1 UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE PATENT TRIAL AND APPEAL BOARD
2
WESTERN DIGITAL TECHNOLOGIES,)
3 INC.,)
)
4 Petitioner,)
)
5 Vs.)
)
6 GODO KAISHA IP BRIDGE 1,)
)
7 Patent Owner.)
_____/
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9
10
11 Case No. IPR2024-01494
12 U.S. Patent Number 11,968,909
13
14 VIDEOTAPED DEPOSITION OF CAROLINE A. ROSS, Ph.D.
15 (Taken Virtually by Petitioner)
16 Friday, September 19th, 2025
17 9:02 a.m. EDT
18
19
20
21
22 Certified Stenographic Court Reporter
Amy A. Brauser, RPR, RMR, CRR

1 VIRTUAL APPEARANCES

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12

13 ALSO PRESENT:

14 Mitchell Mahon, Videographer

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WD EX1102
Western Digital v IP Bridge, IPR2024-01494
Page 2

1 VIDEOTAPED DEPOSITION OF CAROLINE A. ROSS,
2 Ph.D., a witness called on behalf of Petitioner,
3 before Amy A. Brauser, RPR RMR CRR, Certified
4 Stenographic Court Reporter and Notary Public, in
5 and for the Commonwealth of Virginia, on Friday, the
6 19th day of September, 2025, commencing at 9:02 a.m.
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1 INDEX OF EXAMINATIONS

2 By Mr. Wilson . . . . . Page 6

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5 (NO EXHIBITS MARKED)

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1 P R O C E E D I N G S
2 THE VIDEOGRAPHER: We are going on the
3 record. This is File Number 1 of the
4 deposition of Dr. Caroline A. Ross, taken in
5 the matter of Western Digital versus IP
6 Bridge, Cause Number IPR2014-01494. Sorry.
7 The date is September 19th, 2025. This
8 deposition is being held remotely via Zoom
9 video conference.
10 My name is Mitchell Mahon. I'm the
11 legal videographer for Digital Evidence Group.
12 The court reporter is Amy Brauser in
13 association with Digital Evidence Group. The
14 time is 9:02.
15 Will counsel, please, introduce
16 themselves for the record?
17 MR. WILSON: Douglas Wilson of Armond
18 Wilson LLP for Petitioner Western Digital.
19 And with me is Spencer Ririe.
20 MR. HRYCYSZYN: Jerry Hrycyszyn with
21 Wolf Greenfield for IP Bridge.
22

CAROLINE ANNE ROSS, Ph.D.,
after having been first duly sworn by the certified stenographer, was examined and testified as follows:

EXAMINATION

BY MR. WILSON:

Q. Good morning, Dr. Ross.

A. Good morning.

Q. And you understand today's deposition is for IPR0224-01494?

A. Yes, I do.

Q. Okay. And that involves U.S. Patent Number 11,968,909?

A. Yes.

Q. And if I refer to that as the '909 Patent, you'll know what I mean?

A. I will.

Q. Okay. You understand you're under oath this morning, correct?

A. Yes.

Q. And if I ask a question and you don't understand the question, please ask for clarification.

A. Understood.

Q. Okay. If you answer a question without asking for clarification, I'll assume that you understood it. Okay?

A. Okay.

Q. Is there any reason, medical or otherwise, why you cannot testify fully, truthfully and accurately as you sit here today?

A. There's no reason.

Q. Okay. And can you, please, state your full name?

A. Caroline Anne Ross.

Q. Okay. And again, you are testifying today on behalf of IP Bridge, correct?

A. Correct.

Q. And you've been retained by Wolf Greenfield on behalf of IP Bridge?

A. Yes.

Q. And you're being compensated by IP Bridge for your time today?

A. Yes, although I'm being paid by Wolf Greenfield.

1 Q. Okay. Now, today we have a single
2 declaration, Exhibit 2053, for the 1494 IPR.
3 Do you have that declaration in front
4 of you?
5 A. I do.
6 Q. And if you can turn to page 106.
7 That's your signature on page 106?
8 A. Yes, it is.
9 Q. And it's dated July 12th, 2025,
10 correct?
11 A. Correct.
12 Q. And the next page, you see Appendix A,
13 materials considered, starting at page 107 and
14 running through page 110?
15 A. Yes.
16 Q. Okay. And if we go back up in your
17 declaration to Paragraph 11 on page 7, you identify
18 the materials considered as the documents cited or
19 referenced in your declaration, including in
20 Appendix A, correct?
21 A. Yes, it identifies the materials I
22 reviewed and considered, the Petition, the

1 institution decision, and Appendix A.
2 Q. Okay. Is that a complete list of the
3 materials that you considered and relied on in
4 forming the opinions expressed in Exhibit 2053?
5 A. Yes, that's right.
6 Q. And Exhibit 2053 is a complete
7 statement of the opinions that you are offering in
8 this IPR 1494, correct?
9 A. Correct.
10 Q. Now, what did you do to prepare for
11 your deposition this morning?
12 A. For this morning, I read through many
13 of those documents again.
14 Q. Okay. You reviewed your declaration,
15 Exhibit 2053?
16 A. Yes.
17 Q. Did you find anything that you thought
18 needed to be corrected?
19 A. I didn't find anything in this
20 document. I did find something in the
21 '167 declaration from yesterday.
22 Q. So you're saying since yesterday

or . . .

A. Yes. Based on one of the questions you asked me.

Q. So there's something in your '167 declaration that you thought of after the deposition yesterday that you think needs to be corrected in your '167 declaration?

A. Yes, I did.

Q. Okay. What is that?

A. So Paragraph 296 on page 104 where I'm talking about the thin crystallized layers of cobalt iron boron, which Yuasa's APL paper says could have formed next to the MgO barrier layer, I'd said in my declaration in that paragraph that this satisfies the entirely crystallized limitation. But thinking about that some more, given that not all of the cobalt iron boron is crystallized, I think that is inconsistent with my other opinions. So I believe that's an error.

Q. Okay. Did you reach that decision in consultation with counsel for IP Bridge?

A. No. I was thinking about it after we

had exchanged questions and answers about this yesterday, and I wanted to think about it some more later in the day. But I do believe that the thin crystallized layer is crystallized, fully crystallized, adjacent to the MgO, but not throughout the entire cobalt iron boron layer. So that statement is, I believe, an error.

Q. Okay. And so just so we're clear, you think the claims, both -- or the '167 claims specifically, when they say that a layer is entirely crystallized, you think that means that all of the cobalt iron boron that is present has to be fully crystallized in order to constitute an entirely crystallized cobalt iron boron layer, correct?

A. What I'm -- what I'm saying is in relation to this Paragraph 296, where I'm commenting on how Yuasa's APL paper provides a nexus to the claims as part of the secondary considerations.

So what I'm -- what my opinion is, is that the thin cobalt iron boron layer adjacent to

1 the MgO doesn't satisfy the entirely crystallized
2 limitation.
3 Q. Okay. So let's -- so I'm just trying
4 to understand why you've changed your opinion.
5 You're saying you now feel like if only
6 a portion of the cobalt iron boron layer is
7 crystallized, that it doesn't meet the entirely
8 crystallized limitation in the '167 claims,
9 correct?
10 A. What I'm saying is that Yuasa's thin
11 monolayers or several layers of cobalt iron boron
12 crystallized material that he describes in his APL
13 paper don't meet the entirely crystallized claim.
14 So my opinion is -- what I'm explaining
15 to you now is related to that secondary
16 consideration of what the Yuasa APL paper actually
17 says.
18 Q. Right. And I'm trying to understand
19 why that is the case. Is it the case that you
20 believe that the entire cobalt iron boron layer
21 that exists there needs to be crystallized to meet
22 the entirely crystallized limitation?

A. Well, what I'm -- my opinion is that in Yuasa's APL paper, he shows images of his structure where he says he can't exclude the possibility of there being crystallized regions adjacent to the MgO barrier layer, which he describes as a few monolayers or monolayers of crystallized cobalt iron boron.

There's clearly amorphous cobalt iron boron remaining in that structure. So, therefore, this doesn't satisfy the entirely crystallized limitation.

Q. Okay. So I think what you're saying, and correct me if I'm wrong, is if you have a cobalt iron boron layer in which there remains some amorphous cobalt iron boron, then that cobalt iron boron layer is not entirely crystallized --

A. I'm just --

Q. -- in your opinion?

A. Oh, sorry. I'm just saying that I don't believe Yuasa's example, the paper in -- the APL paper, is a secondary consideration that satisfies that claim.

1 I don't want to correct the opinions
2 beyond that paragraph, because the other opinions I
3 have in the document I stand by. But this
4 particular paragraph is where I believe I made an
5 error when I said that the crystallized monolayers
6 adjacent to the MgO barrier satisfy the entirely
7 crystallized limitation.
8 Q. Right. I understand that you believe
9 you made an error. And I'm trying to understand
10 why, the rationale behind the error you believe you
11 made. And I believe what you're saying is that if
12 you have, as Yuasa did, a cobalt iron boron layer
13 in which a portion of that layer remains amorphous,
14 it is not entirely crystallized as required by some
15 of the claims of the '167 Patent, correct?
16 MR. HRYCYSZYN: Objection, beyond the
17 scope.
18 THE WITNESS: So I'm not offering any
19 opinions about the construction or the
20 meaning of "entirely crystallized." What I
21 am giving a revised opinion on is whether
22 Yuasa's APL paper reveals an entirely

1 crystallized layer. And since Yuasa's
2 description has a layer of -- or some
3 monolayers of crystallized material and some
4 region of noncrystallized material, then it
5 doesn't satisfy the entirely crystallized
6 limitation.
7 So that's the extent of my opinion on
8 this Paragraph 296.
9 BY MR. WILSON:
10 Q. Okay. And you agree, then, that the
11 Yuasa APL 2005 paper, Exhibit 2006, does not
12 provide any objective evidence of nonobviousness of
13 Claims 2, 4, 6 and 12 through 13 of the
14 '167 Patent, correct?
15 A. I'm not remembering which exact claim,
16 but the entirely crystallized phrases within the
17 claims are not -- the APL paper does not give an
18 example of entirely crystallized cobalt iron boron.
19 Q. Okay.
20 Okay. Any other corrections to
21 Exhibit 2053 for the '909 Patent or your other
22 declarations?

A. No, I didn't find any corrections to be made in the '909 declaration.

Q. Okay. And as you sit here right now, you are confident in all the opinions you express in Exhibit 2053 for the '909 Patent, correct?

A. Yes.

Q. Now, you worked with the law firm Wolf Greenfield in preparing Exhibit 2053 for the '909 Patent?

A. Yes, I did.

Q. Did you work with anyone other than lawyers at Wolf Greenfield?

A. No, I didn't.

Q. Okay. So you didn't work with anyone at IP Bridge in preparing your declaration?

A. No, I don't know anybody at IP Bridge.

Q. Okay. Approximately how much time did you spend preparing your declaration, Exhibit 2053?

A. I don't recall exactly. It's probably the order of 30 hours, roughly.

Q. Okay.

Okay. You understand the '909 Patent

has claims that are directed to a tunnel barrier height, correct?

A. Yes.

Q. Okay. Have you ever been involved in the measurement of tunnel barrier height of a magnetic tunnel junction?

A. I have fabricated them and measured their IV characteristics. I don't recall whether I extracted barrier heights out of that data.

Q. Okay. When is the earliest example you recall fabricating an MTJ in which you measured its IV characteristics?

A. My declaration on Paragraph 8 has a list of papers which I've coauthored on tunnel junctions. So those are some of the examples.

Q. In any of those papers, did you fabricate an MTJ and measure its current voltage characteristics?

A. Most -- all of these are about the fabrication and patterning of magnetic tunnel junctions. I believe most of them have electrical data, although I don't recall exactly.

Q. Okay. So the earliest paper listed in Paragraph 8 is 2015, correct?

A. That's the earliest one listed in Paragraph 8.

Q. So is that the earliest you believe you fabricated a magnetic tunnel junction and measured its current voltage characteristics?

A. I don't actually recall if I've measured or made tunnel junctions prior to 2015.

Q. Okay. In your declaration you reference a paper by Slonczewski. Are you familiar with that?

A. Yes.

Q. Okay. Have you ever in your publications referred to Slonczewski's model?

A. Are you asking if I've cited Slonczewski in any of my papers?

Q. Yes.

A. I don't actually recall what the citations are in any of these papers.

Q. Okay. Were you aware of -- and just for reference, Slonczewski in this proceeding is

Exhibit 2041. But were you aware of Slonczewski's paper, Exhibit 2041, before this case?

A. Yes.

Q. Okay. And you've reviewed Slonczewski's paper, Exhibit 2041, before this case, correct?

A. By reviewing it, do you mean have I read it prior to this case?

Q. Yes.

A. I've been aware of it. I don't recall when.

Q. Okay. And you don't recall ever citing Slonczewski's paper, Exhibit 2041, in any of your work on MTJs, correct?

A. I don't recall citing it.

Q. Okay.

And you're also aware of the Butler paper, which is Exhibit 1044, correct?

A. I'm certainly aware of the Butler paper.

Q. Okay. Do you recall citing the Butler paper in any of your work on magnetic tunnel

1 junctions?
2 A. I don't remember whether I've cited it
3 or not.
4 Q. Okay. Were you familiar with the
5 Butler paper before this case?
6 A. Yes. It's extremely famous.
7 Q. Okay. And so you have reviewed
8 Butler's paper, Exhibit 1044, and were familiar
9 with its content before this case, correct?
10 A. Yes.
11 Q. Okay. Is there any publication you're
12 aware of that you were involved in as an author in
13 which you reported the resistance area product of a
14 magnetic tunnel junction?
15 A. I don't recall. I would have to look
16 back through my papers to remind myself what
17 electrical data we may have reported. So I don't
18 recall at this point whether we cited or measured
19 RA data.
20 Q. Now, you're familiar with Exhibit 1031,
21 which is Simmons' paper on tunneling, correct?
22 A. Yes.

Q. And you were familiar with Exhibit 1031, Simmons' paper, before this case, correct?

A. Yes, broadly speaking.

Q. And you reviewed Simmons' paper as part of preparing your declaration, Exhibit 2053, in this case, correct?

A. Yes.

Q. Now, if you take a look at Exhibit 1017, which is the '909 Patent.

Now, if you take a look at Column 7, starting at about line 39, there's a discussion of Simmons' paper there.

Do you see that?

A. Yes.

Q. Okay. And on the top right in Column 8, equation 2 there is Simmons' formula, correct?

A. That is Simmons' formula in a specific circumstance, which is a low-bias voltage.

Q. Okay. If we take a look at Exhibit 1031, which is Simmons' paper.

A. I will have to ask for some help to find this on the computer.

Q. Okay.

(Brief pause.)

THE WITNESS: Okay.

BY MR. WILSON:

Q. So you have Simmons' paper, Exhibit 1031?

A. I do.

Q. Okay. And as you just articulated, the equation, the Simmons' equation that's -- that's recited in the '909 Patent is Simmons' equation for a low-voltage range. You'll find that on page 1796 of Simmons in the lower right-hand corner.

(Witness reviews document.)

A. I'm not seeing exactly this one. Is this equation 24 in Simmons?

Q. It is, yes.

A. Okay. It's written a little differently.

Q. Okay. Well, with a little time to review it, do you agree that that's equation 24 in

Simmons? Equation 2 in the '909 Patent is equation 24 in Simmons?

(Witness reviews document.)

A. Well, equation 24 has a parameter capital A, which is defined somewhere else. And that appears in Column 8 of the '909 Patent. It is written out explicitly. So 24 doesn't include everything that's in equation 2 of the '909 Patent.

Q. Okay. If you take a look on page 1795. In the lower left-hand corner, do you see the definition of A?

(Witness reviews document.)

A. Yes, there's a definition of A. This is in a current voltage relationship for generalized barrier.

Q. Okay. With that definition of A, do you believe that equation 24 in Simmons is the same as equation 2 in the '909 Patent?

A. I would have to look back at -- back through Simmons because the definition of capital A in Simmons' equation 10 has a term "beta" in it which is defined in the appendix. And so the --

there's yet another part of that Simmons equation in this paper.

Q. Okay. Fair to say that the '909 Patent attributes this equation 2 in Column 8 to Simmons, correct?

A. Yes. It says the Simmons formula can be described as follows in the low-bias voltage regime, in Column 8.

Q. Okay. You would agree that Simmons' paper and the '909 Patent are in the same field of art, correct?

A. Simmons is describing tunneling, but not magnetic tunnel junctions. So the science of tunneling in Simmons is a part of tunnel junctions, but the field of the '909 Patent as in Column 1 relates to a magnetic tunnel junction device and a method of manufacturing the same.

Q. Okay. So in your opinion, Simmons is not in the same field of art as the '909 Patent?

A. I haven't considered whether Simmons is in the same field of art since Simmons is the common way of describing tunneling phenomena.

Yuasa has used it in his analysis for the '909 Patent.

Q. Okay. Doesn't that suggest that they're in the same field of art?

A. I don't know if -- if I can answer that. I didn't consider that question.

Q. Okay.

A. I just considered Simmons since it's cited by the '909 Patent.

Q. Okay. Simmons is reasonably pertinent to the problem to be solved by the '909 Patent, correct?

A. Simmons describes a theoretical model, which many people use to analyze tunneling phenomena. So it's a very broadly applied model.

Q. Okay. When you refer to Simmons' model, are you referring to Figure 1 in Simmons on page 1794?

A. Hang on.

(Witness reviews document.)

A. Well, Simmons' Figure 1 is a general schematic of what the energy levels are in a stack

as you go from one electrode through an insulating barrier and then into another electrode. That's a general expression of how one might start to describe "tunneling phenomena."

Q. Okay.

A. And Simmons goes on to analyze that model and calculate the -- analytically calculate what the IV curves would be under various situations.

Q. Okay. So in Simmons' insulator in Figure 1 is not any particular material, correct?

A. Simmons' insulator is a nonconducting material.

Q. Okay. It's -- it's not specifically magnesium oxide, correct?

A. I don't believe Simmons defines what material he's thinking about.

Q. Right. Simmons' insulator is just a generic nonconducting material, correct?

A. Yes.

Q. And Simmons' electrodes are not assumed to be ferromagnetic, correct?

A. Simmons' electrodes are just metals.
Q. And as you mentioned earlier, Simmons' Figure 1 model is not of a magnetic tunnel junction, correct?
A. That's right. It could be. It doesn't have specific materials. It's -- Simmons doesn't exclude magnetic electrodes, but Figure 1 doesn't specify the materials.
Q. Okay. In fact, Simmons was published in 1963, correct?
A. Yes.
Q. And that was before the discovery of the tunnel magnetoresistance effect, correct?
A. It was before the 1975 Jullière model.
Q. Which is when the tunnel magnetoresistance effect was discovered, correct?
A. That's generally agreed to be the start of tunneling magnetoresistance.
Q. So Simmons' concept of barrier height, of tunnel barrier height, was defined before magnetic tunnel junctions were discovered, correct?
A. Yes.

Q. You would agree that all metals have a conduction band, correct?

A. All metals have a partially filled band with a Fermi level partway in the band. It's not always described as a conduction band.

Q. Okay. All metals have a Fermi level, correct?

A. Every material has a Fermi level.

Q. Okay. And as you just said, I believe, the Fermi level lies in what can be called the conduction band in a metal, correct?

A. In a metal which is characterized by having mobile electrons. The Fermi level is within a band of allowed states such that that band is partially occupied. And those electrons near the top, near the Fermi level, are the ones which provide the conductivity.

Q. Okay. Insulators also have a conduction band, correct?

A. Insulators have bands as well. You can call them conduction bands and valence bands and so forth, but in an insulator there aren't any, or

very few carriers in the conduction band or the upper band that would allow for conductivity.

Q. Okay. In insulators, by definition, there is a gap between the valence band and the conduction band, correct?

A. The Fermi level is in the gap between two bands. So that one -- the lower band is fully occupied and the upper band is empty. That's what characterizes insulators and also semiconductors.

Q. Okay. And in general, when you have a metal -- let me strike that.

In general, when you have a metal insulator interface, the difference between the Fermi level of the metal and the conduction band in the insulator is what is defined as the barrier height, correct?

A. That's certainly a common way of looking at it.

Q. So let's take a look at Exhibit 2039.

MR. HRYCYSZYN: Do you need help or were you able to get it?

THE WITNESS: You find it.

MR. HRYCYSZYN: You said 2039?

MR. WILSON: Yes, 2039. It's Soukup's dissertation.

BY MR. WILSON:

Q. Okay. You have in front of you Exhibit 2039?

A. Yes.

Q. And this is the dissertation, the Ph.D. dissertation, of Rodney Soukup?

A. Yes.

Q. Okay. And you're familiar with Exhibit 2039, correct?

A. Broadly.

Q. Okay. You reviewed it and cited it in your declaration, Exhibit 2053, correct?

A. I reviewed it to get some additional insight into the Soukup paper.

Q. Okay. If we take a look at page 125, which is PDF page 139, if you're trying to jump straight there.

Do you have that page?

A. You said page 125?

Q. Yes. Numbered page 125 in the exhibit.
A. Okay. It's labeled as Appendix 2.
Q. Right. That's the right page.
You see the first sentence at the top of that page, Soukup says: (Reading)
The barrier height is defined as the energy difference between the bottom of the conduction band and the Fermi level at the interface.
Did I read that correctly?
A. Yes.
Q. And that's the definition that we just established for barrier height, correct?
A. Right.
Q. And if you take a look back at the '909 Patent, Exhibit 1017, Column 3, line 24. It says: (Reading)
In a preferred embodiment, the band discontinuity value, parentheses, the height of the tunnel barrier, close parentheses, between the bottom of the conduction band of the MgO(001)

1 layer and the Fermi energy of the
2 Fe(001) layer is smaller than an ideal
3 value of a perfect single crystal
4 without defect.
5 Did I read that correctly?
6 A. You did.
7 Q. And so the '909 Patent defines the
8 height of the tunnel barrier in the same way as
9 Soukup, correct?
10 A. Yes.
11 Q. And you've reviewed Soukup's paper,
12 correct?
13 A. Exhibit 1028?
14 Q. Yes, Exhibit 1028.
15 A. Yes, I've reviewed it.
16 Q. And you understand that Soukup reports
17 barrier heights for the MgO barriers made as part
18 of his experiment, correct?
19 A. He reports -- excuse me. He reports
20 barrier heights calculated using several different
21 approaches, primarily using a Schottky model in
22 which the IV relationship is different from

tunneling.

Q. Okay. But the concept that Soukup is defining as the barrier height is the same as in the '909 Patent, correct?

A. The concept that Soukup is considering is a model of Schottky which considers electrons hopping over a barrier of a certain shape. So the barrier height that Soukup is describing is with reference to a Schottky mechanism.

Q. Right. The Schottky mechanism is the mechanism by which electrons get around or over the barrier. But the barrier height that Soukup is calculating is the same barrier height defined in the '909 Patent, correct?

(Witness reviews document.)

A. Soukup isn't defining his barrier height other than through relationship with conductivity models, Poole-Frenkel, Schottky and so forth.

Q. Okay. The different models that are used, whether it's Simmons, Poole-Frenkel or Schottky, are trying to get at the same concept of

1 barrier height, correct?
2 A. They're trying to get at a barrier
3 height which is defined in the respective models.
4 So in Soukup -- sorry. In the Simmons paper that
5 we just looked at, it was the maximum height shown
6 in that Figure 1.
7 Some of the models have different
8 shapes of the barriers, so one would have to go
9 back and look at the models which are being used
10 here to see how each one of those models defines
11 the barrier height.
12 Q. Okay. They all define the barrier
13 height as the difference between the Fermi level in
14 the electrode and the conduction band in the
15 insulator, correct?
16 A. I would have to go back and check
17 whether that's the working definition, because in
18 some of these models, the barrier is not
19 rectangular so that definition would be different
20 on both sides of the barrier.
21 Q. Well, even if the barrier is not
22 rectangular, the concept that's being addressed by

1 barrier height is still the difference between the
2 Fermi level and the electrode and the height of --
3 sorry, let me strike that.
4 Even if the barrier is not rectangular,
5 the concept that's being addressed by barrier
6 height is the difference between the Fermi level
7 and the electrode in the bottom of the conduction
8 band and the insulator, correct?
9 A. Well, as I've said, each model has its
10 own approximation to what the barrier looks like in
11 terms of the potential as a function of distance
12 through the stack. And they're not all
13 rectangular. Some have triangular shapes or
14 parabolic shapes. So each one will define its
15 barrier height in its own way.
16 Q. Okay. So even if the barrier is not
17 rectangular, there are different ways of
18 approximating the bottom of the conduction band
19 given that it might change through the thickness of
20 the barrier. But the concept that's being
21 addressed by barrier height is the difference
22 between the Fermi level and the electrode and the

1 bottom of the conduction band, whether that be the
2 average bottom of the conduction band or some other
3 mathematical model for the bottom of the conduction
4 band in the insulator, correct?
5 A. Well, that's a very long set of
6 questions, I think.
7 I would say that the difference between
8 the bottom of the conduction band and the Fermi
9 level is certainly relevant to the barrier height,
10 but whether it's exactly defined as the barrier
11 height depends on which model you're looking at.
12 Q. Well, all of the models are trying to
13 get at that difference between the Fermi level and
14 the electrode and the bottom of the conduction band
15 and the insulator, even if they make different
16 approximations for the bottom of the conduction
17 band, correct?
18 A. Well, scientifically, these are all
19 models which approximate a complex physical
20 structure with a simple physical model that's
21 amenable to being analyzed.
22 So as an example, you can have band

1 bending near the interface, which means that the
2 levels are not actually flat right at the
3 interface. So then your definition is more nuanced
4 than just looking at that difference between the
5 bottom of the conduction band and the Fermi level.
6 Q. Right. And that's, in fact, what
7 Simmons shows in Figure 1, correct?
8 A. Can you remind me which exhibit is
9 Simmons?
10 Q. Exhibit 1031.
11 (Witness reviews document.)
12 A. So Figure 1 in Simmons actually doesn't
13 label a conduction band. He's measuring the vacuum
14 level, mentioning the vacuum level and the Fermi
15 level.
16 Q. Okay. Do you see Figure 1?
17 A. I see Figure 1.
18 Q. And Figure 1, there is a barrier there
19 that is not shown as a uniform rectangle, correct?
20 A. Yes, there's a barrier there.
21 Q. And do you see the symbol phi(x)?
22 A. There is a phi, brackets, X.

Q. Okay. That is what Simmons is referring to as the barrier height, correct?
A. I would have to look at the paper to see his definitions there.
Q. Well, if you look right under the figure, do you see the notations?
A. I see electrode 1, insulator electrode 2.
Q. No, I'm -- go down the column. Do you see the heading "Notation"?
A. Okay.
Q. And do you see about four lines up from the bottom, there is a phi with a bar over it?
A. Yes.
Q. And that is defined as the mean barrier height, which is the average barrier height, correct?
A. That's what it says.
Q. And above that, you see a phi sub 0?
A. Yes.
Q. Which is the height of a rectangular barrier, correct?

A. Correct, that's what it says.

Q. So Simmons is distinguishing between the average height of the barrier and the height of a rectangular barrier, correct?

A. Well, none of this is in Figure 1.

Q. But Simmons does distinguish between the height of a rectangular barrier, an idealized construct, and the mean barrier height, correct?

A. Well, he's given them different symbols.

Q. Okay. A person of ordinary skill in the art, or even a scientist at this stage, was -- understood of that the concept that's being addressed by barrier height is the difference between the Fermi level and the electrode and the barrier height, or sorry, and the bottom of the conduction band of the insulator regardless of how that bottom of the conduction band is measured or approximated, correct?

(Witness reviews document.)

A. Simmons' model considers a rectangular barrier and a real barrier and approximates a real

1 barrier with some mean height as a rectangle
2 because otherwise the analysis becomes beyond what
3 one could do analytically. But I don't recall
4 whether Simmons himself equates the barrier height
5 with the difference between the conduction band and
6 the Fermi level. He's defining it in terms of the
7 work function, which is a different thing.
8 Q. Okay. Well, whether it's defined in
9 terms of the work function or the way we've
10 described it with reference to the bottom of the
11 conduction band of the insulator, the concept is
12 the same, correct?
13 A. Which concept?
14 Q. The concept of barrier height.
15 A. Barrier height is approximated in these
16 models of Simmons or Schottky or Poole-Frenkel as a
17 parameter that is present in the IV curve. So one
18 fits the IV curve and obtains a barrier height.
19 Q. Right. And the barrier height concept
20 in those models, whether it's Poole-Frenkel or
21 Schottky or Simmons is the same concept, correct?
22 A. I disagree.

1 Q. What's different about them?
2 A. The barrier height is an approximation
3 that's placed into a model which has a number of
4 physical approximations. For example, in Schottky,
5 one is considering how the distribution of
6 electrons around the Fermi level has the
7 probability of transitioning over the top of a
8 barrier, whereas in a tunneling model, one is
9 considering a quantum mechanical phenomenon where
10 the wave function of the electron is continuous on
11 either side of a barrier.
12 So these models have different physical
13 bases, and each one of them defines a barrier
14 height which one obtains from fitting of one's data
15 to that model.
16 Q. Okay. So if -- let's talk about the
17 concept of barrier height in Soukup, Soukup's
18 paper, which you're familiar with, correct?
19 A. Yes.
20 Q. Okay. In some cases, he finds that
21 tunneling is the dominant current mechanism. In
22 others, he believes it might be, but is not certain

that it is Schottky emission, correct?

A. Soukup finds that -- all of his devices can be described as Schottky conduction, and one of them, I believe -- one particular device, PYG381, he modeled with a tunneling conduction.

Q. Okay. Now, if Schottky emission is the actual dominant current flow mechanism in a particular barrier under a particular set of conditions, you cannot use the Simmons model to calculate the barrier height of that particular situation, correct?

A. I would say that if you had a scenario of Schottky conductivity, the data would fit to Schottky's equation. And if you had a scenario of tunneling, it would fit to Simmons' equation.

Q. In other words, what you're saying is, if you have a situation that is Schottky field emission across a barrier, Simmons would give you an incorrect result for barrier height, correct?

A. It will give you a different result.

Q. Well, that result would be incorrect, right?

A. Well, it depends what is physically going on. All of these are approximations.

Q. Okay. Well, what if what is physically going on is Schottky emission, then applying Simmons' equation to calculate the barrier height using those current voltage data, would give you an incorrect barrier height, right?

A. It would certainly give you a different -- or I would say I would expect it to give a different result.

Q. Okay. And a person of ordinary skill in the art would consider that to be an incorrect result, right?

A. A person of skill in the art would, as Soukup did, take some data and then look at how various models fit to that data and then conclude what the mechanism is.

Q. And if a model doesn't fit the data, such as in the case when Schottky field emission is what's actually occurring, and I'm applying this Simmons model to that data, then the Simmons equation wouldn't hold for that data and it would

1 give me an incorrect result for barrier height,
2 correct?
3 A. I agree with you that if the conduction
4 mechanism were Schottky conduction, then I wouldn't
5 expect the Simmons model to give me a fit to that
6 data, and therefore, it would be difficult to
7 extract a value of barrier height out of a model if
8 one didn't have a good fit.
9 MR. WILSON: Okay. We've been going
10 for about an hour. I'm happy to take a break
11 now or we can keep going. Whatever you guys
12 want to do.
13 MR. HRYCYSZYN: It's up to you,
14 Dr. Ross.
15 THE WITNESS: We could take a few
16 minutes.
17 MR. WILSON: Okay. Ten minutes?
18 MR. HRYCYSZYN: That works. So back at
19 10:16?
20 MR. WILSON: Sure.
21 THE VIDEOGRAPHER: We are going off the
22 record. The time is 10:06.

(Recess taken.)

THE VIDEOGRAPHER: We're going back on the record. The time is 10:16.

BY MR. WILSON:

Q. Now, Dr. Ross, you are familiar with Butler, Exhibit 1044, correct?

A. Yes.

Q. All right. Let's take a look at Butler.

MR. HRYCYSZYN: I think it's Exhibit 1044.

THE WITNESS: I have it.

BY MR. WILSON:

Q. Okay. Now, this Butler, Exhibit 1044, is the same Butler you referred to earlier as being very famous, correct?

A. Yes.

Q. For what is Butler, Exhibit 1044, famous?

A. They made predictions about the behavior of these epitaxial iron MgO iron stacks, which suggested a different type of

1 magnetoresistance or magnetic -- I should say a
2 different mechanism of tunneling compared to the
3 simple models described by previous authors like
4 Simmons.
5 Q. Okay. So as you said, Butler,
6 Exhibit 1044, presents a mathematical model for a
7 certain type of magnetic tunnel junction, correct?
8 A. Yeah, it's a computational model. It's
9 not purely analytical.
10 Q. Okay. And the -- Butler's particular
11 magnetic tunnel junction consists of iron(100),
12 MgO(100) and iron(100) sandwiches, correct?
13 A. Yes, that's right.
14 Q. And the iron(100) is a body-centered
15 cubic structure, correct?
16 A. Yes, that's right.
17 Q. And MgO(100) is also a body-centered
18 cubic structure?
19 A. No.
20 Q. MgO(100) is not a body-centered cubic
21 structure?
22 A. No. MgO is a face-centered cubic rock

salt structure.

Q. Okay. Okay. So in a body-centered cubic structure, the (100) plane is the same as the (001) plane, correct?

A. Yes.

Q. Now, Butler's computational model, as you referred to it, recognized the existence of certain block states in the iron electrodes, correct?

A. Yes, that's right.

Q. And the block states in the iron electrodes have certain symmetries, correct?

A. Well, by "certain symmetries," you can distinguish block states with different symmetries.

Q. Okay. Okay. So Butler recognized the existence of Delta 1, Delta 5, Delta 2 and Delta 2 prime symmetries in iron(100), correct?

A. Well, he recognized the existence of different block states which were described with these delta numbers, which designate the symmetry.

Q. Okay. Butler also recognized the existence of certain evanescent states in the

magnesium oxide barrier, correct?

(Witness reviews document.)

A. Well, they're not exclusive descriptions. Evanescent means it decays quickly.

Q. Right. But the evanescent states in the magnesium oxide barrier have certain symmetries as well, correct?

A. I think it may be more precise to say that the different states, the Delta 5, Delta 2, Delta 2 prime and so forth, propagate differently in the MgO, leading to some evanescent character, which means that some of those decay quickly.

Q. So, for example, if we look at page 6 of Butler, in the right-hand column, first full paragraph, Butler says: (Reading)

Majority block states with Delta 1 symmetry in the iron electrodes decay as evanescent states with Delta 1 symmetry and magnesium oxide.

Correct?

A. You're looking -- I just want to find

that. You're looking at page 6?

Q. Page 6, right-hand column, first sentence of the first full paragraph.

A. Okay. So what's the question?

Q. It says: (Reading)

Majority block states with Delta 1 symmetry in the iron electrodes decay as evanescent states with Delta 1 symmetry in magnesium oxide.

Did I read that correctly?

A. That's what it says.

Q. Okay. And in that, Butler is recognizing that the evanescent states in the magnesium oxide also have symmetry, correct?

A. It's more precise to say that the Delta 1 states which are propagating in the metallic iron become evanescent when they enter the MgO, with the result that they decay in the MgO.

Q. Okay. But it's also accurate to say that their symmetry is preserved in the evanescent state, correct?

A. Well, "evanescent" just means it decays quickly. So Butler's model is based on the preservation of the symmetry of these various block states as they transition through the iron MgO iron(100) sandwich.

Q. Okay. So although the symmetry is preserved as the electrons decay through the magnesium oxide barrier, the decay rates for the different symmetries are different in magnesium oxide, correct?

A. Well, the decay rates for not just the different symmetries, but for the majority and minority electrons decay differently.

Q. Okay. If we go back to the introduction or the abstract. Or sorry, the introduction, actually, first paragraph and second sentence here in the introduction. And this is Butler describing sort of the history of magnetic tunnel junctions. He says: (Reading)

Most of the interest for applications currently centers on systems with amorphous aluminum oxide

1 tunneling barriers because of the
2 relative ease of growing adherent
3 aluminum oxide without pinholes.
4 Did I read that correctly?
5 A. That's what he wrote.
6 Q. He goes on to say: (Reading)
7 Unfortunately, these systems
8 are difficult to characterize and
9 model because of the noncrystalline
10 nature of the oxide and the lack of
11 any known epitaxial relationship
12 between the oxide and the
13 ferromagnetic electrodes.
14 Did I read that correctly?
15 A. Yes.
16 Q. So the prevalent alumina barriers were
17 noncrystalline, correct?
18 A. The ones he's discussing in this
19 paragraph, it says: (Reading)
20 Most of the interest for
21 applications currently centers on
22 systems with amorphous aluminum oxide

1 tunneling barriers.
2 So those are the ones he's discussing,
3 the amorphous ones.
4 Q. And what he also says is for those
5 amorphous aluminum oxide barriers, there is no
6 known epitaxial relationship between the alumina
7 barriers and the iron electrodes, correct?
8 A. Well, he describes the lack of any
9 known epitaxial relationship, although he's not
10 citing, but that's what it says.
11 Q. Okay. In an amorphous alumina barrier,
12 the electron symmetry in the electrodes does not
13 affect the tunneling of the electrons through the
14 amorphous alumina, correct?
15 A. I don't know that there is no
16 relationship. Certainly that scenario is not
17 addressed by Butler because it is a scenario that
18 can't be addressed using the kind of techniques
19 that Butler is applying to these crystalline
20 structures.
21 Q. Well, in general, in an amorphous
22 alumina barrier, electrons are transmitted through

the barrier without regard to their symmetry, correct?

A. I don't have an opinion about that because I haven't reviewed that specific literature.

The electrons will have a range of wave vectors related to their symmetry, and those are actually traveling in different directions, which can affect how they interact with the barrier. So I think the answer to that question is rather complex and it's not something I've considered.

Q. Okay. Take a look at Exhibit 1057, which is Dieny textbook.

A. Okay. I have that.

Q. Okay take a look at page 16, which is PDF page 35, and Section 1.2.4.1. You see where it references incoherent tunneling through an amorphous alumina barrier?

A. Yes.

Q. Toward the bottom of that paragraph, about four lines up from the bottom, it refers to Jullière's model. Do you see that?

1 A. Yes, it refers to Jullière's model.
2 Q. It says: (Reading)
3 Jullière's model, previously
4 introduced, assumes equal tunneling
5 probabilities independent of the
6 electrons block states in the
7 electrodes. This is true only if the
8 tunneling process is incoherent,
9 meaning that the coherency of the
10 block states is not conserved during
11 tunneling. In the case of an
12 amorphous barrier, there is no
13 crystallographic symmetry in the
14 barrier. Consequently, electron wave
15 functions from the injector, no matter
16 their symmetry, couple identically to
17 any tunneling evanescent states in the
18 barrier through which they will
19 propagate and decay.
20 Did I read that correctly?
21 A. Yes.
22 Q. So in incoherent tunneling, as occurs

in an amorphous barrier like alumina, the block states of the electrons in the electrode are not preserved as they go through the barrier, correct?

A. Jullière's model certainly assumes that by having no dependence on block states.

Q. Okay. And Jullière's model is accurate for an incoherent amorphous barrier like alumina, correct?

A. Jullière's model is a very simple model which doesn't consider the wave vectors or the block states at all. So it's a simple approximation which makes the assumption that there's no -- let me go back. It makes the assumption, as stated here, that all the electron wave functions couple identical -- couple identically to any evanescent states.

Q. Okay. And it turns out to be accurate for alumina barriers, correct?

A. It's a successfully applied model to alumina barriers.

Q. Okay. Let's go back to Butler and let's look at Figure 7.

A. Okay.

Q. So Figure 7 shows the tunneling density of states for assuming K parallel of 0 for the iron MgO iron MTJ, correct?

A. Well, it shows four different panels for different -- different, what should I say, different majority and minority carriers and parallel and antiparallel magnetization of the electrodes.

Q. Okay. And so in the upper left-hand corner, we can see the parallel majority density of states, correct?

A. Upper left corner shows the density of states for the majority carriers with parallel alignment of the magnetization in the two electrodes.

Q. You can see that there is a Delta 1 block state represented there in the upper left-hand corner figure?

A. Yes.

Q. And it is the dominant electron flow mechanism in the parallel majority state, correct?

A. It's got the largest density of states.

(Brief pause.)

THE VIDEOGRAPHER: Did we lose somebody?

THE CERTIFIED STENOGRAPHER: I believe so. Let's go --

THE VIDEOGRAPHER: It looks like we lost Mr. Wilson. Okay. We are going off the record. The time is 10:38.

(Discussion held off the record.)

THE VIDEOGRAPHER: We are going back on the record. The time is 10:39.

MR. WILSON: Okay. Sorry about that.

BY MR. WILSON:

Q. All right. Now, we were looking at Butler's Figure 7. And if we look at the upper right-hand corner, Butler Figure 7 shows the parallel configuration in the minority density of states, correct?

A. The top -- the top right, the minority density of states for the parallel configuration. That's what we're looking at?

Q. Yes. And you can see that in the minority density of states in the parallel configuration, there is no Delta 1 represented, correct?

A. That's right. It's not on this -- shown up on this plot.

Q. So Butler determined that in the iron MgO iron MTJ, the iron electrodes have Delta 1 spin-up states, but no Delta 1 minority states, correct?

(Witness reviews document.)

A. Well, he's plotted that density of states in Figure 3.

Q. So are you saying that Figure 3 shows that or are you not sure?

A. Well, Figure 3 shows the density of states for the iron near the MgO interface, although it's not labeled with the symmetry of the states. I would have to reread this to answer your question precisely about what the population of Delta 1 symmetry states are for minority electrons.

Q. So take a look at page 5 of Butler.

Do you see Section B in the right-hand column, "Effective symmetry at K parallel equals zero"?

A. Yes.

Q. In the second paragraph, the third sentence -- well, fourth sentence -- actually, four lines down from the top. It says "in the majority channel."

Do you see that?

A. Yeah, I see that.

Q. Butler says: (Reading)

In the majority channel, there is a Delta 1 state, a doubly degenerate Delta 5 state and a Delta 2 prime state. The minority channel has four states with the same symmetries as the states of the majority channel with the crucial exception that the majority Delta 1 state is replaced by a Delta 2 minority state.

Did I read that correctly?

A. That's what it says.

Q. Butler recognized that there was a Delta 1 majority state but not a Delta 1 minority state, correct?

A. He says the Delta 1 state in the majority channel is replaced by a Delta 2 state in the minority channel.

Q. In other words, there is not a Delta 1 minority state, correct?

A. Well, he doesn't exactly say that. He says it's replaced by a Delta 2 state.

Q. Okay. A person of ordinary skill in the art reading Butler would understand there is a Delta 1 majority state and there is no Delta 1 minority state, correct?

A. I imagine they would infer that from the statement.

Q. Okay. Now, if we go back to page 1 of Butler, again in the introduction, the second paragraph under the introduction, Butler says: (Reading)

Recently, Heinrich, et al., have grown iron(100) MgO(100)

1 iron(100) magnetic tunnel junctions by
2 depositing MgO epitaxially onto iron
3 whiskers and then depositing another
4 iron electrode epitaxially on top of
5 the MgO.
6 Did I read that correctly?
7 A. That's what it says.
8 Q. And if you look at Footnote 5, you can
9 see that the Heinrich paper in the Applied Physics
10 Letter at the end there is actually to be
11 published?
12 A. Well, Footnote 5 cites two references.
13 Q. Right. So the first one is the Physics
14 of Low Dimensions, published in 2000?
15 A. Right.
16 Q. And the second one is a paper in
17 Applied Physics Letters to be published, correct,
18 yes?
19 A. Yes.
20 Q. Okay. So attributing the 2000 date to
21 this, are you aware of anyone making a magnesium
22 oxide magnetic tunnel junction before the year

2000?

A. Am I aware of a MgO tunnel junction before 2000? I haven't looked at that question.

Q. Okay. Heinrich is Exhibit 1043.

A. Do you mean Wulfhekel, the one in the Applied Physics Letters?

Q. So, actually, this is the first one. Well, sorry, it's not either of those, actually. It is just an -- what appears to be an extract of the same thing. But if you look at Exhibit 1043.

A. 1043?

Q. Yes.

You can see, it's entitled "Single-crystal tunnel junctions." And the first sentence says: (Reading)

> We have grown single-crystal epitaxial magnetotunnel junctions using iron whisker substrates, MgO(001) oxide spacers and iron nickel gold(001) top electrodes.

Do you see that?

A. Yes.

Q. Okay. And if you look at the bottom, this is dated 2000 from IEEE, correct?

A. That's what it says.

Q. Okay. So if you look down on the lower right, do you see where it says "in conclusion," five lines up from the bottom?

A. Yes.

Q. It says: (Reading)

In conclusion, we have shown that we have grown highly perfect crystalline epitaxial MTJ structures using MgO dielectric layers. We have demonstrated that a conducting tip of AFM system can be used to study ballistic tunneling, allowing one to investigate local tunneling characteristics with the lateral resolution of 2-by-2 square nanometers. A small fraction of the scanned area showed defects in MgO layers. However, the spikes do not dominate the total tunneling current.

Did I read that correctly?

A. Yes, you did.

Q. Okay. So Heinrich reported the successful fabrication of an MTJ with an MgO barrier layer in 2000, correct?

A. He has an iron substrate, an MgO layer, and then an iron layer. And he measures tunneling characteristics using AFM, actually conductive AFM. So he is measuring tunneling in that structure.

Q. And you're not aware of anyone successfully fabricating a magnetic tunnel junction with magnesium oxide before Heinrich in 2000?

A. I haven't looked into earlier literature.

Q. Okay. And you see that one of the authors with Heinrich is Wulfhekel?

A. Yes.

Q. Okay. Let's take a look at Exhibit 1047, which is Wulfhekel.

A. Yes.

Q. You've reviewed Wulfhekel, correct?

A. I've reviewed it.

Q. Okay. And you can see that this was published in January 2001?

A. Yes.

Q. And you can also see that Heinrich is a coauthor?

A. He is the last author.

Q. Okay. Now, if you take a look in the left-hand column on the first page, about midway through, do you see the reference to Keavney?

(Witness reviews document.)

Q. Do you see that?

A. I'm just reading through. I see Keavney, et al.

Q. Okay. Wulfhekel and Heinrich, among others, reported that: (Reading)

Keavney, et al., prepared crystalline epitaxial iron MgO iron(001) trilayers using MgO(001) substrates. Unfortunately, pinholes due to rough bottom iron layer resulted in shorts in the junction.

Did I read that correctly?

A. That's what it says.

Q. Okay. Exhibit 1047 goes on to say: (Reading)

To allow studies of intrinsic tunneling in crystalline and flat iron MgO iron junctions, we have grown iron MgO iron(100) junctions by molecular-beam epitaxy or pulsed-laser deposition of MgO and iron on polished single-crystal iron(100) substrates and iron whiskers and have characterized the quality of the MgO barrier locally.

Did I read that correctly?

A. That's what they wrote.

Q. Okay. So the earlier attempt at growing an iron MgO iron MTJ by Keavney, et al., failed, correct?

A. I haven't reviewed Keavney, et al. Is that one of the exhibits in this case?

Q. I don't think so.

A. Well, I don't know what Keavney, et al.

1 did. Wulfhekel states that their measurement
2 failed, but I don't have any further opinions about
3 Keavney.
4 Q. Okay. Let's take a look at
5 Exhibit 1051, which is Meyerheim.
6 A. Okay. I have that.
7 Q. Now, you reviewed Exhibit 1051,
8 correct?
9 A. Yes, I have.
10 Q. Okay. You can see that Meyerheim was
11 published in August 2001?
12 A. Right.
13 Q. Okay. And if you look on the first
14 page of the actual article, lower left-hand column,
15 about one, two -- seven, eight lines up from the
16 bottom, "as a consequence of this situation."
17 Do you see that?
18 A. I see that sentence.
19 Q. It says: (Reading)
20 As a consequence of this
21 situation, single crystalline oxide
22 barriers appear to be primary

1 candidates for the preparation of TMR
2 junctions, since they offer the
3 opportunity to control their
4 structural and physical properties in
5 a more reproducible way.
6 Did I read that correctly?
7 A. Yes.
8 Q. Now, if we go up to the top right-hand
9 column, about midway through that first paragraph,
10 do you see "although first attempts"?
11 A. Right.
12 Q. It says: (Reading)
13 Although first attempts to
14 prepare a crystalline iron MgO
15 iron(001) junction using a MgO(001)
16 crystal were not successful because of
17 pinholes leading to an Ohmic contact,
18 recent experiments depositing MgO by
19 electron beam deposition on a
20 iron(001) whisker were able to
21 demonstrate ballistic tunneling at
22 room temperature, although due to

1 equipment limitations, the TMR effect
2 could not be measured.
3 Did I read that correctly?
4 A. Yes.
5 Q. And you can see cite 12 is to Keavney?
6 A. I see in the reference list 12 is a
7 Keavney paper.
8 Q. And cite 13 is to Wulfhekel, correct?
9 A. It's a Wulfhekel paper.
10 Q. Okay. So several papers report
11 Keavney's unsuccessful attempt to fabricate an MgO
12 magnetic tunnel junction, correct?
13 A. Well, you've shown me two citations to
14 Keavney, but I haven't looked at Keavney itself.
15 Q. Okay. And several papers by Wulfhekel,
16 Heinrich and others report the successful
17 fabrication of an MgO magnetic tunnel junction
18 around the year 2000, correct?
19 A. Well, many of these people are from the
20 same group, producing several papers about the same
21 system, which in this case is a single-crystal iron
22 whisker or polished single crystal on which they

have deposited MgO and then iron and measured that. So that's what these papers are about.

Q. Okay. But it was a successful fabrication of a magnesium oxide magnetic tunnel junction around the year 2000, correct?

A. It was a fabrication of magnesium oxide and iron on top of a single crystal of iron and a measurement of tunneling magnetoresistance.

Q. Okay. And as you sit here today, you're not aware of a fabrication of a working magnesium oxide magnetic tunnel junction prior to 2000, correct?

A. As I said, that's not a question I've looked into.

Q. Okay. So let's take a look at Slonczewski, Exhibit 2041.

Now, Slonczewski presents a computational model for magnetic tunnel junctions, correct?

A. Well, this one, I believe, is an analytical model.

Q. Okay. Slonczewski presents an

1 analytical model for magnetic tunnel junctions,
2 correct?
3 A. Yes. It's a model that describes
4 transmission coefficients between the two
5 electrodes on either side of a barrier.
6 Q. And Slonczewski's model is a simplistic
7 model, correct?
8 A. It's not simplistic compared to
9 Jullière, for example. It certainly contains
10 approximations. But "simplistic" is something of a
11 value judgment here.
12 Q. Okay. Slonczewski's model does not
13 assume iron electrodes, correct?
14 A. It doesn't specify a particular
15 magnetic composition.
16 Q. Okay. And it doesn't specify a
17 particular crystalline arrangement of the
18 electrodes, correct?
19 A. No, it just treats them as S electron
20 conductors. S, the letter S, S electron
21 conductors.
22 Q. So Slonczewski does not recognize that

1 the Delta 1 conduction band is only present for
2 majority electrons in an iron electrode, correct?
3 A. He doesn't talk about those block
4 states.
5 Q. And Slonczewski did not address a
6 magnesium oxide barrier specifically, correct?
7 A. His model is just a rectangular
8 barrier.
9 Q. And he did not assume that the
10 rectangular barrier was crystalline, correct?
11 A. I don't recall him discussing the
12 composition of the barrier.
13 Q. Okay. And Slonczewski did not assume
14 that block state symmetry would be preserved
15 through the barrier, correct?
16 A. Well, Slonczewski doesn't discuss block
17 states. His model isn't based on block states, so
18 he doesn't comment on whether their symmetry would
19 be preserved or any of those kinds of factors.
20 Q. Okay. He doesn't take into account any
21 distinct preservation of different block states as
22 they travel through the barrier as would occur in

1 magnesium oxide, correct?
2 A. His model isn't formulated in terms of
3 block states, so he doesn't have anything to say
4 about block states.
5 Q. So as far as what Slonczewski considers
6 about the barrier, Slonczewski considers the
7 characteristics of the barrier, but only the
8 barrier's height and thickness, correct?
9 A. His model treats the barriers, a
10 rectangular barrier, with a certain thickness and a
11 certain height.
12 Q. Now, Slonczewski's paper, Exhibit 2041,
13 was published in 1989, correct?
14 A. Yes.
15 Q. And you're not aware of any successful
16 magnesium oxide MTJs in 1989, correct?
17 A. As I've said, I haven't looked into the
18 question of the prior MgO tunnel barriers or tunnel
19 junctions.
20 Q. Okay. Let's take a look at
21 Slonczewski, Exhibit 2041, as page 6998, which is
22 the fourth page.

A. Okay.

Q. You see equation 3.6?

A. I do.

Q. So Slonczewski equation 3.6 reports tunneling conductance G for a ferromagnetic barrier -- Sorry, let me strike that.

Slonczewski equation 3.6 reports tunneling conductance G for a ferromagnet barrier ferromagnet structure, correct?

A. Well, the paper is about conductance through that structure, ferromagnet barrier ferromagnet.

Q. Okay. And that's what equation 3.6 is intended to capture, correct?

A. I'd have to reread it to remind myself what that specific equation is about. It's certainly showing a conductance.

Q. Okay. Do you understand the significance of the term at the end of equation 3.6, E to the minus 2 kappa D?

A. Significance in what sense?

Q. Do you understand what that term

1 represents?
2 A. Well, it's an attenuation. D is a
3 distance and kappa is a decay. It represents the
4 decay of the -- of the electrons, if you like, the
5 transport of the electrons.
6 Q. Okay. Let's go back to Dieny,
7 Exhibit 1057.
8 A. Okay.
9 Q. Take a look at page 14, PDF page 33.
10 Do you see heading 1.2.3, "The Slonczewski Model"?
11 A. Yes.
12 Q. Okay. Under heading 1.2.3.1, "The
13 Model," you see it says: (Reading)
14 In Slonczewski model, several
15 assumptions are made, similar to those
16 of Jullière's model.
17 Do you see that?
18 A. Yes.
19 Q. So if we go down, about the middle of
20 that paragraph on that page, do you see, "finally"?
21 A. Okay.
22 Q. So below there, do you see the equation

that's presented there for kappa?

A. Yes, he gives an equation for kappa as a function of E.

Q. Okay. And assuming that K parallel equals -- or does not equal 0, correct?

A. Well, that's in the sentence.

Q. Okay. And kappa, as you just explained, is the decay coefficient, correct?

A. It's a decay coefficient. It's labeled here as such.

Q. Okay. Now, if we go back up to that sentence "finally," it says: (Reading)

The model assumes that only electrons propagating perpendicular to the layers, that is K is approximately equal to K perpendicular and K parallel is approximately 0, can efficiently tunnel through the barrier.

Did I read that correctly?

A. That's what it says.

Q. Okay. So in Slonczewski's model,

1 K parallel is assumed to be 0 and only
2 perpendicular -- electrons tunneling perpendicular
3 to the barrier are considered, correct?
4 A. Well, that's one of the assumptions in
5 Slonczewski's model to make it tractable to
6 analysis.
7 Q. Okay. And "K" refers to the electron
8 wave vector, correct?
9 A. Typically.
10 Q. Okay. Okay. Do you agree with Dieny's
11 characterization of the model in Slonczewski?
12 A. Well, Dieny has a whole section on this
13 model. Are you asking me if I agree with all of
14 it?
15 Q. I'm asking if you agree with the parts
16 that we've just discussed.
17 A. I haven't analyzed whether that Dieny
18 says is -- about Slonczewski's model is correct, so
19 I don't know if I can answer that simply.
20 Q. Well, do you have any reason to
21 disagree with what Dieny says about Slonczewski's
22 model?

A. Well, Dieny is only, at least in the part you've asked me to look at, Dieny is only describing Slonczewski's model, and the understanding of that is, as far as I can tell, correct.

Q. Okay. Let's take a look at Exhibit 2037, which is Saito or Saito. I'm not sure how you pronounce it.

A. Saito.

Q. Saito.

You're familiar with Saito, Exhibit 2037, correct?

A. Yes.

Q. Now, Saito, like Slonczewski, does not describe distinct block states in iron ferromagnetic electrodes, correct?

A. Well, Saito uses Slonczewski's model with all of its approximations.

Q. Okay. So Saito would be subject to the same limitations as Slonczewski, correct?

A. Well, Saito is using Slonczewski's model. Slonczewski's model is based on free

electron metals and a rectangular barrier, not on block states in the barrier.

Q. Okay. So it would not recognize any distinct decay rates for different block states in, for example, a magnesium oxide barrier, correct?

A. Well, Saito is about alumina barriers, so I don't see how it can be discussing MgO barriers.

Q. Okay.

A. At least it's describing experimental data on alumina barriers.

Q. Okay.

MR. WILSON: We've been going for a little over an hour. I'm happy to keep going or we can take a quick break.

THE WITNESS: Can I just finish my comment on Saito and then I'm happy to take a break.

BY MR. WILSON:

Q. Sure, sure.

A. So Saito's paper makes tunnel barriers out of alumina with different height and uses

Slonczewski's model or compares his results to Slonczewski's model. So his assumptions are the same as Slonczewski's. But he compares TMR with barrier height for these alumina junctions.

Q. Okay. Is that it?

A. Yes.

Q. Okay.

THE VIDEOGRAPHER: Let's go ahead and go off the record. Right, sir, ready to hop off?

MR. WILSON: Yes.

THE VIDEOGRAPHER: Just making sure.

We are going off the record. The time is 11:19.

(Recess taken.)

THE VIDEOGRAPHER: We are going back on the record. The time is 11:29.

BY MR. WILSON:

Q. Dr. Ross, let's turn back to Butler, Exhibit 1044.

A. Okay.

Q. Now, if we take a look at the first

1 page of Butler, right-hand column, first full
2 paragraph. You see the first sentence there says:
3 (Reading)
4 Most previous theories of
5 tunneling conductance and
6 magnetoconductance have emphasized the
7 density of states of the electrodes.
8 The tunneling matrix elements are
9 almost always neglected or treated as
10 inert factors.
11 Now, the tunneling matrix -- first, did
12 I read that correctly?
13 A. Yes.
14 Q. Okay. The tunneling matrix Butler
15 refers to is the insulator, correct?
16 A. Well, the tunneling matrix elements
17 represent how one would describe the conductivity
18 of that tunnel barrier. So it's not the barrier
19 itself, it's the elements of the matrix which
20 describe how it conducts current.
21 Q. Butler goes on to say in the next
22 sentence: (Reading)

1 One of our conclusions is that
2 this approach is completely inadequate
3 for understanding tunneling.
4 Did I read that correctly?
5 A. Yes.
6 Q. Now, Slonczewski was one of the models
7 that Butler is addressing, correct?
8 A. He doesn't cite any specific models in
9 that comment about most previous theories of
10 tunneling conductance.
11 Q. But Slonczewski treats the tunneling
12 matrix as an inert factor, correct?
13 A. I don't know if Slonczewski uses the
14 term "tunneling matrix elements."
15 Q. Well, as we previously discussed,
16 Slonczewski assumes that there is a rectangular
17 barrier of no particular composition, correct?
18 A. Correct.
19 Q. So the particular distinguishing
20 factors of magnesium oxide as a tunneling barrier
21 are not considered or taken into account at all in
22 Slonczewski's model, correct?

A. Slonczewski's model is a general model which considers a rectangular barrier.

Q. So the answer to my question is "yes"?

A. The answer is that Slonczewski doesn't refer to specific materials.

Q. Okay. Slonczewski treats the characteristics of the barrier as inert factors, correct?

A. I would say Slonczewski treats the barrier as a rectangular barrier. "Inert factors" is a bit difficult to know what Butler means exactly by that, so I can't comment on what he meant by that particular statement.

Q. You would agree that for a magnetic tunnel junction with a magnesium oxide (001) barrier layer, one must account for the properties of the barrier layer in order to -- in order to adequately understand its tunneling properties, correct?

A. I would say that you can model tunnel behavior by a variety of different models, and it depends what you're trying to accomplish as to how

1 you analyze your data.
2 Q. Okay. The next sentence, Butler says:
3 (Reading)
4 The nature of the states, both
5 in the electrodes and in the barrier
6 layer, are extremely important in
7 determining the tunneling conductance.
8 Did I read that correctly?
9 A. Yes.
10 Q. And we agreed that Slonczewski ignores
11 the nature of the states in the barrier layer,
12 correct?
13 A. Slonczewski treats the barrier as a
14 rectangular barrier, and he describes the electrons
15 in the -- electrodes as based on an exchange
16 split-free electron model. I don't know if he
17 had -- I don't recall what he said about the nature
18 of the electrons in the barrier. I believe he
19 mentioned the directions of propagation.
20 Q. But he does not discuss or apply any
21 distinct decay rates for electrons with different
22 symmetries in the barrier layer, correct?

A. Well, I've mentioned before, he doesn't use the same approach as Butler to analyze tunneling. His assumptions are based on a free electron model and a rectangular barrier, which is different from what Butler did.

Q. And it's different in the respect that it does not take into account distinct decay rates for different electron symmetries in the magnesium oxide barrier layer, correct?

A. It doesn't describe the electrons in terms of block waves with specific symmetries.

Q. And in so doing, it also doesn't account for the distinct decay rates of the different block symmetries in a magnesium oxide barrier, correct?

A. Well, as I've said, it doesn't treat the electrons in that manner.

Q. Now, let's take a look deeper in Butler at equation 9, which is on page 7.

Now, if you take a look at equation 9 on page 7 of Butler, and I want you to compare equation 9 to the equation for kappa as a function

of E on page 14 of Dieny. And my question is, are those the same equation for kappa?

A. I'd really have to look at these papers in detail to look at that. Some of the terms are labeled differently, and this isn't something I considered in my declaration.

Q. Okay. So you don't have any opinion on whether equation 9 in Butler is the same as the equation for kappa in Section 1.2.3.1 of Dieny, correct?

A. That's not a question I've been asked to consider.

Q. And as a result, you have no opinion on it, correct?

A. Well, at this point, I have no opinion on it.

Q. Now, if we look just above equation 9 there in Butler, you can see Butler refers to the theory for tunneling through a simple barrier.

Do you see that?

A. Yes.

Q. And that's what he's attributing

equation 9 to, correct?

A. Well, I don't know. It's referring to Footnote 20, which is not a paper I've looked into.

Q. Okay. Well, Butler says, according to the theory for tunneling through a simple barrier, the transmission should vary with K parallel as E to the negative 2 D kappa, where D is the thickness of the barrier and kappa is given by equation 9, correct?

A. Well, that's what it says in Butler, but I don't have an opinion about this particular equation.

Q. Okay. Now, if we go up one paragraph above equation 9. Do you see the sentence at the beginning of Section C, it's -- where Butler says: (Reading)

> It is generally believed that the simple barrier model is appropriate for describing the tunneling of electrons through insulating barriers.

Do you see that?

A. Yes, I see that.

Q. Butler says: (Reading)

In the preceding section, we showed, contrary to that model, that states with different symmetry decay at different rates as they tunnel through the barrier. In this section, we address the variation of the tunneling current with K parallel and show that the barrier model fails for this aspect of tunneling as well.

Did I read that correctly?

A. Yes.

Q. So Butler is explaining why the simple barrier model fails for magnesium oxide, correct?

A. Well, he's making a statement about what he believes. I haven't assessed that statement myself.

Q. Okay. But he does make that statement, correct?

A. Well, he makes the statements which are stated in his paper.

Q. Okay. And if we look at Figure 9 in the upper right-hand column, Butler shows majority transmission probability as a function of K parallel using both the simple barrier model and his own computational model, correct?

A. Well, he's plotting transmission probability of majority electrons under certain conditions in his model.

Q. Right. And in Figure 9, he's comparing his model to the simple barrier model, correct?

A. Well, there's data labeled "simple barrier model."

Q. Okay. And there's quite a divergence between the results from the simple barrier models and his results, Butler's results, correct?

A. Well, there's certainly a difference.

Q. In fact, his results show an oscillation that's not reflected at all in the simple barrier, correct?

A. Yes, he has an oscillatory behavior.

MR. WILSON: Okay. We don't have any further questions. We'll pass the witness.

MR. HRYCYSZYN: Why don't we take a short break here and we'll get -- we'll see if we have any follow-up questions.

MR. WILSON: Okay.

MR. HRYCYSZYN: Okay. Thanks.

THE VIDEOGRAPHER: Let's go off the record. The time is 11:45.

(Recess taken.)

THE VIDEOGRAPHER: We are going back on the record. The time is 11:54.

MR. HRYCYSZYN: IP Bridge has no redirect questions.

MR. WILSON: Okay. I think we're done.

THE VIDEOGRAPHER: If there's no further questions, this concludes the deposition. The time is 11:54. Thanks.

(Signature reserved.)

(Deposition concluded at 11:54 a.m. EDT)

- - -

CERTIFICATE OF NOTARY PUBLIC

I, Amy A. Brauser, RPR RMR CRR, the officer before whom the foregoing deposition was taken, do hereby certify that the witness was duly sworn by me prior to the taking of the foregoing deposition; that the testimony of said witness was taken by me to the best of my ability and thereafter reduced to typewriting under my direction; that I am neither counsel for, related to, nor employed by any of the parties to the action in which this deposition was taken, and further that I am not a relative or employee of any attorney or counsel employed by the parties thereto, nor financially or otherwise interested in the outcome of the action.

This is the 25th day of September, 2025.

Amy A. Brauser, RPR RMR CRR
Notary Public
for the Commonwealth of Virginia

Notary Registration No.: 7675529

My Commission Expires: January 31, 2028

Case: Western Digital vs Godo Kaisha IP Bridge 1
Witness Name: Caroline A. Ross, Ph.D.
Deposition Date: 09/19/2025

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Witness Name: Caroline A. Ross, Ph.D.

Deposition Date: 09/19/2025

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1 Errata Sheet

2 NAME OF CASE: Western Digital vs Godo Kaisha IP Bridge 1

3 DATE OF DEPOSITION: 09/19/2025

4 NAME OF WITNESS: Caroline A. Ross, Ph.D.

5 Reason Codes: 1. To clarify the record.

6 2. To conform to the facts.

7 3. To correct transcription errors.

8 Page _____ Line _____ Reason _____

9 From _____ to _____

10 Page _____ Line _____ Reason _____

11 From _____ to _____

12 Page _____ Line _____ Reason _____

13 From _____ to _____

14 Page _____ Line _____ Reason _____

15 From _____ to _____

16 Page _____ Line _____ Reason _____

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21 _____

22 CAROLINE A. ROSS, PH.D.

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