 But that is not true for these
17 highest line electrons in the conduction band
18 or the holes in the valence band. They are
19 not bound to the positive nuclei by
20 springlike forces. They are --
21 THE REPORTER: They are not
22 bound --

1 THE WITNESS: They are not
2 bound by springlike forces, contrary
3 to what Dr. Glew seemed to imply.
4 They are free to move around, but not
5 free as in space. Their masses get
6 modified into effective mass.
7 Q. (BY MR. WHITEHURST) So you
8 look at the first category of forces to get
9 the effective mass of the electron, right?
10 A. Yes.
11 Q. And then once you get the
12 effective mass of the electron, you move to
13 the second and third category of forces in
14 order to determine the movement of the
15 electron in the semiconductor?
16 A. That is correct.
17 Q. So by getting the effective
18 mass of the electron, it's a handy way of
19 then looking at the second and third category
20 of forces?
21 A. Great. You got an A in my
22 class. Exactly.

1 THE REPORTER: Wait, what did
2 you say? I missed that.
3 MR. WHITEHURST: He said I
4 could get an A in his class. I'm
5 doing the best I can.
6 Q. (BY MR. WHITEHURST) So let's
7 now assume we have gotten the effective mass
8 of the electron. Why do we have to look at
9 the second and third category of forces in
10 order to determine the movement of the
11 electron in the semiconductor?
12 MR. PAUL: Objection to form.
13 THE WITNESS: Yes, so these
14 electrons in the conduction band,
15 which now are moving with an effective
16 mass, are moving in all kinds of
17 random directions. And that is this
18 Brownian motion that we are talking
19 about.
20 In fact, at room temperature in
21 silicon, as I think I mentioned in my
22 report, there are speeds of up to ten

1 million centimeters per second.
2 However, even though they are
3 moving around, because they are moving
4 around in all kinds of random
5 directions and you have a large number
6 of electrons for unit value, there is
7 not going to be any net motion of
8 electrons, and therefore no net
9 current, unless --
10 THE REPORTER: And no net --
11 THE WITNESS: Current,
12 C-U-R-R-E-N-T, current.
13 Unless you apply external
14 voltages or external forces and then
15 it could have a net current flowing.
16 But when it's responding to these
17 external forces, they do not travel
18 unimpeded. Every now and then they
19 are scattered or they collide with
20 these time dependent lattice vibration
21 forces or time independent static
22 forces, such as due to the dopants.

1 And that is what determines the
2 mobility, which, in turn, determines
3 the resistivity of the semiconductor.
4 Q. (BY MR. WHITEHURST) Again, it
5 sound very complicated.
6 You mentioned net motion. What
7 did you mean when you said net motion?
8 A. So these electrons or holes are
9 moving around in all kind of directions. So
10 if one chose a particular location in a
11 semiconductor device, statistically you have
12 as many electrons moving to the right as to
13 the left, thereby canceling out the current.
14 Net current would be zero.
15 However, if you apply a battery
16 to the ends of a semiconductor bar, for
17 example, that would create an external
18 electric field and that can then cause what
19 is called a drift motion, which is
20 superimposed on top of this random Brownian
21 motion, which you cannot stop.
22 And in the case of holes, that

1 drift velocity will be in the direction of
2 the electric field because holes have a
3 positive charge. Electrons, because they
4 have a negative charge, would move opposite
5 to the electric field.
6 However, because electrons have
7 a negative charge, if they move to the left,
8 the current of the electrons would move to
9 the right -- would be to the right in the
10 direction of the electric field.
11 Q. Why do --
12 A. And all of -- all of this is
13 described in the report.
14 Q. Why do electrons move in the
15 opposite direction of the electric field?
16 A. Because they have a negative
17 charge.
18 Q. And is that always true?
19 MR. PAUL: Objection to form.
20 THE WITNESS: So if I have
21 electric field in one that's pointing
22 to the right, for example, they would

1 move to the left, but that motion --
2 it is called drift velocity -- is
3 superimposed on top of this random
4 Brownian motion whose speeds are
5 actually typically much higher than
6 this drift velocity.
7 So you have this whole ensemble
8 of electrons moving around in all
9 kinds of random directions and then
10 you superimpose on top of this
11 ensemble a drift velocity, which would
12 be opposite the direction of the
13 electric field that's applied.
14 Q. (BY MR. WHITEHURST) Let me see
15 if I've got this right.
16 So if an electric field points
17 to the right, the electron will move to the
18 left because the electron has a negative
19 charge?
20 A. That's correct.
21 Q. How do you know that?
22 A. Well, do you believe Maxwell's

1 equations?
2 Q. So Maxwell's equations tells us
3 that if an electric field points to the
4 right, the electron will move to the left?
5 A. In Maxwell's equations, he has
6 something called the Lorentz law. From that,
7 you can gather the electrons that would move
8 opposite to the electric field.
9 Q. Can you spell Lorentz law?
10 A. L-O-R-E-N-T-Z.
11 Q. And Lorentz law tells us that
12 if an electric field points to the right, the
13 electron will move to the left?
14 A. There will be a force on the
15 electron to the left and there will be a net
16 motion to the left, superimposed on top of
17 this random Brownian motion.
18 Q. So there would be a force to
19 the left.
20 Did I get that right?
21 A. If the electric field is to the
22 right, yes, there would be a force to the

1 left.
2 Q. Why do you say "force to the
3 left"?
4 MR. PAUL: Objection to form.
5 THE WITNESS: That's the
6 Lorentz law that I just mentioned,
7 which tells you that the force on a
8 charged particle is given by the
9 charge times the electric field.
10 And there is a second term to
11 the magnetic fields that we need not
12 worry about here.
13 Q. (BY MR. WHITEHURST) How do you
14 determine whether the electron actually moves
15 to the left?
16 A. You can -- suppose you have a
17 semiconductor bar, like a semiconductor
18 resistor. You would apply a battery to the
19 ends of the bar, which provides a voltage,
20 and, therefore, determines the magnitude as
21 well as a sign of the electric field,
22 depending on the polarity of the battery.

1 And then you could hook up an ammeter,
2 A-M-M-E-T-E-R, which measures the current
3 that's flowing.
4 Now, if the ammeter registers
5 a -- registers a current, I know there's a
6 net motion. And in the case of electrons, if
7 the electric field due to the battery points
8 to the right, the electrons will have a net
9 motion to the left.
10 But then because of the
11 negative charge, that would point to the
12 right in the same direction as the electric
13 field and that is the current that would be
14 registered by the ammeter.
15 Q. So there could be multiple
16 fields? Is that what you said?
17 A. It could be the field in this
18 case due to the battery that I'm hooking up
19 to a resistor, a piece of semiconductor,
20 which would act essentially like a resistor.
21 Now, if this semiconductor was doped
22 uniformly, that is the field that's relevant.

1 But going back to the patents
2 at issue, you could also have a scenario
3 where the doping concentration in the
4 semiconductor is not unform, is a gradation,
5 and that self-generates additional electric
6 fields, which would be superimposed on the
7 externally applied electric fields due to the
8 battery. You either do a vector sum of the
9 built-in static electric fields to the doping
10 gradient, as well as the externally applied
11 fields, which can change from, you know, one
12 situation to the other, depending on, you
13 know, where I'm hooking up the battery,
14 magnitude of the voltage, et cetera, et
15 cetera.
16 But the built-in electric
17 field, once that made the semiconductor
18 device with a certain doping gradient, it's
19 static. It's not going to change.
20 Q. So, again, it sounds very
21 complicated and let me see if I understood
22 what you said.

First of all, you mentioned a vector sum. What is a vector sum?

A. A vector quantity is something which has both a magnitude and a direction. So if I have the electric field pointing to the right and another electric field pointing to the right, you simply can add them up. But if the second electric field points to the left, you take the difference of the two electric fields.

On the other hand, suppose the second electric field was perpendicular to the first electric field, you can't just add them up. That's when you do this vector sum, taking into account both the magnitude and the direction of those fields.

Q. So you can have multiple vectors; is that right?

A. Depending on the scenario, yes. And then you get a resulting vector and that's what the --

Q. So if you have multiple

1 vectors, you need to look at all of the
2 vectors; is that right?
3 A. Yes.
4 Q. And that's how you get the
5 vector sum?
6 A. Yes.
7 Q. So you could have a first field
8 creating a first vector; is that right?
9 MR. PAUL: Objection to form.
10 THE WITNESS: Yes.
11 Q. (BY MR. WHITEHURST) You could
12 have a second field creating a second vector;
13 is that right?
14 A. Yes.
15 Q. And if the two vectors are
16 pointing in the same direction, you can add
17 them together?
18 A. Yes.
19 Q. But if the two vectors are
20 pointing in the opposite direction, what
21 happens?
22 A. You can get a cancellation

1 effect and the larger vector wins. So the
2 net vector will point in the direction of the
3 larger vector.
4 Q. So if you have a vector
5 pointing to the right -- well, let me -- let
6 me back up.
7 When we talk about vectors, do
8 vectors have units?
9 A. Yes.
10 Q. What would the units be for the
11 vector?
12 A. So in the case of electric
13 fields, it could be volts per centimeter.
14 THE REPORTER: It could be
15 what?
16 THE WITNESS: Volts, V-O-L-T-S,
17 per centimeter.
18 Q. (BY MR. WHITEHURST) So when
19 we're looking at an electron in a
20 semiconductor, we could have multiple forces
21 acting on it?
22 MR. PAUL: Objection to form.

1 THE WITNESS: Well, as I told
2 you, you have the three broad
3 categories of forces, but now focusing
4 on the second category, which are
5 externally applied forces or built-in
6 forces due to doping gradients, those
7 could also have multiple components to
8 it and you have to take the vector
9 sum.
10 Q. (BY MR. WHITEHURST) So when
11 you have multiple forces, you have to look at
12 the vector sum?
13 A. To get the net motion, yes.
14 Q. So in order to determine the
15 net motion, you have to look at the vector
16 sum?
17 A. In order to --
18 MR. PAUL: Objection to form.
19 THE WITNESS: In order to look
20 at the net motion, you have to look at
21 the vector sum. But then the net
22 motion itself, velocity also is a

1 vector, so you could consider the
2 velocity also as responding to the
3 individual forces and then you take
4 the net vector sum of the velocities.
5 Q. (BY MR. WHITEHURST) When you
6 use the term "vector sum," could you also
7 call that the net field?
8 A. If what I'm summing
9 are electric fields pointing in different
10 directions, you could call it the net field,
11 net electric field.
12 Q. So in order to determine the
13 net motion, you look at the vector sum?
14 MR. PAUL: Objection to form.
15 THE WITNESS: If you want to
16 decompose the resulting electric field
17 into its initial component electric
18 fields, the ultimate velocity would
19 depend on the net electric field. The
20 ultimate velocity would also be
21 considered as the vector sum of
22 electric field 1 pointing to the right

and electric field 2 may be pointing upwards, as an example.

Q. (BY MR. WHITEHURST) Why does the net movement depend on the net electric field?

MR. PAUL: Objection to form.

THE WITNESS: As I told you, the Lorentz force is equal to the charge times electric field. And if I'm interested in the net motion, the electric field would be the vector sum of all of the electric fields, or recurrently, you can treat the problem as each component of electric field getting its component of velocity and then you take the vector sum of that velocity.

Q. (BY MR. WHITEHURST) So when you have multiple electric fields or multiple forces, in order to determine the net motion, you look at the vector sum?

MR. PAUL: Objection to form.

1 THE WITNESS: If you want to
2 look at the net motion, you have to
3 look at the vector sum.
4 Q. (BY MR. WHITEHURST) And why do
5 you have to look at the vector sum in order
6 to get the net motion?
7 MR. PAUL: Objection to form.
8 THE WITNESS: At a certain
9 location in a semiconductor, you have
10 an electric field with a certain
11 magnitude and a certain direction.
12 That's what I'm calling the net
13 electric field, but that could be
14 composed by, you know, electric fields
15 created by different sources. Either
16 external voltages apply or, in this
17 case, for example, internal
18 self-generated electric fields with
19 doping gradients.
20 Q. (BY MR. WHITEHURST) I just
21 want to help our court reporter. When you
22 say vector sum, that's S-U-M, correct?

A. Yes.

THE REPORTER: I know.

Q. (BY MR. WHITEHURST) Now, you mentioned electric fields and sources. Just like we did before, you know, how we broke down the categories of forces, let's break down so that we can talk about each of those separately all of the different electric fields or sources that may affect this net sum. Can you help me out and then we'll go through and unpack each one?

What are some of the different electric fields or forces?

MR. PAUL: Objection to form.

THE WITNESS: So now I'm talking about what I call actually two forces, not the periodic crystalline forces, which you already accounted for via the effective mass.

Q. (BY MR. WHITEHURST) Let's make a list of all of the category 2 forces.

A. Okay. So first would be

1 built-in forces due to doping gradient, and
2 that's essentially what the patents are
3 about. These do not require any external
4 batteries to hook up to the semiconductor.
5 On top of that, you could also
6 hook up a battery --
7 Q. I apologize. Before we move
8 on, are there different types of built-in
9 forces? Can you think of different types of
10 built-in forces?
11 A. In this context the built-in
12 force that's relevant is that generated,
13 self-generated by doping concentration
14 gradients?
15 Q. Can you think of any other
16 built-in forces?
17 A. You could in certain
18 semiconductors, but not in silicon.
19 Q. Let's talk about some of the
20 other semiconductors. What are some of the
21 other built-in forces that you can think of?
22 MR. PAUL: Objection to form,

scope.

THE WITNESS: For these patents, I'm talking about silicon technology. You can't have what are called older semiconductors where the two atoms -- in the case of silicon, all of the atoms are of the same type. They are all silicon. But certain semiconductors can have two different types of atoms and there you can squeeze a crystal mechanically and that can give rise to what are called these electric fields. But that's not relevant in the case of silicon in this case.

Q. (BY MR. WHITEHURST) Let's put this into context a little bit better.

When you were working at TI, what types of semiconductors did you work with?

A. At TI, it was -- at TI, I worked on silicon.

1 Q. Did you work on any other
2 types?
3 A. On other semiconductors?
4 Q. Yes, sir.
5 A. Yes, I have, both in grad
6 school and at the University of Texas.
7 Q. What other semiconductors have
8 you worked with besides silicon?
9 A. Gallium aresenide is one.
10 THE REPORTER: Pardon?
11 THE WITNESS: Gallium,
12 G-A-L-L-I-U-M; second word, arsenide,
13 A-R-S-E-N-I-D-E.
14 Q. (BY MR. WHITEHURST) Any
15 others?
16 MR. PAUL: Objection to scope.
17 THE WITNESS: I work on other
18 semiconductors now at the university.
19 Q. (BY MR. WHITEHURST) What are
20 some of the other --
21 A. Such as molybdenum disulfide --
22 THE REPORTER: What was the

first word?

Q. (BY MR. WHITEHURST) Would you spell that for our court reporter?

A. Yeah, M-O-L-Y-B-D-E-N-U-M. I will be respectful of those kids who go on spelling bees. It's not easy.

Disulfide, D-I-S-U-L-F-I-D-E.

Q. Any others?

MR. PAUL: Objection to scope.

THE WITNESS: Tungsten deselenide. T-U-N-G-S-T-E-N; deselenide, D-I-S-E-L-E-N-I-D-E.

Q. (BY MR. WHITEHURST) Any others?

MR. PAUL: Same objection.

THE WITNESS: Germanium, I have worked on germanium. G-E-R-M-A-N-I-U-M.

Q. (BY MR. WHITEHURST) Any others?

MR. PAUL: For the record, objection to this entire line of

1 questioning as beyond the scope.
2 MR. WHITEHURST: You don't have
3 to object each time. Your objection
4 is noted.
5 Q. (BY MR. WHITEHURST) Any
6 others?
7 A. I have worked on -- I have
8 worked on forms of carbon --
9 THE REPORTER: Forms of --
10 THE WITNESS: Carbon,
11 C-A-R-B-O-N, which sometimes can act
12 as a semiconductor.
13 Q. (BY MR. WHITEHURST) Anything
14 else?
15 A. None that I can remember
16 offhand.
17 Q. When you were working with
18 silicon galcium arsenide --
19 A. Gallium arsenide.
20 Q. Thank you.
21 When you were working with
22 silicon galcium arsenide --

A. Let me spell that.
G-A-L-L-I-U-M, gallium; arsenide,
A-R-S-E-N-I-D-E.
Q. I'm not getting an A in your
class anymore. Let me try again.
When you were working with
silicon and gallium arsenide and molybdenum,
something, and Tungsten and forms of carbon,
did you ever encounter any built-in forces?
MR. PAUL: Objection to form
and scope.
THE WITNESS: Yes, I do -- or
yes, I did.
Q. (BY MR. WHITEHURST) What
built-in forces did you encounter?
A. So any time you make devices,
you have to dope them. And to make devices,
you typically dope them from the front
surface, which will lead to a nonuniform
doping, generally decreasing doping as a
function of depth, sort of like the patents
I'm talking about.

In fact, in the undergrad course that I teach where the students make transistors, they make that sort of doping profile, and they have been doing that since the 1980s. It's very well-known art.

So any time you have flash doping gradient, physics says they will lead to built-in electric fields.

THE REPORTER: It will -- wait.

THE WITNESS: It will lead to built-in, B-U-I-L-T, hyphen, I-N, electric fields.

Q. (BY MR. WHITEHURST) If I remember correctly, we talked about earlier that you measure the force of the field as volts divided by centimeter.

Did I get that correct?

A. Yes.

Q. When you're looking at these built-in fields, how would you calculate the force of these built-in fields?

MR. PAUL: Objection, scope.

1 THE WITNESS: So these built-
2 in fields cannot be measured
3 externally with a volt meter because
4 with a volt meter what you measure is
5 another complicated concept called the
6 electrochemical potential. A volt
7 meter only measures differences of
8 electrostatic potential.
9 Now, when you have doping
10 gradients, you introduce variations of
11 what are called electrochemical
12 potentials. So the only way we can
13 infer that is by solving the relevant
14 equations, and then you see if that
15 matches with externally measured data.
16 Q. (BY MR. WHITEHURST) Remember
17 how we were talking about the vector sum
18 earlier?
19 A. Yes.
20 Q. If we were going to add up all
21 of the vectors and include the built-in
22 fields, how would we do that?

MR. PAUL: Objection to form.

THE WITNESS: So as I describe in my report, suppose you have a doping -- let me pull my report up and see which direction I show the gradient. It doesn't matter. I mean, you can have the gradient in any direction.

Suppose I had a doping concentration profile that decreased with depth. I must first know whether I'm looking at donors or acceptors that will then tell you that we have a built-in electric field either pointing downwards or upwards.

And then you then apply external voltages, also in the vertical direction, to make things simple. You can then get the vector sum by either adding or subtracting the external electric fields with the built-in electric fields.

Q. (BY MR. WHITEHURST) But you remember how we were talking about if a vector points one direction and another vector points in the opposite direction, they cancel each other out and you have to find the difference, how would we know the units for the built-in forces that you mentioned?

MR. PAUL: Objection to form.

THE WITNESS: So the doping gradients give rise to an internal built-in electric field and when doing the summation, you have to use the same units.

Q. (BY MR. WHITEHURST) Why do you have -- why do you have to use the same units?

A. That's like asking add up five oranges to three apples, how many apples and oranges are you getting? You have to use the same units, right.

Q. So when you're doing the vector sum, you have to get everything to the same

1 units?
2 A. Yes.
3 Q. And you mentioned gradient.
4 Do you recall that?
5 A. Radium?
6 Q. I believe you said gradient; is
7 that right?
8 A. Gradient, yeah.
9 Q. What did you mean when you said
10 gradient?
11 A. Gradient means slope. So if
12 you have a doping concentration which is not
13 uniform, but is --
14 THE REPORTER: If you have a
15 doping concentration --
16 THE WITNESS: Which is not
17 uniform, but is decreasing as a
18 function of depth, the gradient would
19 be the rate at which the dopant
20 concentration decreases as a function
21 of depth.
22 Q. (BY MR. WHITEHURST) Why is the

1 gradient important?
2 A. The gradient is important
3 because that drives one of the two area of
4 movement mechanisms in the semiconductor. It
5 leads to what is called diffusion of carriers
6 due to this random Brownian motion that we
7 were talking about from a high concentration
8 region to the low concentration region.
9 So if you have -- suppose we
10 get acceptor ions, for example, which give
11 rise --
12 THE REPORTER: Suppose what?
13 THE WITNESS: Acceptor ions.
14 Did you get it?
15 THE REPORTER: Sector ions?
16 THE WITNESS: Acceptor,
17 A-C-C -- accept, O-R. Acceptor,
18 A-C-C-E-P-T-O-R.
19 THE REPORTER: Okay.
20 THE WITNESS: Did you get it?
21 THE REPORTER: Yes.
22 THE WITNESS: Okay. Suppose

I'm looking at acceptor ions where the concentration is decreasing as a function of depth. The acceptor ions themselves do not move. They are stuck in the lattice, but they accept electrons from the crystal, and thereby create these positive mobile holes in the valence band, which do move with random Brownian motion.

And that random Brownian motion would cause a statistical floor of the holes from the top where the higher acceptor doping, and therefore higher full concentration per unit volume to the lower depths where I have a lower acceptor doping, and therefore a lower hole concentration.

It's only the holes which can diffuse when acceptor ions get stuck in the lattice, and it's those acceptor ions which would generate the static electric field.

1 Q. (BY MR. WHITEHURST) Does the
2 gradient affect the vector sum?
3 A. The gradient will affect the
4 manageability of the built-in electric field.
5 If I apply other electric fields, you have to
6 do the vector sum of those other fields with
7 this built-in electric field.
8 Q. So the gradient affects the
9 magnitude of the vector, which affects the
10 vector sum?
11 A. Are you talking about multiple
12 sources of electric fields now?
13 Q. Yes, sir.
14 A. Yes, so the gradient will
15 determine the direction and the magnitude of
16 the built-in electric field vector, which is
17 static, does not change once I have
18 constructed the device.
19 On top of that, if you now
20 choose to apply other voltages, which would
21 generate their own external electric fields,
22 to get the net electric field, you have to do

1 the vector sum.
2 Q. So the gradient determines the
3 direction and magnitude of the vector for the
4 field, and in order to get the net movement,
5 you have to get the vector sum; is that
6 right?
7 MR. PAUL: Objection to form.
8 THE WITNESS: If in addition to
9 the static doping gradient, which will
10 generate the static built-in electric
11 field, you choose to apply other
12 voltages at different locations where
13 those externally applied electric
14 fields point in other directions. To
15 get the net electric field, you have
16 to take the vector sum and that would
17 give rise to the net velocity.
18 But, as we were discussing, the
19 built-in doping gradient, which is
20 generating the static electric field,
21 will cause what is called the drift
22 motion of the carriers. The direction

1 depends on, you know, the type of
2 dopants you're talking about. And
3 that is static. That's invariant.
4 But then to get the net motion
5 of those electrons or holes, you would
6 have to add the velocity vector to the
7 static invariant electric field with
8 the doping gradient to the electric
9 field that can vary from problem to
10 problem.
11 Q. (BY MR. WHITEHURST) You talk
12 about problem to problem. And I think, you
13 know, we started this process, but I don't
14 think we -- we never finished it.
15 Let's go back to the category 2
16 forces that you mentioned. I think it would
17 be helpful to get a list of the category 2
18 forces. We have been talking about built-in
19 electric fields. What are some of the other
20 forces in category 2?
21 A. The other forces that are very
22 relevant would be the electric fields that

are generated when you hook up a battery, for example, to your semiconductor device.

THE REPORTER: Where you hook up --

THE WITNESS: Hook up a battery, a battery to your semiconductor device.

Q. (BY MR. WHITEHURST) Okay. What else would be in category 2?

MR. PAUL: Objection to form.

THE WITNESS: Those are the two categories that are relevant in this context.

Q. (BY MR. WHITEHURST) Earlier, you mentioned externally applied forces.

Do you remember that?

A. Yes.

Q. What did you --

A. But that's not relevant -- that's not relevant for silicon, as I mentioned.

Q. Okay. What did you mean by

1 externally applied forces?
2 MR. PAUL: Objection to scope.
3 THE WITNESS: Okay. Here, the
4 force that I'm talking about is
5 mechanical force versus electrical
6 forces. Okay?
7 So you would take a piece of a
8 solid, such as a semiconductor, and
9 you could mechanically squeeze it.
10 That's a mechanical force. That, in
11 turn, can generate electric fields
12 inside that solid if it's a so-called
13 PEO electric solid. But that's not
14 relevant in the case of silicon.
15 Q. (BY MR. WHITEHURST) Okay.
16 Now, you told me that when you were at TI,
17 you were designing semiconductors.
18 Do you recall that?
19 A. I worked with semiconductors.
20 Q. And you mentioned silicon --
21 and I'm going to get it right this time --
22 gallium arsenide and you mentioned moly --

1 A. Those I did not work on when I
2 was at TI. I worked on those either in
3 graduate school or at the University of
4 Texas.
5 Q. Okay. And what was the other
6 semiconductor that you mentioned, moly
7 something?
8 A. Disulfide.
9 Q. And you also mentioned
10 Tungsten?
11 A. Deselenide.
12 Q. And then you also mentioned
13 forms of carbon.
14 Do you recall that?
15 A. Yes, and germanium.
16 Q. Any -- any others?
17 A. There are probably others I
18 can't remember offhand.
19 Q. When you were working on these
20 semiconductors, what were the category 2
21 forces that you encountered?
22 A. So in any of these, if you hook

1 up a battery to any of them, that will
2 generate a category 2 force. And in these
3 semiconductor devices, if I had any type of
4 doping variation, that will also generate a
5 category 2 force, except that this is a
6 static built-in force where once I've made
7 the device, I cannot change that, whereas the
8 external batteries, I can have different
9 battery voltages or I can apply the battery
10 at different terminals of the device.
11 Q. Can you think of any other
12 category 2 forces?
13 A. Yes. I could apply temperature
14 gradients where the temperature is not the
15 same throughout and that can give you what
16 are called thermoelectric effects.
17 Q. Anything else?
18 MR. PAUL: Objection, form.
19 THE WITNESS: I could apply
20 magnetic fields. That's part of this
21 Lorentz force. So if you have a
22 magnetic field in the semiconductor

and the carriers are moving the force with this perpendicular pull in the direction of the motion and the magnetic field.

Q. (BY MR. WHITEHURST) What do you mean when you say "a magnetic field"?

A. I mean, a magnet, for example, generates a magnetic field, or if you have a current loop and you flow a current through that, that generates a magnetic field along the axis of that current loop.

Q. You mentioned temperature and magnetic field. Can you think of any other category 2 fields?

MR. PAUL: Objection to form.

THE WITNESS: Offhand, I can't. Maybe there are others.

Q. (BY MR. WHITEHURST) Do you mention category 2 forces in your textbook?

A. Yes. So anytime you apply voltages, that's a category 2 force. Anytime you have broken gradations, that's a built-in

1 category 2 force. Yes, we discuss those in
2 the textbook.
3 Q. Do you describe any other
4 category 2 forces in your textbook?
5 A. Yes, the Lorentz force; B cross
6 B, that's known as the Hall effect.
7 THE REPORTER: It's known as
8 what?
9 THE WITNESS: The Hall effect,
10 sorry. H-A-L-L, capital H.
11 Q. (BY MR. WHITEHURST) What is
12 the Hall effect?
13 A. The Hall effect happens when
14 you apply a magnetic field, say in the
15 vertical direction, and you apply and you
16 have the velocity of the particles in the
17 horizontal direction. That will create a
18 force in the mutually perpendicular
19 direction, so in the depth direction away
20 from me. And that's known as the Hall
21 effect.
22 Q. Do you mention temperature in

1 your textbook?
2 A. Yes.
3 Q. Where do you mention
4 temperature in your textbook?
5 A. Everywhere in the textbook.
6 Q. And temperature affects the
7 movement of electrons in a semiconductor?
8 A. Temperature affects --
9 MR. PAUL: Objection to form.
10 THE WITNESS: Temperature
11 affects the random scattering of
12 electrons or holes because high
13 temperatures cause more violent
14 vibrations of these atoms, and that's
15 a greater deviation from the periodic
16 arrangement of atoms. And anything
17 that is a deviation from the RSD
18 causes collisions or scattering. And
19 that would increase the mobility,
20 increases resistivity.
21 MR. PAUL: Alan, I think we
22 have been going on about 45 minutes or

so. Are you nearing a break soon?

MR. WHITEHURST: Yeah, I can take a break now.

MR. PAUL: We can break for lunch?

MR. WHITEHURST: Sure. Let's go off the record and we can talk logistics.

THE VIDEOGRAPHER: Going off the record, the time is 12:20.

(Lunch recess from 12:20 p.m. to 1:17 p.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 1:17.

Q. (BY MR. WHITEHURST) Welcome back, Dr. Banerjee. I hope you had a good lunch break.

A. Yes, thank you.

Q. I want to go over some of the things that we were discussing this morning. Hopefully you remember talking about the three categories of forces?

A. Yes.

Q. And we discussed how the category 1 forces affect the effective mass of the electron.

Do you recall that?

A. Yes.

Q. Does the effective mass depend on the specific semiconductor?

A. Yes.

Q. Why is that?

A. Why is that?

Q. Yes, sir.

A. That's because each semiconductor has a different crystal lattice spacing and the atoms are different, so therefore the coulombic core potential is going to be different in silicon versus germanium and the spacing is also going to be different.

Once you put that periodic potential into the Schrodinger equation and you solve it, you get slightly different

1 results for different semiconductors leading
2 to different masses.
3 Q. Would the effective mass affect
4 the magnitude of the internal force?
5 A. No.
6 Q. Why not?
7 A. Because a force is given by the
8 charge of the particle and its electric
9 field, and neither of those depend on mass.
10 Q. What are internal periodic
11 crystal forces?
12 A. Sorry?
13 Q. What are internal periodic
14 crystal forces?
15 A. The atoms in the crystal, such
16 as silicon, have a periodic arrangement in
17 space. The atoms themselves are made up of
18 positively charged nuclei --
19 THE REPORTER: Of what?
20 Charged --
21 THE WITNESS: Of positively
22 charged nuclei because the protons in

1 the nucleus are positively charged and
2 they are surrounded by electrons in
3 different orbits, known as Bohr
4 orbits, B-O-H-R.
5 The lower energy orbits are
6 closely tied to the nucleus because
7 unlike charges affect each other. But
8 the higher up you go in energy, by the
9 time you go to the valence shell,
10 those are less weakly bound for two
11 reasons. They are farther away from
12 the nucleus and the core electrons,
13 which are negatively charged, shield
14 some of the positive charge. That's a
15 process called screening.
16 And as a result, the periodic
17 potential that the autonomous
18 electrons see has a smaller depth than
19 the periodic potential that the inner
20 core electrons see.
21 So the inner core electrons are
22 indeed bound to the nucleus with

1 springlike forces, as Dr. Glew said,
2 but it is not true for the outer
3 electrons. They are almost free like
4 electrons, except that the mass
5 becomes the effective mass.
6 Q. (BY MR. WHITEHURST) This
7 morning I believe you referred to the
8 category 1 forces as periodic crystalline
9 potential.
10 Do you recall that?
11 A. Yes.
12 Q. Is that the same thing as
13 internal periodic crystal forces?
14 A. We talked about two types of
15 internal forces. The internal periodic
16 forces are the same as the internal periodic
17 potential because that gradient of the
18 potential is what gives rise to our force.
19 But on top of that, we also
20 talked about category 2 internal forces,
21 which is really germane to these patents, and
22 that is given by -- that is generated,

1 self-generated, by doping concentration
2 variation.
3 Q. So when you talk about internal
4 periodic crystal forces, do you account for
5 those with the effective mass?
6 A. That is correct.
7 Q. Does the effective mass fully
8 account for the internal periodic crystal
9 forces?
10 A. Pretty good approximation.
11 Q. Okay.
12 A. Solving the full quantum
13 mechanical equation with all of the electrons
14 in the solid is actually an unsolved problem.
15 It's not solvable because you're now talking
16 about roughly an Avogadro number of
17 electrons.
18 THE REPORTER: Talking about --
19 THE WITNESS: A-V-O-G-A-D-R-O,
20 number of electrons, approximately,
21 and nobody knows how to solve that
22 many-bodied problem exactly. If one

1 did, one would win a Nobel prize.
2 So you make approximations and
3 this is a pretty darn good
4 approximation that's worked.
5 Q. (BY MR. WHITEHURST) And I
6 believe you testified this morning that once
7 you account for the internal periodic crystal
8 forces with the effective mass, then you can
9 look to the category 2 and category 3 forces.
10 Did I get that right?
11 A. That's correct.
12 Q. And before we broke for lunch,
13 we were talking about the category 2 forces.
14 Do you recall that?
15 A. Yes.
16 Q. Now, you talk about in your
17 declaration -- well, strike that.
18 What is Brownian?
19 A. Brownian.
20 Q. Have you used the term
21 "Brownian" in your report?
22 A. Yes. That's a random motion in

all directions with different speeds that the electrons and the holes have at room temperature. The higher the temperature, the greater the speed of those electrons and holes.

Q. Now, what do you mean when you say "random"?

A. Random from the sense that velocity by itself is a vector having both a magnitude and a direction. The magnitude itself of velocity is known as speed, but then when you also consider the direction of motion, that becomes a vector known as the velocity.

So these electrons will bounce around in all kinds of directions and this whole ensemble of electrons will have different speeds, different directions, such that if you did not apply an external voltage, there would be no net motion from one side to the other and no net current.

THE REPORTER: And no net --

1 THE WITNESS: Current.
2 THE REPORTER: Okay.
3 Q. (BY MR. WHITEHURST) When you
4 talk about Brownian motion, can you determine
5 whether an electron moves in a particular
6 direction?
7 A. It's a statistical mechanics
8 problem. If you don't even try to monitor
9 the motion of individual electrons, okay, you
10 look at this whole ensemble and that's when
11 you can measure and can see the effects of
12 that.
13 Q. And if you were going to look
14 at the ensemble of electrons, how would you
15 determine whether there is motion in a
16 particular direction?
17 MR. PAUL: Objection to form.
18 THE WITNESS: If there's an
19 ensemble of electrons and there are no
20 external forces, there would be no net
21 motion. You would have as many going
22 to the right as to the left.

1 Q. (BY MR. WHITEHURST) And this
2 morning, we discussed that in order to
3 determine the net motion, you look to the
4 vector sum.
5 Do you recall that?
6 A. Yes.
7 Q. And would the category 2 and
8 category 3 forces be part of the vector sum?
9 A. As I told you, the way you
10 break down this complicated problem is you
11 put the forces into three categories and you
12 treat them differently. We've already talked
13 about category 1, the effective mass.
14 You talked then about category
15 2, which are these external forces or
16 built-in forces and you apply a modified
17 version of Newton's law to that.
18 And as they are moving, every
19 now and then they will undergo collisions or
20 scattering. That's your category 3. And
21 that part of the effect is captured through
22 what is the called the mobility, which, in

1 turn, determines the resistivity of the
2 force.
3 Q. Why is the -- strike that.
4 Why is the resistivity relevant
5 to the net motion?
6 A. Resistivity --
7 MR. PAUL: Objection to form.
8 THE WITNESS: Resistivity is
9 relevant in the sense that you apply a
10 certain voltage on a piece of
11 semiconductor, and assume that the
12 semiconductor was uniformly doped, it
13 would behave like a resistor where you
14 can apply Ohm's law --
15 THE REPORTER: You can apply --
16 THE WITNESS: Ohm's, O-H-M,
17 apostrophe S. And all of this is
18 described in my declaration.
19 Ohm's law is the current, this
20 is the net current, but with applied
21 external voltage divided by the
22 resistance, which, in turn, depends on

1 the resistivity and the geometric
2 laying cross-section of the device.
3 The resistivity, in turn,
4 depends on the mobility. The higher
5 the mobility, the lower the
6 resistivity. And you have higher
7 mobility if you have less collisions
8 of scattering in the material. But
9 that part of the force is a random
10 force. It's more like a dynamic
11 frictional force. It's not something
12 that pulls the particles back like a
13 spring.
14 Q. (BY MR. WHITEHURST) So you
15 remember how we were talking about you have
16 to look at the net field in order to
17 determine the net movement and you mentioned
18 something about apples and oranges, that we
19 have to have the same units for each of the
20 fields before we can calculate the net field.
21 Do you recall that?
22 A. Yes.

1 MR. PAUL: Objection to form.
2 Q. (BY MR. WHITEHURST) Do the
3 category 3 forces have a unit?
4 A. Yes, these forces will also
5 have the same unit, but it -- they are not
6 treated the same way as category 2 forces
7 because they are random.
8 THE REPORTER: They are not --
9 THE WITNESS: They are not
10 treated the same way as category 2
11 forces because they are random. You
12 treat them using a different formula
13 in quantum mechanics called scattering
14 theory.
15 But if you look at snapshots of
16 these random forces in time or space,
17 yes, those forces would also have the
18 same units as category 2 forces, but
19 you don't handle them with the same
20 techniques as category 2 because
21 that's not practical or convenient.
22 Q. (BY MR. WHITEHURST) Now I'm

1 confused, and hopefully you can help me sort
2 things out.
3 When we were talking about the
4 category 2 forces that go into the vector
5 sum, we talked about volts per centimeter.
6 Do you recall that?
7 A. Yes.
8 Q. When you're looking at the
9 category 3 forces, can you use the same
10 units, the volts per centimeter?
11 A. You can.
12 Q. How do you use volts per
13 centimeter for the category 3 forces?
14 A. You don't do a vector sum of
15 those forces to the category 2 forces because
16 that's not an efficient way of handling the
17 problem, okay, because you have random
18 category 3 forces, again, measured in units
19 of volts per centimeter, random volt in time
20 because of the lattice vibrations being a
21 time-dependent phenomena, as well as random
22 position because the dopants can have random

1 locations or you can have structural defects
2 that are random that you can't determine
3 externally.
4 So it is not possible -- I
5 mean, in theory, it might be possible. But
6 from a practical point of view, the smart way
7 of doing them, handling them, is to disaffirm
8 the mobility. Just as effective mass was a
9 nice compact way of factoring the category 1
10 force, category 3 forces are nicely and
11 compactly captured by the strong mobility.
12 Specifically, if you look the
13 mobility expression that I have in my report,
14 you see that mobility is given by the charge
15 of the electron of the hole times what is
16 called a scattering time, a collision of
17 time, which is the average time between these
18 random collisions.
19 So that is what you use as a
20 shorthand way to capture category 3 forces
21 divided by the effective mass, which is a
22 shortened way of capturing category 1 forces.

1 Q. I don't understand -- this is
2 true about a lot of things in life. There is
3 a smart way to do things and then a maybe not
4 so smart way, as you put it.
5 When we talk about the category
6 2 forces, we talked about how you need to sum
7 up the forces to get the vector sum in order
8 to determine the net movement. And you
9 mentioned that each vector has a direction
10 and a magnitude.
11 Do you recall that?
12 A. Yes.
13 MR. PAUL: Objection to form.
14 Q. (BY MR. WHITEHURST) When you
15 look at the category 3 forces, if you wanted
16 to use the vector sum approach, could do you
17 that with the category 3 forces?
18 A. Not in a practical sense
19 because category 3 forces, as I mentioned,
20 are random.
21 Q. So you testified that the
22 category 2 forces have a direction and a

1 magnitude. When we look at the category 3
2 forces, do they have a magnitude?
3 A. Yes.
4 Q. Do they have a direction?
5 A. Yes.
6 Q. What is the direction of a
7 category 3 force?
8 A. For different types of
9 category 3 forces, again, going in all kinds
10 of random directions and can vary with time.
11 So with the phonons or the lattice
12 vibrations, it varies not only with time, but
13 can vary with direction depending on how the
14 atoms are vibrating.
15 Then you have ionized
16 impurities --
17 THE REPORTER: You have what?
18 THE WITNESS: Ionized
19 impurities.
20 THE REPORTER: Okay.
21 THE WITNESS: They generally
22 give rise to a relatively symmetric

1 scattering potential, but the space
2 and location of those sites is random.
3 You cannot measure those or predict
4 those. That's why you use the
5 principles of statistical mechanics to
6 handle such problems.
7 Q. (BY MR. WHITEHURST) When
8 you're talking about category 3 forces, are
9 they relevant to the net movement?
10 MR. PAUL: Objection to form.
11 THE WITNESS: They are relevant
12 only as far as impacting the
13 scattering time between collisions,
14 and therefore the mobility, and
15 therefore the resistivity.
16 So with a certain category 3
17 force, the whole ensemble of electrons
18 will move with an average drift
19 velocity, but the magnitude of the
20 drift velocity will depend on the
21 category 3 forces through the mobility
22 of the resistivity level.

1 Q. (BY MR. WHITEHURST) So the
2 category 3 forces do affect the net -- strike
3 that.
4 So the category 3 forces affect
5 the net movement?
6 MR. PAUL: Objection to form.
7 THE WITNESS: For certain --
8 certain magnitude and direction of
9 category 2 forces, the category 3
10 forces could impact the magnitude of
11 the velocity, but it would not impact
12 the onset of that motion.
13 Category 3 forces, as I told
14 you, are not a springlike force that
15 has to overcome before the electrons
16 start moving, contrary to what
17 Dr. Glew says in his report. It's
18 totally wrong.
19 Q. (BY MR. WHITEHURST) When will
20 the category 3 forces affect the net
21 movement?
22 MR. PAUL: Objection to form.

1 THE WITNESS: Category 3 forces
2 will impact the net movement only in
3 as far as the magnitude of the drift
4 velocity is in response to category 2
5 forces, but they do not create a
6 special force that electrons have to
7 overcome before they start moving.
8 These are two different statements, as
9 I described in my report.
10 Q. (BY MR. WHITEHURST) Do
11 category 3 forces increase or decrease the
12 magnitude of the vector sum from the category
13 2 forces?
14 MR. PAUL: Objection to form.
15 THE WITNESS: Category 3 forces
16 vary higher and higher. That would
17 reduce the mobility, and thereby
18 increase the resistivity, and
19 therefore decrease the net velocity
20 vector through the category 2 forces.
21 It will not impact the
22 magnitude of the category 2 forces.

It would impact the velocity in response to category 2 forces, the magnitude of that, but not the onset of the motion.

Q. (BY MR. WHITEHURST) Is it fair to say -- let me ask this a different way.

You know, we talked about in order to determine the net motion, you have to look at the net electric field.

Do you follow me so far?

A. Yes.

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) One thing we haven't discussed yet is distance. How do you determine how far the net electric field will or will not move something?

A. That is determined by category 3 forces in terms of what is called the mean three act, which is the average distance between collisions. Once again, this estimate is elaborate.

Q. Is it fair to say that the

1 category 3 forces will reduce the distance
2 that a given net field will move a particular
3 carrier?
4 MR. PAUL: Objection to form.
5 THE WITNESS: Net distance in a
6 set interval of time.
7 Q. (BY MR. WHITEHURST) So a
8 category 3 force will reduce the distance
9 that a given net field moves a carrier in a
10 set interval of time?
11 MR. PAUL: Objection to form.
12 THE WITNESS: So if you have
13 the category 2 forces, you do the
14 vector sum, you can have velocity in
15 response to each component of that
16 vector sum. You get a net velocity
17 vector, which will correspond to the
18 vector sum of the electric fields.
19 But the rate at which they move will
20 decrease with increasing scattering in
21 category 3.
22 So we can view category 3

1 forces, once again, as inanimate
2 frictional force or a viscous force.
3 We can slow down this average motion
4 of this whole ensemble of electrons.
5 But remember, in addition to
6 that, these electrons are also
7 undergoing rapid Brownian motion in
8 all directions with the average of
9 that by itself is zero motion. But,
10 again, superimpose a nonzero component
11 in response to category 2 forces, but
12 the magnitude of that could decrease
13 with increasing category 3 forces.
14 Q. (BY MR. WHITEHURST) But you do
15 agree that category 3 forces affect the
16 distance of the net movement?
17 MR. PAUL: Objection to form.
18 THE WITNESS: Category 3 forces
19 impact the mobility, and therefore it
20 impacts the distance they travel
21 between collisions, the mean three
22 act. So they are scattered, but then

1 speed up again because of
2 category 3 -- category 2 forces,
3 scatter, maybe change directions for a
4 little bit and then travel in the
5 direction of the net force of
6 category 3 forces. That's how you
7 proceed.
8 Q. (BY MR. WHITEHURST) So we look
9 at the category 1 forces in order to get the
10 effective mass of the electron?
11 A. That's correct.
12 Q. Then you look at the category 2
13 forces in order to calculate the net field?
14 A. That's correct.
15 Q. And then you look at the
16 category 3 forces in order to determine the
17 mobility?
18 A. That's correct.
19 Q. And the mobility affects the
20 distance?
21 A. The mobility impacts the
22 velocity. The velocity is given -- the drift

1 velocity, which is this average velocity of
2 this whole ensemble of electrons or holes is
3 given by mobility times the electric field.
4 And once you have the velocity,
5 that will tell you how much on average this
6 whole ensemble will move in a certain unit of
7 time, and that's what you register as an
8 external current using an ammeter, for
9 example.
10 Q. And do you agree that the
11 velocity affects the distance?
12 MR. PAUL: Objection to form.
13 THE WITNESS: In a certain unit
14 of time, the velocity will impact how
15 far it travels.
16 Q. (BY MR. WHITEHURST) So let me
17 see if I got this right. The category 3
18 forces will affect the mobility, correct?
19 A. That's correct.
20 Q. The mobility will affect the
21 velocity, correct?
22 A. In response to category 2

1 forces.
2 Q. And the velocity will affect
3 the distance in a particular interval of
4 time; is that right?
5 A. Yes, for the whole ensemble.
6 Q. So when we look at electrons in
7 a semiconductor, we look at the category 1
8 forces in order to get the effective mass of
9 the electrons?
10 A. Yes, but you only solve that
11 problem once. Someone has done that for us.
12 You can look at handbooks for these effective
13 masses, in our textbook or the Sze
14 textbook --
15 THE REPORTER: In our case,
16 look at the --
17 THE WITNESS: Sorry, effective
18 mass in our textbook or the textbook
19 by Sze, S-Z-E.
20 So an engineer would not even
21 bother with category 1 forces. It's a
22 fixed number for silicon. They worry

about category 2 primarily. And then category 3, once I have made a device with a certain number of dopants, if I'm at room temperature, category 3 also would give a certain mobility. That's not going to change.

It's really category 3 forces from the part of that also. The externally applied category 3 forces are the only ones that you have a handle on. The internal -- sorry, I misspoke -- category 2 forces that you have a handle on. The internal category 2 forces, which is the heart of these patents, you don't have a handle on it.

Once you have made the device with a certain doping gradient, at room temperature those dopant profiles are not going to change. They have the built-in electric field because the doping gradient will not change

that status.

THE REPORTER: Built-in --

THE WITNESS: Electric field.

Q. (BY MR. WHITEHURST) Let me see if I've got this. In order to determine the movement of electrons in a semiconductor, we first want to look and see what type of semiconductor it is; is that --

MR. PAUL: Objection to form.

THE WITNESS: That's correct.

Q. (BY MR. WHITEHURST) Because the type of semiconductor affects the effective mass of the electrons?

A. Yes.

Q. And the effective mass of the electrons, which depends on the type of semiconductor, will reflect the category 1 forces?

A. Yes.

Q. Next, we look at the category 2 forces in order to get the net electric field?

1 A. That's correct. And then the
2 components of the category 2 forces, as we
3 have discussed.
4 Q. And the net electric field will
5 have a direction and a magnitude?
6 A. That's correct.
7 Q. And the direction in magnitude
8 of the net electric field will depend on the
9 vector sum?
10 A. That's correct.
11 Q. Once we have the net electric
12 field, we look at the category 3 forces?
13 A. Yes.
14 Q. And the category 3 forces
15 affect the mobility?
16 A. That's correct.
17 Q. The mobility affects the
18 velocity?
19 A. That's correct, in response to
20 the category 2 forces.
21 Q. And the velocity, in response
22 to the net electric field, will affect the

1 distance in a time interim?
2 A. That's correct.
3 Q. I hope I got at least an
4 A minus.
5 A. Yes, you get an A plus.
6 Q. I certainly appreciate your
7 patience with me.
8 I want to go back to the
9 category 2 forces. We talked about -- we
10 talked about voltages, we talked about
11 built-in electric fields, we talked about
12 temperature, we talked about magnetic fields,
13 the Hall effect and --
14 A. That's -- that's caused by the
15 magnetic field. It's not a separate event.
16 Q. Got it. So the magnetic field
17 can create a Hall effect; is that correct?
18 A. Yes, yes.
19 Q. And what is the relationship
20 between the Hall effect and Lorentz?
21 A. Lorentz force?
22 Q. Correct.

1 A. It's caused by part of the
2 Lorentz force. The Lorentz force is given by
3 the charge per particle times electric field,
4 and that part is the relevant part.
5 And then there is a second part
6 of the Lorentz force, which is given by the
7 product of the velocity vector and some
8 magnetic field vector, but it is a so-called
9 cross product, if you can remember, where the
10 cross product is in a mutually perpendicular
11 direction to both the velocity vector and the
12 magnetic field vector.
13 Q. Why don't we go through each of
14 those. Can you think of any other category 2
15 forces?
16 A. In this context, it's really
17 the category 2 forces due to built-in
18 electric fields are externally applied
19 electric fields that are relevant.
20 Q. Now, you discuss in your book
21 temperature, correct?
22 A. So just to make sure we're

1 talking about the same temperature effects,
2 one is if you heat up the whole semiconductor
3 at a certain uniform temperature, that will
4 cause increased scattering, and therefore
5 reduced mobility.
6 The other temperature effect
7 that we talked briefly is if you have two
8 different temperatures at two ends of a
9 semiconductor, that can develop a voltage due
10 to what are called thermoelectric effects.
11 Once again, that's not really relevant.
12 Q. Let's talk about the
13 thermoelectric effects. In thermoelectric --
14 MR. PAUL: Objection to form.
15 Q. (BY MR. WHITEHURST) Can
16 thermoelectric effects affect the voltage --
17 strike that.
18 Can thermoelectric effects
19 affect the vector sum?
20 A. Did I discuss thermoelectric
21 effects in my report?
22 Q. I'm sorry, did you understand

1 my question?
2 A. I did, but I'm asking you, did
3 I discuss thermoelectric effects in my report
4 anywhere?
5 Q. Are you unable to answer my
6 question?
7 A. I can, but my understanding was
8 this was going to relate to my report.
9 Q. Dr. Banerjee, did your lawyers
10 tell you at any time today to not answer a
11 question if it's not about your declaration?
12 A. No, they did not.
13 MR. PAUL: I'll just caution
14 the witness not to reveal the
15 substance of his conversations --
16 Q. (BY MR. WHITEHURST) Do you
17 realize that you're under oath -- do you
18 realize that you're under oath today?
19 A. Yes, but they did not.
20 Q. Okay. Are you able to answer
21 my question, yes or no?
22 A. Yes, I can.

Q. Did you understand my question?
A. Yes.
Q. Was there anything unclear about my question?
A. Just repeat your question. You said if you have --
Q. I'm going to repeat my question and if there is anything unclear about my question, let me know.
Dr. Banerjee, can thermoelectric effects affect the vector sum?
MR. PAUL: Objection to form. Relevance.
THE WITNESS: If you have temperature gradients in a semiconductor, that can generate long-range voltages, and therefore long-range electric fields, and that will add to the vector sum of all the electric fields in category 2.
Q. (BY MR. WHITEHURST) Please explain how long-range electric fields can

1 affect the vector sum.
2 MR. PAUL: Objection to scope.
3 THE WITNESS: Electric fields
4 are vectors, as we discussed, having
5 both a magnitude and a direction. So
6 if you have two different vectors in
7 two different directions, you have to
8 consider both the magnitudes of those
9 components, as well as the relative
10 angle between those components to get
11 the resulting electric field vector.
12 That is what a vector sum means.
13 Now, earlier we talked about
14 category 3 forces, which also create
15 electric fields. Those are random and
16 short range. And although,
17 principally, you could also do a
18 vector sum with those, it doesn't make
19 sense from a competition point of view
20 or it's not even possible to do that
21 in a practical point of view. That's
22 why you handle those using this

1 concept of mobility.
2 Q. (BY MR. WHITEHURST) And I
3 believe you testified earlier today that if
4 the vector sum changes, that affects the net
5 movement; is that correct?
6 MR. PAUL: Objection, form.
7 THE WITNESS: The vector sum of
8 electric fields would impact the net
9 vector sum of the different velocity
10 components.
11 Q. (BY MR. WHITEHURST) So it's
12 your testimony that long -- well, strike
13 that.
14 So let me make sure I
15 understand your testimony. Thermoelectric
16 effects can create long-range electric
17 fields, correct?
18 MR. PAUL: Objection, scope.
19 THE WITNESS: Yes, it can.
20 Q. (BY MR. WHITEHURST) Can
21 these --
22 A. It's not relevant.

Q. -- long-range electric -- Dr. Banerjee, let me ask my question, please.

Thermoelectric effects can create long-range electric fields, correct?

MR. PAUL: Objection to scope.

THE WITNESS: Yes, they can.

Q. (BY MR. WHITEHURST) And these long-range electric fields may affect the vector sum, correct?

A. Yes.

Q. And we look at the vector sum in order to determine the net movement, correct?

MR. PAUL: Objection to form. Scope.

THE WITNESS: Yeah, the net movement of this whole ensemble of electrons will respond to the vector sum of all of these electric fields.

Q. (BY MR. WHITEHURST) Now, we also talked about the magnetic fields. How are the magnetic fields created?

A. You create them by having a permanent magnet, for example, a bar magnet, that has magnetic field lines from the north pole to the south pole, or you could pass a coil through a loop or a solenoid, and that --

THE REPORTER: Pass a -- pass --

THE WITNESS: A coil, C-O-I-L, or a solenoid, S-O-L-E-N-O-I-D. And that can create a magnetic field along the axis of the solenoid.

Q. (BY MR. WHITEHURST) Anything else?

A. I think those are the two main categories.

Q. Can you think of any other categories?

A. Not offhand, no.

Q. Do you recall any other categories in your textbook?

MR. PAUL: Objection, asked and

1 answered.
2 MR. WHITEHURST: Again, you're
3 coaching the witness. Please don't
4 make me have to contact the board,
5 sir.
6 THE WITNESS: So bar magnets
7 are an example of what's called a
8 ferromagnet, and I think we discussed
9 that in one of the later chapters.
10 It's in the same category as a bar
11 magnet.
12 Q. (BY MR. WHITEHURST) Do you
13 recall mentioning any other sources of
14 magnetic fields in your textbook?
15 MR. PAUL: Objection to form.
16 THE WITNESS: I can't think of
17 any offhand.
18 Q. (BY MR. WHITEHURST) But you
19 also mentioned a solenoid?
20 A. Yes.
21 Q. And you also mentioned current?
22 A. Well, you flow a current

through a solenoid or a coil, so that would make it an electromagnet.

But a bar magnet is also called a permanent magnet, made up of ferro magnets, and those do loops of current inside the solid.

Q. Is there another name for a bar magnet?

A. We call them ferro magnets.

Q. Any other names besides bar or ferro magnets?

A. I can't remember offhand.

Q. And then you mentioned electromagnets, correct?

A. Yes.

Q. What are some examples of electromagnets?

A. A solenoid is an example of electromagnet. It's a magnetic field that's created by flowing a current through a loop.

Q. Any other examples?

A. I can't think of any offhand.

1 Q. When you have a magnetic field,
2 does it affect the motion of electrons in a
3 semiconductor?
4 MR. PAUL: Objection, scope.
5 Relevance.
6 THE WITNESS: Yes, it does.
7 Q. (BY MR. WHITEHURST) Why does
8 it affect the motion of electrons in a
9 semiconductor?
10 MR. PAUL: Same objections.
11 THE WITNESS: We talked about
12 the Lorentz force, which is given by
13 the charge of that particle, times
14 electric field. That's velocity of
15 the particle cross product with the
16 magnetic field, that component gives
17 rise to force of the magnetic field.
18 Q. (BY MR. WHITEHURST) Does the
19 Lorentz force have a direction and a
20 magnitude?
21 A. Yes.
22 Q. And can the Lorentz force

1 affect the vector sum?
2 MR. PAUL: Objection to form.
3 Scope.
4 THE WITNESS: I'm not sure
5 exactly what you mean by affecting the
6 vector sum. You do the vector sum of
7 the electric field vector and the
8 velocity cross B vector. In that
9 sense, yes.
10 Q. (BY MR. WHITEHURST) And you
11 know how we discussed thermoelectric effects
12 in long-range electric fields. Do you recall
13 that?
14 A. Yes, yes.
15 Q. When you're trying to determine
16 net motion, you want to look at the vector
17 sum of all of the different fields, correct?
18 A. Yes.
19 Q. Because the vector sum
20 determines the net movement, correct?
21 MR. PAUL: Objection, form.
22 THE WITNESS: Yes.

Q. (BY MR. WHITEHURST) The Lorentz force, you said, has a force and a magnitude -- strike that.

I believe you said the Lorentz force has a direction and a magnitude. Did I get it correct that time?

A. Yes.

Q. What are the units for the Lorentz force?

A. The force has units of Newtons or meters, if I remember right.

Q. Now, when we talked about the vector sum, we talked about, you know, you don't want to add apples and oranges; you want to add apples and apples and oranges and oranges.

Do you recall that?

A. Yes.

Q. Is it possible to measure the Lorentz force in volts per centimeter?

A. You can measure the electric field to the forces given by the charge times

1 the electric field and there will be an
2 electric field generated by the velocity
3 cross product with B. And, yes, that can be
4 measured and that is the Hall effect that we
5 talked about.
6 Q. So when we look at a particular
7 magnetic field, we want to look at the Hall
8 effect; is that correct?
9 A. I'm not sure I understand
10 exactly what you mean.
11 Q. If we're trying to determine
12 the net movement of an electron and a
13 semiconductor and we want to determine
14 whether a magnetic field affects the movement
15 of an electron in a semiconductor, we would
16 look at the electric field due to the Hall
17 effect; is that right?
18 MR. PAUL: Objection to form.
19 Scope.
20 THE WITNESS: That's correct.
21 So if you have a bar, you could flow a
22 current in the horizontal direction,

1 you can apply a magnetic field
2 perpendicular to the bar and then you
3 measure the Hall voltage in the
4 mutually perpendicular direction and
5 you can measure that voltage with or
6 without a magnetic field, and that
7 will tell you the effect of the
8 magnetic field.
9 Q. (BY MR. WHITEHURST) So if we
10 have a magnetic field, we can look to the
11 Hall effect to determine what the electric
12 field is due to that magnetic field?
13 A. Yes, you could.
14 Q. And the electric field, due to
15 the magnetic field, will have a direction and
16 a magnitude?
17 A. Yes.
18 Q. And the electric field, due to
19 the magnetic field, can be measured in volts
20 per centimeter?
21 A. Yes.
22 Q. And if we are trying to

1 determine the net movement of an electron in
2 a semiconductor, the electric field, due to
3 the magnetic field, can change the net
4 electric field.
5 Did I get that right?
6 MR. PAUL: Objection to form.
7 Scope.
8 THE WITNESS: Yes, it could,
9 depending on the circumstances.
10 Q. (BY MR. WHITEHURST) So, you
11 know, any time we're trying to determine net
12 movement, we calculate the net field, and a
13 magnetic field can create an electric field
14 that changes the net electric field, correct?
15 MR. PAUL: Objection to form.
16 Scope.
17 THE WITNESS: A magnetic field,
18 in concert with drift velocity, can
19 create a Hall effect. A magnetic
20 field is not enough.
21 Q. (BY MR. WHITEHURST) So a
22 magnetic field can change the net electric

1 field, which changes the net movement?
2 MR. PAUL: Objection to form.
3 Scope.
4 THE WITNESS: A magnetic field
5 cross product with the velocity will
6 generate electric fields and the
7 vector sum of that electric field with
8 other electric fields and that will
9 determine the net movement.
10 Q. (BY MR. WHITEHURST) Let me see
11 if I've got this right. A magnetic field
12 will create an electric field, which will
13 change the net electric field, which will
14 change the net movement?
15 MR. PAUL: Objection to form.
16 Scope.
17 THE WITNESS: Yes.
18 MR. WHITEHURST: Let's take a
19 break. We can go off the record.
20 THE VIDEOGRAPHER: Going off
21 the record, the time is 2:09.
22 (Recess from 2:09 p.m. to

1 2:27 p.m.)
2 THE VIDEOGRAPHER: We're back
3 on the record, the time is 2:27.
4 Q. (BY MR. WHITEHURST)
5 Dr. Banerjee, welcome back. I wanted to
6 clarify one small point. We've talked a lot
7 today about calculating the net electric
8 field in order to determine -- strike that.
9 We've discussed today
10 calculating the net electric field in order
11 to determine the net movement of an electron
12 in a semiconductor.
13 Do you recall that?
14 A. Yes.
15 Q. Would your answers have changed
16 had we been talking about holes?
17 A. No, except that the holes move
18 in the direction of electric field, but
19 electrons move opposite to the electric
20 field. But quality they are the same.
21 Q. So in order to determine the
22 net movement of an electron in a

1 semiconductor, we would calculate the net
2 electric field and then the electron would
3 move in a direction opposite the net electric
4 field.
5 Did I get that correct?
6 MR. PAUL: Objection to form.
7 Q. (BY MR. WHITEHURST) That a
8 hole would move in the same direction as the
9 net electric field?
10 MR. PAUL: Objection to form.
11 THE WITNESS: The drift
12 velocity of the hole would be in the
13 same direction, yes.
14 Q. (BY MR. WHITEHURST) But for
15 both an electron and a hole, in order to
16 determine the net movement, we first
17 determine the net electric field, correct?
18 MR. PAUL: Objection to form.
19 THE WITNESS: Yes, that's true.
20 Q. (BY MR. WHITEHURST) I want to
21 ask you some questions regarding your
22 declaration. I have marked your supplemental

1 declaration, I should say, as Exhibit 2. The
2 copy I'm looking at is marked Cirrus
3 Exhibit 1060.
4 (Exhibit 2 marked)
5 Q. You should see that on the
6 screen in front of you.
7 A. Yes. I also have an unmarked
8 hard copy in front of me.
9 Q. Terrific.
10 I'm going to just read into the
11 record that what I have marked as Exhibit 2
12 to your deposition is captioned "Supplemental
13 Declaration of Dr. Sanjay Banerjee in Support
14 of Petitioners' Reply."
15 Did I read that correctly?
16 A. Yes.
17 Q. And you submitted this same
18 declaration for seven IPR numbers, the first
19 of which is 2024-00001.
20 Do you see that?
21 A. Yes.
22 Q. And then the other numbers end

in 16, 17, 18, 19, 20 and 21.
Do you see that?
A. Yes.
MR. WHITEHURST: Mr. Videographer, I think we can take that down now. Unless I need to pull it back up, I'm just going to refer to the paragraph numbers.
Q. (BY MR. WHITEHURST) Dr. Banerjee, I assume you're familiar with this document?
A. Yes.
Q. Is there anything that you would like to change or edit about your declaration?
A. I don't think so.
Q. Do you believe it's accurate?
A. I think so.
Q. And do you stand by it?
A. Yes.
Q. I want to ask you some questions about paragraph 19, which begins

on -- I don't know what the PDF number is, but the bottom of the page says No. 10.

A. Yes.

Q. And do you see that figure 19 [sic] continues on to page 11? Do you see that?

A. Yes, yes.

Q. On page 11, there is a Figure 1.

Do you see that?

A. Yes.

Q. Do you see how there is a little a and a little b?

A. Yeah.

Q. Do you recall where Figure 1 came from?

A. From Sze, page 48, Exhibit 1063.

Q. And then you also cite to what's called here Streetman, but that's a textbook you helped write, correct?

A. From the fourth -- the third or

1 the fourth or the fifth edition onwards,
2 starting in 1999, or maybe sooner than that.
3 I can't remember. Yes, I think I quoted not
4 the original version, but subsequent
5 versions.
6 Q. What does the figure on the
7 left, which is marked little "a" show?
8 A. Was that a question?
9 Q. Yes. What does Figure 1(a)
10 show?
11 A. Figure 1(a) is a cartoon view
12 of this random Brownian motion of one
13 individual electron in the absence of a
14 category 2 force electric field.
15 Q. Let's break that down. So what
16 does it mean when it says "E = 0"?
17 A. That means there are no
18 long-range electric fields, either due to
19 externally applied voltages or doping
20 gradients.
21 Q. And is this showing random
22 thermal motion?

A. In a cartoon sort of way, yes.

Q. What do you mean when you say "cartoon"?

A. I mean, it's a schematic representation of what might happen in a solid. So in segment 1, it's traveling from the blue dot to the end of the arrow without any collisions. Even though there are many periodic atoms in between, those don't cause any collisions. Their effect is effective mass.

And then when the vector 1 meets vector 2, the sudden change of direction and, in this case, also magnitude, that would be an example of the impact of this category 3 force, random collisions, which could be due to be -- yeah, that is vibrations with increasing temperature or defects or dopants. It travels between that point and -- in the straight-line segments, it's traveling without collisions or scattering. And whenever these arrows change

1 direction or magnitude, there is scattering
2 or collision going on.
3 Q. Can we refer to this as random
4 thermal motion?
5 A. Yes.
6 Q. Can we refer to this as
7 Brownian motion?
8 A. Yes.
9 Q. Can we refer to this as random
10 motion?
11 A. Yes, a random thermal motion.
12 Q. And what are the two blue dots?
13 A. So this shows kind of a time
14 snap, if you will, between some instance of
15 time and maybe a few seconds later, where
16 this particular electron ends up at the
17 second blue dot --
18 THE REPORTER: The second what?
19 THE WITNESS: The second blue
20 dot.
21 THE REPORTER: Oh, blue dot,
22 okay.

1 THE WITNESS: Yeah. But, as
2 you can see, these two dots don't
3 coincide. But, remember, we don't
4 have just a single electron. We have
5 a whole ensemble of electrons and when
6 you average over the whole ensemble,
7 the center of gravity of the whole
8 ensemble will not go anywhere.
9 Q. (BY MR. WHITEHURST) I believe
10 you added highlighting to this figure?
11 A. I think so, yes.
12 Q. Somebody has highlighted the
13 two dots with a blue circle.
14 Do you see that?
15 A. Yes.
16 Q. And shown here in Figure 1(a),
17 we see this random motion going from one to
18 two to three to four to five to six.
19 Do you see that?
20 A. Yes.
21 Q. And according to this figure,
22 when you get to six, it's close to where you

1 started?
2 A. In this document, yes.
3 Q. And is this what you would
4 refer to as zero net displacement?
5 A. No, not for an individual
6 electron. If you recall, you have a huge
7 number of electrons, right? So for the whole
8 ensemble, there would be zero net
9 displacement, but individual electrons could
10 have a nonzero displacement, as illustrated
11 over here.
12 Q. So rather than looking at a
13 single electron, you would look at the
14 ensemble of electrons?
15 MR. PAUL: Objection to form.
16 THE WITNESS: Yes, to get the
17 net current, yes.
18 Q. (BY MR. WHITEHURST) And if the
19 electric field equals zero, you get zero net
20 displacement of the ensemble; is that
21 correct?
22 MR. PAUL: Objection to form.

1 THE WITNESS: Yeah, that's
2 correct.
3 Q. (BY MR. WHITEHURST) Now,
4 something different happens in 1(b), correct?
5 A. Yes.
6 Q. There is an arrow at the top.
7 Do you see that?
8 A. Yes.
9 Q. And it says "E" and the arrow
10 is pointing to the left.
11 Do you see that?
12 A. Yes.
13 Q. Do we know what the units are
14 for this electric field?
15 A. It could be volts per
16 centimeter or you could choose other units
17 also, such as volts per meter, if you want.
18 It's some volts per unit of distance.
19 THE REPORTER: It's some --
20 THE WITNESS: Volts per unit of
21 distance.
22 Q. (BY MR. WHITEHURST) Now, in

1 this -- well, first of all, is it fair to
2 call this a cartoon figure?
3 A. Yes.
4 Q. And in this cartoon figure, you
5 have a blue dot before the one.
6 Do you see that?
7 A. Yes.
8 Q. And it goes from one to two to
9 three to four to five to six.
10 Do you see that?
11 A. Yes.
12 Q. And ultimately, six is farther
13 to the right than where it started.
14 Do you see that?
15 A. Yes.
16 Q. Now, it says that this is an
17 electron.
18 Do you see that?
19 A. Yes.
20 Q. So this electron has moved from
21 the beginning to the end in a direction that
22 is opposite the direction of the electric

field?

A. Yes.

Q. So the electric field is pointing from the right to the left?

A. Yes.

Q. But the electron has moved from the left at No. 1 to the right at No. 6, correct?

A. Yes.

Q. And this is because electrons move in a direction that is opposite the direction of the electric field?

A. That's correct.

Q. Is there any way to tell from this figure what the magnitude of the electric field is?

A. No. It's a cartoon view.

Q. Is there any way to tell what the distance is from one to six?

A. That's also a cartoon view and this cartoon is a highly magnified version. They don't really travel that far in the

1 semiconductor. It's short collisions.
2 Q. Can you tell from this figure
3 whether it's a single field or a net field
4 due to multiple fields?
5 A. No. I mean, it's meant to be
6 the ultimate field, the net field.
7 Q. Why is it meant to be the
8 ultimate field?
9 A. We were trying to illustrate
10 what the net motion would be as a result of
11 the net electric field, but you could break
12 down that electric field vector into
13 different components, a component due to the
14 built-in field in the dopant gradient, for
15 example, vector sum with an external field.
16 Q. But this figure is showing the
17 net movement due to the net field, correct?
18 MR. PAUL: Objection to form.
19 THE WITNESS: The cartoon view,
20 yeah, that's what we're trying to
21 show.
22 Q. (BY MR. WHITEHURST) Now,

1 earlier today we discussed gradients.
2 Do you remember that?
3 A. Yes.
4 Q. And we discussed that the
5 gradient determines the direction and
6 magnitude of the electric field.
7 Do you recall that?
8 A. The gradient of the
9 electrostatic potential determines the
10 magnitude and the direction.
11 Q. And then in order to determine
12 the net electric field, we would have to look
13 at the other category 2 forces?
14 MR. PAUL: Objection to form.
15 THE WITNESS: By category 2, if
16 you mean the built-in fields with the
17 doping gradients, the answer is yes.
18 Q. (BY MR. WHITEHURST) And in
19 order to determine the net movement, we look
20 at the net field, right?
21 A. Yes.
22 Q. But I want to go back to the

gradient. You understand what I mean when I say "gradient," right?

A. Yes.

Q. What do you understand me to be saying when I say "gradient"?

A. Gradient means a slope, which in three dimensions would have both a direction and a magnitude.

Q. And what would the magnitude -- strike that.

Would the magnitude of the gradient have units?

A. The magnitude of the gradient of the electrostatic potential, which is electric field decimal unit. Electrostatic potential is units of volts and then the voltage is dropped across a certain distance. That's what decides the electric field of volts per centimeter.

Q. Are they directly proportional? Is there a linear relationship between -- strike that.

1 What is the relationship
2 between the gradient and the magnitude of the
3 electric field?
4 A. So gradients are defined at
5 every point. If the voltage between two
6 points dropped linearly, the slope is
7 constant from point A to point B, then the
8 electric field would be constant between A
9 and B.
10 In the general case, if you
11 have a nonlinear variation of electrostatic
12 potential distance, then the local slopes at
13 every point would give rise to different
14 electric fields at each point.
15 Q. So when you look at the
16 dopants, the dopants could be uniform in some
17 areas and have a gradient in other areas,
18 correct?
19 MR. PAUL: Objection to form.
20 THE WITNESS: The doping
21 concentration you mean?
22 Q. (BY MR. WHITEHURST) Yeah.

A. Yes.

Q. Maybe I -- maybe we should agree on a term that we can both use. Do you understand what I mean when I say "a doping profile"?

A. Yes.

Q. So when you -- what does the term "doping profile" mean?

A. It refers to the doping concentration, number of dopants per unit volume, started as a function of position.

Q. And what do you mean when you say "position"?

A. Location in the semiconductor. For instance, in these patents it talks about a doping profile decreasing as a function of depth on the surface, so the depth direction is the position.

Q. So the doping profile would show the doping concentrations at different depths in the semiconductor?

A. Yes.

Q. Where depth zero would be the surface of the semiconductor?

A. You could say that's the origin, yes.

Q. Did you look at the doping profile in the Kawagoe reference?

A. Yes.

Q. Did you ever calculate the gradient of the doping profile?

MR. PAUL: Objection to form.

THE WITNESS: For the purposes of my analysis, I did not need to. Any time you have a doping gradient that is nonzero, it will give rise to a nonzero built-in electric field, which, as we're discussing, would lead to a nonzero drift velocity component.

Q. (BY MR. WHITEHURST) But just so the record is clear, you never calculated the slope of the doping profile in Kawagoe, correct?

MR. PAUL: Objection to form.

1 THE WITNESS: I wasn't asked to
2 by the counsel and I don't remember if
3 Kawagoe has the depth dimensions. And
4 if you don't have it, you cannot
5 calculate that.
6 Q. (BY MR. WHITEHURST) Why can
7 you --
8 A. I didn't calculate it. Sorry.
9 Q. -- not calculate the gradient
10 if you don't have the depth dimensions?
11 A. Because you need to have both
12 information between the concentration at
13 point A and the concentration at point B.
14 And then the slope, if it's a linear slope,
15 it would be concentration at A minus
16 concentration at B divided by the distance at
17 A minus the distance at B.
18 Q. So --
19 A. So if you don't have the depth
20 information, you cannot calculate the
21 gradients.
22 Q. So when you look at Kawagoe, it

1 doesn't mention the depth dimensions,
2 correct?
3 A. I don't recall, but I don't
4 think it does. But it doesn't matter anyway.
5 Anytime I see a non -- non-flat dopant
6 profile, anything with a finite gradient, it
7 has to lead to a built-in electric field and
8 that has to lead to a nonzero drift velocity,
9 regardless of the magnitude of that field, as
10 we were discussing earlier.
11 Q. So you don't know the depth
12 dimensions for Kawagoe, right?
13 MR. PAUL: Objection to form.
14 THE WITNESS: I didn't look at
15 it. Maybe it does. I probably have
16 in front of me. I don't know if the
17 figures have any depths mentioned. I
18 don't know if the specs do. I need to
19 look into that.
20 Q. (BY MR. WHITEHURST) So you're
21 not aware of any depth dimensions for the
22 doping profile in Kawagoe, correct?

1 MR. PAUL: Objection to form.
2 Scope.
3 THE WITNESS: I don't recall,
4 sitting here, if there is. And once
5 again, that's irrelevant to my
6 opinion.
7 Q. (BY MR. WHITEHURST) And you
8 never calculated the gradient for the doping
9 profile in Kawagoe, correct?
10 A. I did not. But that's
11 irrelevant, as I said.
12 Q. And you did not calculate a
13 magnitude for an electric field due to the
14 doping profile, correct?
15 A. I did not. But, once again,
16 it's not relevant because any gradient would
17 lead to a nonzero built-in electric field.
18 It must, necessarily must happen. And any
19 built-in electric field, no matter how small,
20 would necessarily give rise to a nonzero
21 drift velocity.
22 Q. You cannot tell me what the

1 magnitude of the electric field due to the
2 doping profile in Kawagoe is?
3 MR. PAUL: Objection to form.
4 Scope.
5 Q. (BY MR. WHITEHURST) And I'll
6 re-ask it. I'll withdraw that question.
7 Dr. Banerjee, you never
8 calculated a magnitude for an electric field
9 due to the doping profile in Kawagoe, did
10 you?
11 A. I did not. I don't know if
12 there is enough information in Kawagoe to do
13 that. But regardless of that, it's not
14 important because anytime I see a doping
15 variation, it tells me there has to be a
16 built-in electric field. And regardless of
17 the magnitude of the electric field, it has
18 to lead to a nonzero drift velocity,
19 and that's the essence of this patent.
20 Q. And just so the record is
21 clear, you didn't calculate a magnitude for
22 the electric field due to the doping profile

in any of the prior art references, did you?

A. I did not. But, once again, it's not necessary. Anytime I see a gradient in Kawagoe or -- my knowledge as an expert tells me it must lead to a built-in nonzero electric field and that must lead to a nonzero drift velocity. And that's all that I need for the analysis of this patent.

Q. Dr. Banerjee, do you agree that if the doping profile is flat or a particular depth of the semiconductor device, the electric field would be zero due to the doping profile?

MR. PAUL: Objection, scope. Foundation.

Q. (BY MR. WHITEHURST) Let me -- let me withdraw that question so that I can ask a clearer one.

When you were analyzing the prior art references, you never calculated the magnitude for any of the electric fields, correct?

1 A. I did not calculate those.
2 Q. Did you ever look at the doping
3 profiles to determine whether the doping
4 profiles were uniform at certain depths?
5 MR. PAUL: Objection, form.
6 THE WITNESS: What I had for me
7 in these patents are schematic logs of
8 the doping profiles --
9 THE REPORTER: Are what?
10 THE WITNESS: Schematic logs.
11 THE REPORTER: Schematics,
12 okay.
13 THE WITNESS: And those
14 indicated downward sloping gradient.
15 Q. (BY MR. WHITEHURST) I
16 understand that you contend that doping
17 profiles are downward sloping in certain
18 areas. But did you ever look to see whether
19 they were uniform in certain areas?
20 MR. PAUL: Objection, form.
21 Scope.
22 Q. (BY MR. WHITEHURST) Just so

1 the record is clear, you are looking at a
2 document right now, correct?
3 A. Yeah, I'm looking at Kawagoe.
4 Sorry. That's Exhibit 1007.
5 Q. And what are you looking for?
6 A. I'm looking for schematic
7 doping profiles. So, for example, Figure 17
8 has the solid line, doping as a function of
9 depth and below a depth of W -- substrate W,
10 it shows that the doping concentration is
11 constant and there will be no built-in fields
12 in that region.
13 Q. So it's your --
14 THE REPORTER: Would be no
15 what?
16 THE WITNESS: There would not
17 be any built-in electric fields in
18 that region.
19 Q. (BY MR. WHITEHURST) So it's
20 your testimony today that wherever the doping
21 concentration is constant, there would not be
22 a built-in electric field in those sections,

1 correct?
2 MR. PAUL: Objection to form.
3 THE WITNESS: Yeah, the doping
4 concentration is constant or a
5 substantial region. It would not lead
6 to built-in electric fields.
7 Q. (BY MR. WHITEHURST) Do you
8 understand what the term "active region"
9 means?
10 A. Yes.
11 Q. If the doping profile is
12 constant in the active region, would you
13 agree that there is no built-in electric
14 field in the active region?
15 MR. PAUL: Objection,
16 foundation. Scope.
17 THE WITNESS: Can you point me
18 to a figure in Kawagoe of the prior
19 art?
20 Q. (BY MR. WHITEHURST) Do you
21 understand my question?
22 A. I think there is a substantial

1 region in the active region where the doping
2 profile was constant that would not have a
3 nonzero built-in electric field in that
4 region. But it has to be over a reasonable
5 landscape, which is known as a screening
6 lane, by the way.
7 THE REPORTER: Known as a --
8 THE WITNESS: Screening.
9 THE REPORTER: Spinning?
10 Q. (BY MR. WHITEHURST) Can you
11 please -- can you please spell that?
12 A. Screening.
13 THE REPORTER: Screening lane?
14 THE WITNESS: Yes, screen as in
15 screen, screening lane.
16 Q. So if the doping profile is
17 constant in the active region, there would be
18 no built-in electric field in the active
19 region, correct?
20 MR. PAUL: Objection,
21 foundation. Scope.
22 THE WITNESS: Are you talking

about the doping concentration being constant over the entire active region or a portion of the active region?

Q. (BY MR. WHITEHURST) If the doping profile is constant for the entire active region, there would be no built-in electric field for the active region, correct?

MR. PAUL: Same objection.

THE WITNESS: The active region, I believe for the purpose of this case, the claimed term has been defined as region or transistor action patents, and that requires one to form a source scope region and a drain scope region with a channel in between. So in the lateral direction, it cannot be used on the go. You would not get a transistor.

Now, hypothetically, if you just focus on the middle part of the channel, you could have a situation

where there is no variation of doping as a function of depth in the middle part of the channel, and in that case there would be no built-in electric field. But transistors are almost always -- in manufacturing, you're going to have a depth variation.

Q. (BY MR. WHITEHURST) So if we look at the transistor and we look halfway between the source and the drain, do you follow me so far?

A. Yes.

Q. And then we move from the surface in the downward direction, do you follow me so far?

A. Yes.

Q. If the doping profile is constant in the middle of the channel region in the downward direction, then there will be no electric field in the active region; isn't that right?

MR. PAUL: Objection,

1 foundation. Scope.
2 THE WITNESS: There would be no
3 built-in field due to the doping
4 gradient and the other factors in the
5 transistor --
6 Q. (BY MR. WHITEHURST) So there
7 would be no built-in electric field due to
8 the doping profile, correct?
9 A. There would be no built-in
10 electric field in the middle of the channel
11 as a function of depth if the doping
12 concentration did not vary as a function of
13 depth in the middle of the channel. But
14 there's other structures that can also
15 cause built-in electric fields.
16 Q. And in order to determine net
17 movement, we would have to look through those
18 other electric fields, right?
19 A. There could be other built-in
20 electric fields even with external voltages
21 because of the presence of the gate
22 electrode, gate oxide. So those are also

1 examples of built-in electric fields, but not
2 due to doping gradients; due to structural
3 effects.
4 Q. Why can the gate electrode
5 create a built-in electric field even if the
6 doping profile is constant?
7 A. It can because a gate electrode
8 in general will have different electronic
9 properties than the channel. And the
10 property that I'm talking about is known as
11 the work function, which is defined as the
12 energy between the forming level and the
13 vacuum level, the vacuum level being a
14 reference to potential energy.
15 In general, the work function
16 in the gate would be different from the work
17 function in the semiconductor in the channel.
18 That can also cause built-in fields in the
19 channel. But that's not really the subject
20 of this patent --
21 Q. And you also mentioned --
22 A. -- that we are talking about.

1 MR. PAUL: He was finishing his
2 statement. You can go ahead and
3 finish your statement.
4 THE WITNESS: In my opinion,
5 the main subject matter that's
6 relevant in the context of this patent
7 is the built-in electric field in the
8 channel due to the doping gradients to
9 the channel.
10 Q. (BY MR. WHITEHURST) I want to
11 talk about the built-in field created by the
12 gate electrode and the gate oxide.
13 Do you follow me?
14 A. Yes.
15 Q. Okay. I want to go back up to
16 your testimony. You testified there could be
17 other built-in electric fields even without
18 external voltages because of the gate
19 electrode and the gate oxide.
20 Do you recall that?
21 A. Yes.
22 Q. And you already explained how

the gate electrode can create a built-in electric field even without an external voltage.

How can the gate oxide create a built-in electric field even without an external voltage?

A. A gate oxide can attract charges and that can cause an electric field to be created in the semiconductor channel.

But that's not the subject of this patent. This patent is dealing with built-in electric fields due to doping gradients in the channel.

Q. But you agree that both the gate and the gate oxide can create electric fields in the active region, even when an external voltage is not applied, right?

MR. PAUL: Objection to form.

THE WITNESS: Yeah, the gate and gate oxide can create fields in the channel, even without external voltages.

1 Q. (BY MR. WHITEHURST) And the
2 electric fields created by the gate and the
3 gate oxide will affect the net electric
4 field, right?
5 A. Yes. But, once again, that's
6 not the subject matter of these patents.
7 Q. And you already testified today
8 that the net electric field affects the net
9 movement.
10 Do you recall that?
11 MR. PAUL: Objection to form.
12 THE WITNESS: Yes, electric
13 field does affect net movement.
14 Q. (BY MR. WHITEHURST) So this
15 means that the electric field created by the
16 gate and the gate oxide will affect the net
17 electric field and the net carrier movement,
18 correct?
19 MR. PAUL: Objection to form.
20 THE WITNESS: The gate
21 composition and the gate oxide
22 composition can create built-in

electric fields.

Q. (BY MR. WHITEHURST) And you didn't calculate the magnitude for the electric field due to the gate or the gate oxide, did you?

A. No one can, unless you give me specific information.

Q. Let's take a break. Going off the record.

THE VIDEOGRAPHER: Yeah. It takes me a minute to get there.

Going off the record, the time is 3:07.

(Recess from 3:07 p.m. to 3:28 p.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 3:28.

Q. (BY MR. WHITEHURST) Dr. Banerjee, hopefully you still have in front of you a copy of your declaration, which we have marked as Exhibit 2 to your deposition. If you could please turn to

1 page 14 of that declaration.
2 A. The declaration or the
3 supplemental?
4 Q. My apologies. The supplemental
5 declaration.
6 A. Yes.
7 Q. The same one that we were
8 talking about before. Hopefully you have
9 turned to page 14 of the supplemental
10 declaration, and you see a figure at the top,
11 right before paragraph 24 begins?
12 A. Yes.
13 Q. Where did this figure come
14 from?
15 A. I think I sketched it and then
16 the lawyers or the paralegals drafted it up
17 nicely. It's a cartoon view.
18 Q. So this did not come from a
19 textbook?
20 A. I don't think so.
21 Q. This was created from a sketch
22 that you did?

A. I believe that's correct.
Q. Okay.
A. I think that's correct, yeah.
Q. And you don't recall seeing this before you sketched it?
A. Sorry?
Q. You don't recall seeing this figure before you sketched it?
A. I don't think so.
Q. Would you say that this shows a dopant profile?
A. Yes.
Q. And I think you occasionally refer to it as a doping profile?
A. Yes.
Q. Would you agree that a dopant profile and a doping profile are the same thing?
A. In this context, yes.
Q. The Y axis has been labeled "Dopant Concentration."
Do you see that?

A. Yes.
Q. But there are no units on this axis, is there?
A. Yes.
Q. And then you have annotated the X axis, "Surface," "Well region," and "Substrate."
Do you see that?
A. Yes.
Q. What is the surface?
A. The surface of the wafer, silicon wafer.
THE REPORTER: The surface of the --
THE WITNESS: Silicon wafer.
THE REPORTER: Okay.
THE WITNESS: Silicon wafer, W-A-F-E-R.
THE REPORTER: I know. I just -- okay.
Q. (BY MR. WHITEHURST) And then as we go deeper into the semiconductor,

1 you've annotated "Well region."
2 Do you see that?
3 A. Yes.
4 Q. And then you've drawn a dashed
5 line.
6 Do you see that?
7 A. Yes.
8 Q. And then you've labeled to the
9 right of the dashed line "Substrate."
10 Do you see that?
11 A. Yes.
12 Q. Is it your position that the
13 well region is different from the substrate?
14 MR. PAUL: Objection to form.
15 THE WITNESS: The wells are
16 typically made in a substrate, starts
17 with a substrate, and then you do
18 implants and implant the needles to
19 form wells in them. But exact
20 terminology may depend on specific
21 patents.
22 Q. (BY MR. WHITEHURST) Do you

recall analyzing the claims to see whether there were differences across the claims?

A. I think the different patents in this group use slightly different terminologies.

Q. Do some of the claims refer to the well region as part of the substrate?

A. If you refer to me a specific claim in a specific patent, I can tell you that.

Q. But you don't recall one way or the other?

A. No. It's in seven -- in seven patents and it's been a while.

Q. I understand.

You've labeled surface, well region, and substrate. I don't see on here active region. Do you know what I mean when I say "active region"?

A. Yes.

Q. Can tell me where on the X axis the active region would be?

A. The active region would be closer to the surface and occupy a portion of the well. So it would be on the left-hand side of this figure.

Q. Is it -- strike that.

I don't know if it's my imagination or not, but right to the left of "Well region," it looks like there is a small little dash or line.

Do you see that?

A. On the axis itself?

Q. Well, do you see where it says "Well region"?

A. Yes.

Q. And do you see where the W is capitalized?

A. Right, yeah, I see that, yes, small dash, yes.

Q. Do you know why that small dash is there?

A. Like I said, I did a rough sketch and then the paralegals drew it up. I

1 don't think it has any particular
2 significance.
3 Q. Would the active region be to
4 the left or the right of that small dash?
5 A. It would be on the left of the
6 small dash.
7 Q. Why would it be on the left of
8 that small dash?
9 A. Because you do the source/drain
10 implants from the surface, which is on the
11 left of the vertical axis. So the structure
12 would be to the left of that small dash
13 extending up the vertical axis.
14 Q. Do you agree that the active
15 region would be at the surface of the
16 semiconductor?
17 MR. PAUL: Objection to form.
18 THE WITNESS: You should be
19 treating a surface as a
20 three-dimensional object. It would be
21 near the surface. It has a certain
22 depth to it also.

Q. (BY MR. WHITEHURST) Would it start at the surface of the semiconductor device?

A. So in the little picture, it's not a universal definition of "active regions." I mean, different POSITAs would use that term maybe slightly differently.

But, by and large, I believe for the purposes of the patent, both sides agree that it's a region with a transistor action or patent. So you start at the surface and extend --

THE REPORTER: It's --

THE WITNESS: You start at the surface and extend depth-wise certain depth.

Q. (BY MR. WHITEHURST) How deep would it go?

A. So that depends on the level of the technology. So the source/drain junction depths have been shrinking as the channel lengths have been shrinking. That's the

1 principal of scaling of MOSFETs. But really
2 broadly, each would be on the order of a
3 thousand angstroms or so. It depends on
4 the --
5 THE REPORTER: Really
6 broadly -- I'm having a hard time.
7 Q. (BY MR. WHITEHURST) The court
8 reporter -- I'm sorry.
9 A. A thousand angstroms,
10 A-N-G-S-T-R-O-M-S, angstroms.
11 THE REPORTER: Okay.
12 THE WITNESS:
13 A-N-G-S-T-R-O-M-S. Did you get it?
14 THE REPORTER: Yes, but --
15 okay. I just didn't get the rest of
16 the sentence.
17 THE WITNESS: It would be of
18 the order of a thousand angstroms.
19 THE REPORTER: Okay.
20 Q. (BY MR. WHITEHURST) So that we
21 have a clean record, I'm going to start over
22 again and see if I can not talk over you.

1 I'll ask a question and I'll pause and I'll
2 make sure you completely answer before I ask
3 my next question.
4 Dr. Banerjee, would the active
5 region start at the surface of the
6 semiconductor device?
7 A. Yes.
8 Q. And then the active region
9 would be a certain depth, correct?
10 A. Yes.
11 Q. What is the depth of the active
12 region?
13 A. So that would roughly
14 correspond to the depth of the source/drain
15 junction, which depends on the technology
16 node, but could be of the order of a thousand
17 angstroms or so.
18 Q. Now, looking back at the figure
19 on page 14 of your supplemental declaration,
20 do you see the dashed line?
21 A. On the right-hand side?
22 Q. Yes, sir.

A. Yes.

Q. And do you see a green line to the right of the dashed line?

A. Yes.

Q. Did you intend to draw this as a uniform dopant concentration?

A. In this case, yes.

Q. So the doping concentration to the right of the dashed line is uniform, right?

A. Yes.

Q. And this means that there would be no built-in field due to the doping profile, right?

A. There would be no built-in field in the substrate region where the doping is constant.

THE REPORTER: In the --

THE WITNESS: There would be no built-in electric field in the substrate region where the doping is constant.

THE REPORTER: Thank you.

Q. (BY MR. WHITEHURST) Would there be other built-in electric fields?

MR. PAUL: Objection to form.

THE WITNESS: On the substrate?

Q. (BY MR. WHITEHURST) Yes, sir.

MR. PAUL: Objection to form.

THE WITNESS: There may be, but I can't think of any offhand.

Q. (BY MR. WHITEHURST) Why could there be other built-in electric fields in the substrate where the doping concentration is uniform?

A. As I said, I cannot think of any offhand.

Q. When you looked at the doping profile or the different prior art references, did you look to see whether the doping profile was uniform in certain regions?

A. Yes.

Q. And would you agree that where

it is uniform, there would be no electric field due to the doping profile?

A. Yes, if the doping concentration was constant or a substantial region, there would be no built-in electric fields because of the doping gradient.

Q. And why is that?

A. Because the built-in electric fields are created by the mechanism shown in this figure on page 14. If the doping concentration is uniform, that means they have the same concentration of majority carriers created by the dopants at different locations. These carriers are not stationary. They are random Brownian motion.

As a result, there would not be any net diffusion and, as a result, in the absence of any applied voltages where there cannot be any net current, the drift current which opposes the diffusion current to the concentration radiant must also be zero. Currents depend on electric fields. The

relativity of electric field has to be zero and that, in turn, makes the minority carrier drift current zero and the minority carrier diffusion current is also zero.

Q. So when the doping profile is uniform, like what you have shown to the right of the dashed line, there is no built-in electric field, correct?

A. There is no built-in electric field in that field, but there is to the left of the dashed line.

Q. Now, I want to go back briefly to Figure 1(b) on page 11 of your declaration.

A. Okay.

Q. Do you see where No. 1 is?

A. On Figure 1(b)?

Q. Yes, sir.

A. Yes.

Q. And do you see a blue circle around the dot?

A. Yes.

Q. Do you know what I mean when I say "the starting point"?

A. Yes.

Q. And then if you look at six, there is another blue circle around a dot?

A. Yes.

Q. And do you know what I mean when I say "endpoint"?

A. Yes, in this time snapshot, yes.

Q. When you were looking at the prior art, did you look at the starting point and the ending point of the carriers?

MR. PAUL: Objection to form.

THE WITNESS: So as I told you before, this cartoon view shows one out of billions and billions of electrons or holes in this ensemble.

So I did not look -- I mean, nobody can look at the trajectory of individual electrons or holes. You look at what happens to the collective

1 ensemble, the center of gravity and
2 how that center of gravity moves in
3 response to electric fields.
4 And that center of gravity of
5 this whole ensemble of holes once
6 again moves in the direction of
7 electric field, electron's center of
8 gravity also would move opposite to
9 the electric field. But that velocity
10 is superimposed on top of this random
11 velocities of these unusual particles
12 in that ensemble.
13 Q. (BY MR. WHITEHURST) When you
14 were looking at the prior art, did you
15 determine the starting point for the ensemble
16 of electrons?
17 MR. PAUL: Objection to form.
18 THE WITNESS: There is no
19 single starting point for the whole
20 ensemble. There is a large number of
21 electrons and suppose they start the
22 movie at time zero, all of these

1 billions and billions of electrons --
2 actually, larger than that -- Avogadro
3 number of electrons who have different
4 locations in space.
5 So the starting points would be
6 different for each electron. Each of
7 them would have these random motions.
8 And then if I start the movie after,
9 say, one second, an individual
10 electron may start at position 1 and
11 end at 6, but electron No. 2 may start
12 somewhere else and somewhere else, and
13 so on, and so forth.
14 Q. (BY MR. WHITEHURST) So it's
15 your testimony today that when you look at
16 Figure 17 of Kawagoe, it's not possible to
17 determine the starting point for the ensemble
18 of electrons?
19 Did I get that right?
20 MR. PAUL: Objection, form.
21 Scope.
22 THE WITNESS: It's not possible

to find the starting point of any individual electron ensemble or any individual hole.

THE REPORTER: Any individual coil?

THE WITNESS: No, individual hole. Sorry.

Now, if you look at the whole ensemble, we are looking at a scenario where there is no externally applied voltages.

Q. (BY MR. WHITEHURST) That's what I'm trying to figure out.

A. Okay.

Q. What did you do when you looked at the prior art?

A. Yes.

Q. Did you account for external voltages? Did you determine a starting point for the ensemble of the electrons? What did you do when you looked at Figure 17 of Kawagoe?

A. I --

MR. PAUL: Objection to form.

THE WITNESS: I considered every scenario. So let's start with the transistor in the "off" state where no external voltages apply. Under those conditions, there would be zero net current and what would happen is all of this majority and minority carrier drift and diffusion currents in the collective ensemble will add up to zero.

And if you look at Figure 17 of Kawagoe, if one were to, you know, visualize this ensemble of electrons, you would have a cloud of electrons. They are not static. They are constantly moving around.

Suppose I started the clock at time zero. Before time zero, the electrons -- electrons are stationary. They are constantly moving around. So

1 I start the clock and I run the
2 clock -- run the movie, for, I don't
3 know, a second. It's a moving,
4 dynamic thing. And then if I focus on
5 one of those individual electrons, I
6 make it a cartoon view, as shown in
7 Figure 1(b).
8 Okay. Now, if you apply
9 external voltages that add external
10 field, it's vector sum with any
11 built-in electric field into the
12 doping gradient and now you get a net
13 current.
14 Q. (BY MR. WHITEHURST) So you
15 agree that it's important to determine the
16 starting point and the endpoint, correct?
17 MR. PAUL: Objection to form.
18 THE WITNESS: What's happening
19 is a continuous process, right? I
20 guess because you and I decide to do
21 the analysis right now at this moment
22 on a piece of semiconductor does not

1 mean that electrons prior to that
2 moment were stationary, are starting
3 the journey at that point, right?
4 I'm just choosing to take a
5 snapshot of the movie, of these
6 dynamic Brownian motion electrons,
7 plus any superimposed drift velocity
8 from time 1, T1 to T2, say, right.
9 And, once again, at time T1,
10 these electrons would have some
11 distribution applications and
12 velocities. And that -- for that full
13 ensemble, it's like choose one
14 particular electron, it could be this
15 cartoon art in Figure 1(b), right?
16 And then I start the clock at time T2.
17 That particular one would end up at
18 line 6 in this figure, right, if all
19 of those other electrons start at
20 different points, end up at different
21 points.
22 But, collectively, the absence

of external voltages will all cancel out and that's why --

THE REPORTER: But -- wait, wait, it's getting a little fast here.

THE WITNESS: Oh, sorry, sorry.

THE REPORTER: Different points and end up at different points -- I lost it.

THE WITNESS: Sorry. Where do you want me to start? Sorry, my apologies.

THE REPORTER: Those other --

THE WITNESS: All those other --

THE REPORTER: Go ahead.

THE WITNESS: No, I interrupted you. How far did you get?

THE REPORTER: Not that far. Other electrons start at different points, end up at different points, but -- I don't know.

THE WITNESS: Yeah, right,

1 different points.
2 But, collectively, the average
3 location of all of this entire
4 ensemble of electrons does not move in
5 the absence of external voltages.
6 That's what happens in the off state
7 of the transistor.
8 Q. (BY MR. WHITEHURST) Let me --
9 are you finished?
10 A. Okay.
11 Q. I'm sorry, I didn't mean to
12 interrupt you. I was going to provide a
13 figure to hopefully put all of this in
14 context because I'm not sure we're on the
15 same page and without a figure to put all of
16 this into reference, I think it's -- I think
17 a picture would help.
18 If you don't mind, please turn
19 to Figure 17 of your declaration.
20 A. Not the supplemental, the
21 original declaration?
22 Q. No, sir. My apologies.

1 Page 17 --
2 A. Oh, page 17.
3 Q. -- of your supplemental
4 declaration. Just to be clear, I haven't
5 marked your original declaration as an
6 exhibit. All of my questions are about your
7 supplemental declaration.
8 A. Okay, yes. You said Figure 17,
9 that's why I was confused. Yeah, I see the
10 figure on page 17.
11 Q. And I know it's getting late in
12 the day and we're all tired, but we need to
13 be careful not to talk over one another. We
14 need to not make our court reporter -- make
15 her job any more difficult than we already
16 are. So I'm going to ask my question, I'll
17 pause, give you a chance to answer and I'll
18 be extra careful to let you finish your
19 answer before I ask my next question.
20 Do you see Figure 3 at the top
21 of page 17?
22 A. Yes.

Q. And do you see how the X axis is marked "Depth"?

A. Yes.

Q. What does it mean when it says "10"?

A. In this case, it means that location is ten microns below the surface of the wafer.

Q. And do you see how there are two arrows? Do you see what I'm referring to?

A. Yes.

Q. There is one arrow pointing towards the surface.

Do you see that?

A. Yes, yes.

Q. Can we say that arrow is pointing in the upward direction?

A. Yes.

Q. And then to the right of ten microns, do you see an arrow pointing in the downward direction?

A. Yes.

Q. Looking at the electric field on the left, what direction would holes move in response to the upward electric field?

A. They would move to the left.

Q. Now, to the right, or we could say deeper than the ten microns, we see an electric field pointing in the downward direction.

Do you see that?

A. Yes.

Q. What direction would holes want to move in response to a downward direction?

A. Once again, the holes would move to the right, to the drift mechanism. But in the absence of external voltages, there would be no net movement of holes either upward or downward.

Q. So, as we discussed earlier, in order to determine net movement, you need to know the net electric field, correct?

A. Net movement into drift, yes.

1 Overall movement also is governed by
2 diffusion. Remember, we talked about that.
3 Q. But we agree that net movement
4 will depend on the vector sum, right?
5 MR. PAUL: Objection to form.
6 THE WITNESS: Net movement as
7 in drift velocity would depend on the
8 vector sum.
9 Q. (BY MR. WHITEHURST) Now, this
10 figure does not show where the active region
11 is. Can you tell me where the active region
12 would be?
13 A. I haven't looked at the Kamins
14 reference in a while, but I suspect it's on
15 the left-hand side where this p+ dope region
16 meets the doping of ten to the 15, roughly in
17 that region.
18 THE REPORTER: Meets the doping
19 of --
20 THE WITNESS: Ten to the power
21 of 15; ten, superscript, 15.
22 Q. Let's see if we can make a

1 better record. So do you agree that the
2 active region would start where it says
3 depth, zero?
4 MR. PAUL: Objection to form.
5 Foundation.
6 THE WITNESS: I haven't looked
7 at Kamins in a while. So if you show
8 me that, I will be able to give you a
9 more accurate answer.
10 Q. (BY MR. WHITEHURST) Are you
11 able today to tell me whether the active
12 region is at the surface of the semiconductor
13 device?
14 A. Once again, without having
15 looked at Kamins in a while, I believe that
16 is the case.
17 Q. Now, you and I discussed this a
18 little while ago. I think we were on
19 page 14.
20 Do you recall that?
21 A. Yes.
22 Q. If you could please turn to the

1 figure on page 14.
2 A. Yes.
3 Q. And do you recall testifying
4 that the active region would start at the
5 surface where the semiconductor depth is
6 zero. Do you recall that?
7 A. Yes.
8 Q. Now, let's turn back to
9 figure 3 on page 17.
10 Are you there?
11 A. Yes.
12 Q. Would the same be true in
13 Figure 3? Would the active region be at the
14 Y axis where the depth is zero?
15 MR. PAUL: Objection to form.
16 Foundation.
17 THE WITNESS: I believe that's
18 the case, but I really should look
19 at Kamins to answer that definitely.
20 Q. (BY MR. WHITEHURST) Where
21 would the active region end?
22 MR. PAUL: Objection to form

and foundation.

THE WITNESS: Once again, I really should look at Kamins to give you a definitive answer. But it would be where -- it would be roughly in this region labeled 26, where the curve which is marked "B superscript plus" meets the horizontal line, which is labeled "ten superscript 15," roughly in that range.

Q. (BY MR. WHITEHURST) So that the record is clear, there is a curved line labeled reference numeral 26.

Do you see that?

Q. And the curved line labeled No. 26 goes from a dash on the Y axis, ten to the 19th power.

Do you see that?

A. Yes.

Q. And it goes down to the X axis at a depth that's greater than zero, but less than ten microns.

1 Do you see that?
2 A. Yes.
3 Q. Can we say that is roughly
4 2.5 microns?
5 A. Approximately.
6 Q. In your experience, would an
7 active region go deeper than 2.5 microns?
8 A. As I told you, it depends on
9 the level of technology. What's happened
10 over the years is when channel lengths are
11 long, junction depths are deep.
12 It also depends on what device
13 you're talking about. I cannot remember from
14 memory exactly what this particular Kamins
15 reference talks about, and there is also not
16 an absolutely universal definition of what
17 "active region" is. I can't remember if this
18 is a transistor over here or I think it was a
19 CMOS imager, maybe. So there is no fixed
20 depth of active region.
21 As technology has evolved, I
22 can tell you in a general sense that active

1 regions have gotten shallower and shallower.
2 There is no fixed number.
3 Q. But you agree that the active
4 region would be somewhere to the left of this
5 line that's numbered 26?
6 MR. PAUL: Objection to form
7 and foundation.
8 THE WITNESS: It would be
9 somewhere in that region, I believe,
10 yes.
11 Q. (BY MR. WHITEHURST) So the
12 active region would be somewhere between the
13 number zero and where the line labeled 26
14 intersects the X axis?
15 A. Approximately in that field.
16 Q. Where would the substrate be?
17 A. So the substrate in this case
18 would be, I believe, at -- so, once again,
19 there is no -- the patent uses the term
20 "substrate" in a slightly different context.
21 Same in that literature. So sometimes
22 people use the term "substrate" as the

1 starting material on which to start making
2 devices --
3 THE REPORTER: So sometimes --
4 THE WITNESS: Use the term
5 "substrate" as the starting material
6 on which to start making devices.
7 In this context, they are
8 talking about epi. Epi is a shorthand
9 for epitaxial layer. Sometimes people
10 talk about growing an epitaxial layer
11 on top of the substrate, but then
12 sometimes we will keep -- sometimes
13 the company will call this epi layer
14 on the substrate as the starting
15 substrate.
16 So there is no universal
17 definition of these terms. But in
18 this context, I think the vertical
19 line at ten micron depth was meant to
20 be the starting substrate on which
21 they grew a 10-micron anti epitaxial
22 layer and --

1 THE REPORTER: On which they --
2 THE WITNESS: Anti epitaxial,
3 E-P-I-T-A-X-I-A-L, layer at the doping
4 level of ten to the 15, ten to the
5 power of 15.
6 Q. (BY MR. WHITEHURST) To help
7 our court reporter, can you please spell
8 epitaxial?
9 THE REPORTER: He did. I mean,
10 I have it now, but --
11 MR. WHITEHURST: Just trying to
12 help you out.
13 THE REPORTER: I know.
14 MR. WHITEHURST: I believe it's
15 E-P-I-T-A-X-I-A-L.
16 THE REPORTER: Yes.
17 Q. (BY MR. WHITEHURST) Does that
18 sound right?
19 A. That's correct, yes.
20 Q. Okay. Let's make sure we're on
21 the same page. So we've got an active region
22 somewhere to the left of where line 26

1 intersects the X axis.
2 Do you follow me so far?
3 A. Yes.
4 Q. And then we have a substrate
5 deeper than ten microns.
6 Do you follow me?
7 A. I think in the Kamins
8 reference, that's correct.
9 Q. Now, do you see how to the
10 right of the line 26, there is a flat line?
11 A. Yes.
12 Q. And do you see where there is a
13 line that says ten -- strike that.
14 Do you see the line labeled ten
15 to the 15th power?
16 A. Yes.
17 Q. And do you see how the line is
18 flat to the right of the line labeled 26?
19 A. Yes.
20 Q. And then it goes up at some
21 point around 7.5 until it maxes out at
22 roughly ten microns?

A. Yes.

Q. My question is about the flat section to the right of line 26 before it goes up.

A. Okay.

Q. Would there be an electric field in that flat region?

A. There should not be any built-in electric fields in that flat region.

Q. Why not?

A. Because the doping concentration isn't changing as a function of depth.

Q. Now, do you see the electric field that's pointing to the left or, in this case, the upward direction?

A. Yes.

Q. Where does that electric field begin?

A. In this case, it will begin at ten microns, which is the peak of curve 24.

Q. And where will that electric

1 field end?
2 A. So that depends on the shape of
3 the doping. That would depend on the shape
4 of the entire donor doping profile marked 24.
5 Because I have a doping gradient, the
6 electrons would tend to diffuse to the right
7 and diffuse to the left on either side of the
8 peak region.
9 And because they tend to
10 diffuse and they cannot be the net current,
11 there has to be a built-in electric field and
12 those are the two electric field deckers that
13 you're talking about. Those electric fields
14 then will generate opposing drift lines so
15 that electron drift and electron diffusion
16 current at every energy has cancelled out,
17 and that is what I show in the figure on
18 page 14 of my report.
19 These same electric fields and
20 donor dopant concentration gradients will
21 also generate, in this case, minority carrier
22 volt drift and diffusion currents --

1 THE REPORTER: In this case --
2 will generate --
3 THE WITNESS: Minority carrier
4 volt drift and diffusion currents,
5 which will also cancel out, and there
6 will be no net current of either
7 electrons or volts.
8 Q. (BY MR. WHITEHURST) And let's
9 stay together. My question is much simpler
10 than that, Dr. Banerjee. I've got a very
11 simple question.
12 Do you see the electric field
13 pointing in the upward direction, yes or no?
14 A. Yes, yes.
15 Q. Do you agree that that electric
16 field ends before the surface?
17 A. Yes.
18 Q. Do you agree that that electric
19 field ends before the active region?
20 A. In this case, yes.
21 Q. Now, we have talked about
22 holes. I know that we need to look at the

vector sum in order to determine net carrier movement. But looking just at the electric field shown here in Figure 3, can that electric field shown here in Figure 3 aid the movement of holes from the surface to the substrate?

MR. PAUL: Objection to form. Scope.

THE WITNESS: In this case, electric field that's pointing towards the surface will cause the holes to move via drift towards the surface.

Q. (BY MR. WHITEHURST) Would you agree with me that the electric field in Figure 3 pointing in an upward direction would not aid carrier movement of holes from the surface to the substrate, correct?

MR. PAUL: Objection to form. Scope.

THE WITNESS: That electric field will not aid carrier motion of holes via drift from the surface to

1 the substrate.
2 Q. (BY MR. WHITEHURST) Very
3 similar question. You agree that the
4 electric field pointing in an upward
5 direction in Figure 3 will not aid the
6 movement of holes from the active region to
7 the substrate?
8 MR. PAUL: Same objections.
9 THE WITNESS: This electric
10 field on the left-hand side of
11 curve -- left-hand side of the
12 vertical line on curve 24 will not
13 help holes move from the surface
14 towards the substrate in that degree.
15 Q. (BY MR. WHITEHURST) Can you
16 please explain why the electric field
17 pointing in the upward direction will not
18 make -- strike that.
19 Would you please explain why
20 the electric field shown in Figure 3 that
21 points in the upward direction will not aid
22 the movement of holes from either the surface

1 or the active region to the substrate?
2 MR. PAUL: Objection to form.
3 Scope. Relevance.
4 THE WITNESS: As shown in this
5 figure, this left-pointing electric
6 field towards the surface doesn't
7 extend -- doesn't extend all the way
8 to the surface or even to the vicinity
9 of the active field, so it will not
10 cause holes in that region to move
11 from the surface in the depth-wise
12 direction.
13 Q. (BY MR. WHITEHURST) So in
14 order to aid movement from this surface or
15 the active region, the electric field needs
16 to extend all the way into the active region
17 or to the surface, right?
18 MR. PAUL: Objection to form.
19 THE WITNESS: As shown, the
20 electric field is pointing to the
21 left. So if you're talking about
22 holes, the holes would tend to move

via drift to the left, even if the electric field extended all of the way to the surface.

Q. (BY MR. WHITEHURST) So the electric field shown in Figure 3 that points in an upward direction will not aid movement of holes from the surface or the active region to the substrate for two reasons: One, because the electric field does not extend to the surface or the active region; and, two, because holes move in the same direction of the electric field.

Did I get that right?

MR. PAUL: Objection to form. Scope.

THE WITNESS: Yes, that electric field doesn't extend all the way to the surface. Therefore, there cannot be any drift velocity of the holes due to that electric field.

And, furthermore, even if it did extend to the surface, it points

in the wrong direction and will cause the holes to move via drift towards the surface. But, remember, there is always an opposing diffusion part.

Q. (BY MR. WHITEHURST) You agree that the drift field will not aid movement of holes from the surface or the active region to the substrate for the two reasons that we discussed?

MR. PAUL: Same objections.

THE WITNESS: So if you -- once again, so that you're clear, if you just look at the electric field pointing to the left, that is your surface at a depth of about, I guess, what, about seven to ten microns. That does not extend as shown for surface. The drift velocity would be zero.

But even, hypothetically, if that field did extend to the surface, the vector is pointing in a direction

1 where the holes will drift towards the
2 surface, not away from the surface.
3 Q. (BY MR. WHITEHURST) Now, let's
4 stay with Figure 3, but turn to the electric
5 field that's to the right pointing in the
6 downward direction.
7 Do you see that?
8 A. Yes.
9 Q. Do you agree that the electric
10 field that's pointing in the downward
11 direction will not aid movement of holes from
12 the surface or the active region to the
13 substrate?
14 MR. PAUL: Objection to form.
15 Scope.
16 THE WITNESS: That electric
17 field points in the current direction.
18 It enabled holes to drift towards the
19 substrate, but it is too far away from
20 the active region, and therefore will
21 not have any impact in terms of drift
22 motion of the holes on the active

1 region towards the substrate.
2 Q. (BY MR. WHITEHURST) Now,
3 because the electric field shown to the right
4 of ten microns is too far from the surface in
5 the active region, it will not aid movement
6 of holes from the surface or the active
7 region to the substrate?
8 MR. PAUL: Objection to form.
9 Scope.
10 THE WITNESS: Will not aid
11 movement from the surface to the
12 substrate of the holes in the active
13 region due to the drift mechanism.
14 Q. (BY MR. WHITEHURST) Do you
15 remember me asking you about starting point
16 and ending point in Figure 1(b) of your
17 supplemental?
18 A. Yes.
19 Q. In order to aid movement from
20 the active region or the substrate, the
21 sub -- starting point needs to be in the
22 active region, correct?

1 MR. PAUL: Objection to form.
2 THE WITNESS: If you recall, I
3 said that you have -- you don't have
4 just one electron. You have a whole
5 bunch of electrons, which forms a
6 cloud of different electrons at
7 different locations. And they are not
8 static. They are executing random
9 Brownian motion.
10 So this -- will you repeat the
11 question? I lost track.
12 Q. (BY MR. WHITEHURST) The reason
13 the electric field in Figure 3 that points in
14 the downward -- strike that.
15 So when you look at the
16 electric field in Figure 3 that points in the
17 downward direction, it can't aid movement of
18 holes from the active region to the substrate
19 because to the extent it moves any holes in
20 the downward direction, these holes didn't
21 start in the active region, right?
22 MR. PAUL: Objection to form.

1 Scope.
2 THE WITNESS: So if you have --
3 as long as it's in the active region,
4 that particular hole would not see the
5 effect of this electric field pointing
6 to the right.
7 But that hole is not
8 stationary. It's bouncing around all
9 over the place due to random Brownian
10 motion and it's possible that at some
11 time, just because of this random
12 Brownian motion, that hole might
13 appear on the right-hand side of
14 vertical line N, where it sees
15 electric field, then they move. Okay?
16 But that's not a correct way to
17 view things, in my opinion, because --
18 THE REPORTER: That's what?
19 That's --
20 THE WITNESS: That's not the
21 correct viewpoint, in my opinion. One
22 doesn't look at the trajectory of

1 individual electrons or holes. You
2 should look at the elective ensemble
3 and what's happening to the center of
4 gravity, if you will, of the ensemble,
5 and that center of gravity will not --
6 that center of gravity of the
7 distribution that you're looking at is
8 in the active region, yeah, that will
9 not move away from the surface
10 towards -- towards the object.
11 Q. (BY MR. WHITEHURST) I just
12 want to make sure we're on the same page. I
13 think we are, but I just want to confirm.
14 So when you're trying to
15 determine whether an electric field will aid
16 carrier movement from the active region to
17 the substrate, you have to know more than
18 just the direction of the electric field.
19 You also need to know where the electric
20 field starts.
21 Did I get that right?
22 MR. PAUL: Objection to form.

1 THE WITNESS: Yes, you need to
2 know the direction and the spatial
3 location here the electric field is
4 existing in order to determine the
5 drift motion.
6 Q. (BY MR. WHITEHURST) And why do
7 you need to know the specific location of the
8 electric field?
9 A. Because this collective
10 ensemble is the center of gravity, or a part,
11 if you will, of this collective ensemble of
12 holes, it's sensitive to the direction,
13 magnitude, and whether there is a nonzero
14 electric field in that center point of this
15 ensemble, if you will.
16 Q. And I think we agree if the
17 electric field starts or ends below the
18 active region, it will not aid carrier
19 movement from the active region?
20 A. If the electric field isn't
21 present in the active region, it will not aid
22 carrier movement via the drift mechanism for

1 this ensemble of failures in the active
2 region.
3 Q. We spent a lot of time in your
4 declaration discussing majority carriers and
5 minority carriers.
6 Do you recall that?
7 A. Yes.
8 Q. I don't want to get into a
9 debate with you -- it's too late in the
10 day -- about majority and minority carriers,
11 but I want to ask a different question.
12 Did you read the specification
13 in order to see how majority and minority
14 carriers are used in the specification?
15 A. In the patents?
16 Q. Yes, sir.
17 A. I don't recall. I mean, the
18 terms, majority and minority carriers, are
19 well-known terms in the art, but I
20 didn't resort to the language of the
21 specifications.
22 Q. Now, I understand that, to you,

1 majority and minority carriers refers to
2 what's the majority or the minority carrier
3 in the well.
4 Did I summarize that fairly?
5 A. The majority carriers refer to
6 carriers that are provided by the dopant and
7 the other side is the minority carrier. If
8 you have a region where you have donors that
9 comes with the majority falls to the
10 minority.
11 Q. And I understand that that's
12 the position you have taken in your
13 declaration. My question is different.
14 My question is, did you read
15 Dr. Rao's specification to see how he used
16 majority carrier and minority carrier in his
17 specification?
18 MR. PAUL: Objection to form.
19 THE WITNESS: I read the
20 patents, but I can't remember sitting
21 here right now. If you have a
22 different definition that you can

point me to a section of the patents, then --

Q. (BY MR. WHITEHURST) Do you recall how Dr. Rao used the term "majority carrier" in his specification?

MR. PAUL: Objection to form.

THE WITNESS: I recall a figure in his patents, I believe on the cover page, in fact, where he shows these arrows drawing minority carriers away from the surface. I don't recall exactly what language he may have used in the specification.

Q. (BY MR. WHITEHURST) Do you recall how he used the term "minority carrier" in his specification?

A. As I said, I see minority carriers in these patents here, I see minority carriers listed on the figure on the cover page and being pulled away from the surface. I don't recall how he used those terms in the classification.

1 Q. Do you think it's relevant how
2 Dr. Rao used the terms "majority carrier" and
3 "minority carrier" in his specification?
4 MR. PAUL: Objection to form.
5 THE WITNESS: Yes, it is
6 relevant, but I don't believe those
7 were the same terms that are in
8 dispute. So, once again, if you show
9 me specific paragraphs, I can take a
10 look at it.
11 Q. (BY MR. WHITEHURST) So you
12 stated in your declaration that in a p-well,
13 a majority carrier is a p-type dopant; is
14 that right?
15 A. For the carriers of the holes
16 or electrons, the p-well is doped with
17 acceptors and that will create majority
18 carrier holes.
19 Q. Now, if Dr. Rao used the terms
20 the other way around in his specification,
21 would you want to know that?
22 MR. PAUL: Objection to form.

1 THE WITNESS: Sure.
2 Q. (BY MR. WHITEHURST) And why
3 would you want to know how Dr. Rao used the
4 terms "majority" and "minority carrier"?
5 A. You know, you interpret the
6 same language in the Rao patents in light of
7 the specifications.
8 Q. And why do you interpret the
9 claims in light of the specification?
10 MR. PAUL: Objection to form.
11 THE WITNESS: I'm not a lawyer,
12 but that's how they do it by my
13 counsel in prior cases also.
14 Q. (BY MR. WHITEHURST) When you
15 were forming your opinions, did you read the
16 specification to see how Dr. Rao used the
17 terms "majority" and "minority carrier"?
18 MR. PAUL: Objection, form.
19 THE WITNESS: I did read the
20 patents. I believe all of the
21 specifications are exactly the same or
22 substantially the same. The claims

are different.

Q. (BY MR. WHITEHURST) Now, in your declaration, you use the term "charge carrier," don't you?

A. Yes, I think I did.

Q. And what is a charge carrier?

A. Charge carrier is a carrier that is mobile and can result in a current and the two flavors, negative electrons or positive holes.

Q. Is the charge carrier -- okay.

Do you know what a MOSFET is?

A. Yes.

Q. And do you know what the source in a MOSFET is?

A. Yes.

Q. And do you know what the drain in a MOSFET is?

A. Yes.

Q. And what do you call the holes or electrons that travel from the source to the drain?

1 A. Those are the charge carriers
2 that allow current to flow.
3 Q. Right.
4 THE REPORTER: Allow what?
5 THE WITNESS: Allow current to
6 flow.
7 THE REPORTER: Okay, current.
8 THE WITNESS: Current.
9 THE REPORTER: Okay.
10 MR. PAUL: Alan, we have been
11 going for about an hour. Do you have
12 much longer or should we --
13 MR. WHITEHURST: I got -- do
14 you want to take a break now? I was
15 trying to wrap up this line of
16 questions, but if you would like to
17 take a break, it's fine with me.
18 Q. (BY MR. WHITEHURST) Do you
19 want me to finish up this line or --
20 Dr. Banerjee, do you want to keep going or
21 take a break?
22 A. How much longer are you

1 thinking of going?
2 Q. I can wrap this up in ten
3 minutes, five.
4 A. The whole thing?
5 Q. Oh, no, this line of questions.
6 A. Oh, this line of questions.
7 MR. PAUL: So why don't we take
8 a short break then.
9 MR. WHITEHURST: Okay.
10 THE VIDEOGRAPHER: Going off
11 the record, the time is 4:29.
12 (Recess from 4:29 p.m. to
13 4:43 p.m.)
14 THE VIDEOGRAPHER: We're back
15 on the record, the time is 4:43.
16 Q. (BY MR. WHITEHURST)
17 Dr. Banerjee, welcome back. You know, like
18 we did earlier, I think it's helpful to put
19 everything into perspective with a picture.
20 And earlier you mentioned Figure 5B, I
21 believe it was, of Dr. Rao's invention.
22 At this time I'm going to mark

as Exhibit 3 a copy of a US 11,121,222. This is the '222 patent. The copy that I'm looking at has been marked Cirrus Exhibit 1001.

MR. WHITEHURST: Billy, hopefully you have the copy that I sent you.

(Exhibit 3 marked)

Q. (BY MR. WHITEHURST) Dr. Banerjee, do you have a copy of the '222 patent in front of you?

A. Yes, yes.

MR. WHITEHURST: Just so we're all on the same page, Mr. Videographer, if we could please pull up Figure 5B of the '222 patent. If you would go to page 12 of 17.

THE VIDEOGRAPHER: Okay.

MR. WHITEHURST: If we could please blow this up for the witness.

Q. (BY MR. WHITEHURST) Well, first of all, before we zoom in,

1 Dr. Banerjee, do you see on the screen in
2 front of you where it says Figure 5B?
3 A. Yes.
4 Q. Do you see where it says this
5 is a CMOS substrate for a DRAM? I'm not
6 reading the entire --
7 A. Yeah.
8 Q. Okay. If we could zoom in just
9 on the figure at the top.
10 A. Yes.
11 Q. Does this show a MOS device?
12 A. It shows a DM-cell, which
13 includes a MOS transistor on the left and a
14 MOS capacitor on the right.
15 Q. So where it says "Access
16 Transistor," would that be MOS device?
17 A. They are both MOS devices. I
18 think the MOS spec, the structure, the
19 storage capacitor is a MOS capacitor.
20 Q. So on the left, where it says
21 "Access Transistor," we're looking at a
22 MOSFET?

1 A. Yes.
2 Q. Can you tell me whether this is
3 an NMOS or a PMOS transistor?
4 A. NMOS.
5 THE REPORTER: N, like the
6 letter N?
7 MR. WHITEHURST: I'm going to
8 help out our court reporter. I
9 believe the witness said NMOS, which
10 is capital N-M-O-S.
11 THE REPORTER: Okay.
12 MR. WHITEHURST: As opposed to
13 a PMOS, which would be capital
14 P-M-O-S.
15 Q. (BY MR. WHITEHURST) So,
16 Dr. Banerjee, let me re-ask my question.
17 A. Okay.
18 Q. Figure 5B, where it says
19 "Access Transistor," this is an NMOS
20 transistor?
21 A. Yes.
22 Q. And would you agree that --

1 well, let me back up. Let me set the stage
2 properly.
3 Do you see two semicircles, for
4 lack of a better term?
5 A. Yes.
6 Q. And do you see where it says
7 "n," and I believe that's a typographical
8 error, where it says "t"?
9 A. I think they meant n+.
10 Q. What does n+ mean?
11 A. Sorry?
12 Q. What does n+ mean?
13 A. N means n-type dopants doped
14 with donors and the plus sign means very high
15 levels of doping.
16 Q. So on the left, there is a
17 region that is heavily doped with n-type
18 dopants, correct?
19 A. Yes.
20 Q. And on the right is another
21 region that's also heavily doped with n-type
22 dopants?

A. Yes.

Q. And these presumably should have been labeled "n+"?

A. Yes.

Q. Can you tell me which of these is the force of the NMOS transistor?

A. So which is the source, which is the drain depends on how you bias the thing. The source is grounded. And this -- I used to work on this kind of structure when I was at TI. I'm familiar with every aspect of it.

So in this case, it could be the left-hand side n+ would be grounded if it's a MOSFET, and that would be considered to be the source and you would apply a positive voltage to the drain if you just forget the MOSFET alone. But you could flip the polarities.

THE REPORTER: Wait, I couldn't -- I didn't -- couldn't tell what the last sentence was.

1 THE WITNESS: You could flip
2 the polarities. So basically the
3 carriers flow from the source through
4 the channel into the drain.
5 Q. (BY MR. WHITEHURST) Why do
6 carriers flow from the source through the
7 channel into the drain?
8 A. So in this case, although it's
9 not shown, generally speaking, this NMOS
10 would be made in a p-type channel. The
11 central part would be doped with acceptors.
12 You would have to turn the transistor on by
13 applying a gate voltage at the top in excess
14 of what's called a special voltage. That
15 will create what's called an inversion there
16 of electrons near the top surface connecting
17 the n+ source, the n+ drain, and then you
18 apply a positive voltage to the drain. That
19 will pull the negatively charged electrons
20 from the source to the channel into the
21 drain.
22 Q. Let me make sure I understand

1 this correctly. So Figure 5B shows an NMOS
2 transistor, correct?
3 A. Yes.
4 Q. On the left is a source that is
5 heavily doped with n-type dopant?
6 A. Yes, if -- yeah, if that
7 electrode was grounded.
8 Q. And then on the right is a
9 heavily doped n-type drain?
10 A. Yes, which would generally be n
11 with a positive voltage.
12 Q. And in between the source and
13 the drain would be p-type doping?
14 A. Generally, though you could
15 have other polarity also.
16 Q. And when the transistor is
17 turned on, electrons flow from the source on
18 the left to the drain on the right?
19 A. Yes.
20 Q. So the electrons move from the
21 source towards the drain?
22 A. In a MOSFET. But in this

1 particular structure, it's used as an access
2 transistor in a DRAM cell. In this case,
3 actually, the electrons flow back and forth,
4 depending on whether they are writing to the
5 storage capacitor or reading of the storage
6 capacitor. But I have given you a
7 description of -- the simplest description of
8 just the MOSFET.
9 Q. Now, in this NMOS transistor
10 shown in Figure 5B, electrons move back and
11 forth between the source and the drain,
12 correct?
13 A. If you use the transistor as an
14 access transistor in a DRAM, yes.
15 Q. Now, I believe you said when
16 you build a MOSFET, you have back-to-back p-n
17 junctions.
18 Did I get that correct?
19 A. Yes.
20 Q. Is it possible for the p-type
21 dopants to move into the source or the drain?
22 MR. PAUL: Objection to form.

1 THE WITNESS: During operation
2 or during fabricating?
3 Q. (BY MR. WHITEHURST) During
4 operation.
5 A. No, dopants don't move at room
6 temperature.
7 Q. So the holes do not move into
8 the source or the drain, do they?
9 A. Are you talking about the
10 dopants or the carriers?
11 Q. The carriers.
12 A. Carriers can move, but the
13 dopants don't move.
14 Q. Let's talk about the charge
15 carriers. In this NMOS transistor, the
16 electron carriers will move back and forth
17 between the source and the drain, correct?
18 A. In this particular application
19 where the NMOS transistor is being used as an
20 access transistor, you get electron charges
21 back and forth between the storage capacitor
22 and what's called the bridge line, which is

not shown, that would be connected on the left-hand side.

Q. And just so we're clear, in what's shown in Figure 5B, the electrons will move back and forth between the source and the drain as the transistor is turned on and off?

A. That's correct. That's a dominant current mechanism.

Q. Please explain why it's the electrons that are moving back and forth between the source and the drain when it's turned on and off.

A. Okay. So the middle part of the channel is typically doped p-type and that's what gives you the two back-to-back p-n junctions. And if you didn't do anything to the gate voltage, one of those p-n junctions would be reverse bias and the transistor would be off, regardless of the voltage already applied to the drain, except for tiny amounts of p-n junction leakage

1 currents.
2 But then if we apply a positive
3 voltage to the gate, since light charges with
4 each other, that would push away the mobile
5 majority carrier holes away from the surface
6 in the middle part of the channel and, at
7 some point, not only will it push away the
8 majority carrier holes --
9 THE REPORTER: Not only will
10 it -- not only will it --
11 THE WITNESS: Push away
12 majority carrier holes in the p-type
13 channel and start attracting the
14 minority carrier electrons to the
15 p-type channel, and that forms what is
16 called an inversion layer of electrons
17 connecting the source to the drain and
18 that's when the transistor can be
19 turned on.
20 Q. (BY MR. WHITEHURST) So when
21 the NMOS transistor is turned on, a channel
22 will form between the source and the drain,

1 correct?
2 A. An inversion layer of electrons
3 will form in the channel region between the
4 source and the drain.
5 Q. Now, in an NMOS transistor,
6 when a channel forms between the source and
7 the drain, which charge carrier is moving
8 from the source to the drain?
9 A. It's electrons.
10 Q. Please explain why when the
11 channel forms, the electrons move from the
12 source to the drain.
13 A. So here you have to apply two
14 voltages. You apply a positive gate voltage
15 at the top. That's going to attract
16 electrons towards the surface, but they
17 cannot keep flowing because in between the
18 gate electrode and the surface of the
19 substrate, you have electrical insulator. So
20 the minority carrier electrons will flow
21 towards the surface, but they cannot keep
22 going because they are blocked by an

1 electrical insulator.
2 Then if you apply a voltage to
3 the drain, that creates a lateral electric
4 field along the channel and that's the
5 electric field which will actually cause the
6 electrons to flow from the source, which is
7 generally held at ground potential to the
8 drain, which is held at a positive voltage.
9 Q. And when the channel forms
10 between the source and the drain, what
11 happens to the holes?
12 A. So when you push the holes away
13 by applying a positive gate voltage, you
14 create a diffusion region and the holes do
15 not have any significant role except for a
16 tiny amount of p-n junction leakage current
17 in one of the reverse biased p-n junction.
18 And that is --
19 THE REPORTER: In one of the --
20 THE WITNESS: The reverse bias
21 p-n junction. And in this case, that
22 is the drain channel p-n junction.

1 But those currents are always a
2 magnitude smaller. The dominant
3 current flow in an NMOS is electrons
4 flowing from the source to the drain.
5 And because they have a negative
6 charge, the current vector point is in
7 the opposite direction.
8 Q. (BY MR. WHITEHURST) Is it fair
9 to say that when the transistor is turned on,
10 it's the electrons that are moving from the
11 source to the drain?
12 A. In an NMOS, that's true. In a
13 PMOS, it's the holes.
14 Q. Let's stay with NMOS for now.
15 And when you turn the
16 transistor on and off, the holes are going up
17 and down; is that correct?
18 A. Yes. So when you're turning it
19 on, you're pushing the holes down, but they
20 don't flow except for tiny, tiny amounts of
21 leakage currents.
22 Q. So for the most part, the holes

are not traveling between the source and the drain, correct?

A. That's correct. That's correct.

Q. And when you look at the channel that forms between the source and the drain, there are a lot more electrons than holes, correct?

A. That's correct.

Q. Would you agree that the majority charge carrier is the electron?

A. The majority carrier is electrons in the source and the drain because, as I told you, the definition of majority carriers is the carrier type that is provided by the dopants.

But I do not agree that in the p-type channel, electrons are the majority carriers. Holes are the majority carriers.

Q. Okay. Let's take this one step at a time. Let me back up.

We've got an NMOS transistor

with electrons in the source and electrons in the drain, correct?

A. Yes.

Q. And you've got lots of holes in the p-well between the source and the drain?

A. That's correct.

Q. Now, in your report, you say the majority carrier in this situation is a hole?

A. The majority carrier in the channel is a hole.

Q. When it's off?

A. Whether it's a majority carrier or minority carrier does not depend on if the transistor is on or off. It depends on what the working type is. Okay?

Now, when you turn the thing on, you indeed have more electrons at the surface than holes compared to when it's off, but that does not change what's called a majority carrier or a minority carrier in a certain location of the semiconductor.

Q. Okay. So in your declaration, you say the majority carrier is the hole, right?

A. In the channel region, yes, p-type channel or p-type well.

Q. And you say the minority carrier is the electron, correct?

A. In the channel region or the well region. And, by the way -- by the way, all that I'm saying is they are entirely consistent with the figure as drawn in this patent and as would be applicable for a DRAM. So I can get into those details if you want.

Q. So you understand that -- do you see a solid line going left to right?

A. Yes.

Q. Do you understand that the source and drain are formed in a well region?

A. Yes.

Q. Is that well region a p-well?

A. In this case, yes.

Q. So Figure 5B shows an NMOS

1 transistor in the p-well, correct?
2 A. That's correct, yes.
3 Q. And it's your position in your
4 declaration that when you have an NMOS
5 transistor in a p-well, the majority carrier
6 is a hole and the minority carrier is an
7 electron?
8 A. The majority carrier is a hole
9 and minority is electron in the p-well, but
10 in the n+ --
11 THE REPORTER: Wait, wait, I
12 lost it. I lost it after --
13 THE WITNESS: But in the n+ --
14 THE REPORTER: The majority --
15 THE WITNESS: Yeah, in the
16 p-well, the majority carriers are
17 holes and the minority carriers are
18 electrons. But in the n+ source and
19 drain, majority carriers are
20 electrons, holes are the minority
21 carriers.
22 Q. (BY MR. WHITEHURST) Okay. So

1 you agree that when the channel is formed,
2 the majority carrier is an electron?
3 A. Majority carrier where? You
4 have to specify which location and what the
5 doping type is.
6 Q. Okay.
7 A. I guess for an answer, even
8 when the channel is formed, even though you
9 have a preponderance of electrons in the
10 channel, that's considered to be an inversion
11 region. So even the "on" state majority
12 carrier electrons in the dope n-type source
13 and drain, while in the p-type channel, the
14 majority carriers are holes, minority
15 carriers are electrons.
16 Q. So it's your position that
17 regardless of whether the transistor is
18 turned on or off, that in Figure 5B, the
19 majority carrier is always the hole and the
20 minority carrier is always the electron?
21 A. In the well region, right.
22 That's what you're asking, counsel, right?

1 Q. Is it your position that the
2 majority carrier or minor carrier will change
3 depending on where you are in the
4 semiconductor device?
5 A. Yes. It will depend on what
6 the doping type is in that region. If the
7 doping type is donors, electrons have the
8 majority, holes are the minority. If the
9 doping type is acceptors, holes are the
10 majority, electrons are the minority. And
11 that's not my position. That's accepted
12 terminology.
13 Q. Okay. I think I understand
14 what you're saying.
15 So instead of defining
16 "majority carrier" and "minority carrier" so
17 that it would be the same throughout the
18 source and the drain and the p-well, you
19 define them differently for the source, the
20 drain and the p-well, correct?
21 MR. PAUL: Objection to form.
22 THE WITNESS: I define them

1 differently because they are doped
2 differently.
3 Q. (BY MR. WHITEHURST) Okay.
4 A. You always define majority
5 carrier depending on the dopant type.
6 Q. That's your position.
7 Now, you -- instead of defining
8 "majority carrier" and "minority carrier" so
9 that they would have the same meaning in the
10 source, the drain or the p-well, you picked
11 definitions that will change whether you're
12 in the source, the drain or the p-well?
13 MR. PAUL: Objection,
14 foundation. Mischaracterizes.
15 THE WITNESS: Majority
16 carriers, once again, are defined as a
17 carrier type provided by the dopant.
18 And if you have different doping types
19 in the different regions, majority
20 carriers will be different in the
21 doping regions.
22 Q. (BY MR. WHITEHURST) And we're

1 just going to have to agree to disagree. I'm
2 just trying to understand your position.
3 So one way to define "majority
4 carrier" and "minority carrier" would be to
5 pick a definition that would be the same for
6 the source, the drain and the p-well.
7 Do you understand me so far?
8 A. Yes.
9 Q. And another way would be to
10 define them so that "majority carrier" means
11 one thing and the source and the drain and a
12 different thing in the p-well.
13 Do you understand me so far?
14 A. Yes.
15 Q. So option 1 is you pick
16 definitions for "majority carrier" and
17 "minority carrier" that would be the same
18 whether you're talking about the source, the
19 drain or the well. That's option 1.
20 Do you follow me?
21 A. Yes.
22 Q. And option 2 would be you use

1 different definitions whether you're in the
2 source, the drain or the p-well.
3 Do you follow me?
4 A. Yes. That's my position and
5 that's consistent with this figure.
6 Q. And that's what you did. You
7 picked option 2, you didn't pick option 1?
8 MR. PAUL: Objection,
9 mischaracterizes testimony.
10 Q. (BY MR. WHITEHURST) Is that a
11 fair assumption?
12 A. Yeah, I think that's a fair
13 assumption, yes.
14 Q. You picked option 2 where the
15 majority carrier and the minority carrier
16 will change depending where you are in
17 Figure 5B. That's the option you picked?
18 A. I think the definition of
19 "majority carriers" is the carriers provided
20 by the dopant. And in this case, since the
21 source and the drain have donors that comes
22 from the majority carriers there, since the

1 well is p-type -- is a doped p-type, those
2 are the majority carriers.
3 Q. Okay. Now, when you look at
4 this NMOS transistor, it's electrons flowing
5 between the source and the drain, correct?
6 A. So, once again, in this
7 structure, it's not just the NMOS transistor.
8 It's being used as an access transistor
9 between the storage MOS capacitor on the
10 right, and on the left-hand side, it's
11 connected to what's called the bit line. I
12 can tell you exactly what the figure is.
13 Q. I understand. I'm just -- I'm
14 trying to -- I'm trying to use our time
15 efficiently so you and all of your attorneys
16 can get out of there, and I'm trying to do
17 the same.
18 A. Sure. I can explain this
19 figure in great detail if you allow me one
20 minute.
21 Q. Well, let me ask the question
22 and you answer it and that's -- that's what

1 we're going to do here.
2 Now, when you look at an NMOS
3 transistor in a p-well, like we see in
4 Figure 5B, you agree that an electron will
5 flow from the source to the drain.
6 Do you agree with that part?
7 A. I agree with that part, but in
8 this case, the source and the drain are
9 getting -- during read and write operation of
10 the cell.
11 Q. So let me -- let me make my
12 question more clear.
13 In an NMOS transistor in a
14 p-well, it's electrons that are moving back
15 and forth between the source and the drain,
16 not the holes?
17 A. That's correct.
18 Q. Now, when -- can you please
19 direct your attention to column 3?
20 A. Okay.
21 Q. And you can see column 3,
22 line 36, we're talking about Figures 5A, 5B

1 and 5C.
2 Do you see that?
3 A. Yes.
4 Q. So here in column 3, we're
5 talking about the same Figure 5B that we have
6 been looking at, correct?
7 A. Yes.
8 Q. And then if we go down to
9 line 64, continuing on line 65 and line 66,
10 will you please read aloud the sentence that
11 begins "the graded dopant"?
12 A. "The graded dopant can also be
13 implemented in surface channel MOS devices to
14 accelerate majority carrier towards the
15 drain."
16 Q. And you testified that, in
17 Figure 5B, it's the electrons that are moving
18 back and forth between the source and the
19 drain, not the holes.
20 Do you recall that?
21 A. Yes.
22 Q. So when Dr. Rao used the term

1 "majority carriers" to describe Figure 5B and
2 he is talking about the majority carriers
3 moving back and forth between the source and
4 the drain, he was referring to the electrons?
5 MR. PAUL: Objection to form.
6 THE WITNESS: If it's an NMOS,
7 he's referring to electrons.
8 Q. (BY MR. WHITEHURST) And that's
9 because in the NMOS transistor in a p-well
10 that's shown in Figure 5B, electrons move
11 back and forth between the source and the
12 drain, not the holes, correct?
13 A. Could you repeat that? Sorry.
14 Q. And that's because in the NMOS
15 transistor in a p-well that's shown in
16 Figure 5B, electrons move back and forth
17 between the source and the drain, not the
18 holes, correct?
19 A. Yes.
20 Q. And when the specification
21 says, in line 65 of column 3, that the
22 majority carriers move towards the drain,

it's the electrons that are moving towards the drain, right?

A. Yes.

MR. PAUL: Objection to form.

MR. WHITEHURST: Thank you. I have no further questions. I pass the witness.

Are we done?

MR. PAUL: So we can take a break for --

MR. WHITEHURST: We don't need to take a break. We're good. You can't talk to the witness. Let's go.

MR. PAUL: We're going to take a break.

MR. WHITEHURST: I don't know why. It's a little suspect to me. But I passed the witness and we just took a break.

MR. PAUL: We'll be back in a half hour, Alan.

MR. WHITEHURST: What's that?

MR. PAUL: Half hour.

THE VIDEOGRAPHER: Going off the record, the time is 5:16.

MR. WHITEHURST: No, no, no Billy, I didn't agree to go off the record.

THE VIDEOGRAPHER: Oh, my apologies. All right. Let me take us back on.

MR. WHITEHURST: We can stay on the record.

THE VIDEOGRAPHER: Hold on one moment while I take us back on. My apologies.

MR. WHITEHURST: I'm sorry, counsel, what did you ask?

THE VIDEOGRAPHER: Back on the record, the time is 5:16.

MR. PAUL: No, we're going off the record, Alan. It's a half hour we will be back, Alan.

MR. WHITEHURST: How long do

1 you need, five minutes?
2 MR. PAUL: Half hour.
3 MR. WHITEHURST: Why do you
4 need a half hour?
5 MR. PAUL: I don't think we
6 need to answer that.
7 MR. WHITEHURST: Well --
8 MR. PAUL: You took time -- you
9 took time during the last deposition.
10 We're going to do the same.
11 MR. WHITEHURST: Counsel, do
12 you -- are you planning to talk to the
13 witness during the 30 minutes? Can I
14 ask that on the record? Do you intend
15 to talk to the witness during the 30
16 minutes? I don't understand why we
17 can't finish.
18 Okay. We can stay on the
19 record. And let the record reflect
20 counsel and the witness are leaving
21 the room and apparently they need a
22 30-minute break.

1 We can go off the record now.
2 THE VIDEOGRAPHER: Going off
3 the record, the time is 5:17.
4 (Recess from 5:17 p.m. to
5 6:01 p.m.)
6 THE VIDEOGRAPHER: We're back
7 on the record, the time is 6:01.
8 EXAMINATION
9 BY MR. PAUL:
10 Q. Good evening, Dr. Banerjee.
11 A. Good evening.
12 Q. Just a few follow-up questions
13 about the questions you were asked today.
14 Do you recall being asked about
15 the analysis you performed and the
16 conclusions that you provided for purposes of
17 the IPRs?
18 A. Yes.
19 Q. Okay. And if you could go to
20 your supplemental declaration, do you have a
21 copy of that with you?
22 A. Yes.

Q. And if you can go to page 2, do you see the heading "Summary of Opinions"?

A. Yes.

Q. Okay. And if you could go under that heading to paragraph 8.

A. Yes.

MR. WHITEHURST: Objection, scope. I never asked him about paragraph 8.

Q. (BY MR. PAUL) Okay. And is this part of the summary of opinions that you reached?

A. Yes.

Q. Okay. And could you please read the first sentence?

A. "The direction --"

MR. WHITEHURST: You've got to give me a chance to object, counsel. Objection, scope. I never asked him about paragraph 8. And objection, leading. You're trying to read into the record something from

his declaration I didn't ask him about.

MR. PAUL: Okay.

MR. WHITEHURST: That's improper and it's not evidence. So objection, scope, leading.

Q. (BY MR. PAUL) You can proceed.

A. "The direction of the slope of the graded dopant concentration is sufficient to determine whether the static electric fields created by the graded dopant concentration will aid the movement of carriers in a given direction due to drift. The carriers (holes or electrons) in the conduction band are in constant motion, and the static electric field causes them to drift. At equilibrium (i.e., when the device is off), there cannot be a net movement of carriers. As a result, the movement of carriers due to drift in one direction is compensated by diffusion of those carriers in the opposite direction."

1 Q. And do you agree with the --
2 are these your opinions?
3 A. Yes.
4 Q. And do you stand by them?
5 MR. WHITEHURST: Objection --
6 counsel, you've got to give me a
7 chance to object.
8 Objection, scope, leading. You
9 didn't even ask him a question. You
10 just had him read the declaration and
11 asked whether he agreed.
12 MR. PAUL: Okay.
13 MR. WHITEHURST: Objection,
14 scope, leading. This is not a proper
15 recross.
16 MR. PAUL: Okay. You can
17 limit -- you can limit your objections
18 to a single word as well, Alan.
19 Q. (BY MR. PAUL) So as I was
20 saying, what did you mean when you
21 mentioned -- when you were referring to --
22 strike that.

When you referred to the movement of carriers in a given direction due to drift, do you see that?

A. Yes.

Q. Why are you referring to movement of carriers in a given direction due to drift?

MR. WHITEHURST: Objection, scope, misleading.

THE WITNESS: The patent is talking about built-in electric fields that can be created by dopant gradients. Electric fields cause drift of the carriers and which direction they will drift depends on whether it's downward sloping or upward sloping.

Q. (BY MR. PAUL) And is drift a form of carrier movement?

A. Yes.

MR. WHITEHURST: Objection, scope, leading.

Q. (BY MR. PAUL) Okay. And do you recall being asked a series of questions earlier today about three different categories of force components?

A. Yes.

Q. Okay. And if you could confirm my memory -- the accuracy of my memory here, is the first category that you mentioned periodic crystalline potential?

A. Yes.

Q. And with respect to that first category of force component, did you -- did you -- does that factor hinge on whether or not you're dealing with silicon versus some other semiconductor type?

MR. WHITEHURST: Objection, leading.

THE WITNESS: Different semiconductors will have different --

THE REPORTER: Wait, I can't hear you. I can't hear you, Doctor.

THE WITNESS: Oh, sorry.

1 Different -- different
2 semiconductors will have different
3 periodic potential leading to
4 different effective masses. That's
5 something, in fact, the main issue,
6 which is the static field created by
7 the doping gradient, aiding drift.
8 Q. (BY MR. PAUL) Okay. And just
9 to be clear, if you are dealing with silicon,
10 is that a fixed parameter or is it a
11 parameter that changes?
12 A. It's a fixed parameter.
13 Q. Okay. Did you need to make any
14 measurements for any category 1 forces in
15 order to arrive at the conclusions --
16 A. No.
17 Q. -- you came up with in this
18 matter?
19 MR. WHITEHURST: Counsel, you
20 have got to give me a chance to
21 object.
22 Objection, scope, leading. You

1 basically told him the answer in the
2 question. Objection, leading.
3 MR. PAUL: I disagree with your
4 characterization and please limit
5 your -- your objections.
6 MR. WHITEHURST: Why don't you
7 re-ask the question and I'll object.
8 You guys were talking over one
9 another.
10 Q. (BY MR. PAUL) Okay. Did you
11 need to make any measurements for any
12 category 1 forces in order to arrive at the
13 conclusions you reached in these proceedings?
14 MR. WHITEHURST: Objection,
15 scope, leading.
16 THE WITNESS: No, I did not.
17 Q. (BY MR. PAUL) And why not?
18 A. Because the patent talks about
19 these long -- these long range electric
20 fields created by doping gradients and that
21 is not impacted by the different periodic
22 forces.

Q. Okay. And I believe you mentioned that the second category of force components includes an externally applied fields or doping electric fields; is that accurate?

A. Yes.

Q. Okay. And with respect to doping electric fields, does that include electric fields due to dopant concentration variations?

A. Yes.

Q. And is that force component addressed in your supplemental declaration?

A. Yes.

Q. Okay. Do you recall testifying earlier about thermoelectric temperature effects?

A. Yes.

Q. Okay. And does thermoelectric temperature effects, does that affect whether or not carriers will move via drift due to the dopant electric field created by a graded

1 dopant concentration?
2 MR. WHITEHURST: Objection,
3 scope, leading.
4 THE WITNESS: No, it will not.
5 Q. (BY MR. PAUL) Okay. And,
6 finally, I believe the third category of
7 force component that you mentioned had to do
8 with random collisions or scattering; is that
9 right?
10 A. Yes.
11 Q. And do you recall testifying
12 that that category affects mobility, which,
13 in turn, affects resistivity?
14 A. Yes.
15 Q. Okay. And did you address
16 resistivity in your supplemental declaration?
17 A. Yes.
18 Q. Okay. And, briefly, does the
19 resistivity affect whether or not carriers
20 will move via drift due to a dopant electric
21 field created by a graded dopant
22 concentration?

1 MR. WHITEHURST: Objection,
2 leading.
3 THE WITNESS: Resistivity will
4 not impact whether the carriers will
5 move via drift. But I -- as I
6 mentioned during my deposition, it
7 will impact the speed at which they
8 move.
9 Q. (BY MR. PAUL) Okay. And do
10 the claims at issue in these proceedings call
11 for any particular speed of carrier movement?
12 MR. WHITEHURST: Objection,
13 leading.
14 THE WITNESS: They do not.
15 MR. WHITEHURST: Scope as well.
16 Q. (BY MR. PAUL) Do you recall
17 being asked questions about one's ability to
18 measure movement by applying a battery and
19 using an ammeter?
20 A. Yes.
21 Q. And did you need to apply a
22 battery to any devices or use an ammeter in

order to arrive at any of the conclusions you made regarding the challenged claims?

MR. WHITEHURST: Objection, leading.

THE WITNESS: No, I did not.

Q. (BY MR. PAUL) And -- and why not?

A. Because the claims refer to a built-in electric field because of the dopant gradient. When you apply a battery that's creating external fields --

THE REPORTER: Wait, after gradient.

THE WITNESS: Yeah. So when you apply external voltages, that creates external fields and leads to a net current that can be measured with an ammeter, but that's not the subject matter of these patents.

Q. (BY MR. PAUL) And why is that not the subject matter of this patent -- these patents?

1 MR. WHITEHURST: Objection,
2 leading.
3 THE WITNESS: Because these
4 patents are talking about the built-in
5 field -- internal built-in field
6 created by doping gradient aiding the
7 movement of minority carriers, not
8 what happens if you have additional
9 external fields.
10 Q. (BY MR. PAUL) And, very
11 briefly, do you also recall being asked
12 questions about the ability to measure the
13 strength of an electric field using a volt
14 meter?
15 A. Yes.
16 Q. Did you need to use a volt
17 meter in order to arrive at any of the
18 conclusions you made in these proceedings?
19 MR. WHITEHURST: Objection,
20 leading.
21 THE WITNESS: No, I did not.
22 Q. (BY MR. PAUL) And why did you

not need to use a volt meter?

MR. WHITEHURST: Objection, leading.

Q. (BY MR. PAUL) Is it for the same reasons that you just provided or is it for different reasons?

A. It's the same reasons that I discussed. That is, anytime you have a doping gradient that necessarily creates a built-in electric field to necessarily aid the movement of carriers, minority carriers down the doping gradient.

Q. Were you -- were you finished with your answer?

A. Yes.

Q. Okay. Do you recall being asked a series of questions about the presence of other potential electric fields?

A. Yes.

Q. And do you recall some questions specifically about other electric fields due to the gate oxide or the gate

electrode?

A. Yes.

Q. Okay. Just as a preliminary matter, do any of the claims at issue that you reviewed here for this -- in these proceedings talk about electric fields induced by gate oxide?

A. No.

MR. WHITEHURST: Objection, leading.

Q. (BY MR. PAUL) Do any of the claims at issue here talk about electric fields induced by gate electrodes?

MR. WHITEHURST: Objection, leading.

THE WITNESS: No.

Q. (BY MR. PAUL) Does the specification talk about electric fields due to gate oxide or gate electrodes?

MR. WHITEHURST: Objection, leading.

THE WITNESS: No.

Q. (BY MR. PAUL) In your review, did you review the file history of the asserted patents --

A. Yes.

Q. -- in formulating your opinions?

A. Yes.

MR. WHITEHURST: Counsel, objection, scope. I didn't ask him about the file history. I don't know why you think this is proper.

Q. (BY MR. PAUL) And in your review of the file history, did you encounter any discussion about electric fields due to gate oxide or gate electrode?

A. No.

Q. Does the conclusions that you reached in this case, are they affected by the presence of electric fields due to gate oxide or gate electrodes?

MR. WHITEHURST: Objection, leading.

1 THE WITNESS: No.
2 Q. (BY MR. PAUL) Why are they not
3 affected by electric fields due to gate oxide
4 or gate electrodes?
5 MR. PAUL: Objection, leading.
6 THE WITNESS: All the claims
7 are talking about electric fields
8 created by doping gradient. Gate
9 oxide and gate electrodes are a
10 different matter altogether.
11 THE REPORTER: Gate oxide
12 and --
13 THE WITNESS: And gate
14 electrodes are a different matter.
15 Q. (BY MR. PAUL) Does the drift
16 of carriers due to the built-in field created
17 by a graded dopant concentration, is that
18 altered by the presence of other fields,
19 potential fields stemming from gate oxide or
20 gate electrodes?
21 MR. WHITEHURST: Objection,
22 leading.

1 THE WITNESS: No, they are not.
2 Q. (BY MR. PAUL) Did you need
3 to -- strike that.
4 Do you recall being asked a
5 series of questions about other hypothetical
6 scenarios in which multiple other electric
7 fields may be present?
8 A. Yes.
9 MR. WHITEHURST: Objection,
10 leading.
11 Q. (BY MR. PAUL) As part of the
12 analysis you performed in arriving at your
13 conclusions, did you need to add up different
14 electric field vectors in order to reach your
15 conclusions regarding the challenged claims?
16 MR. WHITEHURST: Objection.
17 THE WITNESS: No, I did not.
18 Q. (BY MR. PAUL) Did you need to,
19 for purposes of arriving at your conclusions
20 for the challenged claims, need to subtract
21 one electric field vector from another
22 electric field vector?

1 A. No, I did not because nothing
2 in the patents --
3 MR. WHITEHURST: Objection,
4 leading. Objection, leading.
5 THE WITNESS: The patents are
6 not dealing with net motion. They are
7 dealing with the drift field
8 specifically of the minority carriers
9 due to the built-in field due to the
10 doping gradient.
11 MR. WHITEHURST: I just want
12 the record to reflect that counsel is
13 reading pre-scripted questions off of
14 a computer screen verbatim and all of
15 the questions are suggesting the
16 answer. They are improper recross.
17 Q. (BY MR. PAUL) Do you recall
18 being asked a series of questions about the
19 Kawagoe prior art reference?
20 A. Yes.
21 Q. Do you recall being asked
22 specifically about Figure 17?

A. Yes.

Q. Does Figure 17 of Kawagoe support the conclusions you reached in these proceedings?

A. Yes.

Q. How does Figure 17 support the conclusions you reached in these proceedings?

MR. WHITEHURST: Objection, scope, leading.

THE WITNESS: If you look at the solid line at the top, it shows the downward slope in the regions labeled 2B and 2S. That's when it created the built-in electric field that's the relevant electric field.

Q. (BY MR. PAUL) Did you identify in Figure 17 of Kawagoe a graded dopant concentration?

A. Yes.

MR. WHITEHURST: Objection, scope, leading.

Q. (BY MR. PAUL) And is the

1 graded dopant concentration that you
2 mentioned you identified in Kawagoe, is that
3 decreasing from the surface of the device to
4 the substrate --
5 MR. WHITEHURST: Objection,
6 scope.
7 Q. (BY MR. PAUL) -- or what is
8 the substrate?
9 A. Yes.
10 Q. And in any -- in all of the
11 other prior art references that you relied
12 upon in these proceedings, did you identify a
13 graded dopant concentration that is
14 decreasing from the surface of the device to
15 the substrate?
16 MR. WHITEHURST: Objection,
17 leading.
18 THE WITNESS: Yes.
19 Q. (BY MR. PAUL) Do you recall
20 being asked questions about Figure 5B of the
21 challenged patent?
22 A. Yes.

1 Q. Do you recall being asked about
2 Figure 5B and portions of the specification
3 for the '222 patent specifically?
4 A. Yes.
5 Q. Do you recall being asked
6 questions with respect to Figure 5B of
7 the '222 patent about what is the majority
8 carrier in certain regions of the device
9 shown in that figure?
10 A. Yes.
11 Q. When providing the answers that
12 you did regarding the majority carrier in
13 certain regions of the device, were you
14 applying a consistent -- consistent
15 definition of the term "majority carrier" in
16 providing those answers?
17 MR. WHITEHURST: Objection --
18 objection, leading. I mean, you're
19 asking him a question and telling him
20 the answer and then listening to a yes
21 or no. I don't know how you think
22 that's not a leading question.

1 Objection, leading.
2 MR. WHITEHURST: This in no
3 way -- I disagree with your
4 assessment, Alan.
5 MR. WHITEHURST: Well, you have
6 obviously never been to court and know
7 what a leading question is.
8 But objection, leading.
9 THE WITNESS: So in this case,
10 the majority --
11 Q. (BY MR. PAUL) Let me re-ask
12 the question for a clean record.
13 Were you applying a consistent
14 definition of "majority carrier," quote,
15 unquote, when you were providing those
16 answers --
17 MR. WHITEHURST: Objection.
18 Q. (BY MR. PAUL) -- regarding
19 Figure 5B?
20 A. Yes.
21 Q. How so?
22 A. So in this case, if it's an

1 NMOS device, the majority carriers in the
2 source and drain electrons, electrons will be
3 flowing from the source to the drain.
4 THE REPORTER: Would be joined?
5 THE WITNESS: Will be flowing
6 from the source to the drain.
7 THE REPORTER: Flowing, thank
8 you.
9 Q. (BY MR. PAUL) Do you recall
10 being asked questions about column 3 of
11 the '222 patent specification?
12 A. Yes.
13 Q. Do you recall being asked,
14 referring to column 3, lines 64 to 66 of the
15 '222 patent -- are you there?
16 A. Yes.
17 Q. Do you recall being asked about
18 the sentence and the specification that
19 reads, "The graded dopant can also be
20 implemented in surface channel MOS
21 devices" -- that's M-O-S devices -- "to
22 accelerate majority carriers towards the

1 drain?" Do you recall being asked that
2 question?
3 A. Yes.
4 Q. And do you see where this
5 sentence is -- withdraw that.
6 When this sentence is
7 mentioning majority carriers, do you have an
8 understanding of what region of the device
9 they are referring to when they mention
10 majority carriers?
11 A. Once again, majority carriers
12 in a region location refer to the carriers
13 created by the dopants. Assuming you are
14 looking at an NMOS, the majority carriers are
15 the source of the electrons and would flow
16 from the source to the drain.
17 Q. So is it your understanding
18 that the -- based on what you just said, that
19 you understand majority carriers, as
20 mentioned in line 65 to 66 of column 3 of the
21 '222 specification, is referring to majority
22 carriers in the source region?

1 A. I believe so.
2 MR. PAUL: I don't have any
3 further questions at this time.
4 FURTHER EXAMINATION
5 BY MR. WHITEHURST:
6 Q. Dr. Banerjee, do you realize
7 you're under oath?
8 A. Yes.
9 Q. Under the penalty of perjury?
10 A. Yes.
11 Q. Did you testify truthfully
12 today?
13 A. Yes.
14 Q. Will you stand by your
15 testimony?
16 A. Yes.
17 Q. I don't normally do this, but
18 this is rather extraordinary. You and your
19 attorneys took a 40-minute break. During
20 that 40-minute break, at any time did you
21 meet with any of the attorneys or other
22 persons sitting at the table with you now?

1 A. Yes.
2 Q. Which of the attorneys sitting
3 at the table did you meet with during the
4 40-minute break? If you can please identify
5 them by name on the record.
6 A. I met with counsel, Raj Paul
7 and Anupam Sharma, and I believe Kent Cooper
8 was also there and Emre.
9 Q. Did you speak with anybody on
10 the phone?
11 A. I did not.
12 Q. Did you speak with anybody
13 other than the attorneys sitting at the table
14 with you?
15 A. I did not.
16 Q. Did you meet with the four
17 attorneys -- how many attorneys did you meet
18 with?
19 A. I believe there are four in the
20 room.
21 Q. Did you meet with those four
22 attorneys for the full 40 minutes?

1 A. I took a bio break and then
2 some of them went in and out of the room. It
3 wasn't for the full 40 minutes. I took a
4 break, Raj Paul took a break.
5 Q. Did you meet with the attorneys
6 for more than 30 minutes?
7 A. I did not keep a record of the
8 time.
9 Q. What's your best approximation
10 of how long you met with the attorneys during
11 the 40-minute break?
12 MR. PAUL: Objection to the
13 relevance of this.
14 THE WITNESS: Probably 20
15 minutes or so because I took a bio
16 break, Raj Paul took a bio break. And
17 for some time, I was walking around in
18 the corridor and they were talking
19 amongst themselves. So maybe half the
20 time.
21 Q. (BY MR. WHITEHURST) During the
22 approximately 20 minutes, did Mr. Paul tell

1 you that he was going to ask you questions?
2 MR. PAUL: I instruct the
3 witness not to discuss conversations
4 you have had with your attorneys.
5 Q. (BY MR. WHITEHURST) I asked
6 you, Dr. Banerjee, did you speak with
7 Mr. Paul during the 20-minute break, yes or
8 no?
9 MR. PAUL: You can answer yes
10 or no.
11 THE WITNESS: Yeah, I did speak
12 to them, Mr. Paul and -- yeah.
13 Q. (BY MR. WHITEHURST) Can you
14 please identify -- did you speak with all
15 four of the attorneys sitting at the table
16 now during the 20 minutes?
17 A. I don't believe I spoke to
18 Mr. Cooper. I spoke to Mr. Paul and
19 Mr. Sharma and I think I met briefly with
20 Mr. Emre.
21 Q. So let me get these names
22 right. Mr. Paul?

A. Yes. Mr. Sharma.
Q. Mr. Sharma. And who else?
A. What's the name of the lawyer from Global?
MR. PAUL: Emre Yuzak.
Q. (BY MR. WHITEHURST) Mr. Emre. Can you please spell his last name?
A. First name is Emre, E-M-R-E. How do you spell his last name?
MR. PAUL: Y-U-Z-A-K.
Q. (BY MR. WHITEHURST) Starting with Mr. Paul, did you talk about your testimony?
MR. PAUL: I instruct you not to answer that question. It calls for privileged information.
Q. (BY MR. WHITEHURST) Can you answer that question yes or no, Mr. -- strike that.
Dr. Banerjee, yes or no, did you talk with Mr. Paul about the questions he just asked you?

1 MR. PAUL: Instruct you not to
2 answer. Calls for privileged
3 information.
4 Q. (BY MR. WHITEHURST)
5 Dr. Banerjee, can you answer my question yes
6 or no?
7 MR. PAUL: Once again, I
8 instruct you not to answer it as it
9 calls for privileged information.
10 MR. WHITEHURST: Okay.
11 Counsel, listen to my question
12 carefully. I didn't ask him yes or
13 no.
14 Q. (BY MR. WHITEHURST)
15 Dr. Banerjee, I'm laying foundation here.
16 Dr. Banerjee, I just asked you whether during
17 the break you spoke with Mr. Paul about your
18 testimony.
19 Do you understand my question?
20 You don't answer it yet. Do you understand
21 my question?
22 A. Yes, I understand your

1 question.
2 Q. Can you answer my question, yes
3 or no?
4 MR. PAUL: Instruct you not to
5 answer. It calls for privileged
6 information.
7 Q. (BY MR. WHITEHURST)
8 Dr. Banerjee, are you able to answer my
9 question?
10 A. I'm instructed by my counsel
11 not to answer. I'm going to listen to his
12 instructions.
13 Q. If he had not instructed you
14 not to answer, are you able to answer my
15 question?
16 MR. PAUL: Objection.
17 Q. (BY MR. WHITEHURST) Do you
18 understand? I'm not asking you to answer it.
19 Are you able to answer my question whether
20 you spoke with Mr. Paul about your testimony?
21 MR. PAUL: Objection,
22 argumentative.

Q. (BY MR. WHITEHURST)
Dr. Banerjee, you can answer.
A. I spoke to Mr. Paul and
Mr. Sharma during the break.
Q. And did you speak with Mr. Paul
about your testimony?
MR. PAUL: Once again, I
instruct you not to answer. Objection
to the question as calling for
privileged information.
Q. (BY MR. WHITEHURST)
Dr. Banerjee, are you going to follow your
attorney's advice?
A. Yes.
Q. And you are going to refuse to
answer my question whether you spoke with
Mr. Paul about your testimony?
A. I'm going to follow my
attorney's advice.
Q. Okay. Did you speak with
Mr. Sharma about your testimony?
MR. PAUL: Once again, instruct

1 you not to answer the question.
2 Objection, calls for privileged
3 information.
4 Q. (BY MR. WHITEHURST)
5 Dr. Banerjee, are you going to follow your
6 attorney's advice and refuse to answer my
7 question?
8 A. Yes.
9 Q. Dr. Banerjee, did you speak
10 with Mr. Yuzak about your testimony?
11 MR. PAUL: Objection, calls for
12 privileged information and instruct
13 you not to answer.
14 Q. (BY MR. WHITEHURST)
15 Dr. Banerjee, are you going to follow your
16 attorney's advice and refuse to answer my
17 question?
18 A. Yes.
19 Q. Dr. Banerjee, thank you for
20 your time today. This concludes your
21 deposition.
22 A. Thank you.

THE VIDEOGRAPHER: We are going off the record. This deposition is concluded at 6:31.

(Proceedings concluded at 6:31 p.m.)

1 REPORTER'S CERTIFICATION OF THE ORAL DEPOSITION OF SANJAY BANERJEE, PH.D.
2 DECEMBER 6, 2024 (Reported Remotely)
I, Donna Wright, a Certified Shorthand
3 Reporter and Notary Public in and for the State of Texas, hereby certify to the
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That the witness, SANJAY BANERJEE,
5 PH.D., was remotely duly sworn by the officer and that the transcript of the oral
6 deposition is a true record of the testimony given by the witness;
7 That the original deposition was delivered to Mr. Raj Paul;
8 That a copy of this certificate was served on all parties and/or the witness
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I further certify that pursuant to FRCP
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COVINGTON & BURLING, LLP
2 850 Tenth Street, NW, One City Center
Washington, DC 20001
3
Case: Cirrus Logic, Inc. et al. v. Greenthread, LLC
4 Date of deposition: December 6, 2024
Deponent: Sanjay Banerjee, Ph.D.
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