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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THE VIDEOGRAPHER: We're on the record. This is the remote video deposition of Dr. Sanjay Banerjee in the matter of Cirrus Logic Incorporated, et al., versus Greenthread, LLC, filed in the United States Patent and Trademark Office.

My name is Billy Fahnert. I am the video technician today. The court reporter is Donna Marie Smith. We both represent Digital Evidence Group. Today's date is December 6th, 2024. The time is 9:14 a.m. Central Daylight Time. All parties have stipulated to the witness being sworn in remotely.

Will counsel please identify yourselves for the record and then the witness will be sworn.

MR. WHITEHURST: Good morning, everybody. This is Alan Whitehurst with McKool Smith for the patent owner, Greenthread.

MR. PAUL: This is Raj Paul of Covington & Burling on behalf of petitioners. Also with me is Anupam Sharma, also with Covington & Burling, on behalf of petitioners. And also with me is Emre Yuzak of GlobalFoundries and Kent Cooper of GlobalFoundries.

MR. BLUESTONE: And also present is David Bluestone with Benesch on behalf of co-petitioner Omnivision.

SANJAY BANERJEE, PH.D.,

having been first duly sworn, testified as follows:

EXAMINATION

BY MR. WHITEHURST:

Q. Good morning, Dr. Banerjee.

A. Good morning.

Q. Happy Friday. I certainly appreciate your time today. I know it's a busy time of the year.

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I don't believe we've ever met before, have we?

A. No, I don't think so.

Q. But I do understand you have testified in a deposition before; is that correct?

A. Yes.

Q. Do you know roughly how many times you have testified in a deposition?

A. I'm guessing probably a couple of dozen times.

Q. So you know how the procedure works. I'm not going to go over all of that now. But you know that under the rules for these IPR proceedings, you're not allowed to talk to anybody during the breaks about your testimony.

Do you understand that rule?

A. Yes.

Q. And do you intend to comply with that rule today?

A. Yes.

Q. Now, like I said, I don't believe we have ever met before, but I have certainly seen your name before. It's nice to finally meet you, at least via Zoom.

I want to go over a little bit, just at a real high level, your educational background. Can you tell me when you got your Ph.D.?

A. 1983.

Q. And where did you get your Ph.D. from?

A. University of Illinois at Urbana-Champaign.

Q. And what did you do after you got your Ph.D.?

A. I started working at Texas Instruments Dallas where I was part of the team that made the world's first 4 MegaBit DRAM.

THE REPORTER: I'm sorry.

THE WITNESS: The world's first 4 MegaBit DRAM, D-R-A-M.

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Q. (BY MR. WHITEHURST) And just to help our court reporter out, Dr. Banerjee, I believe you said 4 MegaBit; is that correct?

A. Yes, yes.

Q. That would be the number four followed by a capital M, capital B?

A. That's correct.

Q. DRAM would be capital D-R-A-M.

Dr. Banerjee, is there a particular reason why you decided to work for TI?

A. TI is a leading company for semiconductors and I had offers from other companies also, but I felt the TI offer allowed me to do R&D.

Q. And I assume TI was a very prestigious company to work for?

A. Yes, it was.

Q. And can you tell me a little bit about your work on the DRAMs at TI, just 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

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mention?

A. For the DRAM I worked on something called a trench transistor where you dig a hole, etch a hole in silicon, you draw the gate dielectrics on the side walls of the trench and you put in a polysilicon gate electrode into the trench, and then you have the source on the top and the drain on the bottom.

So unlike a plainer MOSFET where the current goes laterally, on the trench transistor the current goes up and down the side walls of the trench.

I also worked on other types of transistors such as polysilicon, P-O-L-Y, silicon thin transistors, which are --

THE REPORTER: Silicon --

THE WITNESS: Thin.

THE REPORTER: Tin?

THE WITNESS: Thin, T-H-I-N, which are cleaner transistors where the current goes laterally on the

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surface.

Q. (BY MR. WHITEHURST) Dr. Banerjee, I don't know if you've ever seen a realtime transcript before, but I'm just trying to help our court reporter out. As we go along today and the words get entered into the transcript, it will become easier and easier because it populates using a known dictionary.

Just to help our court reporter out, could you please spell poly -- excuse me -- polysilicon?

A. P-O-L-Y-S-I-L-I-C-O-N.

Q. When did you first learn about DRAMs?

A. Back when I was in graduate school, between 1979 and 1983, you have to take graduate school courses also, so I learned about DRAMs in that context. And prior to that, when I was at -- in my undergrad program at the Indian Institute of Technology --

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THE REPORTER: At where?

THE WITNESS: At the Indian Institute of Technology, we also had to take courses on devices and circuits to learn about semiconductor memories and DRAMs in a broad sense, even then.

Q. (BY MR. WHITEHURST) And when you were at TI would you say that DRAMs were important technology to TI?

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) I'm sorry, I think we had an objection. But, Dr. Banerjee, I hope you heard my question. I will repeat it.

When you were at TI, would you say that DRAM was an important technology to TI?

MR. PAUL: Objection to form.

THE WITNESS: I guess it depends on what exactly you mean by "objection," but TI did do a lot of

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work on DRAMs. So in that sense, it was important.

Q. (BY MR. WHITEHURST) Were you proud of your work on the DRAMs?

A. Yes. In fact, we won a best paper award at the ISSCC, along with my colleagues of that work.

Q. So you were building actual products while you were at TI?

A. I was in the R&D group where you don't make commercial products, but I was involved in the design and the fabrication of memory cells primarily. I got a chance to see a little bit of both circuit design aspects, as well as the device application aspect in the clean room, but I was not on the production team.

Q. So did you write a lot of papers while you were at TI?

A. Yes.

Q. And you helped with the design of products?

A. I had quite a few patents also when I was at TI. It depends on what exactly you mean by "design of products." I was on the R&D team. These are not commercial products in that sense.

Q. Who worked on the commercial products?

A. Other teams at TI.

Q. And you mentioned production team. What is a production team?

A. Production team would take our design that was commercially viable and then manufacture the chips at scale in a foundry or a clean room. It's a large volume, it's very important. When in R&D, you're not trying to make things at scale. You're trying to demonstrate the viability of the technology.

Q. As part of the research group, did you ever work with any of the production teams?

A. Indirectly, we would have --

these teams are quite big, as you probably know, and you have meetings all the time with various R&D groups, as well as, on occasion, production groups. But my interactions were primarily within the R&D team.

Q. So it's fair to say you did not work directly with the production teams?

A. That's probably a fair assessment. Not extensively, at least.

Q. Did you know any of the people on the production teams?

A. Yes, I do. I did.

Q. Do you remember the names of any of the people on the DRAM production teams?

A. I remember one name because after I left TI and I started working at the university, I was asked to write recommendation letters for, you know, several TI employees for different awards. And I believe I wrote letters for a gentleman, Lionel Wright, who used to work in Houston.

He passed away.

Q. Do you remember the names of any of the other team members?

A. Not offhand.

Q. Do you recognize the name Dr. Mohan Rao?

A. Yes.

Q. Did you ever interact with Dr. Rao while you were at TI?

A. Not directly. I heard him give a talk once, but that was the only time.

THE REPORTER: What?

THE WITNESS: I heard him give a talk at TI once.

Q. (BY MR. WHITEHURST) When did you hear him give a talk?

A. When?

Q. Yes, sir. I'm sorry, I'll speak up. Let me re-ask the question. I apologize. I'll try to do a better job.

When did you hear Dr. Rao give a talk?

A. I don't remember exactly, but I worked at TI between 1983 and '87, so it would be sometime in that timeframe.

Q. Do you remember why Dr. Rao gave the talk?

A. No. It was just a company talk. It wasn't a conference talk.

Q. Was it about DRAMs?

A. I do not think so. I do remember one thing. Even though TI was a semiconductor company, I think he started talking about particle physics issues and all of that, just as a preamble.

THE REPORTER: Just as what?

THE WITNESS: Started talking about particle physics as a preamble to the talk. It wasn't directly relevant to TI, but I remember that because it was kind of entertaining at the time.

Q. (BY MR. WHITEHURST) Was Dr. Rao part of a production team?

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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

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certain.

Q. What do you mean when you say you were on a litigation team?

A. I view these proceedings as an example of a litigation. So I was an expert witness and I believe he was the consulting witness. So they did not have him testify or be deposed or anything like that. I was the main witness, but I think he provided some behind-the-scenes input for the team, I think. And I may have met him once in that context, but I can't remember 100 percent.

Q. What do you mean when you said you were on the same team?

A. So in many cases, I think lawyers will hire a primary expert who gets deposed and maybe testifies at the IPC, or whatever, but they sometimes also hire, I believe, consulting experts that they consult with to get additional input, but they don't go out in front of the lawyers and testify.

Q. And do you remember if Dr. Rao

provided consultant help to you on that litigation?

A. I don't think so, but I -- I'm trying to think. It was probably 30 years ago. So it was a very limited interaction so I don't think he did, but I can't remember.

Q. Do you know why he was hired as a consultant?

A. I do not.

Q. I want to go back to the talk that you attended. Was it common for TI employees to give talks?

A. Depends on what you mean by "common." I mean, I have given talks also when I was at TI, internal talks, on technical matters.

Q. And why were you asked to give talks?

A. As I remember, I told you I was working on polysilicon thin film transistors and I found some interesting results on the reliability of these devices and TI wanted me

to present those results. That was one example.

And then, of course, you know, you have meetings on a weekly basis, group meetings, and you typically present at those meetings. I remember presenting to our chief technology officer. It's quite common.

Q. And when you gave these talks, were you helping other people at TI learn about stuff?

A. Hopefully.

Q. And when Dr. Rao gave this talk, was he explaining stuff to people at TI?

A. Like I said, I do not remember the details of the talk, except I remember that he started out talking about something completely different from semiconductors or particle physics, which wasn't relevant, but I found it interesting because I'm also interested in physics.

I believe he has -- I think he

has two Ph.D.s, if I remember right. The first one may have been in physics, so maybe that's why he was trying to educate the crowd.

Q. Do you know many people that have two Ph.D.s?

A. No, I do not.

Q. Have you ever met anyone besides Dr. Rao that has two Ph.D.s?

A. I can't remember.

Q. Would you say that Dr. Rao was highly regarded at TI?

MR. PAUL: Objection to form.

THE WITNESS: I couldn't tell you. I was a junior engineer. He was more senior than me.

Q. (BY MR. WHITEHURST) So when you were at TI, Dr. Rao was a more senior engineer than you?

A. Yes.

Q. And Dr. Rao worked on commercial products?

A. I think so, but I don't know. I don't exactly know what he did. I do think he did work on memories, but I don't know any detailed knowledge other than that.

Q. And as a junior engineer, you were involved in research; is that correct?

A. Research and development.

Q. And as part of the research and development group, you did not directly work on commercial products?

MR. PAUL: Objection, form.

THE WITNESS: I mean, it depends on what you mean by "directly." In R&D, you develop technologies and the more promising ones involve the products. In that sense, there is an indirect connection.

Q. (BY MR. WHITEHURST) But you did not directly work on the commercial products, correct?

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 --

THE WITNESS: Or arsenic, sorry, or arsenic, which has five electrons, skin and shell. When you replace a silicon atom in the crystal with an arsenic atom, for example, four of the arsenic valence electrons satisfy the four covalent bonds, but then the fifth electron is donated to the crystal, making it an n-type semiconductor. So that's an example of doping.

Conversely, you could replace silicon with a column 3 impurity, such as boron, and now if you have -- since you have a deficit of one electron compared to silicon, you create a missing state in the valence band and that --

THE REPORTER: In the what?

THE WITNESS: In the valence, V-A-L-E-N-C-E, band which leads to a positively charged carrier for the

pole, making it a p-type doped semiconductor.

THE REPORTER: I had a hard time understanding.

MR. WHITEHURST: Yeah, miss court reporter, I'll try to help you out.

Q. (BY MR. WHITEHURST) Dr. Banerjee, you can hopefully help me out as well. Could you please spell covalent?

A. C-O-V-A-L-E-N-T.

Q. And I believe you said p-type; is that correct?

A. Yes, I did talk about p-type. So p, hyphen, type, T-Y-P-E.

Q. And what does p-type mean?

A. P-type would be our dope silicon doped with column 3 impurities, such as boron, which are known as acceptor impurities because they accept electrons from neighboring silicon atoms. And by doing so, it creates an empty state in the valence

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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

past, an advanced graduate course on semiconductor physics. That's on the teaching side.

The main role of a professor in a research university, as you probably know, is research, actually bringing in research funding. The graduate students do the hard work. And I have worked on different kinds of semiconductor devices, transistors, different kinds of memories, including flash memory, for example, other kinds of memory, CMOS, C-M-O-S. I believe I have over 1,200 papers and 30 patents on these topics.

Q. Very impressive. And I know how much work it can be, or at least I've heard how much work it can be bringing in research funding.

When did you -- when did it become part of your job to secure research funding?

A. From day one. I mean, if you do not bring in research funding, you do not

get tenure at research universities. They kick you out in six years. So that's probably more important than being a good teacher.

Q. That's exactly what I've been told and I know it's part of the reality in the world we live in.

And I assume you're a tenured professor there at University of Texas?

A. I'm a tenured chair professor. I hold a doctoral chair in electrical engineering and I'm also director of the Microelectronics Research Center.

Q. What is the Microelectronics Research Center?

A. This is a center where over a dozen faculty members who work on all kinds of semiconductor devices, such as transistors, electronic devices such as light-emitting diodes, lasers, detectors, MEMS, M-E-M-S.

These are made in a clean room,

which is kind of like a production foundry, except on a much smaller scale, where you have -- it's -- I mean, these are very expensive facilities. They cost over $100 million. We have probably 100 tools, each costing several million dollars. So I supervise the technicians and the engineers who run and maintain the tools, in addition to my professorial work.

It's also part of a national facility, one of a dozen or so across the country funded by the National Science Foundation. This is a network including Harvard, Stanford, Cornell. It's a pretty serious network, so I'm the director of that also, where outside companies can come in and do R&D. So they make not full production chips, but devices which hopefully will then lead to production.

Q. You mentioned NSF. What is NSF?

A. The National Science

Foundation. This is the main federal agency which funds basic research and R&D.

Q. Is the Microelectronics Center also privately funded?

A. Yes.

Q. Who are some of --

A. So we -- so we bring in funds from companies or consortia, which are made up of companies.

In my case, for example, over the years, I have had a lot of funding from the Semiconductor Research Corporation, which is a consortium of the leading semiconductor companies in the US, and now, in fact, globally. Companies such as Intel, Texas Instruments used to be part of it. I think they are still part of segments of it.

I also have funding directly from companies, including TI and many other companies, Intel, Samsung. I have had funding from the Department of Defense, DARPA. Not just me. Most active faculty

have to bring in funding from sources.

Q. You mentioned a consortium. Does the consortium have a name?

A. This particular consortium is actually located where you went to school in North Carolina, the Semiconductor Research Corporation.

Q. That's interesting. How did you learn about me?

A. I looked you up and you have very impressive credentials.

THE REPORTER: Pardon? I didn't hear. Something, credentials.

THE WITNESS: I said he has impressive credentials. I mean, Duke is a top-notch school.

Q. (BY MR. WHITEHURST) Do you know any of the professors at Duke?

A. Yes.

Q. Any names in particular come to mind?

A. I have interacted with Hisham

Massoud, who is a Stanford Ph.D. I don't know if you know him. He used to be funded by the Semiconductor Research Consortium also and we would interact.

Q. Anybody else?

A. I think there is a guy called Aaron Franklin who joined more recently.

Q. Going back to the consortium, who are some of the other companies that are in the consortium?

A. The SRC, the Semiconductor Research Corporation, was founded, I think in the 1980s, about the time I joined the university, and membership has changed and evolved over the years. So I believe you have all of the leading players, Intel -- initially, it was all US companies only, but now it's Global. I believe Samsung and TSMC are also part of it. I can't tell you exactly what the current membership is, but I know Intel is, I think Applied Materials is, Micron. All of the big players.

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Q. Is GlobalFoundries a member?

A. I think so, but I'm not one 100 percent certain.

Q. Do you remember who you got your first funding from when you joined the University of Texas-Austin?

A. I believe it was from the NSF. I was awarded the Presidential Young Investigator Award. It's a fairly prestigious award for young scientists and engineers. Ronald Reagan was in the White House.

THE REPORTER: Pardon? What was the last thing?

THE WITNESS: I got it when Ronald Reagan was in the White House. I have a certificate signed by him.

Q. (BY MR. WHITEHURST) After NSF, do you remember who else you got funding from?

A. You don't get funding sequentially, so at any time you try to get

funding from many sources. So I believe I also got funding from the State of Texas when I first started. We had a program called the Texas Advanced Technology Program and Texas Advanced Research Program. This is only for Texas-based universities. I remember getting funding from them.

You probably have a copy of my CV and that lists the various funding sources. I have to look at my CV to give you a more detailed answer.

Q. Do you think your CV has a complete list of all of the funding that you have received?

A. I believe so.

Q. Who have you received private funding from?

A. Will you repeat that question, please?

Q. Who have you received private funding from?

A. Depends on how you define

"private" because the Semiconductor Research Corporation is a corporation -- is a consortium of private companies. In that sense, that is also private funding. And I have had a lot of funding from SRC over the years, but I have also been funded directly by several companies, such as AMD, which was a precursor to GlobalFoundries where I worked on flash memories.

I got funding from Texas Instruments. In fact, I have funding from them now. I probably got funding from Samsung. In the past, I had funding from Micron, Intel. I'm trying to think. I think those are some of the immediate ones.

Q. Can you think of any others?

A. So I was also director of another consortium called the Nanoelectronics Research Initiative. So they had established three major centers in the US, and I directed one of them called the Southwest Academy of Nanoelectronics.

That's kind of ironic because the goal of this consortium was to try to invent a new type of transistor which would displace the MOSFET. So in some sense, I was trying to undo the work that I had done in the first part of my career.

Anyway, that was also a consortium of private companies, including Intel, TI -- I'm trying to think -- AMD may have been part of it, but I can't remember. It was a different subset of companies than the main SRC.

So this consortium, NRI, was also managed by SRC, but it was a separate consortium.

Q. To go back, you mentioned AMD, TI, some of the companies that have funded you over the years. Can you think of any other companies that have funded you directly or indirectly?

A. I would have to look at my CV to give you an accurate answer.

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Q. Are you currently receiving any funding directly or indirectly from GlobalFoundries?

A. No, I'm not. I'm trying to think. No, I'm not.

Q. Have you received any funding from GlobalFoundries directly or indirectly in the past?

A. I have not received funding directly from them. But, as I told you, I have received funding from this SRC consortium. I do not remember if -- I don't have any funding from SRC right now. I do not recall if during the years I had SRC funding if Global was a member of the consortium. I couldn't tell you that.

Q. When did you receive funding from SRC?

A. I have had multiple grants from SRC over the years. Once again, I would have to look at my CV. It's all listed in my CV.

Q. How much funding have you

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received from SRC?

A. I couldn't tell you without looking at my CV, but I'm guessing tens of millions of dollars.

Q. Is that a lot?

MR. PAUL: Objection to form.

THE WITNESS: Depends on what you mean by "a lot." I think I have been quite successful among faculty when it comes to raising money in our field. That's why I got this endowed chair and they promoted me to be the director.

But, you know, if you look at a person who works at a company like nuclear fusion, there the expenses are so high that they most likely probably receive a lot more money. So it's all independent, but in our area I think I have been quite successful.

Q. (BY MR. WHITEHURST) And you being successful in raising funding is part

of why you're an endowed chair at UT?

A. Well, the funding is the precursor. The output is the research that we do and the papers. So they look at how much money you're bringing in, what papers you publish and then how much professional recognition you have gotten.

So over the years, I have been fortunate to have received several awards, including, interestingly, the Andrew Grove Award. I know the Grove textbook was cited in the proceedings. Grove was, I think, one of the co-founders or an early employee of Intel. So I got the Andrew Grove Award from IEEE, I-E-E-E. It's the leading award for semiconductor device research. So I was fortunate enough to get that.

So the university looks at things like that when they decide who to give these endowed chairs to.

Q. And that's very impressive.

And one of the things that the

University of Texas looks at when it's making an endowed chair is the amount of funding that's been raised?

A. I suppose.

Q. And you've been very successful at raising funding?

A. I think so. I mean, it depends on your definition of "very."

Q. And you have raised tens of millions of dollars from SRC?

A. Like I said, I'm just guessing. Probably, yeah.

Q. And that's part of why you're now an endowed chair?

MR. PAUL: Objection, asked and answered.

MR. WHITEHURST: That's not a proper objection, my friend. Look at the rules.

Q. (BY MR. WHITEHURST) Dr. Banerjee, and that's part of why you are now an endowed chair?

A. When universities decide who to give these endowments to, they look at multiple aspects of a person's record, right, teaching, research publications, and I'm sure funding is also part of the equation.

Q. When was the most recent that you received SRC funding?

A. I think I -- the last one, I think, ended a couple of years ago. So now SRC also has a mechanism where these member companies can direct a portion of their contribution to the consortium for specific research projects.

In this case, Intel chose to fund me through SRC. I think that project ended maybe last year or the year before. It was fairly recently.

Q. What other companies have funded you through SRC?

A. So the bulk of the funding has been the regular consortium. So all of these companies bring money into a common pot and

then SRC gives grants. So in that sense, every consortium member funded my research through the consortium.

But, as I told you, they also have a mechanism where a portion of the -- a portion of the contribution can be directed funding. So the latest example of that was this funding that I got from Intel, and I believe in the past also, many years ago, I had directed funding also from Intel through the SRC. The vast majority of my SRC funding has been as part of the overall consortium.

Q. What other companies besides Intel have you received directed funding from?

A. I currently have direct funding from Texas Instruments, Samsung. I think currently those are the only two that are active.

Q. How much funding have you received from Samsung?

A. So let me tell you, in many

cases you have also called principal investigator of a grant, and, in this case, Samsung wanted me to be the principal investigator of TI. And over a three-year period, I believe they are giving us close to $3 million, but I also have three other faculty members as part of my grant. So my share of the $3 million is probably roughly half of that, maybe, approximately.

Q. Approximately $1.5 million?

A. Over three years, approximately, yes.

Q. So you've received at least 1.5 million in funding from TI?

A. No, no, this is from Samsung.

Q. My apologies.

You have received at least 1.5 million in funding from Samsung?

A. Approximately.

Q. Have you received additional funding from Samsung at other times?

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

Texas Instruments begin funding you?

A. This latest financial funding started, I think, in April of this year.

Q. And how much have they paid you since April of this year?

A. It's a small amount, something like $90,000; 80-, 90,000.

Q. Going back before April of this year, when has TI funded you?

A. They funded me through SRC right from the outset. I don't think I got direct funding from TI, but I could be wrong.

Q. And when you say "from the outset," I'm trying to remember, was that 1987?

A. Yes.

Q. So TI has been funding you since 1987?

A. Not continuously, but over the years I've had multiple grants from SRC or this Nanoelectronics Research Initiative that I mentioned that I directed one of the

centers, and TI was part of that, along with Micron, Intel.

These grants typically last for three years and sometimes you may get overlapping grants or multiple grants, sometimes you have gaps in funding. But I need to look at my CV to give you a more detailed answer. It's all in my CV.

Q. You mentioned Micron and Intel. Can you recall any other companies?

A. Well, AMD gave me some funding way back. I'm trying to think. Again, without my CV, I can't remember offhand.

Q. Since 1987, has TI ever directly funded you through SRC?

A. If it's funding through SRC, I don't consider that to be direct funding unless it's one of those directed grants like Intel did. TI did not do one of those directed grants through SRC. But, as I told you, I currently have direct funding from TI, not through SRC.

Q. Let me see if I can understand this a little better.

Since 1987, how much has TI funded you directly?

A. I think it's only the most recent grant, which is about 80-, $90,000. I don't recall receiving direct funding from them.

Q. And the grant that you are currently working on for TI, they typically last for three years; is that correct?

A. Not this one. This is a shorter grant, a year. In fact, the money is kind of almost gone.

Q. Are you hoping to get future funding from TI?

A. I'm always hoping to get funding from everybody.

Q. And why are you hoping to get funding from everybody?

A. That's how you pay your graduate students, your postdoctoral fellows.

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Your lab collapses if you don't have money.

THE REPORTER: You what? I didn't -- I'm sorry.

THE WITNESS: Your lab collapses if you don't have funding.

Q. (BY MR. WHITEHURST) And you don't want your lab to collapse?

A. No.

Q. And that's why it's important to get funding?

A. That's true of all research-active faculty.

Q. When did you first receive funding from GlobalFoundries?

A. As I told you, I do not think I have ever received funding from them directly. I have received funding from SRC over the years. I do not recall if Global was a member of SRC during the years I got money from SRC. This membership changes over time. You can actually look at the SRC history and see if there is an overlap, but I

have not received direct funding from Global.

Q. Do you ever interact directly with GlobalFoundries?

MR. PAUL: Objection to form.

THE WITNESS: Depends on what you mean by direct interactions. So when you get these grants from SRC, for example, you have to go to these annual review meetings where the company representatives are present.

Assuming Global was a consortium member during this time, I may have spoken to the Global engineers at those reviews.

We also go to conferences, technical conferences where you have engineers from many companies, including Global. I'm sure I have interacted with them in that context. Some of my students work at Global.

Q. (BY MR. WHITEHURST) How many of your students work at GlobalFoundries?

A. I can't recall. Not a whole lot. The vast majority recently have ended up at Intel. I think there are a couple who entered Global.

Q. Do you remember going to an annual review meeting and a GlobalFoundries person being present?

A. I couldn't tell you. I don't recall.

Q. Have you ever communicated with GlobalFoundries about funding?

A. No, I don't think I have.

Q. Have you ever sought funding from GlobalFoundries?

A. No.

Q. Does GlobalFoundries -- strike that.

Does GlobalFoundries fund any professors or universities?

A. I do not know.

Q. Do you recall what years GlobalFoundries was part of the consortium?

A. I do not know.

Q. How would you find that information?

A. I don't know, but I suppose I could go to the SRC website, maybe, and they probably have a list of the members, but I have not done that research.

Q. When was the last time you went to an annual review meeting?

A. Any annual review or SRC annual review?

Q. Let start with any. When was the last time you went to an annual review meeting?

A. It was during the summer. I went to Korea for the first annual review at Samsung.

Q. Going back, when was the second most recent annual review meeting?

A. That probably was the one with this SRC Intel directed funding. That was last year.

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Q. How many annual review meetings did you go to in 2024?

A. It's only been the one for the Samsung grant. I went to Korea. I think that was the only one.

Q. How many annual review meetings did you go to in 2023?

A. I don't recall. I think the last year of the SRC grant was in 2023. I remember that.

Q. Do you remember who was present at the SRC annual review meeting?

A. No.

Q. Do you remember any of the companies?

A. The Intel guys were definitely there because they were the ones funding me. I'm trying to think. I can't remember.

Q. You can't remember anybody other than Intel?

MR. PAUL: Objection to form.

THE WITNESS: I'm trying to

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think. I think the Samsung guys were also there, if I remember right. Yeah, I think the Samsung guys were there also.

Q. (BY MR. WHITEHURST) Other than Samsung and Intel, can you remember anybody else that was at the annual review meeting?

MR. PAUL: Objection, asked and answered.

MR. WHITEHURST: That's not a proper objection. Please go read the rules.

MR. PAUL: I disagree.

MR. WHITEHURST: Well, we will talk about it offline.

Q. (BY MR. WHITEHURST) And I did not --

A. I --

Q. I'm sorry, Dr. Banerjee. My apologies. I got interrupted there. Let me re-ask the question.

Other than Samsung and Intel,

can you remember anybody else that was at the annual review meeting?

MR. PAUL: Same objection.

THE WITNESS: I do not recall.

Q. (BY MR. WHITEHURST) How would you find that information?

A. You could probably contact SRC. They would probably have an attendance list. They could probably tell you.

Q. And do they keep those attendance lists on a website?

A. I don't know, but I don't think so.

Q. Where do they keep the attendance list?

A. I have no idea.

Q. We have been going for about an hour. Would you like to take a break?

A. Yes, please.

Q. Let's go off the record.

THE VIDEOGRAPHER: Going off the record, the time is 10:13.

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(Recess from 10:13 a.m. to 10:26 a.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 10:26.

Q. (BY MR. WHITEHURST) Dr. Banerjee, welcome back.

A. Thank you.

Q. I want to ask you about some of the work you did once you were at the University of Texas. I believe you have worked on some textbooks in the past?

A. Yes.

Q. When did you begin work on your first textbook? Do you recall?

A. So I'm co-author on a textbook --

THE REPORTER: Pardon? I'm sorry, I couldn't hear.

THE WITNESS: I'm co-author on a textbook with Ben Streetman, who was my Ph.D. advisor back at Illinois. He wrote the original version, I believe,

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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

my CV.

Q. (BY MR. WHITEHURST) And why do you make updates and changes to the textbooks?

A. Because technology evolves. The basic physics doesn't change that rapidly, but details of engineering and technology change more rapidly. That's why engineering textbooks need to be updated. Otherwise, it's not relevant to the students.

Q. What did you mean when you said "the basic physics doesn't change that rapidly"?

A. By "basic physics," I mean, for example -- I know you're an electrical engineer, I think, so you will appreciate this. You know, Maxwell's equations have been known since the mid-19th century --

THE REPORTER: The what?

THE WITNESS: Maxwell's equations have been known since the mid-19th century, and they haven't

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changed. Of course, everything in physics might be overturned if new discoveries are made, but Maxwell's equations are probably here to stay.

The rules of quantum mechanics, which were first developed in the 1920s, haven't changed in a fundamental way, though there have been modifications. So those are the things that have a longer time span.

On the other hand, details of how you make a transistor or works of a transistor, those things change more rapidly and those are the aspects that need more updating.

Q. (BY MR. WHITEHURST) What are Maxwell's equations?

A. What are Maxwell's equations?

Q. I'm just going to help our court reporter out real quick and then I'll re-ask my question.

Dr. Banerjee, how do you spell

Maxwell?

THE REPORTER: No, I know. It might not have come up on there yet.

Q. (BY MR. WHITEHURST) Can you please spell Maxwell?

A. M-A-X-W-E-L-L.

Q. And do you normally write Maxwell, apostrophe, S?

A. When you write Maxwell's equations, yes.

Q. And what are Maxwell's equations?

A. There are four of these that determine the connection between electric and magnetic fields, and then also how these electric fields relate to charges and the magnetic fields relate to currents.

Q. You said four. What did you mean when you said four?

A. There's four partial differential equations that are known as the Maxwell equations.

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Q. And when did you first learn about Maxwell's equations?

A. When I was in undergrad. This would be between 1974 to 1979, sometime in that timeframe.

Q. You also mentioned quantum mechanics. What did you mean by quantum mechanics?

A. So quantum mechanics is the extension of classical mechanics developed by Isaac Newton and others for macroscopic objects.

When people started studying atomic physics, people realized that classical mechanics rules don't seem to be applicable, and that's why quantum mechanics was developed.

Q. Do you write about Maxwell's equations in any of your textbooks?

A. In our textbook we focus on one of the four that's particularly relevant for devices, and that's also known as a Poisson

equation.

THE REPORTER: As a what?

THE WITNESS: Poisson equation, P-O-I-S-S-O-N.

Q. (BY MR. WHITEHURST) Is that something you used while you were at TI?

A. Yes.

Q. When you mentioned basic physics, are there any other rules or laws or equations that you use?

MR. PAUL: Objection to form.

THE WITNESS: I'm not sure exactly what you mean by that.

Q. (BY MR. WHITEHURST) Other than Maxwell's equations, are there any other equations that are useful for understanding physics?

MR. PAUL: Objection to form.

THE WITNESS: Yes.

Q. (BY MR. WHITEHURST) What other equations are helpful?

A. As I mentioned, quantum

mechanics and the main partial differential equation is known as the Schrodinger equation. I use that extensively both in teachings in our textbook, as well as in my research.

Q. What classes are you currently teaching at the University of Texas?

A. I'm teaching two courses. One is a course out of our textbook. It's an undergraduate senior-level textbook on device physics.

And the other one is a combined graduate/undergraduate course on device application where I teach students how to make devices, such as transistors. That also includes a lab where they make the devices and test them.

Q. When you teach your device physics class, what do you typically cover in the first week or so?

A. In the first week, we cover chapter 1 in our textbook, which is crystals

and crystal structure.

Q. Anything else?

A. In the first week, that's generally all that we have time for.

THE REPORTER: Pardon? I couldn't hear.

THE WITNESS: And then maybe towards the end of the first week or definitely by the second week, we start talking about quantum mechanics.

Q. (BY MR. WHITEHURST) I know you have an impressive resume.

When did you first study physics?

A. Well, I studied physics in high school, the equivalent of AP physics in this country.

Q. Do you remember --

A. And then -- and then in undergrad and grad.

Q. And you currently teach about physics?

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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.

Q. (BY MR. WHITEHURST) Let's go back to when you were first studying physics.

Do you remember learning about Newton's laws of motion?

A. Yes.

Q. What are Newton's laws of motion?

A. I don't see how it's relevant to this, but you have the three laws. A body at rest stays at rest, a body in motion stays in a state of constant velocity unless there are external forces, indirect external forces, mass times acceleration equals applied force, and then the third law is a reaction --

THE REPORTER: Pardon, wait. And then the external forces --

THE WITNESS: The mass times accelerations equals applied force. And the third law is every action has an equal and opposite reaction.

Q. (BY MR. WHITEHURST) Let's help

our court reporter, or maybe help me. Sometimes I say for the court reporter and I'm really asking to help me. But, Dr. Banerjee, let's break this down a little bit, and I appreciate your patience. You have been very helpful today and I certainly appreciate your time.

How many Newton laws are there?

A. There are three laws.

Q. What is the first law?

A. That is the law of inertia, which is if the body is at rest, it can stay at rest forever, or if it's moving at a certain velocity, continuing with that velocity forever unless there are external forces.

Q. What is the second Newton law?

A. That's the mass of an object times the acceleration equals the applied force.

Q. Is that sometimes written as "F = ma"?

A. Yes. In fact, the first law is really a subset of the second law. If F becomes zero, A becomes zero.

Q. Do you use the second law of physics in your work at all?

A. Yes.

Q. How do you use it in your work?

A. Not to be facetious, but every time I move something, I'm using Newton's second law. But in my research, you -- you know, these are fundamental laws that, of course, you are using.

Q. What do you mean when you say "fundamental law"?

A. Rules of quantum mechanics would be an example.

THE REPORTER: Pardon?

THE WITNESS: Rules of quantum mechanics would be an example of such a fundamental law.

Q. (BY MR. WHITEHURST) Do you think Newton's second law is still true

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today?

A. Yes, with caveats, with caveats. So classical mechanics is only applicable through macroscopic objects traveling at slow speeds. If we approach speeds comparable to the speed of light, then Einstein modified those equations in the section of the general theories of relativity.

Q. What is something that would be moving at the speed of light?

A. In particle accelerators, you can accelerate subatomic particles close to the speed of light. You cannot move any object with a nonzero mass at the speed of light, but it can actually totally approach that.

Q. What is something that has a nonzero mass?

A. Things like electrons, protons.

Q. So when you talk about electrons, it has a nonzero mass?

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A. It has a nonzero rest mass, yes.

Q. So I believe you said that Newton's second law applies to things with a nonzero mass.

Did I get that right?

A. Newton's laws would apply to particles with a nonzero mass, provided they are not traveling at speeds comparable to the speed of light. And, furthermore, if those objects are tiny, you sometimes have to modify those rules of Newton according to the rules of quantum mechanics.

Q. Would Newton's second law apply to electrons?

A. In what scenario?

Q. Well, let me ask the question a different way.

When would Newton's second law apply to electrons?

A. Newton's second law would apply to electrons, for example, moving in free

space at speeds much slower than the speed of light where it can ignore relativistic corrections.

THE REPORTER: Ignore --

THE WITNESS: Relativistic R-E-L-A -- I feel like I'm at a spelling bee -- relativistic corrections, R-E-L-A-T-I-V-I-S-T-I-C.

Q. (BY MR. WHITEHURST) Have you ever mentioned Newton's second law in your textbook?

A. I don't think so.

Q. Have you ever mentioned F = ma in your textbook?

A. I do not recall using that law in that particular form, but I think I did have that in another form. I could look at my textbook.

So ma is also sometimes written as the momentum, P. And I believe in one of the chapters, we do talk about dP/dt. This 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

to Newton's second law?

A. It is Newton's second law.

Q. It is Newton's --

A. It is.

Q. Okay. How is F = dP divided by dt the same as Newton's second law?

A. Newton's second law, as stated earlier, is F = ma; ma, a is the acceleration, which is given by dV/dt where V is the velocity. Mass times velocity is the momentum, P.

So if you are in the classical regime where mass does not depend on velocity, you can move mass inside the time derivative. So an alternative form of Newton's second law would be F = dm times V over dt or dP/dt.

THE REPORTER: Vpd?

THE WITNESS: T as in time. D, P as in Peter -- D as in dog, P as in Peter, divided by D as in dog, T as in 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?

MR. PAUL: Object to form.

(Discussion off the record).

MR. WHITEHURST: Dr. Banerjee, we're going to go off the record.

THE VIDEOGRAPHER: Going off the record. The time is 10:51.

(Recess from 10:51 a.m. to 11:00 a.m.)

THE VIDEOGRAPHER: We're back on the record. The time is 11:00 a.m.

Q. (BY MR. WHITEHURST) Dr. Banerjee, welcome back. Sorry about the fire alarm, but I'm glad everything is okay now. Before the break, we were talking about Newton's second law.

Do you recall that?

A. Yes.

Q. And you were explaining that one way to write Newton's second law is F = dP divided by dt.

Do you recall that?

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

take into account the subatomic nature of the electrons and you describe the electron quantum mechanically using what is called a wave function. And the first part of the problem is the motion of electron in the periodic crystal potential --

THE REPORTER: In the what?

Wait, I'm sorry, I was on mute.

Motion of electron in the --

THE WITNESS: The periodic, P-E-R-I-O-D-I-C.

THE REPORTER: Oh, periodic.

THE WITNESS: Periodic, yeah.

Crystal potential.

Did you get that?

THE REPORTER: Yes.

THE WITNESS: So that part of the motion is handled quantum mechanically. That leads to something called the band structure. And, in a nutshell, the important result of that part of the force is you change the

actual mass of the electron into what is called an effective mass.

Once you do that, you can sort of forget about the periodic crystal forces and now you can see how these electrons or holes with a modified effective mass respond to the external forces. I believe that's the form of Newton's law we wrote in the textbook.

But there is a third component to the force, which is when electrons or holes are moving in the crystal with this effective mass and responding to externally applied forces or built-in forces, like the built-in electric fields, which is the subject matter of this patent.

They can also undergo random collisions or scattering where the scattering is not caused by the periodic crystalline potential, but deviations from periodic potential,

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such as lattice vibrations or defects or these dopant impurities that you're talking about.

THE REPORTER: What impurities?

THE WITNESS: Dopant impurities, D-O-P-A-N-T.

THE REPORTER: Okay, thank you.

Q. (BY MR. WHITEHURST) Sounds pretty complicated.

A. It is.

Q. And I apologize, but I'm going to try to break down everything you said and hopefully you can be patient with me. And I'll try to do the best job I can, but obviously I don't understand it as well as you do. But, like you said, it's complicated.

So it sounds like to determine movement of an electron in a semiconductor, you have to look at a number of factors, correct?

A. Yes.

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) What are some of the factors you have to look at?

A. Well, as I mentioned, there's three broad categories of forces. The periodic crystalline potential forces.

Q. Okay. And I apologize, we're going to take these one by one. You said there are three broad categories of forces. And, Dr. Banerjee, I apologize for interrupting you. I'm just trying to help our court reporter.

Before we get the three broad categories of forces, can you please spell what the first broad category of force is?

A. I believe I used the term periodic crystalline potential.

THE REPORTER: Periodic crystalline --

THE WITNESS: Crystalline potential, P-O-T-E-N-T-I-A-L.

THE REPORTER: Yes, potential,

okay.

Q. (BY MR. WHITEHURST) So you said that -- strike that.

In order to understand the movement of an electron in a semiconductor, you have to look at three categories of forces, correct?

A. Yes.

Q. And the first category of force that you have to look at is the periodic crystalline potential; is that right?

A. Yes.

Q. What is the second category of force that you have to look at in order to understand the movement of an electron in a semiconductor?

A. Generally --

MR. PAUL: Objection to form.

THE WITNESS: Generally, the second category -- in order to be considered the first, second or third category, that's a matter of

convention.

The second category, in my opinion, would be the externally applied forces or forces that would develop due to these built-in electric fields, such as this doping profile gradient at the --

THE REPORTER: Such as the -- okay.

THE WITNESS: Doping gradient.

THE REPORTER: Okay.

Q. (BY MR. WHITEHURST) So thank you. So in order to understand the movement of an electron in a semiconductor, you have to look at three categories of forces, and one category of forces would be the periodic crystalline potential, correct?

A. Yes.

Q. The second category of force that you would have to look at is externally applied forces or a built-in electric field.

Did I get that correct?

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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 --

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A. I think -- I think I also added the phrase "such as the dopant." I think I said something like that.

Q. Let's get that on the record that the third -- strike that.

The third category of force that you would need to look at in order to understand movement of an electron in a semiconductor would involve dopants; is that right?

MR. PAUL: Objection to form.

THE WITNESS: The dopants would introduce these random static forces because the dopants do not follow a periodic arrangement.

Q. (BY MR. WHITEHURST) And why would these dopants introduce static forces?

A. As we were discussing, the two types of dopants are donors, which donate electrons to the crystal, a negatively charged electron, or acceptors, which accept electrons, and thereby create what is

tantamount to a positively charged carrier in the valence band, which is known as a hole --

THE REPORTER: Which would -- okay. When you talk more slowly, it's easier for me.

THE WITNESS: Yeah, sorry.

THE REPORTER: Create this tantamount --

THE WITNESS: Tantamount.

MR. WHITEHURST: Tantamount.

THE REPORTER: I have that, but I lost it after that.

THE WITNESS: To a positively charged carrier known as a hole, H-O-L-E.

Q. (BY MR. WHITEHURST) And why would the static forces created by the dopants affect the movement of an electron in a semiconductor?

MR. PAUL: Objection to form.

THE WITNESS: So let's look at donors as an example. The phosphorous

or arsenic donor atom itself is a neutral object because the positive charge in the nucleus is counterbalanced by the various electrons in various energy levels.

The lowest energy levels are the core electrons, but then you have the outermost shell, which is the valence shell. When I put it into a silicon crystal and I replace one of the silicon atoms with this phosphorous donor, the fifth electron in the valence shell is donated to the crystal that creates an electron in the conduction band, which can then move around in this periodic crystalline potential, almost like a free particle, like a free electron, but with a modified effective mass because the electron is seeing the periodic crystalline forces.

Now, once the phosphorous or

the arsenic has donated an electron, which can move around, it leaves behind a positively charged donor impurity, which cannot move around. These are the fixed dopants, which once you have created them in the solid, they do not move around at room temperature. And that's what's responsible for the built-in electric field.

Now, in regards to scattering, these donors are acceptors. When you put them into the crystal through a technique, such as ion implantation, they will occupy --

THE REPORTER: Such as ion --

THE WITNESS: Implantation.

THE REPORTER: Implantation, okay.

THE WITNESS: They will occupy random sites in the crystal and 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

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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

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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

move. That's an error in the declaration made by Dr. Glew.

Q. (BY MR. WHITEHURST) I'm just trying to understand this better, Dr. Banerjee, and I certainly appreciate your help.

So let's talk about this first category of forces, which you've referred to as periodic crystalline potential. First of all, what do you mean by "periodic"?

A. A crystal has a periodic arrangement of atoms in space. In the case of silicon, we talk about that in chapter 1 of our textbook, you have atoms in what is called a face-centered cubic lattice, and then you put a second atom associated with these lattice points at a certain location.

And once you do that, you end up with a different structure, which happens to be the same structure as diamond. That's why it's sometimes also called diamond structure. Colloquially, people would call

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that a diamond lattice, but if you want to be accurate, it's a face-centered lattice at the bases of two atoms.

Q. And what do you mean by "crystalline"?

A. So crystalline structure is periodic in space over long distances.

Q. And what --

A. In this case -- in this case, over the entire dimensions of the silicon wafer, for example.

Q. And what do you mean by "potential"?

A. By "potential," I mean the silicon atoms or all atoms have a positive nucleus because they have the heavy protons and the neutral neutrons, which make up the nucleus. And, as I'm sure you know, unlike charges tend to attract to each other, so they create these potential wells, which will draw the negative electrons toward the 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

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masses because they have different periodic crystalline potentials.

THE REPORTER: Different periodic --

THE WITNESS: Periodic crystalline potentials.

Q. (BY MR. WHITEHURST) So let me see if I got this correct. In order to understand the movement of an electron in a semiconductor, you would first need to look at the periodic crystalline potential forces in order to determine the effective mass of the electron.

Did I get that right?

MR. PAUL: Objection to form.

THE WITNESS: You do that for the electrons, especially in the highest line energy levels, in this case, for example, the conduction band in silicon or the holes in the valence band. These are --

THE REPORTER: Or the holes --

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THE WITNESS: Holes in the valence band, V-A-L-E-N-C-E.

THE REPORTER: Right.

THE WITNESS: These carriers are not tied to any specific crystal location -- lattice location. They move around. But the crystal does matter in the sense that it modifies the masses into effective masses. But once you have an effective mass, they are free to move around.

In fact, as I told you, at room temperature these electrons are not going to be static. They are bouncing around in all kinds of random directions and that's known as this random Brownian motion.

THE REPORTER: Random grounding motion?

THE WITNESS: Brownian.

My Zoom screen disappeared.

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

effective mass of the electron.

Do you recall that?

A. Yes.

Q. What is the effective mass of the electron?

A. So the spacing between the atoms and the crystal is generally quite small on the order of angstroms, A-N-G-S-T-R-O-M-S, which is comparable to the quantum mechanical de Broglie wavelength electrons, D-E-B-R-O-G-L-I-E.

When that's the case, you cannot feed these electrons using Newton's laws. You have to invoke quantum mechanics. Specifically, you have to solve the Schrodinger equation, S-C-H-R-O-D-I-N-G-E-R, equation, and that solution leads to a modification of the actual mass into the effective mass.

So the effective mass is a nice compact way of feeding these periodic crystalline forces. And since the periodic

crystalline structure does not change, once you solve that problem, you're done and then you can just focus on the second and the third category of force.

Q. So by calculating the effective mass of the electron, it becomes easier to look at the other two categories of forces; is that correct?

A. That is correct, especially for these highest line electrons in the conduction band or the holes in the valence band. The lower line core electrons are still tied to the nuclei because unlike charges affect each other, so they are connected by springlike forces.

But that is not true for these highest line electrons in the conduction band or the holes in the valence band. They are not bound to the positive nuclei by springlike forces. They are --

THE REPORTER: They are not bound --

THE WITNESS: They are not bound by springlike forces, contrary to what Dr. Glew seemed to imply. They are free to move around, but not free as in space. Their masses get modified into effective mass.

Q. (BY MR. WHITEHURST) So you look at the first category of forces to get the effective mass of the electron, right?

A. Yes.

Q. And then once you get the effective mass of the electron, you move to the second and third category of forces in order to determine the movement of the electron in the semiconductor?

A. That is correct.

Q. So by getting the effective mass of the electron, it's a handy way of then looking at the second and third category of forces?

A. Great. You got an A in my class. Exactly.

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THE REPORTER: Wait, what did you say? I missed that.

MR. WHITEHURST: He said I could get an A in his class. I'm doing the best I can.

Q. (BY MR. WHITEHURST) So let's now assume we have gotten the effective mass of the electron. Why do we have to look at the second and third category of forces in order to determine the movement of the electron in the semiconductor?

MR. PAUL: Objection to form.

THE WITNESS: Yes, so these electrons in the conduction band, which now are moving with an effective mass, are moving in all kinds of random directions. And that is this Brownian motion that we are talking about.

In fact, at room temperature in silicon, as I think I mentioned in my report, there are speeds of up to ten

million centimeters per second.

However, even though they are moving around, because they are moving around in all kinds of random directions and you have a large number of electrons for unit value, there is not going to be any net motion of electrons, and therefore no net current, unless --

THE REPORTER: And no net --

THE WITNESS: Current, C-U-R-R-E-N-T, current.

Unless you apply external voltages or external forces and then it could have a net current flowing. But when it's responding to these external forces, they do not travel unimpeded. Every now and then they are scattered or they collide with these time dependent lattice vibration forces or time independent static forces, such as due to the dopants.

And that is what determines the mobility, which, in turn, determines the resistivity of the semiconductor.

Q. (BY MR. WHITEHURST) Again, it sound very complicated.

You mentioned net motion. What did you mean when you said net motion?

A. So these electrons or holes are moving around in all kind of directions. So if one chose a particular location in a semiconductor device, statistically you have as many electrons moving to the right as to the left, thereby canceling out the current. Net current would be zero.

However, if you apply a battery to the ends of a semiconductor bar, for example, that would create an external electric field and that can then cause what is called a drift motion, which is superimposed on top of this random Brownian motion, which you cannot stop.

And in the case of holes, that

drift velocity will be in the direction of the electric field because holes have a positive charge. Electrons, because they have a negative charge, would move opposite to the electric field.

However, because electrons have a negative charge, if they move to the left, the current of the electrons would move to the right -- would be to the right in the direction of the electric field.

Q. Why do --

A. And all of -- all of this is described in the report.

Q. Why do electrons move in the opposite direction of the electric field?

A. Because they have a negative charge.

Q. And is that always true?

MR. PAUL: Objection to form.

THE WITNESS: So if I have electric field in one that's pointing to the right, for example, they would

move to the left, but that motion -- it is called drift velocity -- is superimposed on top of this random Brownian motion whose speeds are actually typically much higher than this drift velocity.

So you have this whole ensemble of electrons moving around in all kinds of random directions and then you superimpose on top of this ensemble a drift velocity, which would be opposite the direction of the electric field that's applied.

Q. (BY MR. WHITEHURST) Let me see if I've got this right.

So if an electric field points to the right, the electron will move to the left because the electron has a negative charge?

A. That's correct.

Q. How do you know that?

A. Well, do you believe Maxwell's

equations?

Q. So Maxwell's equations tells us that if an electric field points to the right, the electron will move to the left?

A. In Maxwell's equations, he has something called the Lorentz law. From that, you can gather the electrons that would move opposite to the electric field.

Q. Can you spell Lorentz law?

A. L-O-R-E-N-T-Z.

Q. And Lorentz law tells us that if an electric field points to the right, the electron will move to the left?

A. There will be a force on the electron to the left and there will be a net motion to the left, superimposed on top of this random Brownian motion.

Q. So there would be a force to the left.

Did I get that right?

A. If the electric field is to the right, yes, there would be a force to the

left.

Q. Why do you say "force to the left"?

MR. PAUL: Objection to form.

THE WITNESS: That's the Lorentz law that I just mentioned, which tells you that the force on a charged particle is given by the charge times the electric field.

And there is a second term to the magnetic fields that we need not worry about here.

Q. (BY MR. WHITEHURST) How do you determine whether the electron actually moves to the left?

A. You can -- suppose you have a semiconductor bar, like a semiconductor resistor. You would apply a battery to the ends of the bar, which provides a voltage, and, therefore, determines the magnitude as well as a sign of the electric field, depending on the polarity of the battery.

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And then you could hook up an ammeter, A-M-M-E-T-E-R, which measures the current that's flowing.

Now, if the ammeter registers a -- registers a current, I know there's a net motion. And in the case of electrons, if the electric field due to the battery points to the right, the electrons will have a net motion to the left.

But then because of the negative charge, that would point to the right in the same direction as the electric field and that is the current that would be registered by the ammeter.

Q. So there could be multiple fields? Is that what you said?

A. It could be the field in this case due to the battery that I'm hooking up to a resistor, a piece of semiconductor, which would act essentially like a resistor. Now, if this semiconductor was doped uniformly, that is the field that's relevant.

But going back to the patents at issue, you could also have a scenario where the doping concentration in the semiconductor is not unform, is a gradation, and that self-generates additional electric fields, which would be superimposed on the externally applied electric fields due to the battery. You either do a vector sum of the built-in static electric fields to the doping gradient, as well as the externally applied fields, which can change from, you know, one situation to the other, depending on, you know, where I'm hooking up the battery, magnitude of the voltage, et cetera, et cetera.

But the built-in electric field, once that made the semiconductor device with a certain doping gradient, it's static. It's not going to change.

Q. So, again, it sounds very complicated and let me see if I understood 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

vectors, you need to look at all of the vectors; is that right?

A. Yes.

Q. And that's how you get the vector sum?

A. Yes.

Q. So you could have a first field creating a first vector; is that right?

MR. PAUL: Objection to form.

THE WITNESS: Yes.

Q. (BY MR. WHITEHURST) You could have a second field creating a second vector; is that right?

A. Yes.

Q. And if the two vectors are pointing in the same direction, you can add them together?

A. Yes.

Q. But if the two vectors are pointing in the opposite direction, what happens?

A. You can get a cancellation

effect and the larger vector wins. So the net vector will point in the direction of the larger vector.

Q. So if you have a vector pointing to the right -- well, let me -- let me back up.

When we talk about vectors, do vectors have units?

A. Yes.

Q. What would the units be for the vector?

A. So in the case of electric fields, it could be volts per centimeter.

THE REPORTER: It could be what?

THE WITNESS: Volts, V-O-L-T-S, per centimeter.

Q. (BY MR. WHITEHURST) So when we're looking at an electron in a semiconductor, we could have multiple forces acting on it?

MR. PAUL: Objection to form.

THE WITNESS: Well, as I told you, you have the three broad categories of forces, but now focusing on the second category, which are externally applied forces or built-in forces due to doping gradients, those could also have multiple components to it and you have to take the vector sum.

Q. (BY MR. WHITEHURST) So when you have multiple forces, you have to look at the vector sum?

A. To get the net motion, yes.

Q. So in order to determine the net motion, you have to look at the vector sum?

A. In order to --

MR. PAUL: Objection to form.

THE WITNESS: In order to look at the net motion, you have to look at the vector sum. But then the net motion itself, velocity also is a

vector, so you could consider the velocity also as responding to the individual forces and then you take the net vector sum of the velocities.

Q. (BY MR. WHITEHURST) When you use the term "vector sum," could you also call that the net field?

A. If what I'm summing are electric fields pointing in different directions, you could call it the net field, net electric field.

Q. So in order to determine the net motion, you look at the vector sum?

MR. PAUL: Objection to form.

THE WITNESS: If you want to decompose the resulting electric field into its initial component electric fields, the ultimate velocity would depend on the net electric field. The ultimate velocity would also be considered as the vector sum of electric field 1 pointing to the right

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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.

THE WITNESS: If you want to look at the net motion, you have to look at the vector sum.

Q. (BY MR. WHITEHURST) And why do you have to look at the vector sum in order to get the net motion?

MR. PAUL: Objection to form.

THE WITNESS: At a certain location in a semiconductor, you have an electric field with a certain magnitude and a certain direction. That's what I'm calling the net electric field, but that could be composed by, you know, electric fields created by different sources. Either external voltages apply or, in this case, for example, internal self-generated electric fields with doping gradients.

Q. (BY MR. WHITEHURST) I just want to help our court reporter. When you 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

built-in forces due to doping gradient, and that's essentially what the patents are about. These do not require any external batteries to hook up to the semiconductor.

On top of that, you could also hook up a battery --

Q. I apologize. Before we move on, are there different types of built-in forces? Can you think of different types of built-in forces?

A. In this context the built-in force that's relevant is that generated, self-generated by doping concentration gradients?

Q. Can you think of any other built-in forces?

A. You could in certain semiconductors, but not in silicon.

Q. Let's talk about some of the other semiconductors. What are some of the other built-in forces that you can think of?

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.

Q. Did you work on any other types?

A. On other semiconductors?

Q. Yes, sir.

A. Yes, I have, both in grad school and at the University of Texas.

Q. What other semiconductors have you worked with besides silicon?

A. Gallium aresenide is one.

THE REPORTER: Pardon?

THE WITNESS: Gallium, G-A-L-L-I-U-M; second word, arsenide, A-R-S-E-N-I-D-E.

Q. (BY MR. WHITEHURST) Any others?

MR. PAUL: Objection to scope.

THE WITNESS: I work on other semiconductors now at the university.

Q. (BY MR. WHITEHURST) What are some of the other --

A. Such as molybdenum disulfide --

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

questioning as beyond the scope.

MR. WHITEHURST: You don't have to object each time. Your objection is noted.

Q. (BY MR. WHITEHURST) Any others?

A. I have worked on -- I have worked on forms of carbon --

THE REPORTER: Forms of --

THE WITNESS: Carbon, C-A-R-B-O-N, which sometimes can act as a semiconductor.

Q. (BY MR. WHITEHURST) Anything else?

A. None that I can remember offhand.

Q. When you were working with silicon galcium arsenide --

A. Gallium arsenide.

Q. Thank you.

When you were working with 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.

THE WITNESS: So these built-in fields cannot be measured externally with a volt meter because with a volt meter what you measure is another complicated concept called the electrochemical potential. A volt meter only measures differences of electrostatic potential.

Now, when you have doping gradients, you introduce variations of what are called electrochemical potentials. So the only way we can infer that is by solving the relevant equations, and then you see if that matches with externally measured data.

Q. (BY MR. WHITEHURST) Remember how we were talking about the vector sum earlier?

A. Yes.

Q. If we were going to add up all of the vectors and include the built-in 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

units?

A. Yes.

Q. And you mentioned gradient.

Do you recall that?

A. Radium?

Q. I believe you said gradient; is that right?

A. Gradient, yeah.

Q. What did you mean when you said gradient?

A. Gradient means slope. So if you have a doping concentration which is not uniform, but is --

THE REPORTER: If you have a doping concentration --

THE WITNESS: Which is not uniform, but is decreasing as a function of depth, the gradient would be the rate at which the dopant concentration decreases as a function of depth.

Q. (BY MR. WHITEHURST) Why is the

gradient important?

A. The gradient is important because that drives one of the two area of movement mechanisms in the semiconductor. It leads to what is called diffusion of carriers due to this random Brownian motion that we were talking about from a high concentration region to the low concentration region.

So if you have -- suppose we get acceptor ions, for example, which give rise --

THE REPORTER: Suppose what?

THE WITNESS: Acceptor ions.

Did you get it?

THE REPORTER: Sector ions?

THE WITNESS: Acceptor,

A-C-C -- accept, O-R. Acceptor,

A-C-C-E-P-T-O-R.

THE REPORTER: Okay.

THE WITNESS: Did you get it?

THE REPORTER: Yes.

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.

Q. (BY MR. WHITEHURST) Does the gradient affect the vector sum?

A. The gradient will affect the manageability of the built-in electric field. If I apply other electric fields, you have to do the vector sum of those other fields with this built-in electric field.

Q. So the gradient affects the magnitude of the vector, which affects the vector sum?

A. Are you talking about multiple sources of electric fields now?

Q. Yes, sir.

A. Yes, so the gradient will determine the direction and the magnitude of the built-in electric field vector, which is static, does not change once I have constructed the device.

On top of that, if you now choose to apply other voltages, which would generate their own external electric fields, to get the net electric field, you have to do

the vector sum.

Q. So the gradient determines the direction and magnitude of the vector for the field, and in order to get the net movement, you have to get the vector sum; is that right?

MR. PAUL: Objection to form.

THE WITNESS: If in addition to the static doping gradient, which will generate the static built-in electric field, you choose to apply other voltages at different locations where those externally applied electric fields point in other directions. To get the net electric field, you have to take the vector sum and that would give rise to the net velocity.

But, as we were discussing, the built-in doping gradient, which is generating the static electric field, will cause what is called the drift motion of the carriers. The direction

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depends on, you know, the type of dopants you're talking about. And that is static. That's invariant.

But then to get the net motion of those electrons or holes, you would have to add the velocity vector to the static invariant electric field with the doping gradient to the electric field that can vary from problem to problem.

Q. (BY MR. WHITEHURST) You talk about problem to problem. And I think, you know, we started this process, but I don't think we -- we never finished it.

Let's go back to the category 2 forces that you mentioned. I think it would be helpful to get a list of the category 2 forces. We have been talking about built-in electric fields. What are some of the other forces in category 2?

A. The other forces that are very relevant would be the electric fields that

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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

externally applied forces?

MR. PAUL: Objection to scope.

THE WITNESS: Okay. Here, the force that I'm talking about is mechanical force versus electrical forces. Okay?

So you would take a piece of a solid, such as a semiconductor, and you could mechanically squeeze it. That's a mechanical force. That, in turn, can generate electric fields inside that solid if it's a so-called PEO electric solid. But that's not relevant in the case of silicon.

Q. (BY MR. WHITEHURST) Okay. Now, you told me that when you were at TI, you were designing semiconductors.

Do you recall that?

A. I worked with semiconductors.

Q. And you mentioned silicon -- and I'm going to get it right this time -- gallium arsenide and you mentioned moly --

A. Those I did not work on when I was at TI. I worked on those either in graduate school or at the University of Texas.

Q. Okay. And what was the other semiconductor that you mentioned, moly something?

A. Disulfide.

Q. And you also mentioned Tungsten?

A. Deselenide.

Q. And then you also mentioned forms of carbon.

Do you recall that?

A. Yes, and germanium.

Q. Any -- any others?

A. There are probably others I can't remember offhand.

Q. When you were working on these semiconductors, what were the category 2 forces that you encountered?

A. So in any of these, if you hook

up a battery to any of them, that will generate a category 2 force. And in these semiconductor devices, if I had any type of doping variation, that will also generate a category 2 force, except that this is a static built-in force where once I've made the device, I cannot change that, whereas the external batteries, I can have different battery voltages or I can apply the battery at different terminals of the device.

Q. Can you think of any other category 2 forces?

A. Yes. I could apply temperature gradients where the temperature is not the same throughout and that can give you what are called thermoelectric effects.

Q. Anything else?

MR. PAUL: Objection, form.

THE WITNESS: I could apply magnetic fields. That's part of this Lorentz force. So if you have a 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

category 2 force. Yes, we discuss those in the textbook.

Q. Do you describe any other category 2 forces in your textbook?

A. Yes, the Lorentz force; B cross B, that's known as the Hall effect.

THE REPORTER: It's known as what?

THE WITNESS: The Hall effect, sorry. H-A-L-L, capital H.

Q. (BY MR. WHITEHURST) What is the Hall effect?

A. The Hall effect happens when you apply a magnetic field, say in the vertical direction, and you apply and you have the velocity of the particles in the horizontal direction. That will create a force in the mutually perpendicular direction, so in the depth direction away from me. And that's known as the Hall effect.

Q. Do you mention temperature in

your textbook?

A. Yes.

Q. Where do you mention temperature in your textbook?

A. Everywhere in the textbook.

Q. And temperature affects the movement of electrons in a semiconductor?

A. Temperature affects --

MR. PAUL: Objection to form.

THE WITNESS: Temperature affects the random scattering of electrons or holes because high temperatures cause more violent vibrations of these atoms, and that's a greater deviation from the periodic arrangement of atoms. And anything that is a deviation from the RSD causes collisions or scattering. And that would increase the mobility, increases resistivity.

MR. PAUL: Alan, I think we 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

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results for different semiconductors leading to different masses.

Q. Would the effective mass affect the magnitude of the internal force?

A. No.

Q. Why not?

A. Because a force is given by the charge of the particle and its electric field, and neither of those depend on mass.

Q. What are internal periodic crystal forces?

A. Sorry?

Q. What are internal periodic crystal forces?

A. The atoms in the crystal, such as silicon, have a periodic arrangement in space. The atoms themselves are made up of positively charged nuclei --

THE REPORTER: Of what?

Charged --

THE WITNESS: Of positively charged nuclei because the protons in

the nucleus are positively charged and they are surrounded by electrons in different orbits, known as Bohr orbits, B-O-H-R.

The lower energy orbits are closely tied to the nucleus because unlike charges affect each other. But the higher up you go in energy, by the time you go to the valence shell, those are less weakly bound for two reasons. They are farther away from the nucleus and the core electrons, which are negatively charged, shield some of the positive charge. That's a process called screening.

And as a result, the periodic potential that the autonomous electrons see has a smaller depth than the periodic potential that the inner core electrons see.

So the inner core electrons are indeed bound to the nucleus with

springlike forces, as Dr. Glew said, but it is not true for the outer electrons. They are almost free like electrons, except that the mass becomes the effective mass.

Q. (BY MR. WHITEHURST) This morning I believe you referred to the category 1 forces as periodic crystalline potential.

Do you recall that?

A. Yes.

Q. Is that the same thing as internal periodic crystal forces?

A. We talked about two types of internal forces. The internal periodic forces are the same as the internal periodic potential because that gradient of the potential is what gives rise to our force.

But on top of that, we also talked about category 2 internal forces, which is really germane to these patents, and that is given by -- that is generated,

self-generated, by doping concentration variation.

Q. So when you talk about internal periodic crystal forces, do you account for those with the effective mass?

A. That is correct.

Q. Does the effective mass fully account for the internal periodic crystal forces?

A. Pretty good approximation.

Q. Okay.

A. Solving the full quantum mechanical equation with all of the electrons in the solid is actually an unsolved problem. It's not solvable because you're now talking about roughly an Avogadro number of electrons.

THE REPORTER: Talking about --

THE WITNESS: A-V-O-G-A-D-R-O, number of electrons, approximately, and nobody knows how to solve that many-bodied problem exactly. If one

did, one would win a Nobel prize.

So you make approximations and this is a pretty darn good approximation that's worked.

Q. (BY MR. WHITEHURST) And I believe you testified this morning that once you account for the internal periodic crystal forces with the effective mass, then you can look to the category 2 and category 3 forces.

Did I get that right?

A. That's correct.

Q. And before we broke for lunch, we were talking about the category 2 forces.

Do you recall that?

A. Yes.

Q. Now, you talk about in your declaration -- well, strike that.

What is Brownian?

A. Brownian.

Q. Have you used the term "Brownian" in your report?

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 --

THE WITNESS: Current.

THE REPORTER: Okay.

Q. (BY MR. WHITEHURST) When you talk about Brownian motion, can you determine whether an electron moves in a particular direction?

A. It's a statistical mechanics problem. If you don't even try to monitor the motion of individual electrons, okay, you look at this whole ensemble and that's when you can measure and can see the effects of that.

Q. And if you were going to look at the ensemble of electrons, how would you determine whether there is motion in a particular direction?

MR. PAUL: Objection to form.

THE WITNESS: If there's an ensemble of electrons and there are no external forces, there would be no net motion. You would have as many going to the right as to the left.

Q. (BY MR. WHITEHURST) And this morning, we discussed that in order to determine the net motion, you look to the vector sum.

Do you recall that?

A. Yes.

Q. And would the category 2 and category 3 forces be part of the vector sum?

A. As I told you, the way you break down this complicated problem is you put the forces into three categories and you treat them differently. We've already talked about category 1, the effective mass.

You talked then about category 2, which are these external forces or built-in forces and you apply a modified version of Newton's law to that.

And as they are moving, every now and then they will undergo collisions or scattering. That's your category 3. And that part of the effect is captured through what is the called the mobility, which, in

turn, determines the resistivity of the force.

Q. Why is the -- strike that.

Why is the resistivity relevant to the net motion?

A. Resistivity --

MR. PAUL: Objection to form.

THE WITNESS: Resistivity is relevant in the sense that you apply a certain voltage on a piece of semiconductor, and assume that the semiconductor was uniformly doped, it would behave like a resistor where you can apply Ohm's law --

THE REPORTER: You can apply --

THE WITNESS: Ohm's, O-H-M, apostrophe S. And all of this is described in my declaration.

Ohm's law is the current, this is the net current, but with applied external voltage divided by the resistance, which, in turn, depends on

the resistivity and the geometric laying cross-section of the device.

The resistivity, in turn, depends on the mobility. The higher the mobility, the lower the resistivity. And you have higher mobility if you have less collisions of scattering in the material. But that part of the force is a random force. It's more like a dynamic frictional force. It's not something that pulls the particles back like a spring.

Q. (BY MR. WHITEHURST) So you remember how we were talking about you have to look at the net field in order to determine the net movement and you mentioned something about apples and oranges, that we have to have the same units for each of the fields before we can calculate the net field.

Do you recall that?

A. Yes.

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) Do the category 3 forces have a unit?

A. Yes, these forces will also have the same unit, but it -- they are not treated the same way as category 2 forces because they are random.

THE REPORTER: They are not --

THE WITNESS: They are not treated the same way as category 2 forces because they are random. You treat them using a different formula in quantum mechanics called scattering theory.

But if you look at snapshots of these random forces in time or space, yes, those forces would also have the same units as category 2 forces, but you don't handle them with the same techniques as category 2 because that's not practical or convenient.

Q. (BY MR. WHITEHURST) Now I'm

confused, and hopefully you can help me sort things out.

When we were talking about the category 2 forces that go into the vector sum, we talked about volts per centimeter.

Do you recall that?

A. Yes.

Q. When you're looking at the category 3 forces, can you use the same units, the volts per centimeter?

A. You can.

Q. How do you use volts per centimeter for the category 3 forces?

A. You don't do a vector sum of those forces to the category 2 forces because that's not an efficient way of handling the problem, okay, because you have random category 3 forces, again, measured in units of volts per centimeter, random volt in time because of the lattice vibrations being a time-dependent phenomena, as well as random position because the dopants can have random

locations or you can have structural defects that are random that you can't determine externally.

So it is not possible -- I mean, in theory, it might be possible. But from a practical point of view, the smart way of doing them, handling them, is to disaffirm the mobility. Just as effective mass was a nice compact way of factoring the category 1 force, category 3 forces are nicely and compactly captured by the strong mobility.

Specifically, if you look the mobility expression that I have in my report, you see that mobility is given by the charge of the electron of the hole times what is called a scattering time, a collision of time, which is the average time between these random collisions.

So that is what you use as a shorthand way to capture category 3 forces divided by the effective mass, which is a shortened way of capturing category 1 forces.

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Q. I don't understand -- this is true about a lot of things in life. There is a smart way to do things and then a maybe not so smart way, as you put it.

When we talk about the category 2 forces, we talked about how you need to sum up the forces to get the vector sum in order to determine the net movement. And you mentioned that each vector has a direction and a magnitude.

Do you recall that?

A. Yes.

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) When you look at the category 3 forces, if you wanted to use the vector sum approach, could do you that with the category 3 forces?

A. Not in a practical sense because category 3 forces, as I mentioned, are random.

Q. So you testified that the category 2 forces have a direction and a

magnitude. When we look at the category 3 forces, do they have a magnitude?

A. Yes.

Q. Do they have a direction?

A. Yes.

Q. What is the direction of a category 3 force?

A. For different types of category 3 forces, again, going in all kinds of random directions and can vary with time. So with the phonons or the lattice vibrations, it varies not only with time, but can vary with direction depending on how the atoms are vibrating.

Then you have ionized impurities --

THE REPORTER: You have what?

THE WITNESS: Ionized impurities.

THE REPORTER: Okay.

THE WITNESS: They generally give rise to a relatively symmetric

scattering potential, but the space and location of those sites is random. You cannot measure those or predict those. That's why you use the principles of statistical mechanics to handle such problems.

Q. (BY MR. WHITEHURST) When you're talking about category 3 forces, are they relevant to the net movement?

MR. PAUL: Objection to form.

THE WITNESS: They are relevant only as far as impacting the scattering time between collisions, and therefore the mobility, and therefore the resistivity.

So with a certain category 3 force, the whole ensemble of electrons will move with an average drift velocity, but the magnitude of the drift velocity will depend on the category 3 forces through the mobility of the resistivity level.

Q. (BY MR. WHITEHURST) So the category 3 forces do affect the net -- strike that.

So the category 3 forces affect the net movement?

MR. PAUL: Objection to form.

THE WITNESS: For certain -- certain magnitude and direction of category 2 forces, the category 3 forces could impact the magnitude of the velocity, but it would not impact the onset of that motion.

Category 3 forces, as I told you, are not a springlike force that has to overcome before the electrons start moving, contrary to what Dr. Glew says in his report. It's totally wrong.

Q. (BY MR. WHITEHURST) When will the category 3 forces affect the net movement?

MR. PAUL: Objection to form.

THE WITNESS: Category 3 forces will impact the net movement only in as far as the magnitude of the drift velocity is in response to category 2 forces, but they do not create a special force that electrons have to overcome before they start moving. These are two different statements, as I described in my report.

Q. (BY MR. WHITEHURST) Do category 3 forces increase or decrease the magnitude of the vector sum from the category 2 forces?

MR. PAUL: Objection to form.

THE WITNESS: Category 3 forces vary higher and higher. That would reduce the mobility, and thereby increase the resistivity, and therefore decrease the net velocity vector through the category 2 forces.

It will not impact the 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

category 3 forces will reduce the distance that a given net field will move a particular carrier?

MR. PAUL: Objection to form.

THE WITNESS: Net distance in a set interval of time.

Q. (BY MR. WHITEHURST) So a category 3 force will reduce the distance that a given net field moves a carrier in a set interval of time?

MR. PAUL: Objection to form.

THE WITNESS: So if you have the category 2 forces, you do the vector sum, you can have velocity in response to each component of that vector sum. You get a net velocity vector, which will correspond to the vector sum of the electric fields. But the rate at which they move will decrease with increasing scattering in category 3.

So we can view category 3

forces, once again, as inanimate frictional force or a viscous force. We can slow down this average motion of this whole ensemble of electrons.

But remember, in addition to that, these electrons are also undergoing rapid Brownian motion in all directions with the average of that by itself is zero motion. But, again, superimpose a nonzero component in response to category 2 forces, but the magnitude of that could decrease with increasing category 3 forces.

Q. (BY MR. WHITEHURST) But you do agree that category 3 forces affect the distance of the net movement?

MR. PAUL: Objection to form.

THE WITNESS: Category 3 forces impact the mobility, and therefore it impacts the distance they travel between collisions, the mean three act. So they are scattered, but then

speed up again because of category 3 -- category 2 forces, scatter, maybe change directions for a little bit and then travel in the direction of the net force of category 3 forces. That's how you proceed.

Q. (BY MR. WHITEHURST) So we look at the category 1 forces in order to get the effective mass of the electron?

A. That's correct.

Q. Then you look at the category 2 forces in order to calculate the net field?

A. That's correct.

Q. And then you look at the category 3 forces in order to determine the mobility?

A. That's correct.

Q. And the mobility affects the distance?

A. The mobility impacts the velocity. The velocity is given -- the drift

velocity, which is this average velocity of this whole ensemble of electrons or holes is given by mobility times the electric field.

And once you have the velocity, that will tell you how much on average this whole ensemble will move in a certain unit of time, and that's what you register as an external current using an ammeter, for example.

Q. And do you agree that the velocity affects the distance?

MR. PAUL: Objection to form.

THE WITNESS: In a certain unit of time, the velocity will impact how far it travels.

Q. (BY MR. WHITEHURST) So let me see if I got this right. The category 3 forces will affect the mobility, correct?

A. That's correct.

Q. The mobility will affect the velocity, correct?

A. In response to category 2

forces.

Q. And the velocity will affect the distance in a particular interval of time; is that right?

A. Yes, for the whole ensemble.

Q. So when we look at electrons in a semiconductor, we look at the category 1 forces in order to get the effective mass of the electrons?

A. Yes, but you only solve that problem once. Someone has done that for us. You can look at handbooks for these effective masses, in our textbook or the Sze textbook --

THE REPORTER: In our case, look at the --

THE WITNESS: Sorry, effective mass in our textbook or the textbook by Sze, S-Z-E.

So an engineer would not even bother with category 1 forces. It's a 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

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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?

A. That's correct. And then the components of the category 2 forces, as we have discussed.

Q. And the net electric field will have a direction and a magnitude?

A. That's correct.

Q. And the direction in magnitude of the net electric field will depend on the vector sum?

A. That's correct.

Q. Once we have the net electric field, we look at the category 3 forces?

A. Yes.

Q. And the category 3 forces affect the mobility?

A. That's correct.

Q. The mobility affects the velocity?

A. That's correct, in response to the category 2 forces.

Q. And the velocity, in response to the net electric field, will affect the

distance in a time interim?

A. That's correct.

Q. I hope I got at least an A minus.

A. Yes, you get an A plus.

Q. I certainly appreciate your patience with me.

I want to go back to the category 2 forces. We talked about -- we talked about voltages, we talked about built-in electric fields, we talked about temperature, we talked about magnetic fields, the Hall effect and --

A. That's -- that's caused by the magnetic field. It's not a separate event.

Q. Got it. So the magnetic field can create a Hall effect; is that correct?

A. Yes, yes.

Q. And what is the relationship between the Hall effect and Lorentz?

A. Lorentz force?

Q. Correct.

A. It's caused by part of the Lorentz force. The Lorentz force is given by the charge per particle times electric field, and that part is the relevant part.

And then there is a second part of the Lorentz force, which is given by the product of the velocity vector and some magnetic field vector, but it is a so-called cross product, if you can remember, where the cross product is in a mutually perpendicular direction to both the velocity vector and the magnetic field vector.

Q. Why don't we go through each of those. Can you think of any other category 2 forces?

A. In this context, it's really the category 2 forces due to built-in electric fields are externally applied electric fields that are relevant.

Q. Now, you discuss in your book temperature, correct?

A. So just to make sure we're

talking about the same temperature effects, one is if you heat up the whole semiconductor at a certain uniform temperature, that will cause increased scattering, and therefore reduced mobility.

The other temperature effect that we talked briefly is if you have two different temperatures at two ends of a semiconductor, that can develop a voltage due to what are called thermoelectric effects. Once again, that's not really relevant.

Q. Let's talk about the thermoelectric effects. In thermoelectric --

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) Can thermoelectric effects affect the voltage -- strike that.

Can thermoelectric effects affect the vector sum?

A. Did I discuss thermoelectric effects in my report?

Q. I'm sorry, did you understand

my question?

A. I did, but I'm asking you, did I discuss thermoelectric effects in my report anywhere?

Q. Are you unable to answer my question?

A. I can, but my understanding was this was going to relate to my report.

Q. Dr. Banerjee, did your lawyers tell you at any time today to not answer a question if it's not about your declaration?

A. No, they did not.

MR. PAUL: I'll just caution the witness not to reveal the substance of his conversations --

Q. (BY MR. WHITEHURST) Do you realize that you're under oath -- do you realize that you're under oath today?

A. Yes, but they did not.

Q. Okay. Are you able to answer my question, yes or no?

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

affect the vector sum.

MR. PAUL: Objection to scope.

THE WITNESS: Electric fields are vectors, as we discussed, having both a magnitude and a direction. So if you have two different vectors in two different directions, you have to consider both the magnitudes of those components, as well as the relative angle between those components to get the resulting electric field vector. That is what a vector sum means.

Now, earlier we talked about category 3 forces, which also create electric fields. Those are random and short range. And although, principally, you could also do a vector sum with those, it doesn't make sense from a competition point of view or it's not even possible to do that in a practical point of view. That's why you handle those using this

concept of mobility.

Q. (BY MR. WHITEHURST) And I believe you testified earlier today that if the vector sum changes, that affects the net movement; is that correct?

MR. PAUL: Objection, form.

THE WITNESS: The vector sum of electric fields would impact the net vector sum of the different velocity components.

Q. (BY MR. WHITEHURST) So it's your testimony that long -- well, strike that.

So let me make sure I understand your testimony. Thermoelectric effects can create long-range electric fields, correct?

MR. PAUL: Objection, scope.

THE WITNESS: Yes, it can.

Q. (BY MR. WHITEHURST) Can these --

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

answered.

MR. WHITEHURST: Again, you're coaching the witness. Please don't make me have to contact the board, sir.

THE WITNESS: So bar magnets are an example of what's called a ferromagnet, and I think we discussed that in one of the later chapters. It's in the same category as a bar magnet.

Q. (BY MR. WHITEHURST) Do you recall mentioning any other sources of magnetic fields in your textbook?

MR. PAUL: Objection to form.

THE WITNESS: I can't think of any offhand.

Q. (BY MR. WHITEHURST) But you also mentioned a solenoid?

A. Yes.

Q. And you also mentioned current?

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.

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Q. When you have a magnetic field, does it affect the motion of electrons in a semiconductor?

MR. PAUL: Objection, scope. Relevance.

THE WITNESS: Yes, it does.

Q. (BY MR. WHITEHURST) Why does it affect the motion of electrons in a semiconductor?

MR. PAUL: Same objections.

THE WITNESS: We talked about the Lorentz force, which is given by the charge of that particle, times electric field. That's velocity of the particle cross product with the magnetic field, that component gives rise to force of the magnetic field.

Q. (BY MR. WHITEHURST) Does the Lorentz force have a direction and a magnitude?

A. Yes.

Q. And can the Lorentz force

affect the vector sum?

MR. PAUL: Objection to form. Scope.

THE WITNESS: I'm not sure exactly what you mean by affecting the vector sum. You do the vector sum of the electric field vector and the velocity cross B vector. In that sense, yes.

Q. (BY MR. WHITEHURST) And you know how we discussed thermoelectric effects in long-range electric fields. Do you recall that?

A. Yes, yes.

Q. When you're trying to determine net motion, you want to look at the vector sum of all of the different fields, correct?

A. Yes.

Q. Because the vector sum determines the net movement, correct?

MR. PAUL: Objection, form.

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

the electric field and there will be an electric field generated by the velocity cross product with B. And, yes, that can be measured and that is the Hall effect that we talked about.

Q. So when we look at a particular magnetic field, we want to look at the Hall effect; is that correct?

A. I'm not sure I understand exactly what you mean.

Q. If we're trying to determine the net movement of an electron and a semiconductor and we want to determine whether a magnetic field affects the movement of an electron in a semiconductor, we would look at the electric field due to the Hall effect; is that right?

MR. PAUL: Objection to form. Scope.

THE WITNESS: That's correct. So if you have a bar, you could flow a current in the horizontal direction,

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you can apply a magnetic field perpendicular to the bar and then you measure the Hall voltage in the mutually perpendicular direction and you can measure that voltage with or without a magnetic field, and that will tell you the effect of the magnetic field.

Q. (BY MR. WHITEHURST) So if we have a magnetic field, we can look to the Hall effect to determine what the electric field is due to that magnetic field?

A. Yes, you could.

Q. And the electric field, due to the magnetic field, will have a direction and a magnitude?

A. Yes.

Q. And the electric field, due to the magnetic field, can be measured in volts per centimeter?

A. Yes.

Q. And if we are trying to

determine the net movement of an electron in a semiconductor, the electric field, due to the magnetic field, can change the net electric field.

Did I get that right?

MR. PAUL: Objection to form. Scope.

THE WITNESS: Yes, it could, depending on the circumstances.

Q. (BY MR. WHITEHURST) So, you know, any time we're trying to determine net movement, we calculate the net field, and a magnetic field can create an electric field that changes the net electric field, correct?

MR. PAUL: Objection to form. Scope.

THE WITNESS: A magnetic field, in concert with drift velocity, can create a Hall effect. A magnetic field is not enough.

Q. (BY MR. WHITEHURST) So a magnetic field can change the net electric

field, which changes the net movement?

MR. PAUL: Objection to form. Scope.

THE WITNESS: A magnetic field cross product with the velocity will generate electric fields and the vector sum of that electric field with other electric fields and that will determine the net movement.

Q. (BY MR. WHITEHURST) Let me see if I've got this right. A magnetic field will create an electric field, which will change the net electric field, which will change the net movement?

MR. PAUL: Objection to form. Scope.

THE WITNESS: Yes.

MR. WHITEHURST: Let's take a break. We can go off the record.

THE VIDEOGRAPHER: Going off the record, the time is 2:09.

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2:27 p.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 2:27.

Q. (BY MR. WHITEHURST) Dr. Banerjee, welcome back. I wanted to clarify one small point. We've talked a lot today about calculating the net electric field in order to determine -- strike that.

We've discussed today calculating the net electric field in order to determine the net movement of an electron in a semiconductor.

Do you recall that?

A. Yes.

Q. Would your answers have changed had we been talking about holes?

A. No, except that the holes move in the direction of electric field, but electrons move opposite to the electric field. But quality they are the same.

Q. So in order to determine the net movement of an electron in a

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semiconductor, we would calculate the net electric field and then the electron would move in a direction opposite the net electric field.

Did I get that correct?

MR. PAUL: Objection to form.

Q. (BY MR. WHITEHURST) That a hole would move in the same direction as the net electric field?

MR. PAUL: Objection to form.

THE WITNESS: The drift velocity of the hole would be in the same direction, yes.

Q. (BY MR. WHITEHURST) But for both an electron and a hole, in order to determine the net movement, we first determine the net electric field, correct?

MR. PAUL: Objection to form.

THE WITNESS: Yes, that's true.

Q. (BY MR. WHITEHURST) I want to ask you some questions regarding your declaration. I have marked your supplemental

declaration, I should say, as Exhibit 2. The copy I'm looking at is marked Cirrus Exhibit 1060.

(Exhibit 2 marked)

Q. You should see that on the screen in front of you.

A. Yes. I also have an unmarked hard copy in front of me.

Q. Terrific.

I'm going to just read into the record that what I have marked as Exhibit 2 to your deposition is captioned "Supplemental Declaration of Dr. Sanjay Banerjee in Support of Petitioners' Reply."

Did I read that correctly?

A. Yes.

Q. And you submitted this same declaration for seven IPR numbers, the first of which is 2024-00001.

Do you see that?

A. Yes.

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

the fourth or the fifth edition onwards, starting in 1999, or maybe sooner than that. I can't remember. Yes, I think I quoted not the original version, but subsequent versions.

Q. What does the figure on the left, which is marked little "a" show?

A. Was that a question?

Q. Yes. What does Figure 1(a) show?

A. Figure 1(a) is a cartoon view of this random Brownian motion of one individual electron in the absence of a category 2 force electric field.

Q. Let's break that down. So what does it mean when it says "E = 0"?

A. That means there are no long-range electric fields, either due to externally applied voltages or doping gradients.

Q. And is this showing random 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

direction or magnitude, there is scattering or collision going on.

Q. Can we refer to this as random thermal motion?

A. Yes.

Q. Can we refer to this as Brownian motion?

A. Yes.

Q. Can we refer to this as random motion?

A. Yes, a random thermal motion.

Q. And what are the two blue dots?

A. So this shows kind of a time snap, if you will, between some instance of time and maybe a few seconds later, where this particular electron ends up at the second blue dot --

THE REPORTER: The second what?

THE WITNESS: The second blue dot.

THE REPORTER: Oh, blue dot, okay.

THE WITNESS: Yeah. But, as you can see, these two dots don't coincide. But, remember, we don't have just a single electron. We have a whole ensemble of electrons and when you average over the whole ensemble, the center of gravity of the whole ensemble will not go anywhere.

Q. (BY MR. WHITEHURST) I believe you added highlighting to this figure?

A. I think so, yes.

Q. Somebody has highlighted the two dots with a blue circle.

Do you see that?

A. Yes.

Q. And shown here in Figure 1(a), we see this random motion going from one to two to three to four to five to six.

Do you see that?

A. Yes.

Q. And according to this figure, when you get to six, it's close to where you

started?

A. In this document, yes.

Q. And is this what you would refer to as zero net displacement?

A. No, not for an individual electron. If you recall, you have a huge number of electrons, right? So for the whole ensemble, there would be zero net displacement, but individual electrons could have a nonzero displacement, as illustrated over here.

Q. So rather than looking at a single electron, you would look at the ensemble of electrons?

MR. PAUL: Objection to form.

THE WITNESS: Yes, to get the net current, yes.

Q. (BY MR. WHITEHURST) And if the electric field equals zero, you get zero net displacement of the ensemble; is that correct?

MR. PAUL: Objection to form.

THE WITNESS: Yeah, that's correct.

Q. (BY MR. WHITEHURST) Now, something different happens in 1(b), correct?

A. Yes.

Q. There is an arrow at the top.

Do you see that?

A. Yes.

Q. And it says "E" and the arrow is pointing to the left.

Do you see that?

A. Yes.

Q. Do we know what the units are for this electric field?

A. It could be volts per centimeter or you could choose other units also, such as volts per meter, if you want. It's some volts per unit of distance.

THE REPORTER: It's some --

THE WITNESS: Volts per unit of distance.

Q. (BY MR. WHITEHURST) Now, in

this -- well, first of all, is it fair to call this a cartoon figure?

A. Yes.

Q. And in this cartoon figure, you have a blue dot before the one.

Do you see that?

A. Yes.

Q. And it goes from one to two to three to four to five to six.

Do you see that?

A. Yes.

Q. And ultimately, six is farther to the right than where it started.

Do you see that?

A. Yes.

Q. Now, it says that this is an electron.

Do you see that?

A. Yes.

Q. So this electron has moved from the beginning to the end in a direction that 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

semiconductor. It's short collisions.

Q. Can you tell from this figure whether it's a single field or a net field due to multiple fields?

A. No. I mean, it's meant to be the ultimate field, the net field.

Q. Why is it meant to be the ultimate field?

A. We were trying to illustrate what the net motion would be as a result of the net electric field, but you could break down that electric field vector into different components, a component due to the built-in field in the dopant gradient, for example, vector sum with an external field.

Q. But this figure is showing the net movement due to the net field, correct?

MR. PAUL: Objection to form.

THE WITNESS: The cartoon view, yeah, that's what we're trying to show.

Q. (BY MR. WHITEHURST) Now,

earlier today we discussed gradients.

Do you remember that?

A. Yes.

Q. And we discussed that the gradient determines the direction and magnitude of the electric field.

Do you recall that?

A. The gradient of the electrostatic potential determines the magnitude and the direction.

Q. And then in order to determine the net electric field, we would have to look at the other category 2 forces?

MR. PAUL: Objection to form.

THE WITNESS: By category 2, if you mean the built-in fields with the doping gradients, the answer is yes.

Q. (BY MR. WHITEHURST) And in order to determine the net movement, we look at the net field, right?

A. Yes.

Q. But I want to go back to the

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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.

What is the relationship between the gradient and the magnitude of the electric field?

A. So gradients are defined at every point. If the voltage between two points dropped linearly, the slope is constant from point A to point B, then the electric field would be constant between A and B.

In the general case, if you have a nonlinear variation of electrostatic potential distance, then the local slopes at every point would give rise to different electric fields at each point.

Q. So when you look at the dopants, the dopants could be uniform in some areas and have a gradient in other areas, correct?

MR. PAUL: Objection to form.

THE WITNESS: The doping concentration you mean?

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.

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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.

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THE WITNESS: I wasn't asked to by the counsel and I don't remember if Kawagoe has the depth dimensions. And if you don't have it, you cannot calculate that.

Q. (BY MR. WHITEHURST) Why can you --

A. I didn't calculate it. Sorry.

Q. -- not calculate the gradient if you don't have the depth dimensions?

A. Because you need to have both information between the concentration at point A and the concentration at point B. And then the slope, if it's a linear slope, it would be concentration at A minus concentration at B divided by the distance at A minus the distance at B.

Q. So --

A. So if you don't have the depth information, you cannot calculate the gradients.

Q. So when you look at Kawagoe, it

doesn't mention the depth dimensions, correct?

A. I don't recall, but I don't think it does. But it doesn't matter anyway. Anytime I see a non -- non-flat dopant profile, anything with a finite gradient, it has to lead to a built-in electric field and that has to lead to a nonzero drift velocity, regardless of the magnitude of that field, as we were discussing earlier.

Q. So you don't know the depth dimensions for Kawagoe, right?

MR. PAUL: Objection to form.

THE WITNESS: I didn't look at it. Maybe it does. I probably have in front of me. I don't know if the figures have any depths mentioned. I don't know if the specs do. I need to look into that.

Q. (BY MR. WHITEHURST) So you're not aware of any depth dimensions for the doping profile in Kawagoe, correct?

MR. PAUL: Objection to form. Scope.

THE WITNESS: I don't recall, sitting here, if there is. And once again, that's irrelevant to my opinion.

Q. (BY MR. WHITEHURST) And you never calculated the gradient for the doping profile in Kawagoe, correct?

A. I did not. But that's irrelevant, as I said.

Q. And you did not calculate a magnitude for an electric field due to the doping profile, correct?

A. I did not. But, once again, it's not relevant because any gradient would lead to a nonzero built-in electric field. It must, necessarily must happen. And any built-in electric field, no matter how small, would necessarily give rise to a nonzero drift velocity.

Q. You cannot tell me what the

magnitude of the electric field due to the doping profile in Kawagoe is?

MR. PAUL: Objection to form. Scope.

Q. (BY MR. WHITEHURST) And I'll re-ask it. I'll withdraw that question.

Dr. Banerjee, you never calculated a magnitude for an electric field due to the doping profile in Kawagoe, did you?

A. I did not. I don't know if there is enough information in Kawagoe to do that. But regardless of that, it's not important because anytime I see a doping variation, it tells me there has to be a built-in electric field. And regardless of the magnitude of the electric field, it has to lead to a nonzero drift velocity, and that's the essence of this patent.

Q. And just so the record is clear, you didn't calculate a magnitude for 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?

A. I did not calculate those.

Q. Did you ever look at the doping profiles to determine whether the doping profiles were uniform at certain depths?

MR. PAUL: Objection, form.

THE WITNESS: What I had for me in these patents are schematic logs of the doping profiles --

THE REPORTER: Are what?

THE WITNESS: Schematic logs.

THE REPORTER: Schematics, okay.

THE WITNESS: And those indicated downward sloping gradient.

Q. (BY MR. WHITEHURST) I understand that you contend that doping profiles are downward sloping in certain areas. But did you ever look to see whether they were uniform in certain areas?

MR. PAUL: Objection, form. Scope.

Q. (BY MR. WHITEHURST) Just so

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the record is clear, you are looking at a document right now, correct?

A. Yeah, I'm looking at Kawagoe. Sorry. That's Exhibit 1007.

Q. And what are you looking for?

A. I'm looking for schematic doping profiles. So, for example, Figure 17 has the solid line, doping as a function of depth and below a depth of W -- substrate W, it shows that the doping concentration is constant and there will be no built-in fields in that region.

Q. So it's your --

THE REPORTER: Would be no what?

THE WITNESS: There would not be any built-in electric fields in that region.

Q. (BY MR. WHITEHURST) So it's your testimony today that wherever the doping concentration is constant, there would not be a built-in electric field in those sections,

correct?

MR. PAUL: Objection to form.

THE WITNESS: Yeah, the doping concentration is constant or a substantial region. It would not lead to built-in electric fields.

Q. (BY MR. WHITEHURST) Do you understand what the term "active region" means?

A. Yes.

Q. If the doping profile is constant in the active region, would you agree that there is no built-in electric field in the active region?

MR. PAUL: Objection, foundation. Scope.

THE WITNESS: Can you point me to a figure in Kawagoe of the prior art?

Q. (BY MR. WHITEHURST) Do you understand my question?

A. I think there is a substantial

region in the active region where the doping profile was constant that would not have a nonzero built-in electric field in that region. But it has to be over a reasonable landscape, which is known as a screening lane, by the way.

THE REPORTER: Known as a --

THE WITNESS: Screening.

THE REPORTER: Spinning?

Q. (BY MR. WHITEHURST) Can you please -- can you please spell that?

A. Screening.

THE REPORTER: Screening lane?

THE WITNESS: Yes, screen as in screen, screening lane.

Q. So if the doping profile is constant in the active region, there would be no built-in electric field in the active region, correct?

MR. PAUL: Objection, foundation. Scope.

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,

foundation. Scope.

THE WITNESS: There would be no built-in field due to the doping gradient and the other factors in the transistor --

Q. (BY MR. WHITEHURST) So there would be no built-in electric field due to the doping profile, correct?

A. There would be no built-in electric field in the middle of the channel as a function of depth if the doping concentration did not vary as a function of depth in the middle of the channel. But there's other structures that can also cause built-in electric fields.

Q. And in order to determine net movement, we would have to look through those other electric fields, right?

A. There could be other built-in electric fields even with external voltages because of the presence of the gate electrode, gate oxide. So those are also

examples of built-in electric fields, but not due to doping gradients; due to structural effects.

Q. Why can the gate electrode create a built-in electric field even if the doping profile is constant?

A. It can because a gate electrode in general will have different electronic properties than the channel. And the property that I'm talking about is known as the work function, which is defined as the energy between the forming level and the vacuum level, the vacuum level being a reference to potential energy.

In general, the work function in the gate would be different from the work function in the semiconductor in the channel. That can also cause built-in fields in the channel. But that's not really the subject of this patent --

Q. And you also mentioned --

A. -- that we are talking about.

MR. PAUL: He was finishing his statement. You can go ahead and finish your statement.

THE WITNESS: In my opinion, the main subject matter that's relevant in the context of this patent is the built-in electric field in the channel due to the doping gradients to the channel.

Q. (BY MR. WHITEHURST) I want to talk about the built-in field created by the gate electrode and the gate oxide.

Do you follow me?

A. Yes.

Q. Okay. I want to go back up to your testimony. You testified there could be other built-in electric fields even without external voltages because of the gate electrode and the gate oxide.

Do you recall that?

A. Yes.

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.

Q. (BY MR. WHITEHURST) And the electric fields created by the gate and the gate oxide will affect the net electric field, right?

A. Yes. But, once again, that's not the subject matter of these patents.

Q. And you already testified today that the net electric field affects the net movement.

Do you recall that?

MR. PAUL: Objection to form.

THE WITNESS: Yes, electric field does affect net movement.

Q. (BY MR. WHITEHURST) So this means that the electric field created by the gate and the gate oxide will affect the net electric field and the net carrier movement, correct?

MR. PAUL: Objection to form.

THE WITNESS: The gate composition and the gate oxide 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

page 14 of that declaration.

A. The declaration or the supplemental?

Q. My apologies. The supplemental declaration.

A. Yes.

Q. The same one that we were talking about before. Hopefully you have turned to page 14 of the supplemental declaration, and you see a figure at the top, right before paragraph 24 begins?

A. Yes.

Q. Where did this figure come from?

A. I think I sketched it and then the lawyers or the paralegals drafted it up nicely. It's a cartoon view.

Q. So this did not come from a textbook?

A. I don't think so.

Q. This was created from a sketch 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,

you've annotated "Well region."

Do you see that?

A. Yes.

Q. And then you've drawn a dashed line.

Do you see that?

A. Yes.

Q. And then you've labeled to the right of the dashed line "Substrate."

Do you see that?

A. Yes.

Q. Is it your position that the well region is different from the substrate?

MR. PAUL: Objection to form.

THE WITNESS: The wells are typically made in a substrate, starts with a substrate, and then you do implants and implant the needles to form wells in them. But exact terminology may depend on specific patents.

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

don't think it has any particular significance.

Q. Would the active region be to the left or the right of that small dash?

A. It would be on the left of the small dash.

Q. Why would it be on the left of that small dash?

A. Because you do the source/drain implants from the surface, which is on the left of the vertical axis. So the structure would be to the left of that small dash extending up the vertical axis.

Q. Do you agree that the active region would be at the surface of the semiconductor?

MR. PAUL: Objection to form.

THE WITNESS: You should be treating a surface as a three-dimensional object. It would be near the surface. It has a certain 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

principal of scaling of MOSFETs. But really broadly, each would be on the order of a thousand angstroms or so. It depends on the --

THE REPORTER: Really broadly -- I'm having a hard time.

Q. (BY MR. WHITEHURST) The court reporter -- I'm sorry.

A. A thousand angstroms, A-N-G-S-T-R-O-M-S, angstroms.

THE REPORTER: Okay.

THE WITNESS: A-N-G-S-T-R-O-M-S. Did you get it?

THE REPORTER: Yes, but -- okay. I just didn't get the rest of the sentence.

THE WITNESS: It would be of the order of a thousand angstroms.

THE REPORTER: Okay.

Q. (BY MR. WHITEHURST) So that we have a clean record, I'm going to start over again and see if I can not talk over you.

I'll ask a question and I'll pause and I'll make sure you completely answer before I ask my next question.

Dr. Banerjee, would the active region start at the surface of the semiconductor device?

A. Yes.

Q. And then the active region would be a certain depth, correct?

A. Yes.

Q. What is the depth of the active region?

A. So that would roughly correspond to the depth of the source/drain junction, which depends on the technology node, but could be of the order of a thousand angstroms or so.

Q. Now, looking back at the figure on page 14 of your supplemental declaration, do you see the dashed line?

A. On the right-hand side?

Q. Yes, sir.

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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.

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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

ensemble, the center of gravity and how that center of gravity moves in response to electric fields.

And that center of gravity of this whole ensemble of holes once again moves in the direction of electric field, electron's center of gravity also would move opposite to the electric field. But that velocity is superimposed on top of this random velocities of these unusual particles in that ensemble.

Q. (BY MR. WHITEHURST) When you were looking at the prior art, did you determine the starting point for the ensemble of electrons?

MR. PAUL: Objection to form.

THE WITNESS: There is no single starting point for the whole ensemble. There is a large number of electrons and suppose they start the movie at time zero, all of these

billions and billions of electrons -- actually, larger than that -- Avogadro number of electrons who have different locations in space.

So the starting points would be different for each electron. Each of them would have these random motions. And then if I start the movie after, say, one second, an individual electron may start at position 1 and end at 6, but electron No. 2 may start somewhere else and somewhere else, and so on, and so forth.

Q. (BY MR. WHITEHURST) So it's your testimony today that when you look at Figure 17 of Kawagoe, it's not possible to determine the starting point for the ensemble of electrons?

Did I get that right?

MR. PAUL: Objection, form. Scope.

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

I start the clock and I run the clock -- run the movie, for, I don't know, a second. It's a moving, dynamic thing. And then if I focus on one of those individual electrons, I make it a cartoon view, as shown in Figure 1(b).

Okay. Now, if you apply external voltages that add external field, it's vector sum with any built-in electric field into the doping gradient and now you get a net current.

Q. (BY MR. WHITEHURST) So you agree that it's important to determine the starting point and the endpoint, correct?

MR. PAUL: Objection to form.

THE WITNESS: What's happening is a continuous process, right? I guess because you and I decide to do the analysis right now at this moment on a piece of semiconductor does not

mean that electrons prior to that moment were stationary, are starting the journey at that point, right?

I'm just choosing to take a snapshot of the movie, of these dynamic Brownian motion electrons, plus any superimposed drift velocity from time 1, T1 to T2, say, right.

And, once again, at time T1, these electrons would have some distribution applications and velocities. And that -- for that full ensemble, it's like choose one particular electron, it could be this cartoon art in Figure 1(b), right? And then I start the clock at time T2. That particular one would end up at line 6 in this figure, right, if all of those other electrons start at different points, end up at different points.

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,

different points.

But, collectively, the average location of all of this entire ensemble of electrons does not move in the absence of external voltages. That's what happens in the off state of the transistor.

Q. (BY MR. WHITEHURST) Let me -- are you finished?

A. Okay.

Q. I'm sorry, I didn't mean to interrupt you. I was going to provide a figure to hopefully put all of this in context because I'm not sure we're on the same page and without a figure to put all of this into reference, I think it's -- I think a picture would help.

If you don't mind, please turn to Figure 17 of your declaration.

A. Not the supplemental, the original declaration?

Q. No, sir. My apologies.

Page 17 --

A. Oh, page 17.

Q. -- of your supplemental declaration. Just to be clear, I haven't marked your original declaration as an exhibit. All of my questions are about your supplemental declaration.

A. Okay, yes. You said Figure 17, that's why I was confused. Yeah, I see the figure on page 17.

Q. And I know it's getting late in the day and we're all tired, but we need to be careful not to talk over one another. We need to not make our court reporter -- make her job any more difficult than we already are. So I'm going to ask my question, I'll pause, give you a chance to answer and I'll be extra careful to let you finish your answer before I ask my next question.

Do you see Figure 3 at the top of page 17?

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.

Overall movement also is governed by diffusion. Remember, we talked about that.

Q. But we agree that net movement will depend on the vector sum, right?

MR. PAUL: Objection to form.

THE WITNESS: Net movement as in drift velocity would depend on the vector sum.

Q. (BY MR. WHITEHURST) Now, this figure does not show where the active region is. Can you tell me where the active region would be?

A. I haven't looked at the Kamins reference in a while, but I suspect it's on the left-hand side where this p+ dope region meets the doping of ten to the 15, roughly in that region.

THE REPORTER: Meets the doping of --

THE WITNESS: Ten to the power of 15; ten, superscript, 15.

Q. Let's see if we can make a

better record. So do you agree that the active region would start where it says depth, zero?

MR. PAUL: Objection to form. Foundation.

THE WITNESS: I haven't looked at Kamins in a while. So if you show me that, I will be able to give you a more accurate answer.

Q. (BY MR. WHITEHURST) Are you able today to tell me whether the active region is at the surface of the semiconductor device?

A. Once again, without having looked at Kamins in a while, I believe that is the case.

Q. Now, you and I discussed this a little while ago. I think we were on page 14.

Do you recall that?

A. Yes.

Q. If you could please turn to the

figure on page 14.

A. Yes.

Q. And do you recall testifying that the active region would start at the surface where the semiconductor depth is zero. Do you recall that?

A. Yes.

Q. Now, let's turn back to figure 3 on page 17.

Are you there?

A. Yes.

Q. Would the same be true in Figure 3? Would the active region be at the Y axis where the depth is zero?

MR. PAUL: Objection to form. Foundation.

THE WITNESS: I believe that's the case, but I really should look at Kamins to answer that definitely.

Q. (BY MR. WHITEHURST) Where would the active region end?

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.

Do you see that?

A. Yes.

Q. Can we say that is roughly 2.5 microns?

A. Approximately.

Q. In your experience, would an active region go deeper than 2.5 microns?

A. As I told you, it depends on the level of technology. What's happened over the years is when channel lengths are long, junction depths are deep.

It also depends on what device you're talking about. I cannot remember from memory exactly what this particular Kamins reference talks about, and there is also not an absolutely universal definition of what "active region" is. I can't remember if this is a transistor over here or I think it was a CMOS imager, maybe. So there is no fixed depth of active region.

As technology has evolved, I can tell you in a general sense that active

regions have gotten shallower and shallower. There is no fixed number.

Q. But you agree that the active region would be somewhere to the left of this line that's numbered 26?

MR. PAUL: Objection to form and foundation.

THE WITNESS: It would be somewhere in that region, I believe, yes.

Q. (BY MR. WHITEHURST) So the active region would be somewhere between the number zero and where the line labeled 26 intersects the X axis?

A. Approximately in that field.

Q. Where would the substrate be?

A. So the substrate in this case would be, I believe, at -- so, once again, there is no -- the patent uses the term "substrate" in a slightly different context. Same in that literature. So sometimes people use the term "substrate" as the

starting material on which to start making devices --

THE REPORTER: So sometimes --

THE WITNESS: Use the term "substrate" as the starting material on which to start making devices.

In this context, they are talking about epi. Epi is a shorthand for epitaxial layer. Sometimes people talk about growing an epitaxial layer on top of the substrate, but then sometimes we will keep -- sometimes the company will call this epi layer on the substrate as the starting substrate.

So there is no universal definition of these terms. But in this context, I think the vertical line at ten micron depth was meant to be the starting substrate on which they grew a 10-micron anti epitaxial layer and --

THE REPORTER: On which they --

THE WITNESS: Anti epitaxial, E-P-I-T-A-X-I-A-L, layer at the doping level of ten to the 15, ten to the power of 15.

Q. (BY MR. WHITEHURST) To help our court reporter, can you please spell epitaxial?

THE REPORTER: He did. I mean, I have it now, but --

MR. WHITEHURST: Just trying to help you out.

THE REPORTER: I know.

MR. WHITEHURST: I believe it's E-P-I-T-A-X-I-A-L.

THE REPORTER: Yes.

Q. (BY MR. WHITEHURST) Does that sound right?

A. That's correct, yes.

Q. Okay. Let's make sure we're on the same page. So we've got an active region somewhere to the left of where line 26

intersects the X axis.

Do you follow me so far?

A. Yes.

Q. And then we have a substrate deeper than ten microns.

Do you follow me?

A. I think in the Kamins reference, that's correct.

Q. Now, do you see how to the right of the line 26, there is a flat line?

A. Yes.

Q. And do you see where there is a line that says ten -- strike that.

Do you see the line labeled ten to the 15th power?

A. Yes.

Q. And do you see how the line is flat to the right of the line labeled 26?

A. Yes.

Q. And then it goes up at some point around 7.5 until it maxes out at 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

field end?

A. So that depends on the shape of the doping. That would depend on the shape of the entire donor doping profile marked 24. Because I have a doping gradient, the electrons would tend to diffuse to the right and diffuse to the left on either side of the peak region.

And because they tend to diffuse and they cannot be the net current, there has to be a built-in electric field and those are the two electric field deckers that you're talking about. Those electric fields then will generate opposing drift lines so that electron drift and electron diffusion current at every energy has cancelled out, and that is what I show in the figure on page 14 of my report.

These same electric fields and donor dopant concentration gradients will also generate, in this case, minority carrier volt drift and diffusion currents --

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THE REPORTER: In this case -- will generate --

THE WITNESS: Minority carrier volt drift and diffusion currents, which will also cancel out, and there will be no net current of either electrons or volts.

Q. (BY MR. WHITEHURST) And let's stay together. My question is much simpler than that, Dr. Banerjee. I've got a very simple question.

Do you see the electric field pointing in the upward direction, yes or no?

A. Yes, yes.

Q. Do you agree that that electric field ends before the surface?

A. Yes.

Q. Do you agree that that electric field ends before the active region?

A. In this case, yes.

Q. Now, we have talked about 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

the substrate.

Q. (BY MR. WHITEHURST) Very similar question. You agree that the electric field pointing in an upward direction in Figure 3 will not aid the movement of holes from the active region to the substrate?

MR. PAUL: Same objections.

THE WITNESS: This electric field on the left-hand side of curve -- left-hand side of the vertical line on curve 24 will not help holes move from the surface towards the substrate in that degree.

Q. (BY MR. WHITEHURST) Can you please explain why the electric field pointing in the upward direction will not make -- strike that.

Would you please explain why the electric field shown in Figure 3 that points in the upward direction will not aid the movement of holes from either the surface

or the active region to the substrate?

MR. PAUL: Objection to form. Scope. Relevance.

THE WITNESS: As shown in this figure, this left-pointing electric field towards the surface doesn't extend -- doesn't extend all the way to the surface or even to the vicinity of the active field, so it will not cause holes in that region to move from the surface in the depth-wise direction.

Q. (BY MR. WHITEHURST) So in order to aid movement from this surface or the active region, the electric field needs to extend all the way into the active region or to the surface, right?

MR. PAUL: Objection to form.

THE WITNESS: As shown, the electric field is pointing to the left. So if you're talking about 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

where the holes will drift towards the surface, not away from the surface.

Q. (BY MR. WHITEHURST) Now, let's stay with Figure 3, but turn to the electric field that's to the right pointing in the downward direction.

Do you see that?

A. Yes.

Q. Do you agree that the electric field that's pointing in the downward direction will not aid movement of holes from the surface or the active region to the substrate?

MR. PAUL: Objection to form. Scope.

THE WITNESS: That electric field points in the current direction. It enabled holes to drift towards the substrate, but it is too far away from the active region, and therefore will not have any impact in terms of drift motion of the holes on the active

region towards the substrate.

Q. (BY MR. WHITEHURST) Now, because the electric field shown to the right of ten microns is too far from the surface in the active region, it will not aid movement of holes from the surface or the active region to the substrate?

MR. PAUL: Objection to form. Scope.

THE WITNESS: Will not aid movement from the surface to the substrate of the holes in the active region due to the drift mechanism.

Q. (BY MR. WHITEHURST) Do you remember me asking you about starting point and ending point in Figure 1(b) of your supplemental?

A. Yes.

Q. In order to aid movement from the active region or the substrate, the sub -- starting point needs to be in the active region, correct?

MR. PAUL: Objection to form.

THE WITNESS: If you recall, I said that you have -- you don't have just one electron. You have a whole bunch of electrons, which forms a cloud of different electrons at different locations. And they are not static. They are executing random Brownian motion.

So this -- will you repeat the question? I lost track.

Q. (BY MR. WHITEHURST) The reason the electric field in Figure 3 that points in the downward -- strike that.

So when you look at the electric field in Figure 3 that points in the downward direction, it can't aid movement of holes from the active region to the substrate because to the extent it moves any holes in the downward direction, these holes didn't start in the active region, right?

MR. PAUL: Objection to form.

Scope.

THE WITNESS: So if you have -- as long as it's in the active region, that particular hole would not see the effect of this electric field pointing to the right.

But that hole is not stationary. It's bouncing around all over the place due to random Brownian motion and it's possible that at some time, just because of this random Brownian motion, that hole might appear on the right-hand side of vertical line N, where it sees electric field, then they move. Okay?

But that's not a correct way to view things, in my opinion, because --

THE REPORTER: That's what? That's --

THE WITNESS: That's not the correct viewpoint, in my opinion. One doesn't look at the trajectory of

individual electrons or holes. You should look at the elective ensemble and what's happening to the center of gravity, if you will, of the ensemble, and that center of gravity will not -- that center of gravity of the distribution that you're looking at is in the active region, yeah, that will not move away from the surface towards -- towards the object.

Q. (BY MR. WHITEHURST) I just want to make sure we're on the same page. I think we are, but I just want to confirm.

So when you're trying to determine whether an electric field will aid carrier movement from the active region to the substrate, you have to know more than just the direction of the electric field. You also need to know where the electric field starts.

Did I get that right?

MR. PAUL: Objection to form.

THE WITNESS: Yes, you need to know the direction and the spatial location here the electric field is existing in order to determine the drift motion.

Q. (BY MR. WHITEHURST) And why do you need to know the specific location of the electric field?

A. Because this collective ensemble is the center of gravity, or a part, if you will, of this collective ensemble of holes, it's sensitive to the direction, magnitude, and whether there is a nonzero electric field in that center point of this ensemble, if you will.

Q. And I think we agree if the electric field starts or ends below the active region, it will not aid carrier movement from the active region?

A. If the electric field isn't present in the active region, it will not aid carrier movement via the drift mechanism for

this ensemble of failures in the active region.

Q. We spent a lot of time in your declaration discussing majority carriers and minority carriers.

Do you recall that?

A. Yes.

Q. I don't want to get into a debate with you -- it's too late in the day -- about majority and minority carriers, but I want to ask a different question.

Did you read the specification in order to see how majority and minority carriers are used in the specification?

A. In the patents?

Q. Yes, sir.

A. I don't recall. I mean, the terms, majority and minority carriers, are well-known terms in the art, but I didn't resort to the language of the specifications.

Q. Now, I understand that, to you,

majority and minority carriers refers to what's the majority or the minority carrier in the well.

Did I summarize that fairly?

A. The majority carriers refer to carriers that are provided by the dopant and the other side is the minority carrier. If you have a region where you have donors that comes with the majority falls to the minority.

Q. And I understand that that's the position you have taken in your declaration. My question is different.

My question is, did you read Dr. Rao's specification to see how he used majority carrier and minority carrier in his specification?

MR. PAUL: Objection to form.

THE WITNESS: I read the patents, but I can't remember sitting here right now. If you have a 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.

Q. Do you think it's relevant how Dr. Rao used the terms "majority carrier" and "minority carrier" in his specification?

MR. PAUL: Objection to form.

THE WITNESS: Yes, it is relevant, but I don't believe those were the same terms that are in dispute. So, once again, if you show me specific paragraphs, I can take a look at it.

Q. (BY MR. WHITEHURST) So you stated in your declaration that in a p-well, a majority carrier is a p-type dopant; is that right?

A. For the carriers of the holes or electrons, the p-well is doped with acceptors and that will create majority carrier holes.

Q. Now, if Dr. Rao used the terms the other way around in his specification, would you want to know that?

MR. PAUL: Objection to form.

THE WITNESS: Sure.

Q. (BY MR. WHITEHURST) And why would you want to know how Dr. Rao used the terms "majority" and "minority carrier"?

A. You know, you interpret the same language in the Rao patents in light of the specifications.

Q. And why do you interpret the claims in light of the specification?

MR. PAUL: Objection to form.

THE WITNESS: I'm not a lawyer, but that's how they do it by my counsel in prior cases also.

Q. (BY MR. WHITEHURST) When you were forming your opinions, did you read the specification to see how Dr. Rao used the terms "majority" and "minority carrier"?

MR. PAUL: Objection, form.

THE WITNESS: I did read the patents. I believe all of the specifications are exactly the same or 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?

A. Those are the charge carriers that allow current to flow.

Q. Right.

THE REPORTER: Allow what?

THE WITNESS: Allow current to flow.

THE REPORTER: Okay, current.

THE WITNESS: Current.

THE REPORTER: Okay.

MR. PAUL: Alan, we have been going for about an hour. Do you have much longer or should we --

MR. WHITEHURST: I got -- do you want to take a break now? I was trying to wrap up this line of questions, but if you would like to take a break, it's fine with me.

Q. (BY MR. WHITEHURST) Do you want me to finish up this line or -- Dr. Banerjee, do you want to keep going or take a break?

A. How much longer are you

thinking of going?

Q. I can wrap this up in ten minutes, five.

A. The whole thing?

Q. Oh, no, this line of questions.

A. Oh, this line of questions.

MR. PAUL: So why don't we take a short break then.

MR. WHITEHURST: Okay.

THE VIDEOGRAPHER: Going off the record, the time is 4:29.

(Recess from 4:29 p.m. to 4:43 p.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 4:43.

Q. (BY MR. WHITEHURST) Dr. Banerjee, welcome back. You know, like we did earlier, I think it's helpful to put everything into perspective with a picture. And earlier you mentioned Figure 5B, I believe it was, of Dr. Rao's invention.

At this time I'm going to mark

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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,

Dr. Banerjee, do you see on the screen in front of you where it says Figure 5B?

A. Yes.

Q. Do you see where it says this is a CMOS substrate for a DRAM? I'm not reading the entire --

A. Yeah.

Q. Okay. If we could zoom in just on the figure at the top.

A. Yes.

Q. Does this show a MOS device?

A. It shows a DM-cell, which includes a MOS transistor on the left and a MOS capacitor on the right.

Q. So where it says "Access Transistor," would that be MOS device?

A. They are both MOS devices. I think the MOS spec, the structure, the storage capacitor is a MOS capacitor.

Q. So on the left, where it says "Access Transistor," we're looking at a MOSFET?

A. Yes.

Q. Can you tell me whether this is an NMOS or a PMOS transistor?

A. NMOS.

THE REPORTER: N, like the letter N?

MR. WHITEHURST: I'm going to help out our court reporter. I believe the witness said NMOS, which is capital N-M-O-S.

THE REPORTER: Okay.

MR. WHITEHURST: As opposed to a PMOS, which would be capital P-M-O-S.

Q. (BY MR. WHITEHURST) So, Dr. Banerjee, let me re-ask my question.

A. Okay.

Q. Figure 5B, where it says "Access Transistor," this is an NMOS transistor?

A. Yes.

Q. And would you agree that --

well, let me back up. Let me set the stage properly.

Do you see two semicircles, for lack of a better term?

A. Yes.

Q. And do you see where it says "n," and I believe that's a typographical error, where it says "t"?

A. I think they meant n+.

Q. What does n+ mean?

A. Sorry?

Q. What does n+ mean?

A. N means n-type dopants doped with donors and the plus sign means very high levels of doping.

Q. So on the left, there is a region that is heavily doped with n-type dopants, correct?

A. Yes.

Q. And on the right is another region that's also heavily doped with n-type 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.

THE WITNESS: You could flip the polarities. So basically the carriers flow from the source through the channel into the drain.

Q. (BY MR. WHITEHURST) Why do carriers flow from the source through the channel into the drain?

A. So in this case, although it's not shown, generally speaking, this NMOS would be made in a p-type channel. The central part would be doped with acceptors. You would have to turn the transistor on by applying a gate voltage at the top in excess of what's called a special voltage. That will create what's called an inversion there of electrons near the top surface connecting the n+ source, the n+ drain, and then you apply a positive voltage to the drain. That will pull the negatively charged electrons from the source to the channel into the drain.

Q. Let me make sure I understand

this correctly. So Figure 5B shows an NMOS transistor, correct?

A. Yes.

Q. On the left is a source that is heavily doped with n-type dopant?

A. Yes, if -- yeah, if that electrode was grounded.

Q. And then on the right is a heavily doped n-type drain?

A. Yes, which would generally be n with a positive voltage.

Q. And in between the source and the drain would be p-type doping?

A. Generally, though you could have other polarity also.

Q. And when the transistor is turned on, electrons flow from the source on the left to the drain on the right?

A. Yes.

Q. So the electrons move from the source towards the drain?

A. In a MOSFET. But in this

particular structure, it's used as an access transistor in a DRAM cell. In this case, actually, the electrons flow back and forth, depending on whether they are writing to the storage capacitor or reading of the storage capacitor. But I have given you a description of -- the simplest description of just the MOSFET.

Q. Now, in this NMOS transistor shown in Figure 5B, electrons move back and forth between the source and the drain, correct?

A. If you use the transistor as an access transistor in a DRAM, yes.

Q. Now, I believe you said when you build a MOSFET, you have back-to-back p-n junctions.

Did I get that correct?

A. Yes.

Q. Is it possible for the p-type dopants to move into the source or the drain?

MR. PAUL: Objection to form.

THE WITNESS: During operation or during fabricating?

Q. (BY MR. WHITEHURST) During operation.

A. No, dopants don't move at room temperature.

Q. So the holes do not move into the source or the drain, do they?

A. Are you talking about the dopants or the carriers?

Q. The carriers.

A. Carriers can move, but the dopants don't move.

Q. Let's talk about the charge carriers. In this NMOS transistor, the electron carriers will move back and forth between the source and the drain, correct?

A. In this particular application where the NMOS transistor is being used as an access transistor, you get electron charges back and forth between the storage capacitor 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

currents.

But then if we apply a positive voltage to the gate, since light charges with each other, that would push away the mobile majority carrier holes away from the surface in the middle part of the channel and, at some point, not only will it push away the majority carrier holes --

THE REPORTER: Not only will it -- not only will it --

THE WITNESS: Push away majority carrier holes in the p-type channel and start attracting the minority carrier electrons to the p-type channel, and that forms what is called an inversion layer of electrons connecting the source to the drain and that's when the transistor can be turned on.

Q. (BY MR. WHITEHURST) So when the NMOS transistor is turned on, a channel will form between the source and the drain,

correct?

A. An inversion layer of electrons will form in the channel region between the source and the drain.

Q. Now, in an NMOS transistor, when a channel forms between the source and the drain, which charge carrier is moving from the source to the drain?

A. It's electrons.

Q. Please explain why when the channel forms, the electrons move from the source to the drain.

A. So here you have to apply two voltages. You apply a positive gate voltage at the top. That's going to attract electrons towards the surface, but they cannot keep flowing because in between the gate electrode and the surface of the substrate, you have electrical insulator. So the minority carrier electrons will flow towards the surface, but they cannot keep going because they are blocked by an

electrical insulator.

Then if you apply a voltage to the drain, that creates a lateral electric field along the channel and that's the electric field which will actually cause the electrons to flow from the source, which is generally held at ground potential to the drain, which is held at a positive voltage.

Q. And when the channel forms between the source and the drain, what happens to the holes?

A. So when you push the holes away by applying a positive gate voltage, you create a diffusion region and the holes do not have any significant role except for a tiny amount of p-n junction leakage current in one of the reverse biased p-n junction. And that is --

THE REPORTER: In one of the --

THE WITNESS: The reverse bias p-n junction. And in this case, that is the drain channel p-n junction.

But those currents are always a magnitude smaller. The dominant current flow in an NMOS is electrons flowing from the source to the drain. And because they have a negative charge, the current vector point is in the opposite direction.

Q. (BY MR. WHITEHURST) Is it fair to say that when the transistor is turned on, it's the electrons that are moving from the source to the drain?

A. In an NMOS, that's true. In a PMOS, it's the holes.

Q. Let's stay with NMOS for now.

And when you turn the transistor on and off, the holes are going up and down; is that correct?

A. Yes. So when you're turning it on, you're pushing the holes down, but they don't flow except for tiny, tiny amounts of leakage currents.

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

transistor in the p-well, correct?

A. That's correct, yes.

Q. And it's your position in your declaration that when you have an NMOS transistor in a p-well, the majority carrier is a hole and the minority carrier is an electron?

A. The majority carrier is a hole and minority is electron in the p-well, but in the n+ --

THE REPORTER: Wait, wait, I lost it. I lost it after --

THE WITNESS: But in the n+ --

THE REPORTER: The majority --

THE WITNESS: Yeah, in the p-well, the majority carriers are holes and the minority carriers are electrons. But in the n+ source and drain, majority carriers are electrons, holes are the minority carriers.

Q. (BY MR. WHITEHURST) Okay. So

you agree that when the channel is formed, the majority carrier is an electron?

A. Majority carrier where? You have to specify which location and what the doping type is.

Q. Okay.

A. I guess for an answer, even when the channel is formed, even though you have a preponderance of electrons in the channel, that's considered to be an inversion region. So even the "on" state majority carrier electrons in the dope n-type source and drain, while in the p-type channel, the majority carriers are holes, minority carriers are electrons.

Q. So it's your position that regardless of whether the transistor is turned on or off, that in Figure 5B, the majority carrier is always the hole and the minority carrier is always the electron?

A. In the well region, right. That's what you're asking, counsel, right?

Q. Is it your position that the majority carrier or minor carrier will change depending on where you are in the semiconductor device?

A. Yes. It will depend on what the doping type is in that region. If the doping type is donors, electrons have the majority, holes are the minority. If the doping type is acceptors, holes are the majority, electrons are the minority. And that's not my position. That's accepted terminology.

Q. Okay. I think I understand what you're saying.

So instead of defining "majority carrier" and "minority carrier" so that it would be the same throughout the source and the drain and the p-well, you define them differently for the source, the drain and the p-well, correct?

MR. PAUL: Objection to form.

THE WITNESS: I define them

differently because they are doped differently.

Q. (BY MR. WHITEHURST) Okay.

A. You always define majority carrier depending on the dopant type.

Q. That's your position.

Now, you -- instead of defining "majority carrier" and "minority carrier" so that they would have the same meaning in the source, the drain or the p-well, you picked definitions that will change whether you're in the source, the drain or the p-well?

MR. PAUL: Objection, foundation. Mischaracterizes.

THE WITNESS: Majority carriers, once again, are defined as a carrier type provided by the dopant. And if you have different doping types in the different regions, majority carriers will be different in the doping regions.

Q. (BY MR. WHITEHURST) And we're

just going to have to agree to disagree. I'm just trying to understand your position.

So one way to define "majority carrier" and "minority carrier" would be to pick a definition that would be the same for the source, the drain and the p-well.

Do you understand me so far?

A. Yes.

Q. And another way would be to define them so that "majority carrier" means one thing and the source and the drain and a different thing in the p-well.

Do you understand me so far?

A. Yes.

Q. So option 1 is you pick definitions for "majority carrier" and "minority carrier" that would be the same whether you're talking about the source, the drain or the well. That's option 1.

Do you follow me?

A. Yes.

Q. And option 2 would be you use

different definitions whether you're in the source, the drain or the p-well.

Do you follow me?

A. Yes. That's my position and that's consistent with this figure.

Q. And that's what you did. You picked option 2, you didn't pick option 1?

MR. PAUL: Objection, mischaracterizes testimony.

Q. (BY MR. WHITEHURST) Is that a fair assumption?

A. Yeah, I think that's a fair assumption, yes.

Q. You picked option 2 where the majority carrier and the minority carrier will change depending where you are in Figure 5B. That's the option you picked?

A. I think the definition of "majority carriers" is the carriers provided by the dopant. And in this case, since the source and the drain have donors that comes from the majority carriers there, since the

well is p-type -- is a doped p-type, those are the majority carriers.

Q. Okay. Now, when you look at this NMOS transistor, it's electrons flowing between the source and the drain, correct?

A. So, once again, in this structure, it's not just the NMOS transistor. It's being used as an access transistor between the storage MOS capacitor on the right, and on the left-hand side, it's connected to what's called the bit line. I can tell you exactly what the figure is.

Q. I understand. I'm just -- I'm trying to -- I'm trying to use our time efficiently so you and all of your attorneys can get out of there, and I'm trying to do the same.

A. Sure. I can explain this figure in great detail if you allow me one minute.

Q. Well, let me ask the question and you answer it and that's -- that's what

we're going to do here.

Now, when you look at an NMOS transistor in a p-well, like we see in Figure 5B, you agree that an electron will flow from the source to the drain.

Do you agree with that part?

A. I agree with that part, but in this case, the source and the drain are getting -- during read and write operation of the cell.

Q. So let me -- let me make my question more clear.

In an NMOS transistor in a p-well, it's electrons that are moving back and forth between the source and the drain, not the holes?

A. That's correct.

Q. Now, when -- can you please direct your attention to column 3?

A. Okay.

Q. And you can see column 3, line 36, we're talking about Figures 5A, 5B

and 5C.

Do you see that?

A. Yes.

Q. So here in column 3, we're talking about the same Figure 5B that we have been looking at, correct?

A. Yes.

Q. And then if we go down to line 64, continuing on line 65 and line 66, will you please read aloud the sentence that begins "the graded dopant"?

A. "The graded dopant can also be implemented in surface channel MOS devices to accelerate majority carrier towards the drain."

Q. And you testified that, in Figure 5B, it's the electrons that are moving back and forth between the source and the drain, not the holes.

Do you recall that?

A. Yes.

Q. So when Dr. Rao used the term

"majority carriers" to describe Figure 5B and he is talking about the majority carriers moving back and forth between the source and the drain, he was referring to the electrons?

MR. PAUL: Objection to form.

THE WITNESS: If it's an NMOS, he's referring to electrons.

Q. (BY MR. WHITEHURST) And that's because in the NMOS transistor in a p-well that's shown in Figure 5B, electrons move back and forth between the source and the drain, not the holes, correct?

A. Could you repeat that? Sorry.

Q. And that's because in the NMOS transistor in a p-well that's shown in Figure 5B, electrons move back and forth between the source and the drain, not the holes, correct?

A. Yes.

Q. And when the specification says, in line 65 of column 3, that the 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?

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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

you need, five minutes?

MR. PAUL: Half hour.

MR. WHITEHURST: Why do you need a half hour?

MR. PAUL: I don't think we need to answer that.

MR. WHITEHURST: Well --

MR. PAUL: You took time -- you took time during the last deposition. We're going to do the same.

MR. WHITEHURST: Counsel, do you -- are you planning to talk to the witness during the 30 minutes? Can I ask that on the record? Do you intend to talk to the witness during the 30 minutes? I don't understand why we can't finish.

Okay. We can stay on the record. And let the record reflect counsel and the witness are leaving the room and apparently they need a 30-minute break.

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We can go off the record now.

THE VIDEOGRAPHER: Going off the record, the time is 5:17.

(Recess from 5:17 p.m. to 6:01 p.m.)

THE VIDEOGRAPHER: We're back on the record, the time is 6:01.

EXAMINATION

BY MR. PAUL:

Q. Good evening, Dr. Banerjee.

A. Good evening.

Q. Just a few follow-up questions about the questions you were asked today.

Do you recall being asked about the analysis you performed and the conclusions that you provided for purposes of the IPRs?

A. Yes.

Q. Okay. And if you could go to your supplemental declaration, do you have a copy of that with you?

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."

Q. And do you agree with the -- are these your opinions?

A. Yes.

Q. And do you stand by them?

MR. WHITEHURST: Objection -- counsel, you've got to give me a chance to object.

Objection, scope, leading. You didn't even ask him a question. You just had him read the declaration and asked whether he agreed.

MR. PAUL: Okay.

MR. WHITEHURST: Objection, scope, leading. This is not a proper recross.

MR. PAUL: Okay. You can limit -- you can limit your objections to a single word as well, Alan.

Q. (BY MR. PAUL) So as I was saying, what did you mean when you mentioned -- when you were referring to -- 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.

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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.

Different -- different semiconductors will have different periodic potential leading to different effective masses. That's something, in fact, the main issue, which is the static field created by the doping gradient, aiding drift.

Q. (BY MR. PAUL) Okay. And just to be clear, if you are dealing with silicon, is that a fixed parameter or is it a parameter that changes?

A. It's a fixed parameter.

Q. Okay. Did you need to make any measurements for any category 1 forces in order to arrive at the conclusions --

A. No.

Q. -- you came up with in this matter?

MR. WHITEHURST: Counsel, you have got to give me a chance to object.

Objection, scope, leading. You

basically told him the answer in the question. Objection, leading.

MR. PAUL: I disagree with your characterization and please limit your -- your objections.

MR. WHITEHURST: Why don't you re-ask the question and I'll object. You guys were talking over one another.

Q. (BY MR. PAUL) Okay. Did you need to make any measurements for any category 1 forces in order to arrive at the conclusions you reached in these proceedings?

MR. WHITEHURST: Objection, scope, leading.

THE WITNESS: No, I did not.

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

A. Because the patent talks about these long -- these long range electric fields created by doping gradients and that is not impacted by the different periodic 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

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dopant concentration?

MR. WHITEHURST: Objection, scope, leading.

THE WITNESS: No, it will not.

Q. (BY MR. PAUL) Okay. And, finally, I believe the third category of force component that you mentioned had to do with random collisions or scattering; is that right?

A. Yes.

Q. And do you recall testifying that that category affects mobility, which, in turn, affects resistivity?

A. Yes.

Q. Okay. And did you address resistivity in your supplemental declaration?

A. Yes.

Q. Okay. And, briefly, does the resistivity affect whether or not carriers will move via drift due to a dopant electric field created by a graded dopant concentration?

MR. WHITEHURST: Objection, leading.

THE WITNESS: Resistivity will not impact whether the carriers will move via drift. But I -- as I mentioned during my deposition, it will impact the speed at which they move.

Q. (BY MR. PAUL) Okay. And do the claims at issue in these proceedings call for any particular speed of carrier movement?

MR. WHITEHURST: Objection, leading.

THE WITNESS: They do not.

MR. WHITEHURST: Scope as well.

Q. (BY MR. PAUL) Do you recall being asked questions about one's ability to measure movement by applying a battery and using an ammeter?

A. Yes.

Q. And did you need to apply a 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?

MR. WHITEHURST: Objection, leading.

THE WITNESS: Because these patents are talking about the built-in field -- internal built-in field created by doping gradient aiding the movement of minority carriers, not what happens if you have additional external fields.

Q. (BY MR. PAUL) And, very briefly, do you also recall being asked questions about the ability to measure the strength of an electric field using a volt meter?

A. Yes.

Q. Did you need to use a volt meter in order to arrive at any of the conclusions you made in these proceedings?

MR. WHITEHURST: Objection, leading.

THE WITNESS: No, I did not.

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.

THE WITNESS: No.

Q. (BY MR. PAUL) Why are they not affected by electric fields due to gate oxide or gate electrodes?

MR. PAUL: Objection, leading.

THE WITNESS: All the claims are talking about electric fields created by doping gradient. Gate oxide and gate electrodes are a different matter altogether.

THE REPORTER: Gate oxide and --

THE WITNESS: And gate electrodes are a different matter.

Q. (BY MR. PAUL) Does the drift of carriers due to the built-in field created by a graded dopant concentration, is that altered by the presence of other fields, potential fields stemming from gate oxide or gate electrodes?

MR. WHITEHURST: Objection, leading.

THE WITNESS: No, they are not.

Q. (BY MR. PAUL) Did you need to -- strike that.

Do you recall being asked a series of questions about other hypothetical scenarios in which multiple other electric fields may be present?

A. Yes.

MR. WHITEHURST: Objection, leading.

Q. (BY MR. PAUL) As part of the analysis you performed in arriving at your conclusions, did you need to add up different electric field vectors in order to reach your conclusions regarding the challenged claims?

MR. WHITEHURST: Objection.

THE WITNESS: No, I did not.

Q. (BY MR. PAUL) Did you need to, for purposes of arriving at your conclusions for the challenged claims, need to subtract one electric field vector from another electric field vector?

A. No, I did not because nothing in the patents --

MR. WHITEHURST: Objection, leading. Objection, leading.

THE WITNESS: The patents are not dealing with net motion. They are dealing with the drift field specifically of the minority carriers due to the built-in field due to the doping gradient.

MR. WHITEHURST: I just want the record to reflect that counsel is reading pre-scripted questions off of a computer screen verbatim and all of the questions are suggesting the answer. They are improper recross.

Q. (BY MR. PAUL) Do you recall being asked a series of questions about the Kawagoe prior art reference?

A. Yes.

Q. Do you recall being asked 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

graded dopant concentration that you mentioned you identified in Kawagoe, is that decreasing from the surface of the device to the substrate --

MR. WHITEHURST: Objection, scope.

Q. (BY MR. PAUL) -- or what is the substrate?

A. Yes.

Q. And in any -- in all of the other prior art references that you relied upon in these proceedings, did you identify a graded dopant concentration that is decreasing from the surface of the device to the substrate?

MR. WHITEHURST: Objection, leading.

THE WITNESS: Yes.

Q. (BY MR. PAUL) Do you recall being asked questions about Figure 5B of the challenged patent?

A. Yes.

Q. Do you recall being asked about Figure 5B and portions of the specification for the '222 patent specifically?

A. Yes.

Q. Do you recall being asked questions with respect to Figure 5B of the '222 patent about what is the majority carrier in certain regions of the device shown in that figure?

A. Yes.

Q. When providing the answers that you did regarding the majority carrier in certain regions of the device, were you applying a consistent -- consistent definition of the term "majority carrier" in providing those answers?

MR. WHITEHURST: Objection -- objection, leading. I mean, you're asking him a question and telling him the answer and then listening to a yes or no. I don't know how you think that's not a leading question.

Objection, leading.

MR. WHITEHURST: This in no way -- I disagree with your assessment, Alan.

MR. WHITEHURST: Well, you have obviously never been to court and know what a leading question is.

But objection, leading.

THE WITNESS: So in this case, the majority --

Q. (BY MR. PAUL) Let me re-ask the question for a clean record.

Were you applying a consistent definition of "majority carrier," quote, unquote, when you were providing those answers --

MR. WHITEHURST: Objection.

Q. (BY MR. PAUL) -- regarding Figure 5B?

A. Yes.

Q. How so?

A. So in this case, if it's an

NMOS device, the majority carriers in the source and drain electrons, electrons will be flowing from the source to the drain.

THE REPORTER: Would be joined?

THE WITNESS: Will be flowing from the source to the drain.

THE REPORTER: Flowing, thank you.

Q. (BY MR. PAUL) Do you recall being asked questions about column 3 of the '222 patent specification?

A. Yes.

Q. Do you recall being asked, referring to column 3, lines 64 to 66 of the '222 patent -- are you there?

A. Yes.

Q. Do you recall being asked about the sentence and the specification that reads, "The graded dopant can also be implemented in surface channel MOS devices" -- that's M-O-S devices -- "to accelerate majority carriers towards the

drain?" Do you recall being asked that question?

A. Yes.

Q. And do you see where this sentence is -- withdraw that.

When this sentence is mentioning majority carriers, do you have an understanding of what region of the device they are referring to when they mention majority carriers?

A. Once again, majority carriers in a region location refer to the carriers created by the dopants. Assuming you are looking at an NMOS, the majority carriers are the source of the electrons and would flow from the source to the drain.

Q. So is it your understanding that the -- based on what you just said, that you understand majority carriers, as mentioned in line 65 to 66 of column 3 of the '222 specification, is referring to majority carriers in the source region?

A. I believe so.

MR. PAUL: I don't have any further questions at this time.

FURTHER EXAMINATION

BY MR. WHITEHURST:

Q. Dr. Banerjee, do you realize you're under oath?

A. Yes.

Q. Under the penalty of perjury?

A. Yes.

Q. Did you testify truthfully today?

A. Yes.

Q. Will you stand by your testimony?

A. Yes.

Q. I don't normally do this, but this is rather extraordinary. You and your attorneys took a 40-minute break. During that 40-minute break, at any time did you meet with any of the attorneys or other persons sitting at the table with you now?

A. Yes.

Q. Which of the attorneys sitting at the table did you meet with during the 40-minute break? If you can please identify them by name on the record.

A. I met with counsel, Raj Paul and Anupam Sharma, and I believe Kent Cooper was also there and Emre.

Q. Did you speak with anybody on the phone?

A. I did not.

Q. Did you speak with anybody other than the attorneys sitting at the table with you?

A. I did not.

Q. Did you meet with the four attorneys -- how many attorneys did you meet with?

A. I believe there are four in the room.

Q. Did you meet with those four attorneys for the full 40 minutes?

A. I took a bio break and then some of them went in and out of the room. It wasn't for the full 40 minutes. I took a break, Raj Paul took a break.

Q. Did you meet with the attorneys for more than 30 minutes?

A. I did not keep a record of the time.

Q. What's your best approximation of how long you met with the attorneys during the 40-minute break?

MR. PAUL: Objection to the relevance of this.

THE WITNESS: Probably 20 minutes or so because I took a bio break, Raj Paul took a bio break. And for some time, I was walking around in the corridor and they were talking amongst themselves. So maybe half the time.

Q. (BY MR. WHITEHURST) During the approximately 20 minutes, did Mr. Paul tell

you that he was going to ask you questions?

MR. PAUL: I instruct the witness not to discuss conversations you have had with your attorneys.

Q. (BY MR. WHITEHURST) I asked you, Dr. Banerjee, did you speak with Mr. Paul during the 20-minute break, yes or no?

MR. PAUL: You can answer yes or no.

THE WITNESS: Yeah, I did speak to them, Mr. Paul and -- yeah.

Q. (BY MR. WHITEHURST) Can you please identify -- did you speak with all four of the attorneys sitting at the table now during the 20 minutes?

A. I don't believe I spoke to Mr. Cooper. I spoke to Mr. Paul and Mr. Sharma and I think I met briefly with Mr. Emre.

Q. So let me get these names 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?

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MR. PAUL: Instruct you not to answer. Calls for privileged information.

Q. (BY MR. WHITEHURST) Dr. Banerjee, can you answer my question yes or no?

MR. PAUL: Once again, I instruct you not to answer it as it calls for privileged information.

MR. WHITEHURST: Okay. Counsel, listen to my question carefully. I didn't ask him yes or no.

Q. (BY MR. WHITEHURST) Dr. Banerjee, I'm laying foundation here. Dr. Banerjee, I just asked you whether during the break you spoke with Mr. Paul about your testimony.

Do you understand my question? You don't answer it yet. Do you understand my question?

A. Yes, I understand your

question.

Q. Can you answer my question, yes or no?

MR. PAUL: Instruct you not to answer. It calls for privileged information.

Q. (BY MR. WHITEHURST) Dr. Banerjee, are you able to answer my question?

A. I'm instructed by my counsel not to answer. I'm going to listen to his instructions.

Q. If he had not instructed you not to answer, are you able to answer my question?

MR. PAUL: Objection.

Q. (BY MR. WHITEHURST) Do you understand? I'm not asking you to answer it. Are you able to answer my question whether you spoke with Mr. Paul about your testimony?

MR. PAUL: Objection, 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

you not to answer the question.
Objection, calls for privileged information.
Q. (BY MR. WHITEHURST) Dr. Banerjee, are you going to follow your attorney's advice and refuse to answer my question?
A. Yes.
Q. Dr. Banerjee, did you speak with Mr. Yuzak about your testimony?
MR. PAUL: Objection, calls for privileged information and instruct you not to answer.
Q. (BY MR. WHITEHURST) Dr. Banerjee, are you going to follow your attorney's advice and refuse to answer my question?
A. Yes.
Q. Dr. Banerjee, thank you for your time today. This concludes your deposition.
A. Thank you.

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

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

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REPORTER'S CERTIFICATION OF THE ORAL DEPOSITION OF SANJAY BANERJEE, PH.D.
DECEMBER 6, 2024 (Reported Remotely)

I, Donna Wright, a Certified Shorthand Reporter and Notary Public in and for the State of Texas, hereby certify to the following:

That the witness, SANJAY BANERJEE, PH.D., was remotely duly sworn by the officer and that the transcript of the oral deposition is a true record of the testimony given by the witness;

That the original deposition was delivered to Mr. Raj Paul;

That a copy of this certificate was served on all parties and/or the witness shown herein on _____;

I further certify that pursuant to FRCP Rule 30(3) that the signature of the deponent:

__X__ was requested by the deponent or a party before the completion of the deposition and that the signature is to be before any notary public and returned within 30 days from date of receipt of the transcript. If returned, the attached Changes and Signature Page contains any changes and the reasons therefore:

____ was not requested by the deponent or a party before the completion of the deposition.

I further certify that I am neither counsel for, related to, nor employed by any of the parties or attorneys in the action in which this proceeding was taken, and further that I am not financially or otherwise interested in the outcome of the action.

Certified to by me on this, the 11 day of December, 2024.

_____
Donna Wright, CSR No. 1971
Expiration Date: 11/20/26
Firm Registration No. 719

Sanjay Banerjee, Ph.D., c/o
COVINGTON & BURLING, LLP
850 Tenth Street, NW, One City Center
Washington, DC 20001

Case: Cirrus Logic, Inc. et al. v. Greenthread, LLC
Date of deposition: December 6, 2024
Deponent: Sanjay Banerjee, Ph.D.

Please be advised that the transcript in the above referenced matter is now complete and ready for signature. The deponent may come to this office to sign the transcript, a copy may be purchased for the witness to review and sign, or the deponent and/or counsel may waive the option of signing. Please advise us of the option selected. Please forward the errata sheet and the original signed signature page to counsel noticing the deposition, noting the applicable time period allowed for such by the governing Rules of Procedure. If you have any questions, please do not hesitate to call our office at (202)-232-0646.

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Case: Cirrus Logic, Inc. et al. v. Greenthread, LLC
Witness Name: Sanjay Banerjee, Ph.D.
Deposition Date: December 6, 2024

I do hereby acknowledge that I have read and examined the foregoing pages of the transcript of my deposition and that:

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Deposition Date: December 6, 2024

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