

United States Patent and Trademark Office
Before the Patent Trial and Appeal Board

Western Digital Technologies, Inc. et al.

(Petitioner)

v.

Godo Kaisha IP Bridge 1

(Patent Owner)

IPR2024-01494 | **U.S. Patent No. 11,968,909**

IP Bridge Exhibit 2090 Western Digital v. IP Bridge IPR2024-01494

January 23, 2026

The Claims Recite a Magnetoresistive Device With an MgO Barrier Layer and a Particular Barrier Height

'909 Patent

1. A magnetoresistive device comprising a magnetic tunnel junction structure comprising a multi-layer material stack including:

first and second ferromagnetic material layer; and
a tunnel barrier layer between the first and second ferromagnetic material layers such that the tunnel barrier layer is above the first ferromagnetic material layer and below the second ferromagnetic material layer,

wherein said tunnel barrier layer comprises crystalline MgO_x (001) with oxygen vacancy defects and ($0 < x < 1$).

5. The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.

6. The magnetoresistive device of claim 5, wherein the barrier height of the tunnel barrier layer is in a range of 0.2 eV to 0.5 eV.

9. A magnetoresistive device comprising a magnetic tunnel junction structure comprising:

first and second ferromagnetic material layer; and
a tunnel barrier layer between the first and second ferromagnetic material layers,

wherein said tunnel barrier layer comprises magnesium oxide and has a barrier height in a range of 0.1 eV to 0.85 eV.

15. A magnetoresistive device comprising:

a first ferromagnetic material layer;
a tunnel barrier comprising magnesium oxide and having a barrier height in a range of 0.2 eV to 0.5 eV; and
a second ferromagnetic material layer disposed on the tunnel barrier layer and separated from the first ferromagnetic material layer by the tunnel barrier layer.

EX1017 at Claims 1,5,6,9,15

**Over half the challenged Claims (claims 6, 12 and 15-20)
require the narrower barrier height range of 0.2-0.5 eV**

Prior Art MTJs with an MgO Barrier Layer Had Barrier Heights Above Both Claimed Ranges

'909 POR

Reference	Stack	Ideal ϕ	Estimated ϕ
EX1045	Fe/MgO/Fe	3.6 eV	2.5 to 3.6 eV
EX1043	Fe/MgO/Fe-Ni-Au	3.7 eV	3.7 eV (Simmons)
EX1026	Fe/MgO/Fe	Cites EX1047	0.9 eV, 1.1 eV (I(V) temp curves, Simmons)
EX1053	Fe/MgO/FeCo	Not Specified	0.9 eV (Simmons)
EX1047	Fe/MgO/Fe	3.6 eV	1.8 eV (Simmons)
EX2012	CoFe/MgO/CoFe	3.6 eV	1.1 to 1.7 eV (Simmons)

POR at 15

Petitioner Does Not Allege That Either of Its Primary References (Bowen and Nagahama) Meet Either Claimed Barrier Height Range

'909 Petition

Ground 1: Claims 1 and 8 are obvious over Bowen alone or in view of Soukup. Claims 2-6 and 9-20 are obvious over Bowen in view of Soukup. Claim 7 is obvious over Bowen in view of Sunai or Parkin and optionally Soukup.

Ground 2: Claims 1 and 8 are obvious over Nagahama alone or in view of Soukup. Claims 2-6 and 9-20 are obvious over Nagahama in view of Soukup. Claim 7 is obvious over Nagahama in view of Sunai or Parkin and optionally Soukup.

Petition at 16

E. Claim 5: “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”

Bowen in view of Soukup taught or suggested a tunnel barrier height for an MgO barrier layer in the disclosed range of 0.1 to 0.85 eV. EX1024 ¶166. Bowen “place[d] the barrier height at $\phi = 0.9$ eV” for its MgO barrier device. EX1026 at 1656; EX1024 ¶167. Soukup observed a “barrier height” within the disclosed range of “*about 0.33 eV*” for its MgO barrier. EX1028 at Abstract; *id.* at 3231-32, Fig. 5, Table I; EX1024 ¶167.

Petition at 33

E. Claim 5: “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”

Nagahama in view of Soukup taught or suggested an MgO tunnel barrier height for an MgO barrier layer in the claimed range of 0.1 to 0.85 eV. EX1024 ¶¶272-73. Nagahama taught an MgO MTJ. EX1027 ¶¶73-74, Abstract, Figs. 3, 17. Soukup observed a “barrier height” of “*about 0.33 eV*” for its MgO barrier. EX1028 at Abstract; *id.* at 3231-32, Fig. 5, Table I; EX1024 ¶273.

Petition at 57

Petitioner's Grounds Fail for Numerous Independent Reasons

- **Petitioner Failed to Establish Motivation to Lower Barrier Height** (POR at 31-47, Sur-reply at 3-7)
 - **Petition's Allegation that this Would Increase TMR Fails** (POR at 33-34, Sur-reply at 3-4)
 - Undisputed that No Evidence Supports That (POR at 34-37, Sur-reply at 3-4)
 - Petitioner's Expert Refutes it (POR at 34, Sur-reply at 4-5)
 - **Reply Argument that Butler Teaches "Uncertain" Impact Which is Legally Sufficient Motivation Fails** (Sur-reply at 7-19)
 - Improper New Argument that Should Not Be Considered (Paper 29)
 - Fails if Considered (Sur-reply at 7-19)
 - Based on Baseless and Unqualified Bokor Testimony (Sur-reply at 12-14)
 - POSAs never Would Have Added Oxygen Defects into Bowen or Nagahama to Increase TMR (POR at 69-70; Sur-reply at 8-9)
 - An "Uncertain" Expectation is Not Legally Sufficient Motivation (Sur-reply at 18-19)
- **Soukup Would Not Have Motivated POSAs to Modify Bowen or Nagahama to Adopt a 0.33eV Barrier Height to Increase TMR** (POR at 51-57; Sur-reply at 19-25)
 - **Soukup is not an MTJ and Has no TMR** (POR at 56-57, 72-73)
 - Soukup is non-analogous art (POR at 51-57; Sur-reply at 19-20)
 - If analogous Soukup provided no Motivation re TMR (POR at 58-69; Sur-reply at 19-25)
 - **No Evidence Supports that a 0.33eV Barrier Height Would Increase TMR** (POR at 58-60; Sur-reply at 20-21)
 - **Soukup Says Schottky Emissions Dominate at Low Barrier Heights Which Would Decrease TMR** (POR at 63-67; Sur-reply at 21-22)
 - **Soukup Says the 0.33 eV Value is Not the Correct Barrier Height** (POR at 67-69; Sur-reply at 22-24)
 - **Petitioner Relies on Incompatible Soukup Teachings Based on Different Measurement Techniques** (Sur-reply at 24-25)
- **Objective Evidence Shows POSAs Expected Lowering Barrier Height to Decrease TMR and that the Inventor's Results Were Surprising** (POR at 20-29)

Petitioner Needed to Establish Some Supportable Reason Why Soukup Would Have Motivated POSAs to Modify Bowen and Nagahma to Have a 0.33 eV Barrier Height

'909 POR

To demonstrate any claim obvious, Petitioner needed to establish some supportable **reason why** a POSA “would have selected and combined [the] prior art elements” in a manner “yield[ing] the claimed invention.” *Unigene Labs. v. Apotex*, 655 F.3d 1352, 1360 (Fed. Cir. 2011); *see also KSR*, 550 U.S. at 418 (same); *TQ Delta v. Cisco Sys.*, 942 F.3d 1352, 1359 (Fed. Cir. 2019) (reversing the Board’s obviousness determination because the Board “fails to identify any actual **reason why** a skilled artisan would have combined the elements in the manner claimed.”) (internal citations omitted)).

POR at 31

'909 Institution Decision

“Although the *KSR* test is flexible, the Board ‘must still be careful not to allow hindsight reconstruction of references . . . without any explanation as to *how* or **why** the references would be combined to produce the claimed invention.’” *TriVascular, Inc. v. Samuels*, 812 F.3d 1056, 1066 (Fed. Cir. 2016) (quoting *Kinetic Concepts*, 688 F.3d at 1368). Further, an assertion of

Paper 9 at 8

Petitioner Alleged a Single Reason Why POSAs Were Allegedly Motivated to Lower Barrier Height – Because This Would Allegedly Increase TMR

'909 Petition

E. **Claim 5:** “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”

barrier. EX1028 at Abstract, 3232, 3236, EX1024 ¶¶169-71 According to the equation for TMR, lowering the resistance (barrier height) for parallel electrons (R_p) would improve TMR. EX1035 at 3273; EX1027 ¶2; EX1017 at 5:10-16; EX1024 ¶169. TMR was an “important parameter” for improving MRAM performance. EX1055 at 2269; EX1024 ¶170. Skilled artisans, including Bowen, had long been interested in increasing TMR to enable better performing MRAM. EX1026 at Abstract, 1655 (Bowen: “experimental results showing large TMR values” for MgO MTJ); EX1055 at 2271; EX1024 ¶170; *supra* §II.B.

Petition at 33- 34

Ground 1

E. **Claim 5:** “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”

MgO barrier. EX1028 at Abstract, 3232, 3236, EX1024 ¶¶275-77, 281 As explained for Claim 5 in Ground 1, TMR was an “important parameter” and of high interest for improving MRAM performance, and lowering the resistance (barrier height) for parallel electrons would improve TMR.

Petition at 57-58

Ground 2

No Evidence Supports the Petition's Assertion that Lowering R_p By Lowering Barrier Height Would Increase TMR

'909 POR

$$\text{TMR} = \frac{\Delta R}{R_p} = \frac{R_{ap} - R_p}{R_p}$$

POR at 33

Petitioner's Expert Dr. Bokor

Q. If -- if we're talking about reducing the resistances, the only way to increase TMR is if the parallel resistance is decreased by proportionately more than the antiparallel resistance; correct?

A. Correct.

EX2013 at 119:9-14 (cited POR at 33)

EX2053 at ¶66 (cited POR at 33)

Patent Owner's Expert Dr. Ross

66. Second, lowering the barrier height would not increase TMR unless it lowered R_p by a proportionately greater amount than R_{ap} . For completeness, lowering the parallel resistance R_p would increase TMR if: (1) R_{ap} remained unchanged; (2) R_{ap} increased; or (3) R_{ap} decreased, but by proportionally less than the amount by which R_p decreased. All three scenarios fall under the umbrella of the parallel resistance R_p needing to be lowered by a proportionally greater amount than the antiparallel resistance R_{ap} . Dr. Bokor agrees. EX2013, 118:1-119:14. Dr. Bokor in his Declaration testified that “[a]s is evident from the TMR equation [same TMR equation above], lowering the resistance (barrier height) for parallel spin electrons compared to antiparallel improved TMRs.” EX1024, ¶169. I

No Evidence Supports the Petition's Assertion that Lowering R_p By Lowering Barrier Height Would Increase TMR

Petitioner's Expert Dr. Bokor

Q. Okay. So the POSA -- just to be clear, because it reads quite differently here. I want to be clear that your testimony -- it is your opinion that a POSA did not actually know that reducing the barrier height would increase TMR?

A. I do not have evidence for that.

Q. You do not have evidence -- I'm sorry. You do not have evidence that a POSA would have known that reducing barrier height would increase TMR; right?

A. That's what I've been testifying.

EX2013 at 154:9-19 (cited POR at 36)

'909 POR

4. Petitioner's Expert Admitted He Cited No Prior Art Reference Teaching That Lowering Barrier Height Would Have Increased TMR

Petitioner's assertion that lowering barrier height "would improve TMR" cites a string of references and Dr. Bokor's ¶¶169 and 276. Petition, 34 (Ground 1)

Leaving no doubt, Dr. Bokor admitted that *no prior art teaching* he was aware of taught that lowering barrier height would increase TMR, and that he never testified that a POSA would have expected that lowering barrier height would have increased TMR. EX2013, 103:21-104:25, 129:18-130:3, 133:11-134:17, 149:8-23, 150:12-154:11, 154:11-19 (Q: "it is your opinion that a POSA did not actually know that reducing the barrier height would increase TMR? A: I do not have evidence for that. Q: . . . You do not have evidence that a POSA would have known that reducing barrier height would increase TMR; right? A: That's what I've been testifying.").

At the Institution Stage The Board Credited the Petition's Contention that Lowering Barrier Height Would Increase TMR

'909 Institution Decision

Petitioner asserts that “[a]ccording to the equation for TMR,^[3] lowering the resistance (barrier height) for parallel electrons (R_p) would improve TMR.”

Id. (citing Ex. 1017, col. 5, ll. 10–16; Ex. 1024 ¶ 169; Ex. 1027 ¶ 2;

Ex. 1035, 3273). Petitioner contends that “TMR was an ‘important

Paper 9 at 14

'909 Institution Decision

We disagree with Patent Owner's arguments based on the current record. Dr. Bokor testifies that “as is evident from the TMR equation, . . . lowering the resistance (barrier height) for parallel spin electrons [(i.e., R_p)] compared to antiparallel [(i.e., R_{ap})] improved TMRs.” Ex. 1024 ¶ 169 (citing Ex. 1035, 3273) (emphasis added). Dr. Bokor's testimony is consistent with the TMR equation above, which has R_p as the only term in the denominator, and reflects that R_p would be lowered disproportionately, or otherwise the TMR would not have “improved.” *Id.* It also appears to be supported by other evidence of record. See Ex. 1035, 3273 (noting the strong influence of tunnel barrier height on $\Delta R/R$). Patent Owner, by contrast, chooses values for R_p and R_{ap} to support its attorney argument that R_p and R_{ap} might be lowered proportionately, or that R_{ap} could be reduced by a proportionally greater amount than R_p , without any evidence that such values are possible. See Prelim. Resp. 23.

At this stage, Petitioner has provided sufficient support for its contention that a person of ordinary skill in the art would have been motivated to lower the 0.9 eV barrier height of Bowen's device, which would lower R_p and in turn increase the TMR. See Ex. 1024 ¶¶ 45–49, 169, 171–173, 176. As Petitioner points out, Bowen's barrier height of 0.9 eV

Paper 9 at 17-18

Petitioner's Expert Disavowed an Interpretation of His Testimony that the Board Adopted in Instituting this Trial

Petitioner's Expert Dr. Bokor

Q. In paragraph 169 of your declaration, you do not allege that lowering a barrier height in an MTJ will reduce parallel resistance by more than it reduces antiparallel resistance; correct?

A. **That's correct.** This paragraph just says if you reduce the resistance for parallel compared to antiparallel, that would increase the TMR. That's what this paragraph says. And that's - it doesn't say what you just said. I agree with that.

EX2013 at 133:11-20 (cited POR at 33)

'909 Institution Decision

We disagree with Patent Owner's arguments based on the current record. Dr. Bokor testifies that "as is evident from the TMR equation, . . . lowering the resistance (barrier height) for parallel spin electrons [(i.e., R_p)] compared to antiparallel [(i.e., R_{ap})] improved TMRs." Ex. 1024 ¶ 169 (citing Ex. 1035, 3273) (emphasis added). Dr. Bokor's testimony is consistent with the TMR equation above, which has R_p as the only term in the denominator, and reflects that R_p would be lowered disproportionately, or otherwise the TMR would not have "improved." *Id.* It also appears to be supported by other evidence of record. See Ex. 1035, 3273 (noting the strong influence of tunnel barrier height on $\Delta R/R$). Patent Owner, by contrast, chooses values for R_p and R_{ap} to support its attorney argument that R_p and R_{ap} might be lowered proportionately, or that R_{ap} could be reduced by a proportionally greater amount than R_p , without any evidence that such values are possible. See Prelim. Resp. 23.

At this stage, Petitioner has provided sufficient support for its contention that a person of ordinary skill in the art would have been motivated to lower the 0.9 eV barrier height of Bowen's device, which would lower R_p and in turn increase the TMR. See Ex. 1024 ¶¶ 45–49, 169, 171–173, 176. As Petitioner points out, Bowen's barrier height of 0.9 eV

Petitioner's Expert Said a POSA Would Not Have Known Whether Lowering the Barrier Height Would Increase or Undesirably Decrease TMR

'909 POR

Petitioner's expert, Dr. Bokor, admitted repeatedly that a POSA would *not* have known whether lowering the barrier height of the MgO barrier layer in Bowen or Nagahama would have increased or decreased TMR. EX2013, 47:18-49:11, 50:7-51:22, 52:6-20, 52:21-54:3, 54:4-57:6, 57:7-58:16, 79:15-80:24, 125:14-127:19, 129:18-130:3, 154:1-19. While he often said a POSA would have

Paper 18 at 34

Q. In 2004, which direction would a person of ordinary skill in the art have expected the TMR to change?

A. I think it would have been uncertain at that time.

EX2013 at 48:21-25 (cited POR at 34)

Q. The POSA didn't know?

A. A POSA did not have the resources to be able to make a scientifically responsible estimate of that.

EX2013 at 127:16-19 (cited POR at 34)

Q. So a person of ordinary skill in the art in 2004 could not have said that the TMR would have increased or decreased; is that right?

A. That's what I'm saying.

EX2013 at 51:10-13 (cited POR at 34)

Q. Okay. So the POSA -- just to be clear, because it reads quite differently here. I want to be clear that your testimony -- it is your opinion that a POSA did not actually know that reducing the barrier height would increase TMR?

A. I do not have evidence for that.

Q. You do not have evidence -- I'm sorry. You do not have evidence that a POSA would have known that reducing barrier height would increase TMR; right?

A. That's what I've been testifying.

EX2013 at 154:9-19 (cited POR at 36) 12

Petitioner's Assertion that Bokor Testified that Lowering Barrier Height Would Increase TMR is False

'909 Petitioner's Reply

Next, IPB claims Bokor admitted that neither his declaration nor the cited references say “that lowering barrier height would increase TMR.” POR, 35 (citing EX2013-EX2014). Bokor said the opposite: “To increase TMR of an MgO barrier, skilled artisans would have been motivated to explore lower barrier heights to facilitate tunneling of parallel electrons.” EX1024 ¶171; *see also, e.g.*, EX2013, 119:15-124:11 (discussing EX1024 ¶170).

Petitioner's Reply at 8

'909 Motion to Strike Reply

mischaracterizes ¶171. After explaining TMR in ¶169, Bokor alleged lowering barrier height would “facilitate tunneling of parallel electrons.” EX1024, ¶171. Resistance and tunneling conductance are inversely related. EX2086, 71:12-16; EX2053, ¶33. Thus, Bokor’s assertion that lowering barrier height would allegedly “*facilitate tunnelling of parallel electrons*” simply restates the *Petition’s* failed argument that lowering barrier height would “*lower[] the resistance... for parallel electrons*.” Pet., 34. Indeed, while Petitioner misleadingly omits it, ¶171 alleges lowering barrier height would “*increase* TMR.” That is the *Petition’s* failed argument that it is undisputed is not supported by any evidence. POR, 31-43.

Paper 33 at 1-2

Patent Owner's Expert Dr. Ross

33. The reciprocal of resistance is conductance G (i.e., $R = 1/G$). By this reciprocal relationship, the conductance of a MTJ in the antiparallel state (G_{ap}) is lower (higher resistance) than the conductance of the MTJ in the parallel state (G_p) (lower resistance). Thus, TMR can also be expressed in terms of the MTJ's

EX2053 at ¶33 (cited Paper 33 at 1-2)

The Reply Disavows Petitioner’s Reliance on Moodera (EX1035) as Supporting that Lowering Barrier Height Would Increase TMR

’909 Petition

barrier. EX1028 at Abstract, 3232, 3236; EX1024 ¶¶169-71. According to the equation for TMR, lowering the resistance (barrier height) for parallel electrons (R_p) would improve TMR. EX1035 at 3273; EX1027 ¶2; EX1017 at 5:10-16; EX1024 ¶169. TMR was an “important parameter” for improving MRAM performance

Petition at 34

’909 PO Sur-reply

² Petitioner never disputes that Moodera teaches that lowering barrier height *decreased* TMR. POR, 37-43. Petitioner now alleges POSAs would not have considered Moodera—which describes (Al_2O_3) barriers—to inform *any* TMR/barrier height relationship for MgO barriers. Reply, 12-13. That reversal is

Sur-Reply at 4, footnote 2

’909 Patent

~~cussed~~. The magnetoresistance (MR) ratio of a MTJ device can be expressed by the following equation:

$$\Delta R/R_p = (R_{ap} - R_p) / R_p$$

where R_p and R_{ap} indicate the tunnel junction resistance in the cases of parallel and antiparallel magnetization alignments, respectively, of two electrodes. According to the

EX1017 at 5:10-16 (cited Petition at 34)

Nagahama

[0002] The tunnel magnetoresistive effect is a phenomenon in which the electrical resistance of a ferromagnetic tunnel junction including an insulating material between two ferromagnetic metal electrodes is varied depending on the relative magnetization directions of the two ferromagnetic electrodes. The magnitude of magnetoresistance is expressed by the following equation:

$$\text{Magnetoresistive effect} = [(\text{Antiparallel } R - \text{Parallel } R) / \text{Parallel } R] \times 100 (\%) \tag{1}$$

EX1027 at ¶2; (cited Petition at 34)

’909 Petitioner’s Reply

¶39 IPB’s citations to Moodera 1995 (EX1035), Moodera 1996 (EX1038), and Saito (EX2037) that all expressly cite or track Slonczewski’s outdated model are plainly insufficient to show how one of skill, *after* Butler in 2001, would have predicted the impact of barrier height on TMR in MgO. POR, 37-38 (IPB: Moodera “discusses a 1989 theory by Slonczewski” and Saito used “a model ‘roughly consistent’ with Slonczewski’s theory.”); *see also* POR, 37-42; EX1105 ¶¶40-52; EX1102, 78:14-79:8 (Ross: “Saito uses Slonczewski’s model with all of its approximations”). Aside from the outdated model, Saito’s experimental data was

Petitioner’s Reply at 12

The Petition Relied on its Claim 5 Showing for Claim 6

'909 Petition

- F. **Claim 6: “The magnetoresistive device of claim 5, wherein the barrier height of the tunnel barrier layer is in a range of 0.2 eV to 0.5 eV.”**

This claim requiring an overlapping tunnel barrier height “in a range of 0.2 eV to 0.5 eV” was taught or suggested by Bowen in view of Soukup for the reasons provided in Claim 5. *Supra* §VI.E; EX1028 at Abstract (Soukup: MgO barrier height of “about 0.33 eV”); EX1024 ¶181.

Ground 1

Petition at 37

- F. **Claim 6: “The magnetoresistive device of claim 5, wherein the barrier height of the tunnel barrier layer is in a range of 0.2 eV to 0.5 eV.”**

Claim 6’s overlapping barrier height range was obvious over Nagahama in view of Soukup for the reasons provided in Claim 5. *Supra* §VII.E; EX1024 ¶287.

Ground 2

Petition at 59

Petitioner’s Showing for the Barrier Height Limitation in Every Claim

Rest on Its Failed Showing for Claims 5 and 6

'909 Petition

4. Claim 9[c]: “wherein said tunnel barrier layer comprises magnesium oxide and has a barrier height in a range of 0.1 eV to 0.85 eV.”

Supra Claims 1[c] and 5, §§VI.A.4, VI.E; EX1024 ¶204.

- L. Claim 12: “The magnetoresistive device of claim 11, wherein the barrier height is in a range of 0.2 eV to 0.5 eV.”

Supra Claims 6 and 11, §§VI.F, VI.K; EX1024 ¶208.

Petition at 43

'909 Petition

3. Claim 15[b]: “a tunnel barrier comprising magnesium oxide and having a barrier height in a range of 0.2 eV to 0.5 eV; and”

Supra Claims 1[c] and 6, §§VI.A.4, VI.F; EX1024 ¶217.

Petition at 44

Ground 1

'909 Petition

4. Claim 9[c]: “wherein said tunnel barrier layer comprises magnesium oxide and has a barrier height in a range of 0.1 eV to 0.85 eV.”

Supra Claim 1[c] and Claim 5, §§VII.A.4, VII.E; EX1024 ¶306.

- L. Claim 12: “The magnetoresistive device of claim 11, wherein the barrier height is in a range of 0.2 eV to 0.5 eV.”

Supra Claims 6 and 11, §§VII.F, VII.K; EX1024 ¶310.

Petition at 63

'909 Petition

3. Claim 15[b]: “a tunnel barrier comprising magnesium oxide and having a barrier height in a range of 0.2 eV to 0.5 eV; and”

Supra Claims 1[c] and 6, §§VII.A.4, VII.F; EX1024 ¶317.

Petition at 65

Ground 2

The Petition Offered No Other Valid Obviousness Theory

'909 Petition

The claimed tunnel barrier height range of 0.1 to 0.85 eV also would have been obvious. EX1024 ¶173. The claimed range is only slightly below the barrier height at “0.9 eV” taught by Bowen and others. EX1026 at 1656 (citing EX1038); EX1038 at 4725-26; EX1024 ¶173. One of skill was aware that oxygen vacancy

Petition at 35

Patent Owner's Expert Dr. Ross

45. An MTJ's “tunnel barrier height” refers to the energy difference in electron volts (eV) between the Fermi energy (E_F) of the electrode material and the bottom of the conduction band of the barrier material (also referred to as the conduction band minimum (CBM)). The tunnel barrier height thus depends on the electrode and the barrier material. EX1031, 1794-1796, FIGS. 1-2; '909 Patent, 4:2-8. The upper limit of the tunnel barrier height for an electrode/barrier pairing, what the '909 Patent calls its “ideal” value, can be determined from analysis of the band structure of the electrode and barrier materials. The '909 patent uses the 3.6

EX2053 at ¶45; (cited POR at 14)

'909 POR

Bowen's alleged barrier height of 0.9 eV. Petition, 35. Petitioner makes no similar assertion for the claimed 0.2-0.5 eV range so that assertion does not help Petitioner with over half the Challenged Claims. See claims 6, 12 and 15-20. Moreover,

POR at 43

0.85 eV *also* would have been obvious” (Petition, 35) is legal error. The “claimed invention as a whole” must be proven obvious—not an individual claim limitation. 35 U.S.C. §103.

POR at 43

Petitioner's assertion does not establish obviousness of *any* claim. Petitioner cites no authority supporting an assertion that a “slight[er]” difference between a claimed parameter and the prior art renders the claim obvious and obviates the need for Petitioner to establish some *reason why*¹² a POSA would have modified the prior art to meet the claim. That is *not* the law. *In re Patel*, 566 F. App'x 1005, 1009-10 (Fed. Cir. 2014) (“Where differences clearly exist [between the prior art and the claims] and there is no evidence that they are either not meaningful or one of skill in the art would know to discard the limits set by the prior art, *proximity alone is not enough* to establish a prima facie case of obviousness.”).

POR at 43-44

The Petition Offered No Other Valid Obviousness Theory

'909 Petition

The claimed tunnel barrier height range of 0.1 to 0.85 eV also would have been obvious. EX1024 ¶173. The claimed range is only slightly below the barrier height at “0.9 eV” taught by Bowen and others. EX1026 at 1656 (citing EX1038); EX1038 at 4725-26; EX1024 ¶173. One of skill was aware that oxygen vacancy defects impacted the barrier height. Bowen itself hypothesized that the low barrier height they observed, which was “lower than half” of the calculated value for “an ultrathin layer” of MgO, may be due to the “presence of stoichiometric... inhomogeneities in the insulating film.” EX1026 at 1656; EX1024 ¶174. Soukup observed a relationship between barrier height and MgO stoichiometry (oxygen vacancy defects). EX1028 at 3232, 3236 (“[B]arrier height was a function of the amount of oxygen present... with a higher barrier for larger amounts of oxygen present” and “more stoichiometric” MgO film.). Thus, one of skill would have been motivated to adjust oxygen vacancy defects to improve TMR by lowering the barrier height as taught by Soukup.

The Petition Offered No Other Valid Obviousness Theory

'909 Institution Decision

At this stage, Petitioner has provided sufficient support for its contention that a person of ordinary skill in the art would have been motivated to lower the 0.9 eV barrier height of Bowen's device, which would lower R_p and in turn increase the TMR. See Ex. 1024 ¶¶ 45–49, 169, 171–173, 176. As Petitioner points out, Bowen's barrier height of 0.9 eV is only slightly above the 0.1–0.85 eV range recited in claim 5. See Pet. 35. Dr. Bokor testifies that

[t]he claimed upper limit of “0.85 eV” is only marginally lower than the “0.9 eV” barrier height disclosed by Bowen and others, and one of skill would have been motivated using Soukup to try to deposit an MgO barrier with a lower barrier height. . . . One of skill applying Soukup's teachings to Bowen would have readily achieved lowering tunnel barrier height to be within the claimed range.

Ex. 1024 ¶ 173 (citing Ex. 1026, 1656; Ex. 1038, 4725–4726). Thus, based on the current record, the asserted modification to Bowen's device to lower its barrier height from 0.9 eV to fall within the claimed 0.1–0.85 eV range may not be as substantial as Patent Owner appears to suggest. See, e.g., *Titanium Metals Corp. of Am. v. Banner*, 778 F.2d 775, 783 (Fed. Cir. 1985) (concluding that a claim requiring a titanium alloy with 0.3% Mo and 0.8% Ni would have been obvious over a prior art reference disclosing 0.25% Mo–0.75% Ni and 0.31% Mo–0.94% Ni, where “[t]he proportions are so close that prima facie one skilled in the art would have expected them to have the same properties”).

The Petition Offered No Other Valid Obviousness Theory

'909 POR

Additionally, Petitioner never alleges a POSA would have expected that if Bowen's MgO device had its barrier height lowered to 0.85 it would "have the same properties" as Bowen's unmodified device. DI, 19 (quoting *Titanium Metals*). Neither the Petition nor Dr. Bokor attempted to quantify what the TMR would be if Bowen's device were modified to lower its barrier height to 0.85 eV (or 0.33 eV) and Petitioner's expert admitted he did not know. EX2013, 46:12-51:2, 79:15-80:24; *supra* §V.B.3. Petitioner also never addresses the impact lowering Bowen's barrier height would have had on its *RA* (*supra* §II.E). An MTJ's resistance increases as an *exponential* function of barrier height and thickness. Ross, ¶148. At Bowen's 2 nm barrier thickness (EX1026, 1656), reducing the barrier height from Bowen's alleged 0.9 eV value to 0.85 eV would have changed *RA* by 68%. *Id.* A POSA would have considered that *RA* change to be substantial and would not have considered the modified Bowen device to "have the same properties" as Bowen's unmodified device. DI, 19 (quoting *Titanium Metals*); Ross, ¶148.

'909 Petition

been obvious. EX1024 ¶173. The claimed range is only slightly below the barrier height at "0.9 eV" taught by Bowen and others. EX1026 at 1656 (citing EX1038); EX1038 at 4725-26; EX1024 ¶173. One of skill was aware that oxygen vacancy

Petition at 35

Petitioner's Expert Dr. Bokor

- Q. If Bowen had achieved a barrier height of .85 electron volts, what would have been the room temperature TMR?
- A. So you're saying if the barrier height was .05 eV less than the one he measured, you're asking what he would have got for a -- for a TMR?
- Q. Yes.
- A. I can't answer that question. I don't know. I didn't -- I don't know. I don't believe he gives data on that in the paper?

EX2013 at 46:12-21 (cited POR at 46)

POR at 45-46

The Petition Offered No Other Valid Obviousness Theory

Petitioner's Expert Dr. Bokor

Q. Explain.

A. A person of ordinary skill at that time I believe would have had -- based on literature, they would have had an expectation that the TMR would depend on barrier height. But the -- the way that -- the detail mathematical dependence of barrier height on TMR was not definitively known or how to calculate it in detail. It might have been known how to calculate it, but it wasn't published. So there were theorists at the time who probably could have made that calculation, but I'm not aware of any publication where they explicitly gave that dependence. So a person of ordinary skill in the art I don't think would have been able to make that calculation.

Q. So what would a person of ordinary skill in the art in 2004 have expected the TMR of Bowen's device would have increased if Bowen had achieved a barrier height of .85 electron volts?

A. I'm sorry. Please repeat one more time.

Q. Okay. Let me break it up into little pieces here. In 2004, if Bowen had achieved a barrier height of .85 electron volts, would a POSA have expected the TMR of Bowen's device to have increased from the 27 percent TMR that Bowen observed at room temperature?

A. It is my opinion that a POSA would not have had sufficient information to definitively decide what direction the TMR would have gone.

Q. And would they have had an expectation on which direction TMR would have changed even if that expectation was not definitive?

A. What I'm saying is I think a person of ordinary skill in the art at the time would have had a reasonable expectation that the TMR would change. But it would be not -- they would not be able to be certain which way it would go, whether it would go up or it would go down. I think it was understood that TMR could change as a function of barrier height.

EX2013 at 49:12-51:2; (cited POR at 46)

The Petition Offered No Other Valid Obviousness Theory

Patent Owner's Expert Dr. Ross

148. The Petition alleges that “the claimed tunnel barrier height range of 0.1 to 0.85 eV also would have been obvious” because the “claimed range is only slightly below the barrier height at ‘0.9 eV’ taught by Bowen and others.” I disagree for several reasons. First, the Petition does not point to any evidence that a POSA would have been seeking to lower Bowen’s or Nagahama’s barrier height in the first place. To the contrary, Bowen noted that the reported barrier heights were in agreement with some, lower than others and much lower than half the MgO bandgap of 5.5 eV and attributed the differences to unwanted manufacturing defects. EX1026, 1655. Nagahama did not report barrier heights at all. Second, the barrier height of an MTJ is the result of the choice of material for each of the layers in an MTJ and the fabrication processes used to deposit them, not a parameter that a designer of an MTJ merely chooses to employ. Absent the inventor’s insight, the Petition provides no reason that a POSA would have tried to lower Bowen’s barrier height and, for the reasons discussed above, would not have wanted to do so because of the expected increase in TMR. Third, the Petition’s allegation that 0.85 eV is only “slightly below” 0.9 eV ignores that this difference is not slight in the

context of an MTJ. The difference between a 0.85 eV and an 0.9 eV barrier height results in a substantial change in RA because barrier height because an MTJ’s resistance increases as an exponential function of barrier height and barrier thickness. At a 2nm barrier thickness like Bowen’s (EX1026, 1656), a change from 0.9 eV to 0.85 eV results in a change in RA by a factor of 68%—that device would not have the same properties as Bowen’s. This can be seen from a simple calculation using the Simmons formula that describes the RA of a tunnel barrier: $RA = p(t/\sqrt{\phi})\exp(q(t\sqrt{\phi}))$ where p and q are constants involving only physical parameters (Planck’s constant, electron charge, electron mass), t is the thickness of the barrier and ϕ is the barrier height. For a barrier thickness of 2 nm, the ratio $RA(\phi = 0.9 \text{ eV})/RA(\phi = 0.85 \text{ eV}) = 1.68$.

EX2053 at ¶148; (cited POR at 46)

The Reply Newly Alleged that Butler Motivated Lowering Barrier Height to Change TMR in an “Uncertain” Way Which is “Legally Sufficient Motivation”

'909 Petitioner's Reply

IPB unfairly criticizes Bokor's testimony that “a POSA would not have known whether lowering the barrier height of the MgO barrier layer in Bowen or Nagahama would have increased or decreased TMR.” POR, 34. But Bokor explained that one of skill “would have had a reasonable expectation that the TMR would change” were barrier height lowered even if they were not “certain which way it would go.” EX2013, 50:9-51:5, 51:23-52:5.

That is a legally sufficient motivation. A “court can take account of the inferences and creative steps that a person of ordinary skill in the art would employ.” *KSR Int'l v. Teleflex*, 550 U.S. 398, 418 (2007). Bokor's explanation showed that lowering barrier height to improve TMR would have been “‘nothing more than routine’ application of a well-known problem-solving strategy” stemming from “the normal desire of scientists or artisans to improve upon what is already generally known.” *Pfizer v. Apotex*, 480 F.3d 1348, 1368 (Fed. Cir. 2007) (citation omitted).

Butler's predictions about the behavior of parallel and antiparallel electrons crossing MgO rendered barrier height an identified and predictable (if uncertain) strategy to increase TMR. *Id.*; EX2014, 216:15-17 (“[I]f I think that there's a 50/50 chance I'm going to get the improvement that I'm looking for, boy, oh, boy, I'm going to try that.”).

Petitioner's Reply at 7-8

50). In fact, Butler provides data leading one of skill to conclude that lowering barrier height would change TMR.

Petitioner's Reply at 14

The Petition's Citation to Butler's First Page Did Not Allege that Butler Taught a TMR/Barrier Height Relationship

'909 Petition

at Fig. 16; EX1024 ¶68. Butler pointed out that tunneling across an MgO barrier was facilitated by the “symmetry” between the electrodes and barrier material. EX1044 at 1; *see* EX1046 at 1. This symmetry permitted high TMRs because “[t]he tunneling resistance for the parallel” electrons was “estimated to be 100 times smaller than that for the antiparallel” electrons “due to the absence of scattering in the barrier.” EX1045 at 1; *see also* EX1044 at 1; EX1024 ¶69.

Petition at 12

E. Claim 5: “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”

Butler and Mathon taught that MgO barriers would achieve higher TMRs due to improved symmetry matching between the MgO barrier and ferromagnetic electrodes, facilitating tunneling of parallel electrons across the barrier compared to antiparallel tunneling. EX1044 at 1; EX1046 at 1; EX1024 ¶170. One of skill in

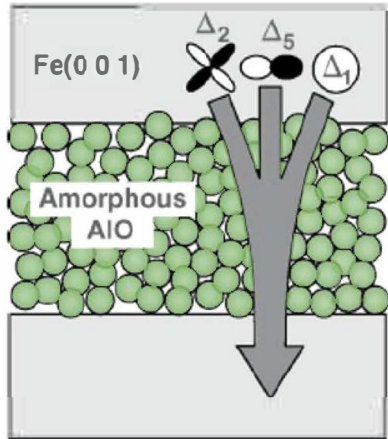
Butler

Mathon

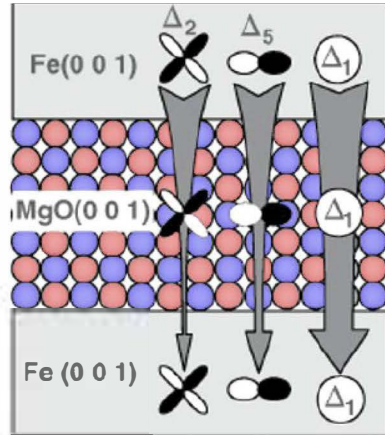
Petition at 33-35

Butler's "Symmetry Matching" Has Nothing to Do With Barrier Height

'909 POR



(a)



(b)

POR at 13

Butler

We present first-principles based calculations of the tunneling conductance and magnetoconductance of epitaxial $\text{Fe}(100)|\text{MgO}(100)|\text{Fe}(100)$ sandwiches. Our results indicate that tunneling is much more interesting and complicated than the simple barrier model used previously. We obtain the following general results: (1) Tunneling conductance depends strongly on the symmetry of the Bloch states in the electrodes and of the evanescent states in the barrier layer. (2) Bloch states of different symmetry decay at different rates within the barrier. The decay rate is determined by the complex energy bands of the same symmetry in the barrier. (3) There may be quantum interference between the decaying states in the barrier. This leads to an oscillatory dependence of the tunneling current on $k_{\parallel}$ and a damped oscillatory dependence on barrier thickness. (4) Interfacial resonance states can allow particular Bloch states to tunnel efficiently through the barrier. For $\text{Fe}(100)|\text{MgO}(100)|\text{Fe}(100)$ our calculations indicate that quite different tunneling mechanisms dominate the conductance in the two spin channels. In the majority channel the conductance is primarily via Bloch electrons with small transverse momentum. One particular state with Δ_1 symmetry is able to effectively couple from the Fe into the MgO. In the minority channel the conductance is primarily through interface resonance states especially for thinner layers. We predict a large magnetoresistance that increases with barrier thickness.

DOI: 10.1103/PhysRevB.63.054416

PACS number(s): 75.70.Cn, 72.15.Gd, 73.40.Gk, 73.40.-c

EX1044 at 1; (cited POR at 12)

Petitioner's Expert Dr. Bokor Conceded that Butler Does Not Explicitly Discuss a TMR/Barrier Height Relationship

Petitioner's Expert Dr. Bokor

Q. Butler doesn't actually teach changing barrier height at all, does he?

A. He doesn't explicitly. But in my opinion, a person of ordinary skill in the art reading Butler would find that teaching in there?

EX2086 at 65:20-24 (cited Sur-reply at 13)

Q. Butler's theory does not describe the effect of changing barrier height on TMR, does it?

A. Butler's paper doesn't explore that particular scenario in the -- in the -- within the confines of the paper. But my -- my opinion is that a person of ordinary skill reading Butler could understand that there should be an energy dependence on the blockage of the antiparallel electrons such that the MR could go up with decreasing barrier height. At least had a good chance.

EX2013 at 71:22-72:7 (cited Sur-reply at 13)

Butler

We present first-principles based calculations of the tunneling conductance and magnetoconductance of epitaxial Fe(100)|MgO(100)|Fe(100) sandwiches. Our results indicate that tunneling is much more interesting and complicated than the simple barrier model used previously. We obtain the following general results: (1) Tunneling conductance depends strongly on the symmetry of the Bloch states in the electrodes and of the evanescent states in the barrier layer. (2) Bloch states of different symmetry decay at different rates within the barrier. The decay rate is determined by the complex energy bands of the same symmetry in the barrier. (3) There may be quantum interference between the decaying states in the barrier. This leads to an oscillatory dependence of the tunneling current on $k_{\parallel}$ and a damped oscillatory dependence on barrier thickness. (4) Interfacial resonance states can allow particular Bloch states to tunnel efficiently through the barrier. For Fe(100)|MgO(100)|Fe(100) our calculations indicate that quite different tunneling mechanisms dominate the conductance in the two spin channels. In the majority channel the conductance is primarily via Bloch electrons with small transverse momentum. One particular state with Δ_1 symmetry is able to effectively couple from the Fe into the MgO. In the minority channel the conductance is primarily through interface resonance states especially for thinner layers. We predict a large magnetoresistance that increases with barrier thickness.

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PACS number(s): 75.70.Cn, 72.15.Gd, 73.40.Gk, 73.40.-c

EX1044 at 1 (cited Petition at 34)

The Reply Relied On New Evidence to Advance Its New Argument That Butler Taught a TMR/Barrier Height Relationship

'909 PO's Sur-reply

Unable to defend the Petition's argument, the Reply advances three new arguments, based on new evidence, alleging: (1) **Butler** motivated POSAs to lower Bowen's/Nagahama's barrier height to increase TMR because (2) **Butler** allegedly teaches this would have changed TMR in some "uncertain" way and (3) this was "legally sufficient motivation." Reply, 7-10 (citing EX2013-EX2014), 13-16 (citing EX1105-EX1106 and Butler pages 2-4 and Figs. 3-4) and 23-25 (citing EX2013). Based on this newly-alleged motivation from Butler, Petitioner alleges

Paper 31 at 7

PO's Motion to Strike

uncertain) strategy to increase TMR"). These new arguments rely on new evidence not cited in the Petition: EX1106, new disclosures in Butler (pages 2-4, Figs. 3-4 and "data"), Bokor's **reply** declaration (EX1105) (all *cited* Reply, 14-16) and Bokor's deposition testimony EX2013-EX2014 (*cited* Reply, 7-8 and 24).

The Petition's citation to Butler does not entitle Petitioner to cite **different** parts of Butler in Reply to advance a **different** argument. *Ariosa Diagnostics v Verinata Health, Inc.*, 805 F.3d 1359, 1367 (Fed. Circ. 2015) (affirming Board's refusal to consider Reply arguments relying "on previously unidentified portions of a prior-art reference to make a meaningfully distinct contention" and *citing* Rule 104(b)(5)). Rule 104 imposes requirements on the Petition's "content" and requires ("must") that the Petition identify "**specific portions** of the evidence that support the challenge." 37 C.F.R. §42.104(b)(5). The Petition never cited Butler pages 2-4, Figs 3-4, or "data" that the Reply belatedly cites. Reply, 7-8 and 14-16.

Paper 29 at 6-7

The Petition Cited Butler and Mathon for Symmetry Matching and Never Cited Butler for a TMR/Barrier Height Relationship

'909 Petition

In 2001, Butler and Mathon separately calculated that MTJs with a crystalline MgO barrier layer would achieve TMRs of over 1000%. EX1053 at 8041, 8043 nn.9-10 (citing EX1044, EX1046). Their publications spurred a scientific gold rush.

Petition at 7

'909 Petition

In 2001, Butler and Mathon separately “calculated [the] optimistic TMR ratio is in excess of 1000% for an MgO barrier.” EX1046 at Abstract; see also EX1044 at Fig. 16; EX1024 ¶68. Butler pointed out that tunneling across an MgO barrier was facilitated by the “symmetry” between the electrodes and barrier material. EX1044 at 1; see EX1046 at 1. This symmetry permitted high TMRs because “[t]he tunneling resistance for the parallel” electrons was “estimated to be 100 times smaller than that for the antiparallel” electrons “due to the absence of scattering in the barrier.” EX1045 at 1; see also EX1044 at 1; EX1024 ¶69.

Butler’s and Mathon’s breakthroughs generated considerable excitement for MgO thin-film MTJs. EX1053 at 8041, 8043 nn.9-10 (citing Butler and Mathon); EX1045 at 1, 8 n.3 (citing Butler); EX1024 ¶72.

Petition at 12

'909 Petition

Butler and Mathon taught that MgO barriers would achieve higher TMRs due to improved symmetry matching between the MgO barrier and ferromagnetic electrodes, facilitating tunneling of parallel electrons across the barrier compared to antiparallel tunneling. EX1044 at 1; EX1046 at 1; EX1024 ¶170. One of skill in

Petition at 34

'909 Petition

As explained in Ground 1, Butler and Mathon taught that MgO barriers improved TMRs due to improved symmetry facilitating tunneling of parallel electrons, and one of skill would have been motivated to explore lower barrier heights to accomplish that. EX1044 at 1; EX1046 at 1; EX1024 ¶¶170-71; supra §VI.E. One of skill seeking to improve Nagakuma’s MTJ would have looked to

Petition at 58

The Statute and the Board's Rules and Practice Foreclose Petitioner's Allegation that the Petition Made the Reply's New Argument

'909 Reply to Motion to Strike

The Petition must state its grounds with “**particularity**” and “**must** include ... [a] **full statement** of the reasons for the relief requested, including a **detailed explanation** of the significance of the evidence.” 35 U.S.C. §312(a)(3); 37 C.F.R.

Paper 33 at 3-4

'909 Motion to Strike

104(b)(5)). Rule 104 imposes requirements on the Petition's “content” and requires (“must”) that the Petition identify “**specific portions** of the evidence that support the challenge.” 37 C.F.R. §42.104(b)(5). The Petition never cited Butler pages 2-4, Figs 3-4, or “data” that the Reply belatedly cites. Reply, 7-8 and 14-16.

Paper 29 at 7

Wasica Fin. GmbH v. Cont'l Auto. Sys., Inc.

“...the expedited nature of IPRs bring with it an obligation for petitioners to make their case in their petition to institute.”



“Here, Continental did not make out its obviousness case in its petition. ... After Wasica pointed out the flaws of this position, Continental's ensuing arguments to the Board and to us effectively abandoned its petition in favor of a new argument. ... **Shifting arguments in this fashion is foreclosed by statute, our precedent, and Board guidelines.**” (citing authority)

Wasica Fin. GmbH v. Cont'l Auto. Sys., Inc., 853 F.3d 1272, 1286–87 (Fed. Cir. 2017)

Ariosa Diagnostics v. Verinata Health, Inc.



“We see no error in the Board's rejection of Ariosa's reliance, in its Reply submissions, on previously unidentified portions of a prior-art reference to make a **meaningfully distinct contention.**”

Ariosa Diagnostics v. Verinata Health, Inc., 805 F.3d 1359, 1367–68 (Fed. Cir. 2015)

Reasons For Failure of Reply Argument that Butler Teaches an “Uncertain” Relationship Which is “Legally Sufficient” Motivation to Inject Defects into the MgO to Reduce Barrier Height

- **Butler and other prior art taught TMR was maximized by a defect-free MgO layer**

(Sur-reply at 8)

- **The prior art taught that lowering barrier height would decrease TMR**

(Sur-reply at 9-11)

- **This argument rests on Bokor’s unreliable opinion that is inadmissible under FRE 702**

(Sur-reply at 12-14; Paper 43; Paper 45)

- **This theory is not “legally sufficient”**

(Sur-reply at 18)

Petitioner's Assertion that Butler Motivated POSAs to Inject Defects Into the MgO to Increase TMR Is Refuted By the Evidence

'909 Petitioner's Reply

example, Simmons. *Supra* §III.A. Aside from being legally incorrect, IPB ignores that the motivation to lower barrier height comes from the knowledge of one of skill based on references like Butler/Mathon, Pet., 34-35, and Soukup provides the mechanism in the form of introducing oxygen defects, which it undoubtedly teaches for MgO, EX1024 ¶168; EX1028, 3232; *supra* §II.A.

Petitioner's Reply at 24-25

'909 POR

Because Bowen and Nagahama sought to experimentally test theoretical predictions that MgO layers could produce high TMR—due to coherent tunneling enhancement (*supra* §II.D)—by using a **perfect defect-free crystalline MgO layer**, Bowen and Nagahama sought to make the MgO layer as defect-free as possible. EX1026, 1655 (citing Butler), 1657; EX1027, ¶14 (citing Mathon), ¶17; Ross, ¶¶47-49, 134, 143. A POSA never would have injected oxygen vacancy **defects** into Bowen or Nagahama in an attempt to increase TMR as Petitioner erroneously alleges. Petition, 33-35, 57-59. A POSA seeking to increase TMR would have done the opposite and tried to eliminate oxygen vacancy defects. Ross, ¶143.

POR at 69

'909 PO Sur-reply

opposite. It is undisputed that Butler/Mathon theorized high TMR using models of perfectly-crystalline MgO with electron symmetries that produced coherent tunneling **enhancement**,³ and Bowen/Nagahama tried to replicate Butler's modelled structure by making their MgO as defect-free as possible in an attempt to maximize TMR. POR, 69-70; EX1024, ¶90; EX2043, ¶¶47-49, 101-102; EX2087, ¶¶17-18; EX2086, 135:18-136:7-20, 138:9-19, 142:21-143:8, 145:1-147:19, 151:14-19. As Petitioner's expert admitted, POSAs would have expected MgO

Sur-Reply at 8

Petitioner's Assertion that Butler Motivated POSAs to Inject Defects Into the MgO to Increase TMR Is Refuted By the Evidence

Petitioner's Expert Dr. Bokor

Q. So this is Bowen telling us that not only did they do everything they could to achieve a perfect single crystal MTJ, but they actually got pretty close; right?

A. They got as close as they could.

Q. Okay. And you agree that Bowen did everything they could to achieve a perfect interface between the iron ferromagnetic electrode and the magnesium oxide barrier?

A. I think that's fair. Yeah. I think that's a fair conclusion. I think they tried as hard as they could to make -- to make a sample as close as they could get to what Bowen modeled.

Q. Uh-huh. Okay. Now --

A. They wanted -- they wanted to test Bowen -- I mean Butler down to the last possible detail.

Bokor on Bowen

EX2086 at 142:21-143:12 (cited Sur-reply at 8)

Q. All right. So you agree Nagahama was also trying to make as high quality material layers as he could for his MgO MTJs?

A. Well, as -- no. He wasn't trying to make a structure as perfect as he could. He was trying to make a -- a device as close as perfect as he could get with other considerations involving practical -- practical fabrication issues.

Bokor on Nagahama

EX2086 at 145:1-10 (cited Sur-reply at 8)

Q. All right. So a POSA that was trying to achieve the high TMRs that Butler and Mathon are predicting for these iron/magnesium oxide/iron MTJs would have done everything that they could to make sure that the interfaces between the ferromagnetic electrodes and the magnesium oxide were perfect; correct?

A. Fair to say they would do everything they could.

Bokor on Butler and Mathon

EX2086 at 136:12-20 (cited Sur-reply at 8)

Petitioner's Assertion that Butler Motivated POSAs to Inject Defects Into the MgO to Increase TMR Is Refuted By the Evidence

Patent Owner's Expert Dr. Ross

18. In the 2004 timeframe when Dr. Bokor alleges a POSA would have been motivated by Butler to “explore lower barrier heights to improve TMR” by introducing oxygen vacancy defects into the MgO barrier layer, it was widely recognized that depositing high quality crystalline MgO that was as defect-free as possible would be needed to realize the high TMR values predicted by Butler’s model of an ideal Fe/MgO structure without defects, and the failure of experiments to demonstrate the high predicted TMRs was attributed to the difficulty in manufacturing defect-free Fe/MgO as I explained in my First Declaration. See EX2053, ¶¶48-49 citing *inter alia*:

- EX1046 (Mathon), 4 (“It is clear from Figs. 3 and 4 that the calculated large TMR ratio R_{TMR} in the asymptotic regime is due, entirely, to a very low spectral density of minority-spin electrons at the Γ point. To observe such a large R_{TMR} it is, therefore, *essential that the Fe/MgO interface is perfect* so that the theoretical minority-spin spectral density is well reproduced.”);

- EX1051, 2 (“*Structural defects strongly influence the electron tunneling in both the majority and the minority channels*. For example, the modification of interface states can result in a less peaked conductance around $k_{\parallel} = 0$, and *reduce considerably the magnetoresistance $\Delta R/R$* .”); EX1047, 509 (“A magnetoresistance of several hundred percent has been predicted for perfect Fe/MgO/Fe junctions due to band structure effects [citing Butler (EX1044)]....MTJs using MgO have enjoyed only limited success. Studies using polycrystalline MgO indicated a low tunneling barrier of ≈ 0.9 eV [] *pointing at a high density of defects in the barrier*.”).

See also EX2043, 101-102; EX1057, 19 (“The difference between the values of experimental and theoretical TMR is mainly due to *imperfections in interface quality and defects in crystal growth of materials due to dislocations, vacancies, and impurities*.”).

Ex. 2087 at ¶18 (Sur-reply at 8)

Both Experts Agree that Defects in the MgO Would Cause Scattering that Would Decrease TMR

Patent Owner's Expert Dr. Ross

21. The “absence of scattering” (EX1045, 1) reduces the resistance (and thus increases conductance) for the parallel orientation relative to the antiparallel orientation because, as I described in my First Declaration, Butler’s predicted high TMR is a result of significant coherent tunneling conductance in the majority channel via effective coupling of the $\Delta 1$ symmetry ($\Delta 1 \uparrow$ states) from the Fe into the MgO and the loss of that conductance path due to the absence of $\Delta 1 \downarrow$ states in the minority channel. EX2053, 89-93. Thus, scattering degrades TMR because it scatters carriers between the majority and minority channels, reducing the majority $\Delta 1$ symmetry current and increasing the minority current.

Ex. 2087 at ¶21 (Sur-reply at 8)

Petitioner's Expert Dr. Bokor

- Q. Tell me how you considered the effects of oxygen vacancy defects, other than to say it would change the Fermi level.
- A. I just said a lot about that. I will repeat what I just said before the break. I did consider that the introduction of some number of oxygen vacancy defects in the MgO could lead to scattering such that the increase in TMR that comes from the majority and minority states could be affected in a -- could be affected. So the -- if you look at Butler -- and we just talked about this quite a bit. Emphasizing scattering. Scattering effects will degrade the TMR. I think a person of ordinary skill understands that. Introducing oxygen defects could increase the amount of scattering and act to reduce TMR. So I did consider that. Without going into all of these nitty-gritty details, what I understood was introducing oxygen defects could lower the TMR.

EX2086 at 90:24-91:17 (Sur-reply at 8)

Petitioner's Attempts to Defend its Assertion that POSAs Would Have Introduced Defects In the Hopes of Increasing TMR Despite Defects Being Known to Decrease TMR Fail

'909 Petitioner's Reply



perfect defect-free crystalline MgO layer” POR, 69-70 IPB does not dispute that a skilled artisan knew that oxygen defects are naturally and intrinsically present in oxides. Pet. 13; EX1024 ¶73 Bowen explicitly recognized the potential “presence



One of skill further recognized that devices could still function as MTJs notwithstanding the defects. EX1026, 1655-56 (“[c]ontinuous and good crystal

Petitioner's Reply at 26

'909 PO's Sur-reply

Recognition that MgO defects could be present and MTJs could “function” despite them (Reply, 26-27) ignores the undisputed facts that Butler/Mathon’s theories were based on defect-free MgO and Bowen/Nagahama taught that *eliminating* oxygen defects to the extent possible would maximize TMR. POR, 69-70. The Reply’s assertion that POSAs—motivated by Butler—would have done the opposite and *introduced* defects into Bowen/Nagahama in an attempt to increase TMR is baseless. Reply, 5-8.

Sur-Reply at 9

Petitioner's Attempts to Defend its Assertion that POSAs Would Have Introduced Defects In the Hopes of Increasing TMR Despite Defects Being Known to Decrease TMR Fail

'909 Petitioner's Reply

 Even if some level of oxygen defects were harmful, which IPB fails to show, POR, 69-70, one of skill recognizing the benefit of lower barrier height would still be motivated to use them. *Novartis v. Torrent Pharms.*, 853 F.3d 1316, 1327-28

Petitioner's Reply at 27

Petitioner's Expert

'909 PO's Sur-reply

Petitioner's remaining argument is nonsensical. Petitioner alleges that despite oxygen vacancies being "harmful ... the benefit of lowering barrier height would still" have motivated POSAs to introduce them. Reply, 27. Defects were believed "harmful" to high TMR. POR, 69-70; EX2086, 80:20-24 (admitting defects "will degrade the TMR"). The "benefit of lowering barrier height" Petitioner alleges is that it would change TMR in an "uncertain" way—it might increase or *decrease*. Reply, 7-8. The hindsight underlying Petitioner's argument is laid bare by the absurd assertion that despite it being undisputed that the art taught that MgO defects would *undesirably lower TMR*, a POSA "still" would have injected MgO defects to allegedly achieve an *uncertain* change to TMR.

Sur-Reply at 9

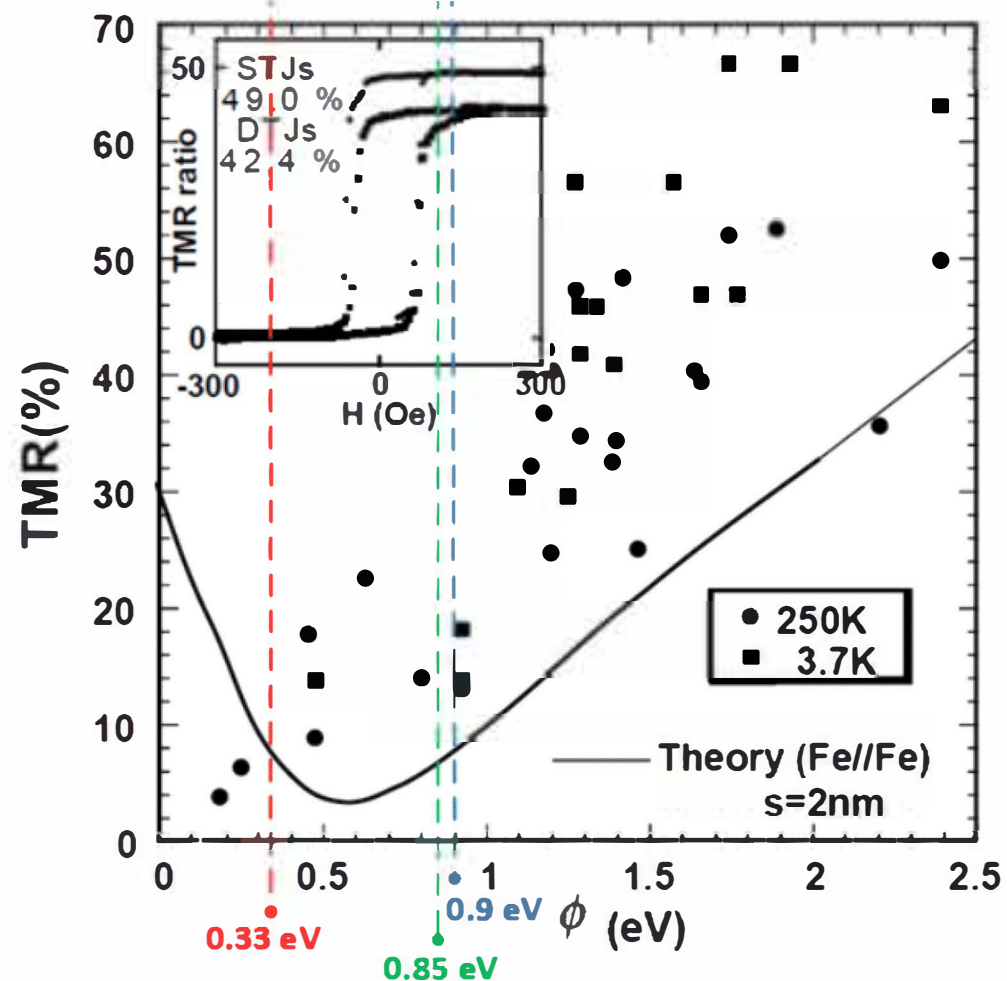
It is Undisputed that the Prior Art Taught that Lowering Barrier Height Would Lower TMR for MTJs with Alumina Barrier Layers

Patent Owner's Expert Dr. Ross

“The Slonczewski theory [13] predicts a decrease in the spin polarization with barrier height... ” on p3276 clarifies Moodera’s understanding of lower barrier height yielding lower TMR. Moodera confirmed that understanding in a subsequent paper (EX1038) for MgO barriers. EX1038, 4728 (“MgO, with its smaller barrier height, is affected more than the Al₂O₃ barrier. This can increase the tunneling probability for the minority spins. The spin polarization of the tunneling current can then be expected to decrease, as discussed in Slonczewski’s theory.”). In other words, a lower barrier leads to lower spin polarization and hence lower TMR.

75. This is understanding in the art is consistent with Slonczewski’s theory and reinforced by Saito’s (EX2037) experiments. Saito (EX2037) published

EX2053 at ¶¶ 74-75 (cited POR at 37-38)



EX2053 at ¶75 (cited POR at 39)

Objective Evidence Shows that Yuasa's High TMR With a Low Barrier Height Was Surprising

Nature Materials

characteristics¹⁵ yield $\phi = 0.37\text{--}0.40$ eV. The barrier height of our MTJs is considerably lower than the values in the literature^{9,10}, which should be due to the oxygen vacancy defects in MgO (see Methods). Oxygen vacancies in MgO can form charge-neutral gap states (*F*-centres) about 1.2 eV below the bottom of conduction band¹⁶, which raises the Fermi level above the vacancy states and makes the barrier height lower than 1.2 eV. It should be noted that the barrier height of an ideal MgO tunnel barrier⁹ (3.7 eV) is too high for the device applications. It should also be noted that for an Al–O tunnel barrier, a lower barrier height yields a lower MR ratio¹⁷. It is surprising that in Fe/MgO/Fe MTJs, there is an enormous TMR effect despite the low barrier height. This is very favourable in applications because both a low *RA* and a high MR ratio can be achieved. Fe/MgO/Fe MTJs with *RA* values ranging from 300 to 10,000 $\Omega\ \mu\text{m}^2$, which are desirable for MRAMs, have huge MR ratios over 150% at room temperature.

EX2017 at 869 (cited POR at 22, 29)

'909 POR

Japanese Journal of Applied Physics ("Yuasa-JJAP," EX2016), in Nature Materials ("Yuasa-Nature," EX2017), and in Applied Physics Letters ("Yuasa-APL," EX2015), collectively the "Yuasa Papers." The Yuasa Papers appear in prominent peer-reviewed journals. Ross, ¶152; EX2013, 24:4-23, 191:20-22 (Petitioner's expert admitting same).

POR at 22

Petitioner's Expert Dr. Bokor

- Q. Is Nature Materials considered a leading journal for magnetic tunnel junction design?
- A. It's one of them. Yes.

EX2013 at 24:19-21 (cited POR at 22)

Contemporaneous Evidence Shows that It Was Expected that Lowering Barrier Height Would Lower TMR and that Dr. Yuasa's Results Were Surprising

Patent Owner's Expert Dr. Ross

81. As discussed above, Dr. Yuasa also expressed that the expectation was that lowering the barrier height in MgO devices would have decreased TMR. EX2017, 869. Mitani (EX1053) expressed the same expectation. Mitani explained for the Fe/MgO/FeCo devices that were fabricated that the “estimated barrier height [0.9 eV] is high enough to observe the TMR effect but is much smaller than the value expected from half of the band gap of bulk MgO.” EX1053, 8042. Mitani also explained that the “TMR of 23%” that was observed at 4.2 K was “smaller than that reported for the Fe/MgO/FeCo MTJ prepared by using laser ablation, suggesting that TMR in the MgO based epitaxial MTJs depends on the barrier and interface structures as well as alumina-based MTJs.” That is, Mitani noted a lower-than-expected barrier height that was “high enough” to observe the TMR effect but that the TMR was also lower than expected. This suggested to Mitani that TMR in MgO based MTJs depend on the barrier like it does for alumina-based MTJs.

EX2053 at ¶81

Nature Materials

for this device applications. It should also be noted that for an Al–O tunnel barrier, a lower barrier height yields a lower MR ratio¹⁷. It is surprising that in Fe/MgO/Fe MTJs, there is an enormous TMR effect despite the low barrier height. This is very favourable in applications because both a low RA and a high MR ratio can be achieved.

EX2017 at 869 (cited POR at 40)

82. For these reasons, it is my opinion that a POSA had the expectation that lowering the barrier height in MgO-based MTJs would decrease TMR as was the expectation for amorphous barriers such as aluminum oxide. Thus, it is my opinion that a POSA would not have been motivated to lower Bowen's or Nagahama's barrier height to increase TMR. A POSA's understanding was that doing so would have decreased TMR.

EX2053 at ¶82

Objective Evidence Shows that Yuasa’s High TMR With a Low Barrier Height Was Surprising

The 23rd Japan Society of Applied Physics Achievement Award (Research Achievement)

Subject Pioneering research on magnesium oxide magnetic tunnel junctions

Winner Dr. Shinji Yuasa (National Institute of Advanced Industrial Science and Technology)

Dr. Shinji Yuasa's pioneering work on magnetic tunnel junctions (MTJs) with magnesium oxide (MgO) tunnel barriers, which have a large room temperature magnetoresistance (MR) ratio, has contributed significantly to the practical application of MgO MTJ devices.

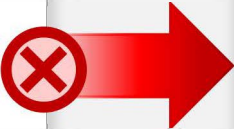
enabled mass production on large-diameter wafers by room-temperature sputter deposition, which opened the door to industrial applications of MgO MTJ devices. In addition, he developed technologies to reduce the resistivity of elements, which is indispensable when increasing the density of HDDs and MRAMs. These are now the core technologies in the

EX2024 at 2-3 (cited Sur-reply at 25)

'909 Petitioner's Reply

- EX2024, 3: JSAP Award for “MTJs combining MgO and [CoFeB] alloys in collaboration with Canon ANELVA.” This award references unnamed “technologies to reduce the resistivity of elements,” but does not link it to the barrier height limitations. See *id.*

Petitioner's Reply at 4



'909 PO's Sur-reply

(HDDs).” EX2029, 2. Petitioner’s only response—that this evidence lacks nexus to the claimed lower barrier height (Reply, 4)—fails because Petitioner never refutes the evidence establishing that reducing barrier height was *how* Yuasa achieved the reduced resistance for which he was praised because it made practical MTJ HDD and MRAM devices possible. POR, 17-20; EX2017, 869.

Sur-Reply at 25-26

Yuasa Achieved a Low Resistance Area (RA) by Introducing Defects to Lower the Barrier Height and Surprisingly Achieved a High TMR

'909 Patent

the effectiveness of the approach of the invention. The resistance-area (RA) product of the MTJ device was on the order of a few $\text{k}\Omega\mu\text{m}^2$, which is suitable for MRAM.

EX1017 at 8:28-30 (cited POR at 19)

Yuasa

characteristics¹⁵ yield $\phi = 0.37\text{--}0.40\text{ eV}$. The barrier height of our MTJs is considerably lower than the values in the literature^{9,10}, which should be due to the oxygen vacancy defects in MgO (see Methods). Oxygen vacancies in MgO can form charge-neutral gap states (*F*-centres) about 1.2 eV below the bottom of conduction band¹⁶, which raises the Fermi level above the vacancy states and makes the barrier height lower than 1.2 eV. It should be noted that the barrier height of an ideal MgO tunnel barrier⁹ (3.7 eV) is too high for the device applications. It should also be noted that for an Al–O tunnel barrier, a lower barrier height yields a lower MR ratio¹⁷. It is surprising that in Fe/MgO/Fe MTJs, there is an enormous TMR effect despite the low barrier height. This is very favourable in applications because both a low RA and a high MR ratio can be achieved. Fe/MgO/Fe MTJs with RA values ranging from 300 to 10,000 $\Omega\mu\text{m}^2$, which are desirable for MRAMs, have huge MR ratios over 150% at room temperature.

Ex. 2017 at 869 (cited POR at 19)

'909 Patent

defects such as MgO_x ($0.9 < x < 1$). When there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current. In the case of a typical Al–O tunnel barrier, the height of the tunnel barrier with respect to Fe(001) electrodes is considered to be 0.7 to 2.5 eV. An ideal tunnel barrier height of a MgO crystal is 3.6 eV, and experimental values of 0.9 to 3.7 eV have been obtained. Using the method according to the present embodiment of the invention, a tunnel barrier height of approximately 0.3 eV is expected, indicating that the resistance of the tunnel barrier can be lowered. However, it

EX1017 at 7:19-31
(cited POR at 19)

Patent Owner's Expert Dr. Ross

56. The inventor of the '909 Patent, Dr. Shinji Yuasa, recognized that the tunnel barrier height for defect-free crystalline MgO (what the '909 Patent refers to as the "ideal value") was too high for MRAM applications because the RA of the MTJ would be too high. EX1017, 6:12-18, 4:66-5:7, 7:26-27; EX2017, 869 ("the barrier height of an ideal MgO tunnel barrier height (3.7 eV) is too high for the device [MRAM] applications."). Dr. Yuasa's solution to that problem was to lower the tunnel barrier height by introducing oxygen vacancy defects into the MgO crystal to lower the bottom of the conduction band of the MgO barrier layer. EX1017, 3:59-61, 7:19-37, 9:4-10 (describing techniques for introducing oxygen vacancy defects); EX2017, 869.

EX2053 at ¶56
(cited POR at 17)

Teachings For Alumina MTJs Not Being Fully Predictive of MgO MTJs Does Not Mean POSAs Would Believe that All Teachings For Alumina MTJ's Were Inapplicable

'909 Petitioner's Reply

IPB's citations to Moodera 1995 (EX1035), Moodera 1996 (EX1038), and Saito (EX2037) that all expressly cite or track Slonczewski's outdated model are plainly insufficient to show how one of skill, *after* Butler in 2001, would have predicted the impact of barrier height on TMR in MgO. **POR**, 37-38 (IPB: Moodera

Petitioner's Reply at 12

'909 POR

enhancement EX1057, 16-17, 44-45. Amorphous Al₂O₃ barriers (above-left) lack crystallographic symmetry and have no coherent tunneling enhancement. **EX1057**,

POR at 13

'909 PO's Sur-reply

No prior art reference taught that *all* Al₂O₃ MTJ teachings relating to TMR were “inapplicable” to MgO MTJs. In two co-pending IPRs, Petitioner told the Board the opposite. Petitioner alleged that some Al₂O₃ MTJ references were predictive of the TMR in MgO MTJs, and that the same Bokor testimony cited here about Al₂O₃ teachings being “inapplicable to MgO MTJs” was not to the contrary. IPR2024-01493, Paper 1 at 24-28 (alleging POSAs would have applied Wang's and Hosomi's material selections for Al₂O₃ MTJs to MgO MTJs to purportedly increase TMR) and Paper 24 at 16 (“*Bokor never opined that all teachings about alumina MTJs would be discarded by a skilled artisan.*”); IPR2024-01447, Paper 1 at 35-37 (similar) and Paper 25, 20 (Dr. Bokor said “findings on Al₂O₃ barriers” were not “*irrelevant*” to MgO MTJs,” citing EX2017, 148:10-18).

Sur-Reply at 10

Petitioner's Argument that Butler Taught a TMR/Barrier Height Relationship is Based on Nothing But Unreliable and Unqualified Bokor Testimony

Petitioner's Expert Dr. Bokor

Q. Butler doesn't actually teach changing barrier height at all, does he?

A. He doesn't explicitly. But in my opinion, a person of ordinary skill in the art reading Butler would find that teaching in there.

EX2086 at 65:20-24 (cited Sur-reply at 13)

Q. You agree that Butler is a famous paper; right?

A. Absolutely. I would call Butler a highly cited paper. 2900, give or take 50 or a hundred, is still a big number for a paper of -- of this type on this topic in this literature. In some -- in some areas of literature, this is not a big citation number. But in this field, for sure, that's a highly cited paper. I think it is reasonable to call it famous.

EX2086 at 21:23-22:7 (cited Sur-reply at 12)

Q. Butler's theory does not describe the effect of changing barrier height on TMR, does it?

A. Butler's paper doesn't explore that particular scenario in the -- in the -- within the confines of the paper. But my -- my opinion is that a person of ordinary skill reading Butler could understand that there should be an energy dependence on the blockage of the antiparallel electrons such that the MR could go up with decreasing barrier height. At least had a good chance.

EX2013 at 71:22-72:7 (cited Sur-reply at 13)

Q. Dr. Bokor, is there a single publication that you can identify that articulates this theory or this understanding of Butler that based on this paragraph you identify in Exhibit 1044, page 1, bottom paragraph on the right-hand column, TMR would be expected -- TMR in a magnesium oxide crystalline barrier layer would be expected to vary with barrier height?

A. I haven't found a publication that explicitly discusses that.

EX2014 at 41:16-25 (cited POR at 12)

Petitioner's Argument that Butler Taught a TMR/Barrier Height Relationship is Based on Nothing But Unreliable and Unqualified Bokor Testimony

Petitioner's Expert Dr. Bokor

Q. Would that person of ordinary skill in the art in 2004 reading Butler have thought it was equally likely that TMR would increase as for it to decrease if Bowen's barrier height had decreased?

A. I -- to be honest, I'm not completely sure. Bowen -- sorry. Butler is a pretty complicated paper. It's a very advanced level of theory. And I think the answer to the question, I think Bowen -- Butler's theory would have the capability to make that estimate, whether the MR would go up or go down. I consider myself to be a person of ordinary skill. I've read through Butler carefully. I have a hard time being able to hand-wave my way one way or the other. Now -- so by that -- by that standard, I would have to answer I don't think a POSA would be able to do that either.

EX2013 at 72:8-25 (cited Sur-reply at 12)

Petitioner's Argument that Butler Taught a TMR/Barrier Height Relationship is Based on Nothing But Unreliable and Unqualified Bokor Testimony

Petitioner's Expert Dr. Bokor

Q. Would that person of ordinary skill in the art in 2004 reading Butler have thought it was equally likely that TMR would increase as for it to decrease if Bowen's barrier height had decreased?

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EX2013 at 72:8-25 (cited Sur-reply at 12)

Q. And in giving those opinions, you didn't take into account how the model was designed and evaluated in order to arrive at the conclusions that Butler gave in his paper; is that right?

A. Not at the -- at the gory level of detail. I'm not a theorist, as I -- I testified before. I do not have the level of expertise required to analyze and evaluate the gory details of this paper. I trust in this paper that it's well accepted by others who are those experts. And I just go by the -- you know, the bottom line conclusions to -- that would be relevant to an experimentalist or person of ordinary skill in the art trying to build a magnetic tunneling junction.

EX2086 at 48:3-16 (cited Sur-reply at 13)

Q. Okay. So you agree that if a person of ordinary skill in the art wanted to determine the density of states for majority or minority spin channels in an iron/magnesium oxide/iron sandwich with oxygen vacancies in the magnesium oxide, they would actually have to come up with a different physical model than Butler used?

A. Well, again, I'm not an expert in this. How different it would have to be, what -- how much they would have to change, I can't -- I can't give an opinion on that. They would have to be different.

EX2086 at 56:4-15 (Paper 43 at 11) 45

Bokor Lacked the “Expertise” to Understand Butler Beyond its Higher Level/Bottom Line Conclusions

Petitioner’s Expert Dr. Bokor

Q. And in giving those opinions, you didn't take into account how the model was designed and evaluated in order to arrive at the conclusions that Butler gave in his paper; is that right?

A. Not at the -- at the gory level of detail. I'm not a theorist, as I -- I testified before. I do not have the level of expertise required to analyze and evaluate the gory details of this paper. I trust in this paper that it's well accepted by others who are those experts. And I just go by the -- you know, the bottom line conclusions to -- that would be relevant to an experimentalist or person of ordinary skill in the art trying to build a magnetic tunneling junction.

EX2086 at 48:3-16 (cited Sur-reply at 13)

A. My general opinion this is a paper that had a big impact on the field as you just showed. And I give -- I give opinions based on the bottom line -- essentially the higher level conclusions of the paper, without going into the gory details of every little number that he put in his model and in his calculation.

EX2086 at 47:10-16 (cited Sur-reply at 13)

Q. Butler doesn't actually teach changing barrier height at all, does he?

A. He doesn't explicitly. But in my opinion, a person of ordinary skill in the art reading Butler would find that teaching in there.

Q. Butler does not include barrier height as a parameter in his model, does he?

A. He shows -- okay. The narrow -- the answer to your narrow question is no.

EX2086 at 65:20-66:3 (cited Sur-reply at 13)

Q. Butler's theory does not describe the effect of changing barrier height on TMR, does it?

A. Butler's paper doesn't explore that particular scenario in the -- in the -- within the confines of the paper. But my -- my opinion is that a person of ordinary skill reading Butler could understand that there should be an energy dependence on the blockage of the antiparallel electrons such that the MR could go up with decreasing barrier height. At least had a good chance.

EX2013 at 71:22-72:7 (cited Sur-reply at 13)

Petitioner Bears the Burden to Show That Bokor's Testimony is Reliable For it to Be Admitted as an Expert Opinion

The Federal Rules of Evidence apply. 37 C.F.R. § 42.62(a). To offer an expert opinion, the witness must be “qualified as an expert by knowledge, skill, experience, training, or education.” FRE 702. Additionally, a qualified expert's

Paper 43 at 8

FRE Rule 702. Testimony by Expert Witnesses

A witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if the proponent demonstrates to the court that it is more likely than not that:

- (a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue;
- (b) the testimony is based on sufficient facts or data;
- (c) the testimony is the product of reliable principles and methods; and
- (d) the expert's opinion reflects a reliable application of the principles and methods to the facts of the case.

Bokor Did Not Follow Butler's Reliable Methodology That Required a Reliable Physical Model

Butler

In this paper we use first-principles electronic structure techniques to calculate the tunneling between Fe(100) electrodes separated by MgO tunneling barriers. In order to calculate the electronic and magnetic properties of Fe|MgO|Fe sandwiches it is necessary to have a reliable physical model for the interface between Fe (100) and MgO. The structure that we used is described in Sec. II. This model for the physical structure was then used for calculations of the electronic and magnetic structures. These are described in Sec. III. Based on the physical electronic and magnetic structures the tunneling conductance and magnetoconductance were calculated. The results of these calculations are described in Sec. IV.

EX1044 at 1 (cited Sur-reply at 14-15)

Patent Owner's Expert Dr. Ross

16. Furthermore, Dr. Bokor's allegation that Butler's calculation had an "assumption about barrier height" and "uses a model value for the barrier height" is a misreading of Butler. EX2086, 101:7-102:14.¹ A POSA would have understood that Butler's "first principles" calculations assumed only the fundamental properties of his physical model. EX1044, 1-3. Dr. Bokor alleged that a POSA would have shifted the Fermi level by injecting oxygen vacancy defects into the MgO layer. To understand what effect that would have on the density of states, a POSA would have had to modify Butler's model to include oxygen vacancy defects in the MgO barrier and Butler did not teach how to do that. I agree with Dr. Bokor that Butler presents an "advanced level of theory" and a sophisticated model. EX2013, 72:13-25. Modeling an Fe/MgO interface with oxygen vacancy defects would have been far more difficult and would have been well beyond the capabilities of a POSA.

EX2087 at ¶16 (cited Sur-reply at 15)

Bokor's Opinion is Based on Moving the Fermi Level on Butler's Figures

Petitioner's Expert Dr. Bokor

11. As can be readily seen from Butler's Figures 3 and 4 (reproduced above), moving the level of the Fermi energy (see red annotations) will have a significant impact on the densities of states of majority and minority electrons.

Although Butler's calculations would need to be repeated to see what would happen to the densities of states in Figures 3 and 4 with the change in Fermi level, one of skill in the art would understand the Fermi energy level shift depicted in red would result in a significant change in the densities of states available in the majority and minority channels, even if it is not quite as simple as moving the energy level on the static Figures 3 and 4. TMR directly results from the difference in spin polarizations (majority versus minority) of the two electrodes, which in turn directly results from the difference in densities of states of the two electrodes, as shown in the following formula:

$$\begin{aligned} \text{TMR ratio} &= \frac{R_a - R_p}{R_p} = \frac{2P_1 P_2}{1 - P_1 P_2}, \\ P_{1(2)} &= \frac{D_{1(2)\uparrow} - D_{1(2)\downarrow}}{D_{1(2)\uparrow} + D_{1(2)\downarrow}}, \end{aligned} \quad (1)$$

EX1050 (Yuasa) at page 2427. Thus, changing the density of states of majority versus minority electrons in either or both electrodes unquestionably will change TMR.

Q. You said the calculation would be straightforward to repeat. Did you repeat it?

A. It would be straightforward for somebody with the capability to make that calculation to repeat. I can't repeat it. When I meant straightforward, I meant that the co-authors who did this calculation, they pick one number for the Fermi level. Yeah. For the Fermi level. And if all we were going to do was change the Fermi level, I -- my opinion is that that's something that they could do.

EX2086 at 103:5-15 (cited Sur-reply at 13)

Bokor's Opinion is Based on Moving the Fermi Level on Butler's Figures

Petitioner's Expert Dr. Bokor

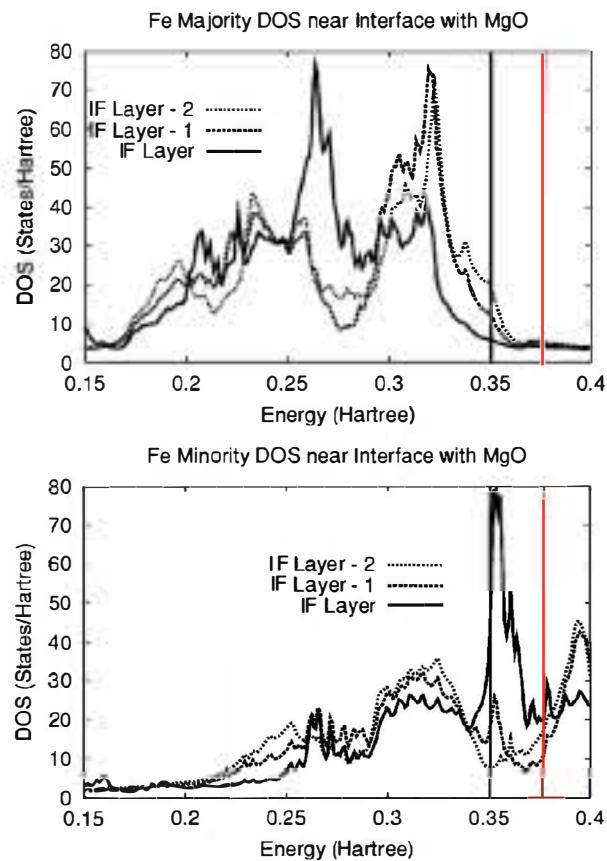


FIG. 3. Density of states for each atomic layer of Fe(100) near an interface with MgO. One hartree equals 27.2 eV.

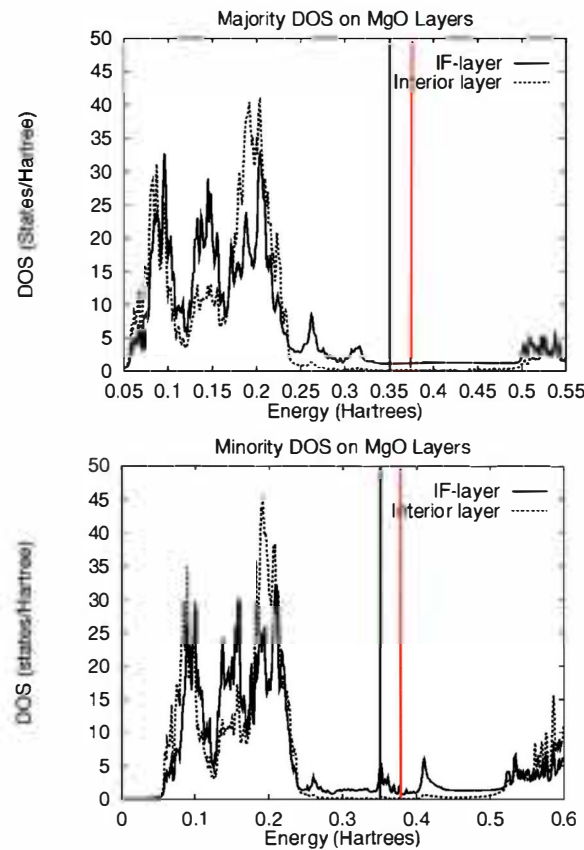


FIG. 4. Density of states for each of the atomic layers of MgO near an interface with Fe(100).

Bokor Admitted the Equation He Relied on in His Reply Declaration Was Not Correct

Petitioner's Expert Dr. Bokor

11. As can be readily seen from Butler's Figures 3 and 4 (reproduced above), moving the level of the Fermi energy (see red annotations) will have a significant impact on the densities of states of majority and minority electrons. Although Butler's calculations would need to be repeated to see what would happen to the densities of states in Figures 3 and 4 with the change in Fermi level, one of skill in the art would understand the Fermi energy level shift depicted in red would result in a significant change in the densities of states available in the majority and minority channels, even if it is not quite as simple as moving the energy level on the static Figures 3 and 4. TMR directly results from the difference in spin polarizations (majority versus minority) of the two electrodes, which in turn directly results from the difference in densities of states of the two electrodes, as shown in the following formula:

$$\text{TMR ratio} = \frac{R_a - R_p}{R_p} = \frac{2P_1 P_2}{1 - P_1 P_2}, \quad (1)$$
$$P_{1(2)} = \frac{D_{1(2)\uparrow} - D_{1(2)\downarrow}}{D_{1(2)\uparrow} + D_{1(2)\downarrow}},$$

EX1050 (Yuasa) at page 2427. Thus, changing the density of states of majority versus minority electrons in either or both electrodes unquestionably will change TMR.

Q. Dr. Bokor, you site Exhibit 1050 for this Equation 1 in your declaration at paragraph 11.

A. I do.

Q. You didn't cite Butler for it, though, did you?

A. No. What I'm saying now is that was an oversight when I wrote the declaration.

Q. And so you're changing your testimony; is this -- is that right?

A. I'm correcting -- yes, I'm correcting my testimony. I'm making a modification of my testimony.

Q. And you didn't cite any authority that applies the understanding you just stated; meaning TMR can be expressed as a ratio of tunneling density of states as shown in your Equation 1, did you?

A. I'm saying that Butler is my support for that.

Q. Butler doesn't do it either, does he?

A. He doesn't. But from the text, reading Butler, and how he explains what the tunneling density of states is, I believe a person of ordinary skill would use this equation with the tunneling density of states to get a good representation of TMR ratio.

EX2086 at 110:13-111:13 (cited Sur-reply at 13)

EX1105 at ¶11 (cited Sur-reply at 13)

Petitioner's Argument that Butler Taught a TMR/Barrier Height Relationship is Based on Nothing But Unreliable and Unqualified Bokor Testimony

'909 PO's Reply Opposition to Motion to Exclude Evidence

It is WD's burden to show that Bokor's approach is reliable. *Supra* § II. In the leading case on FRE 702, the Supreme Court listed factors judges should consider in assessing "whether the reasoning or methodology underlying the testimony is **scientifically valid**." *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579, 592-94 (1993). Those factors include: (1) whether the methodology "can be (and has been) tested"; (2) whether it "has been subjected to peer review and publication"; (3) whether the methodology has a "known or potential rate of error"; and (4) whether it has gained "[w]idespread acceptance." *Id.* (techniques with minimal support in the community "may properly be viewed with skepticism"). WD did not even attempt to show that any of these factors is met. None is. There is no **evidence of anyone having ever applied the methodology Bokor applied**. Bokor fabricated this methodology out of whole cloth. That is the furthest thing from reliable expert testimony. *Daubert v. Merrell Dow Pharmaceuticals*, 43 F.3d

The only evidence WD cites to support its assertion that Bokor's methodology is reliable is Bokor's naked say-so. Opp., 14 ("According to Dr. Bokor"). That fails as a matter of law. *Daubert*, 43 F.3d at 1319 ("the experts' assurances of reliability" are "not enough"); *United States v. Pen*, 963 F.3d 1207, 1221 (11th Cir. 2020) (a bald ipsedixit assertion by the expert "cannot carry the *Daubert* burden"); *General Electric v. Joiner*, 522 U.S. 136, 146 (1997) ("Nothing in either *Daubert* or the [FRE] requires a district court to admit opinion evidence that is connected to existing data only by the ipse dixit of the expert").

Paper 45 at 3-5

'909 Petitioner's Motion to Exclude Evidence

IPB is wrong that "[i]t is undisputed that to understand what (if any) impact a 'lower' barrier height resulting from MgO defects would have had on TMR, POSAs would have needed to develop a **different model**" and repeat Butler's calculations. Mot., 14 (emphasis in original). In fact, Dr. Bokor opined and testified that if MgO defects were introduced to lower the barrier height, skilled practitioners knew on the basis of Butler's Figures 3 and 4 that the densities of states would change "significant[ly]," EX1105 ¶11; "[c]hanging the density of states will unquestionably change TMR," EX2086 114:13-14, 122:19-21; "TMR had to change," EX2013, 154:1-8; and "some change in the TMR, not just zero" would occur, EX2014, 215:3-4. Dr. Bokor further testified that skilled practitioners would "find [a] teaching" to change barrier height in Butler even if it is not stated explicitly, EX2086, 65:20-24, and skilled practitioners "expect a change in TMR with barrier height" in view of Butler, *id.* 10:21-11:5. Dr. Bokor's foregoing opinions squarely contradict IPB's argument that a different model was needed to know merely whether TMR would change with barrier height. According to Dr. Bokor, all that was needed was Butler's Figures 3 and 4. (And according to IPB's Dr. Ross, skilled practitioners knew this even absent Butler. EX2087 ¶¶24-29.). IPB's disagreement with Dr. Bokor's opinion does not render it unreliable or inadmissible.

Paper 44 at 14-15



Daubert v. Merrell Dow Pharmaceuticals

"We've been presented with only the experts' qualifications, their conclusions and their assurances of reliability. Under *Daubert*, that's not enough."

Daubert v. Merrell Dow Pharmaceuticals, 43 F.3d 1311, 1319 (9th Cir. 1995)

Bokor's Handwaving is Breathtaking

'909 PO's Sur-reply

Bokor's handwaving is breathtaking. He admits POSAs would have expected MgO defects to cause scattering and degrade TMR. EX2086, 93:20-96:11. Undaunted, Bokor alleges it was "reasonable to expect" that lowering barrier height *might* "overcome the degradation of TMR that comes from scattering" despite POSAs being unable to "predict" if that were true and despite Bokor not doing any experimentation to test his theory. EX2086, 93:20-96:11; *see also id.*, 99:18-101:3 (admitting neither Bokor nor POSAs could figure out how oxygen defects would affect Butler's calculations, alleging "optimist[ic]" POSAs would have tried anyway, but admitting Bokor searched and failed to find anyone in the prior art having tried this), 79:12-82:19 (POSAs could not "predict" the impact on TMR of lower barrier height or scattering from defects).

An Unknown Impact on TMR is Not “Legally Sufficient Motivation” to Lower Barrier Height

'909 Petitioner's Reply

IPB unfairly criticizes Bokor's testimony that “a POSA would not have known whether lowering the barrier height of the MgO barrier layer in Bowen or Nagahama would have increased or decreased TMR.” POR, 34. But Bokor explained that one of skill “would have had a reasonable expectation that the TMR would change” were barrier height lowered even if they were not “certain which way it would go.” EX2013, 50:9-51:5, 51:23-52:5.

That is a legally sufficient motivation. A “court can take account of the inferences and creative steps that a person of ordinary skill in the art would employ.” *KSR Int'l v. Teleflex*, 550 U.S. 398, 418 (2007). Bokor's explanation showed that lowering barrier height to improve TMR would have been “‘nothing more than routine’ application of a well-known problem-solving strategy” stemming from “the normal desire of scientists or artisans to improve upon what is already generally known.” *Pfizer v. Apotex*, 480 F.3d 1348, 1368 (Fed. Cir. 2007) (citation omitted). Butler's predictions about the behavior of parallel and antiparallel electrons crossing MgO rendered barrier height an identified and predictable (if uncertain) strategy to increase TMR. *Id.*; EX2014, 216:15-17 (“[I]f I think that there's a 50/50 chance I'm going to get the improvement that I'm looking for, boy, oh, boy, I'm going to try that.”).

An Unknown Impact on TMR is Not “Legally Sufficient Motivation” to Lower Barrier Height

Pfizer v. Apotex



“‘[O]bvious to try’ is **not** the proper standard by which to evaluate obviousness.”

* * *

“However, on the *particularized facts of this case*, consideration of the “routine testing” performed by Pfizer is appropriate because the prior art provided not only the means of creating acid addition salts but also predicted the results, which Pfizer merely had to verify through routine testing. *Merck*, 874 F.2d at 809. The evidence shows that, upon making a new acid addition salt, it was routine in the art to verify the expected physicochemical characteristics of each salt, including solubility, pH, stability, hygroscopicity, and stickiness, and Pfizer’s scientists used standard techniques to do so. These type of experiments used by Pfizer’s scientists to verify the physicochemical characteristics of each salt are not equivalent to the trial and error procedures often employed to discover a new compound where the prior art gave no motivation or suggestion to make the new compound nor a reasonable expectation of success.”

Pfizer v. Apotex, 480 F.3d 1348, 1365-67 (Fed. Cir. 2007) rehearing denied 488 F. 3d 1377, cert denied 552 U.S. 941 (2007) (cited Sur-reply at 18)

KSR v. Teleflex



“The same constricted analysis led the Court of Appeals to conclude, in error, that a patent claim cannot be proved obvious merely by showing that the combination of elements was “[o]bvious to try.” *Id.*, at 289 (internal quotation marks omitted). When there is a design need or market pressure to solve a problem and there are a finite number of identified, predictable solutions, a person of ordinary skill has good reason to pursue the known options within his or her technical grasp. If this leads to the anticipated success, it is likely the product not of innovation but of ordinary skill and common sense. In that instance the fact that a combination was obvious to try might show that it was obvious under § 103.”

KSR Int’l Co. v. Teleflex Inc., 550 U.S. 398, 421 (2007) (cited Sur-reply at 18)

Petitioner Relies on Soukup To Teach a 0.33eV Barrier Height Within Both Claimed Ranges and to Purportedly Establish an Expectation of Success

'909 Petition

E. **Claim 5: “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”**

One of skill would have been motivated to apply Soukup’s teachings about an MgO thin-film barrier with a “barrier height” of “about 0.33 eV” to Bowen’s MgO barrier. EX1028 at Abstract, 3232, 3236; EX1024 ¶¶169-71. According to the

One of skill would have had a reasonable expectation of success in achieving a tunnel barrier height in the claimed range in Bowen’s MTJ. EX1024 ¶172. Soukup fabricated an MgO barrier that achieved a height of 0.33 eV, EX1028 at Abstract, and one of skill in the art would have been motivated to achieve Soukup’s barrier height in an MgO MTJ to improve tunneling and hence TMR, EX1028 at Abstract, 3232, 3236; EX1024 ¶172. One of skill would have predictably followed the trail

Petition at 33-35

Ground 1

'909 Petition

E. **Claim 5: “The magnetoresistive device of claim 1, wherein a barrier height of the tunnel barrier layer is in a range of 0.1 eV to 0.85 eV.”**

One of skill would have been motivated to apply Soukup’s teachings about an MgO thin-film barrier with a “barrier height” of “about 0.33 eV” to Nagahama’s MgO barrier. EX1028 at Abstract, 3232, 3236; EX1024 ¶¶275-7, 281. A

One of skill would have had a reasonable expectation of success in achieving Soukup’s tunnel barrier height in Nagahama’s MTJ. EX1024 ¶282. Soukup had already shown that an MgO barrier achieved a height of 0.33 eV, EX1028 at Abstract, and that the barrier height was varied by adjusting the oxygen vacancy defects in the MgO barrier layer, EX1028 at Abstract, 3232, 3236; EX1024 ¶282. One of skill

Petition at 57-59

Ground 2

Soukup Would Not Have Motivated POSAs to Modify Bowen or Nagahama to Adopt a 0.33eV Barrier Height to Increase TMR

- **Soukup is not an MTJ and Has no TMR** (POR at 56-57, 72-73)
 - Soukup is non-analogous art (POR at 51-57; Sur-reply at 19-20)
 - If analogous Soukup provided no Motivation re TMR (POR at 58-69; Sur-reply at 19-25)
 - No Evidence Supports that a 0.33eV Barrier Height Would Increase TMR (POR at 58-60; Sur-reply at 20-21)
- **Soukup Says Schottky Emissions Dominate at Low Barrier Heights Which Would Decrease TMR** (POR at 63-67; Sur-reply at 21-22)
- **Soukup Says the 0.33 eV Value is Not the Correct Barrier Height** (POR at 67-69; Sur-reply at 22-24)
- **Petitioner Relies on Incompatible Soukup Teachings Based on Different Measurement Techniques** (Sur-reply at 24-25)

Petitioner Cannot Defend Its Assertion that Soukup Would Have Motivated POSAs Seeking Increased TMR to Adopt a 0.33eV Barrier Height

'909 Petitioner's Reply

According to IPB, Soukup would not have motivated one of skill to lower barrier height because Bowen's/Nagahama's MTJs relied on tunneling conductance, had magnetic electrodes, and therefore possessed an intrinsic TMR, all of which Soukup's devices purportedly lacked. POR, 60-63. IPB again incorrectly assumes that one of skill was unable to learn from a reference describing non-MTJs like, for example, Simmons. *Supra* §III.A. Aside from being legally incorrect, IPB ignores that the motivation to lower barrier height comes from the knowledge of one of skill based on references like Butler/Mathon, Pet., 34-35, and Soukup provides the mechanism in the form of introducing oxygen defects, which it undoubtedly teaches for MgO, EX1024 ¶1 68; EX1028, 3232; *supra* §II.A.

That Soukup itself was not an MTJ with magnetic electrodes and TMR is irrelevant to a skilled artisan's motivation and the resulting combination. EX1105 ¶¶61-67. Ross admits that barrier height is an intrinsic property of every insulator-conductor junction. EX1102, 29:12-18. Insulator-conductor junctions like Soukup's Au-MgO junctions have barrier heights just as much as the Bowen/Nagahama ferromagnetic-MgO junctions do. *Id.* There is no serious dispute that Soukup's barrier height teachings for MgO can inform the barrier heights of other MgO insulator-conductor junctions, including in MTJs. EX1105 ¶¶61-67; EX1102, 32:7-10. Skilled artisans are not automatons, but rather persons of ordinary creativity. *KSR*, 550 U.S. at 421.

Petitioner's Failure to Dispute Soukup's Teaching that Non-Tunnelling Current Sources Dominate at an Alleged Barrier Height of 0.33 eV is Fatal

Sur-reply at 21

'909 POR

POSAs understood that lowering the barrier height to where the dominant current-flow mechanism is Schottky emissions—or *any* mechanism other than spin-dependent tunneling—would *decrease* TMR. Ross, ¶¶134-136. That is because TMR results from magnetic-state-dependent tunneling (i.e., the quantum mechanical effect of spin-dependent tunneling). *Supra* §§II.B-II.D; Ross, ¶¶35-43, 135. Thermionic emissions like Schottky emissions are not intrinsically spin-dependent so lowering the barrier height to where thermionic emissions become the dominant current-flow mechanism would reduce the percentage of current flow that is magnetic-state-dependent and thus decrease TMR. Ross, ¶¶136-138 (citing EX1057, 19; EX2037, L1037) (showing how TMR decreases via magnetic-state-independent conductance using the TMR equation). This is similar to the effect Saito saw (discussed *supra* §V.B.5) where at low barrier heights the measured TMR was less than predicted by spin-dependent tunneling models. Ross, ¶138.

'909 PO's Sur-reply

Petitioner never disputes that Soukup says the dominant current-flow mechanism for its devices with alleged barrier heights of 0.33 eV was Schottky emission, nor that POSAs would have avoided barrier heights where Schottky emissions were significant because that would decrease TMR. POR, 63-67. ***Dr. Bokor's reply declaration did not dispute either point.***

Paper 31 at 21

Both experts agree a POSA would have avoided barrier heights in an MTJ that were so low that a significant percentage of the current flowing through the MTJ was from non-tunnelling thermionic emissions (like Schottky emissions) because that would decrease TMR. Ross, ¶¶136-139; EX2013, 86:21-88:15. And both experts agree that for the Soukup devices with alleged barrier heights (including 0.33 eV) within the claimed ranges, the “*dominant* current mechanism in these devices was Schottky emission.” EX2013, 185:11-17; Ross, ¶¶105-106, 110, 120;

POR at 64-65

It is Undisputed that the Dominant Current Flow Mechanism in the Soukup Devices Petitioner Relies on Was Not Tunnelling

Patent Owner's Expert Dr. Ross

105. Soukup first “ruled out” tunneling as the electron process of importance for 12 of his 13 devices (3230, 3235) because the I - V characteristics “did not plot as a straight line on a $\ln(I/V^2)$ vs I/V plot” as would have been expected if tunneling was of significance (3230). The only device (PY-G-38(1)) for which Soukup found “the injection mechanism could now be tunneling,” Soukup calculated barrier heights of 1.9 eV and 1.74 eV. EX1028, 3232-3233; Table I (annotated below).

EX2053 at ¶105 (cited POR at 59)

Soukup

These studies have involved fabrication and study of 60 thin-film sample sets each of which contained three overlayer films. Of these, 13 devices were studied in detail.

The I - V characteristics of these devices did not plot as a straight line on a $\ln(I/V^2)$ vs I/V plot. Thus, the Fowler-Nordheim¹⁸ equation does not hold for these devices. The other injection process which is possible

EX1028 at 3230 (cited POR at 59)

Soukup

SUMMARY

* * *

four orders-of-magnitude of voltage. The conclusion drawn is that the electron flow in these devices could very well be that of emission of electrons over the potential barrier into the conduction band of the oxide by a Schottky-type process and subsequent acceleration by the strong electric field to the collection electrode.

EX1028 at 3235
(cited POR at 64)

'909 Institution Decision

We disagree with Patent Owner's arguments based on the current record. Petitioner relies on Bowen, not Soukup, as teaching the three-layer structure of the magnetoresistive device recited in claim 5, and relies on Soukup for Petitioner's asserted motivation to lower the barrier height of Bowen's device. See Pet. 19–25, 33–36. Also, Soukup does not reach a “definite conclusion[]” as to what current flow mechanism was taking place in its tested devices. See Ex. 1028, 3232, 3235–3236. Soukup explains as

Paper 09 at 21

Petitioner's Expert Dr. Bokor

- Q. So if the data is consistent with the Schottky model, doesn't that mean that the current transport mechanism in devices was Schottky emission?
- A. That -- it means that the dominant current mechanism in these devices was Schottky emission.

It is Undisputed that POSAs Would Have Avoided Low Barrier Heights Where Current Flow Mechanisms Other Than Tunneling are Significant

Patent Owner's Expert Dr. Ross

136. A POSA understood that lowering the barrier height to where the dominant current-flow mechanism is Schottky emission, or any mechanism other than spin-dependent tunneling, would disadvantageously decrease TMR because of the increased percentage of the MTJ's conductance being contributed by current-flow mechanisms that do not depend on the magnetic state of the MTJ—i.e., an increase in the conductance in both parallel and antiparallel states. This result comes straight from the TMR equation, which can be most easily shown using the equivalent conductance ratio.

$$TMR = \frac{\Delta G}{G} = \frac{G_p - G_{ap}}{G_{ap}} = \frac{R_{ap} - R_p}{R_p}$$

EX1057, 13 (Eq. 1.9); EX2005, 37 (Eq. 3); EX1033, 225-226

137. Any additional thermionic current flow such as Schottky current (where, unlike tunneling, electrons have sufficient energy to surmount the energy barrier—EX1028, 3229 and EX1031, 1794) or any other spin-independent current flow (i.e., a current flow mechanism that does not depend on the magnetic state) would add an additional conductance component to the conductance of the MTJ in both states. Thus, an MTJ that is modified so that it has an additional magnetic-state-independent conductance G_I would have a lower TMR than it had before the modification, as shown by the TMR equation below.

$$\frac{(G_p + G_I) - (G_{ap} + G_I)}{(G_{ap} + G_I)} = \frac{G_p - G_{ap}}{(G_{ap} + G_I)} < \frac{G_p - G_{ap}}{G_{ap}}$$

EX2053 at ¶¶136-137 (cited POR at 65)

Petitioner's Expert Dr. Bokor

Q. Would a POSA have been concerned that lowering the barrier height in Bowen's MTJ far enough would have resulted in a significant fraction of the current through the MTJ being attributed to thermionic emission?

A. Would have a POSA have been concerned about that?

Q. Yes.

A. I think that's a consideration that a POSA should consider.

Q. So would this have been a reason to avoid lowering the barrier height in Bowen's MTJ?

A. Well, in the general case, I would have to say yes. I've already said if the barrier height went to zero, then there would be no tunneling left. It would only be thermionic. So certainly that is a consideration that a POSA would need to take into account. And I'm -- I'm not willing to go as far as how -- how low the barrier height has to be before that becomes a significant consideration that a POSA would have to take into account.

Q. All right. Would a POSA have expected that a barrier height of .33 electron volts in Bowen's device would have increased the thermionic emission current through the device?

A. Would a person -- would a POSA have been -- repeat the question.

Q. Okay. If Bowen's device had achieved a barrier height of .33 electron volts, would a POSA have expected that this device with the .33 electron volts would have had more thermionic emission current than the device that Bowen actually built?

A. I believe that a POSA would be aware that the thermionic emission current would increase as the barrier height decreases. Now, at .33, would they have -- they would know that the thermionic -- thermionic emission current would increase compared to .9. How significant that would be in their considerations is -- I can't say

IPR2024-01384 Institution Decision

The Soukup dissertation presents testing results related to barrier heights as a function of temperature, including data for the device with the relied-upon 0.33 eV apparent barrier height (PY-G-11(1)). *See* Ex. 2007, 88–89, Fig. 40. The results of this testing indicate that “*barrier heights do increase with increasing temperature. Thus, the slope of the Arrhenius plot will give a value for the barrier height which is actually less than the real barrier height, as seen in these experiments.*” *Id.* at 89 (emphasis added). Accordingly, this evidence provides support that the “real” barrier height will be higher than the values determined from Arrhenius plots, including the relied-upon barrier height of 0.33 eV.

As discussed above, Petitioner fails to explain why one of ordinary skill in the art would have selected the barrier height value it relies upon. And given the disparity of Soukup's barrier tunnel values under the different methods of analyses, the reference is, at best, ambiguous as to which values are accurately representative of barrier height. Additionally, the evidence supports that the apparent barrier height value that Petitioner relies upon (“about 0.33 eV”) will be a different higher value, so the actual value of the barrier height is uncertain. Accordingly, we do not find that Petitioner has met its burden to sufficiently demonstrate that a person of ordinary skill in the art would have understood Soukup to teach or suggest the claimed range of limitation 1[e] in that there is insufficient evidence presented that supports that the selected Soukup barrier height value represents an accurate value.

Patent Owner's Expert Dr. Ross

TABLE I. Summary of device data.

Device No.	S^a	S_0^b	φ_1^c	φ_2^{d1}	$P_{O_2}^e$
PY-G-11(1)	80	200	0.714	0.33	
PY-G-16(3)	105	...	0.721	...	...
PY-G-17(1)	200	194	0.721	0.33	...
PY-G-18(1)	105	...	0.694	0.34	...
PY-G-18(2)	105	222	0.700	0.35	...
PY-G-19(2)	70	133	0.710	0.33	...
PY-G-20(1)	680	...	0.695	...	...
PY-G-20(3)	680	...	0.695	...	...
PY-G-21(3)	90	...	0.732	0.34	...
PY-G-22(2)	90	209	0.780	0.21	10^{-8}
PY-G-25(3)	60	200	0.823	0.11	10^{-7}
PY-G-38(1)	120	...	1.9, 1.74 ^f	...	10^{-6} , ...

^a S = oxide thickness, in Å.

^b S_0 = overlayer thickness, in Å.

^c φ_1 = barrier obtained by zero intercept method, in eV.

^d φ_2 = barrier obtained from slope of Arrhenius plot, in eV.

^e P_{O_2} = pressure of admitted O_2 during MgO deposition, in Torr.

^f The barrier was obtained from the slope of the Fowler-Nordheim plot.

Soukup's Dissertation

ture. It can be seen from this figure that the barrier heights do increase with increasing temperature. Thus the slope of the Arrhenius plot will give a value for the barrier height which is actually less than the real barrier height, as seen in these experiments.

EX2039 at 89 (cited Sur-reply at 22)

Soukup

to the barrier height and would not be a straight line. If $d\phi_R^*(T)/dT$ is positive, i.e., if the barrier increases with increasing temperature, then $d\phi_R^*(T)/d(1/T)$ is negative and the slope of the $\ln(I_0/T^2)$ vs $1/T$ plots will give a number which is smaller than the actual barrier, this was seen here. These results were not checked with

EX1028 at 3234-3235 (cited Sur-reply at 22-23)

The barrier height also appeared to become higher with higher temperature.

EX2053 at ¶106 (cited POR at 59)

EX1028 at 3236 (cited Sur-reply at 23)

Soukup

TABLE I. Summary of device data.

Device No.	S ^a	S ₀ ^b	φ ₁ ^c	φ ₂ ^d	P _{O₂} ^e
PY-G-11(1)	80	200	0.714	0.33	
PY-G-16(3)	105	***	0.721	***	***
PY-G-17(1)	200	194	0.721	0.33	***
PY-G-18(1)	105	***	0.694	0.34	***
PY-G-18(2)	105	222	0.700	0.35	***
PY-G-19(2)	70	133	0.710	0.33	***
PY-G-20(1)	680	***	0.695	***	***
PY-G-20(3)	680	***	0.695	***	***
PY-G-21(3)	90	***	0.732	0.34	***
PY-G-22(2)	90	209	0.780	0.21	10 ⁻⁸
PY-G-25(3)	60	200	0.823	0.11	10 ⁻⁷
PY-G-38(1)	120	***	1.9, 1.74 ^f	***	10 ⁻⁵ , ...

^a S = oxide thickness, in Å.
^b S₀ = overlayer thickness, in Å.
^c φ₁ = barrier obtained by zero intercept method, in eV.
^d φ₂ = barrier obtained from slope of Arrhenius plot, in eV.
^e P_{O₂} = pressure of admitted O₂ during MgO deposition, in Torr.
^f The barrier was obtained from the slope of the Fowler-Nordheim plot.

EX1028 at 3233 (POR at 59)

'909 Petitioner's Reply

EX2053 ¶107 (noting this is the source of 0.33 eV barrier height) One of skill would conclude that Soukup corrected the PY-G-11(1) data before publication in his 1970 paper. EX1105 ¶¶68-69.

Soukup's Dissertation

Table II

BARRIER HEIGHTS FOR DIFFERENT DEVICES AS OBTAINED BY THE
ZERO FIELD INTERCEPT AND THE SLOPE OF THE
ln(I₀/T²) vs. 1/T PLOT

DEVICE NO.	S (Å)	φ _R (eV) (Zero Field)	φ _R (eV) (Slope)
PY-G-19(2)	79	.71	.33
PY-G-11(1)	89	.71	.33
PY-G-18(2)	109	.70	.35
PY-G-17(1)	159	.72	.33

EX2039 at 57 (Sur-reply at 24)

'909 Petitioner's Reply

IPB does not address Soukup's specific findings. POR, 59-60. For sample PY-G-11(1), Soukup found a barrier height of 0.71 eV using the zero-intercept method and 0.33 eV using the Arrhenius plot. EX1028, 3233, Table 1. He noted the Arrhenius plot was valid for sample PY-G-11(1) because it showed an expected linear plot in Figure 5. EX1028, 3232 (plot should be straight and is straight in the case of Figure 5); EX2053 ¶107 ("Soukup... notes that the plot is a straight line.").

Petitioner's Assertion that Soukup Corrected its Data so 0.33 eV Is the Correct Barrier Height for PY-G-11(1) Fails

- **Soukup repeats the thesis's conclusion that the Arrhenius plot values are less than the real barrier height values.**

(Sur-reply at 22; see slide 63)

- **Soukup's barrier height value for PY-G-11(1) is the same 0.33 eV value the thesis says is wrong.**

(Sur-reply at 23; see slide 64)

- **Soukup reports a 0.714 eV value for the same device and Petitioner never explains why POSAs would accept the 0.33 eV value rather than the 0.714 eV value.**

(Sur-reply at 23-24; see slide 66)

Soukup Reports a 0.714 eV Value for the Same Device and Petitioner Never Explains Why POSAs Would Have Accepted the 0.33 eV Value Rather Than the 0.714 eV Value

Petitioner's Expert Dr. Bokor

15 Q Okay. So let's look at device PY-G-11,
16 on the top row.
17 A Okay.
18 Q The barrier height estimate from the
19 zero-intercept method is 0.714 electron volts;
20 right?
21 A Right.
22 Q And the barrier height estimate for
23 extracted from the slope of the Arrhenius plot is
24 0.33 electron volts; right?
25 A Correct.

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1 Q which one is right?
2 A Good question.
3 Q They both can't be right, can they?
4 A That is true.
5 Q Okay.
6 A Soukup discusses this. Right?
7 Q You tell me.
8 A I can tell you, Soukup discusses this.
9 Q Uh-huh.
10 A And I can go -- I can point you to that,
11 if that's -- if you're asking me to do that.
12 Q I -- I want to know which of these is the
13 POSA would have regarded as correct.
14 A So reading Soukup, the -- Soukup himself
15 says he's not sure which is correct. So a POSA
16 reading Soukup would have the same -- could only
17 have that same uncertainty. Which one is correct?
18 Soukup isn't sure. And I'm -- you didn't ask, but

EX2013 at 173:15-174:18 (POR at 60)

'909 Petition

EX1028 at 3232; EX1024 ¶168. In other words, Soukup suggested a higher level of oxygen vacancy defects lowered the barrier height. *See id.* One of skill reading

Petition at 34

'909 Petitioner's Reply

Soukup's article and thesis observed an inverse relationship between oxygen defects and MgO barrier height. The parties largely agree regarding what Soukup

Paper 24 at 20

'909 Institution Decision

Petitioner and Dr. Bokor cite Soukup as allegedly teaching an inverse relationship between the amount of oxygen vacancy defects in the barrier layer and the barrier height, i.e., that “a higher level of oxygen vacancy defects lowered the barrier height.” *See* Pet. 33–34; Ex. 1024 ¶ 168 (“Soukup taught there was an inverse correlation between oxygen vacancy defects and the barrier height of the MgO layer”). That relationship applies with respect to the zero-field intercept method of determining barrier height.⁷ Soukup discloses that “[t]he zero-field intercept of the Schottky

⁷ We recognize that the opposite relationship appears to apply for the Arrhenius plot method. *See* Ex. 1028, 3229 (Abstract), 3233.

Paper 09 at 22

IPR2024-01384 Institution Decision

We agree with Patent Owner that Petitioner is inconsistent in relying on one method as allegedly teaching a barrier height within the claimed range, while at the same time relying on the other method for a motivation under its obviousness theory. Prelim. Resp. 45–49. If a person of ordinary skill in the art would have understood that the Arrhenius plot method was the appropriate method for determining barrier height, as Petitioner argues in asserting that Soukup teaches a barrier height of 0.33 eV, that person would have understood that “the barrier height *increases* as oxygen vacancies increase” (in blue above), and Petitioner’s obviousness theory of adding oxygen vacancies to lower Bowen’s barrier height is incorrect. *See id.* at 47. If, however, a person of ordinary skill in the art would have looked to the zero-field intercept method, that person “would have understood that *all* of Soukup’s tested samples . . . had barrier heights” (in yellow above) “above the claimed range of 0.2–0.5 eV.” *See id.* at 48. **Petitioner cannot have it both ways.**

IPR2024-01384, Paper 10 at 24-25 (cited Sur-reply at 24-25)

'909 Petitioner's Reply

Arrhenius plots were not). A skilled artisan like Soukup would not have relied upon the Arrhenius plots for PY-G-22(2)/PY-G-25(3) due to their non-linearity. EX1028,

Petitioner's Reply at 21

Soukup

The voltage-current characteristics of Au-MgO-Au thin-film emission diodes formed by electron beam evaporation of Au and MgO are consistent with an expression derived for Schottky field emission into the conduction band of the oxide. These results however indicate a potential barrier height of about 0.72 eV when determined from the zero-field intercept of the straight line $\log I$ vs $V^{1/2}$ plot and about 0.33 eV when obtained from an Arrhenius plot. These apparent barrier heights were different for devices fabricated by depositing the MgO film in an oxygen atmosphere. The apparent barrier height determined from the zero-field intercept went up for increasing oxygen pressure and the barrier height determined from the Arrhenius plot went down. Emission of electrons into vacuum was observed from each device at very low sample biases indicating that preferential emission through pinholes in the Au overlayer was occurring.

EX1028 at 3229 (cited Sur-reply at 24)

Additional Slides

Nexus For Secondary Consideration Evidence Can Be Shown to a Claimed Combination

'909 PO's Sur-reply

Petitioner's assertion that secondary considerations cannot apply because the barrier height limitation—in isolation—was known (Reply, 2) misstates the law. Showing *individual* claim elements were known does not refute objective secondary consideration evidence refuting Petitioner's hindsight *combinations*. *Chemours Co. FC v. Daikin Indus*, 4 F.4th 1370, 1378 (Fed. Cir. 2021) (citations omitted) (“Contrary to the Board’s decision, the separate disclosure of individual limitations [in the art], where the invention is a unique combination ... does not negate a nexus. Concluding otherwise would mean that nexus could never exist where the claimed invention is a *unique combination of known elements* from the prior art.”).

Sur-Reply at 26-27

Dr. Bokor Agreed with Dr. Ross that a POSA Could Not Model the Effects of Oxygen Defects

Patent Owner's Expert Dr. Ross

OBSERVATION 3:

In Exhibit 1107, on pages 42:21-43:8, the witness testified:

Q. ... You would agree that Giordano was able to calculate densities of states and Fermi level after adding oxygen vacancy defects to magnesium oxide..., correct?

A. Well, that's what figure 3 is showing according to Giordano.

The testimony is relevant because it contradicts Dr. Ross' prior testimony that skilled artisans needed to, but would not have been able to, model the effects of oxygen vacancy defects in MTJs in order to be motivated to explore lower barrier heights:

"Modeling an Fe/MgO interface with oxygen vacancy defects would have been far more difficult and would have been well beyond the capabilities of a POSA."

EX2087 ¶ 16; *see also* EX1107 at 41:18-42:4.

Paper 41 at 2-3

Petitioner's Expert Dr. Bokor

Q. So you could choose to model oxygen vacancies just at the interface with the iron layer if you wanted to; right?

A. Well, you said you. I couldn't.

Q. Why not?

A. A theorist -- I don't know how to do that. I'm not a theorist. I couldn't do that calculation.

Q. Would a person of ordinary skill in the art know how to make that calculation?

A. As I have testified already, no. I think this calculation -- and now if you start to add additional features to the calculation, you want to make a model even more complicated, then I even more strongly would testify that a person of ordinary skill in the art would not be able to make the full detailed calculation.

EX2086 at 60:16-61:7 (cited Sur-reply at 16)

