

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

WESTERN DIGITAL TECHNOLOGIES, INC.,
Petitioner,

v.

GODO KAISHA IP BRIDGE 1,
Patent Owner.

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

REPLY DECLARATION OF JEFFREY BOKOR, PH.D.

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I, Jeffrey Bokor, hereby declare as follows:

I. INTRODUCTION

1. I have prepared this Reply Declaration in connection with Western Digital Technologies, Inc.’s Petition for *Inter Partes* Review of U.S. Patent No. 11,968,909 (“the ’909 Patent”) (EX1017). In preparing this Declaration, I was asked only to respond to certain specific points asserted by Dr. Ross. I have identified those points and provided my responses in sections below.

2. I previously prepared a declaration in support of Western Digital’s Petition in this case. My compensation and my qualifications are set forth in my previous declaration and my curriculum vitae. EX1024 (First Declaration) ¶¶3-9; EX1025 (Bokor CV).

II. MATERIALS CONSIDERED

3. In addition to the documents I reviewed in my First Declaration, EX1024 ¶10, and in addition to any other documents cited or referenced herein, in preparing this Reply Declaration, I have reviewed Dr. Ross’ declaration (EX2053), my deposition transcripts (EX2013-EX2014), the Board’s Institution Decision (Paper 9), and IPB’s Patent Owner’s Response (Paper 18), as well as the following materials.

Exhibit No.	Description
1102	Transcript of Deposition of Caroline A. Ross, Ph.D., taken September 19, 2025
1106	Giordano et al., <i>Characteristics of Pd adsorption on the MgO(100) surface: Role of oxygen vacancies</i> , 64 <i>Physical Review B</i> 075417 (2001)
2005	Zhu et al., <i>Magnetic tunnel junctions</i> , 9 <i>Materials Today</i> 36-45 (2006)
2008	Yuasa citations, Google Scholar, https://scholar.google.com/citations?view_op=view_citation&hl=en&user=kb5EQcsAAAAJ&citation_for_view=kb5EQcsAAAAJ:3fE2CSJIrl8C
2009	Yuasa citations 2, Google Scholar, https://scholar.google.com/citations?view_op=view_citation&hl=en&user=kb5EQcsAAAAJ&citation_for_view=kb5EQcsAAAAJ:kNdYIxmWkoC
2015	Djayaprawira et al., <i>230% room-temperature magnetoresistance in CoFeB/MgO/CoFeB magnetic tunnel junctions</i> , 86 <i>Appl. Phys. Letters</i> 092502 (2005)
2016	Yuasa et al., <i>High Tunnel Magnetoresistance at Room Temperature in Fully Epitaxial Fe/MgO/Fe Tunnel Junctions due to Coherent Spin-Polarized Tunneling</i> , 43 <i>Japanese J. Appl. Phys.</i> L588 (2004)
2017	Yuasa et al., <i>Giant room-temperature magnetoresistance in single crystal Fe/MgO/Fe magnetic tunnel junctions</i> , 3 <i>Nature Materials</i> , 868-871 (2004)
2019	Marrows, <i>Spin-polarised currents and magnetic domain walls</i> , 54 <i>Advances in Physics</i> 585-713 (2005)
2020	Tsymbal et al., <i>Handbook of Spin Transport and Magnetism</i> (Tsymbal et al. eds. 2012)
2021	Nagamine et. al., <i>Ultralow resistance-area product of $0.4 \Omega (\mu\text{m})^2$ and high magnetoresistance above 50% in CoFeB/MgO/CoFeB magnetic tunnel junctions</i> , 89 <i>Appl. Phys. Letters</i> 162507 (2006)

Exhibit No.	Description
2022	Nakatani et al., <i>Read sensor technology for ultrahigh density magnetic recording</i> , 43 MRS Bulletin 106-111 (2018)
2024	<i>The 23rd (FY2022) Japan Society of Applied Physics Achievement Award Recipients</i> (with English translation), The Japan Society of Applied Physics
2026	2021 New Fellows, IEEE Japan Council
2028	Dr. Shinji Yuasa profile, Japan Science and Technology Agency
2029	<i>AIST wins three Science and Technology Awards in the 2016 Minister of Education, Culture, Sports, Science and Technology Commendation for Science and Technology</i> , https://www.aist.go.jp/aist_j/news/prize/pr20160412_3.html
2032	AIST: 20th Tsukuba Prize winner, https://www.aist.go.jp/aist_j/news/prize/itemid025-000077.html
2033	Announcing the winners for “Tsukuba Prize,” “Esaki Leona Prize,” and “Tsukuba Encouragement Prize,” Ibaraki Prefectural Science and Technology Promotion Foundation (with English translation), https://www.tsukuba-sci.com/cms/?p=9853
2037	Saito et al., <i>Correlation between barrier width, barrier height, and dc bias voltage dependences on the magnetoresistance ratio in Ir-Mn exchange biased single and double tunnel junctions</i> , 39 Jpn J. Appl. Phys. L1035–L1038 (2000)
2038	Maat et al., <i>Physics and Design of Hard Disk Drive Magnetic Recording Read Heads</i> , Handbook of Spintronics (2014)
2039	Soukup, <i>Hot Electron Transport in Vacuum Deposited Thin Film Emission Diodes</i> , A Thesis Submitted to the University of Minnesota (1969)
2041	Slonczewski, <i>Conductance and exchange coupling of two ferromagnets separated by a tunneling barrier</i> , 39 Phys. Rev. B 6995-7002 (1989)

III. RELEVANT LAW

4. I am not an attorney. For the purposes of this Reply Declaration, I have been informed about certain aspects of the law that are relevant to my opinions. My understanding of the relevant law is summarized in my First Declaration, EX1024 ¶¶11-23.

5. In addition to the relevant law in my First Declaration, for the purpose of responding to Dr. Ross' specific opinions, I have been informed that in order to be considered within the knowledge of a person of ordinary skill in the relevant art, a particular reference must be analogous art to the challenged patent, that is, it must be either in the same field as the challenged patent or, alternatively, must be reasonably pertinent to the particular problem to which the claimed invention is directed. I understand that the field of the challenged patent may be established by looking to the specification of the challenged patent, including its title, claims (including the function and structure of the claims), abstract, and written description. However, I also understand that the field of the invention and the particular problem to which the claimed invention is directed are viewed from the perspective of a person of ordinary skill in the art, including that person's knowledge.

6. As I explained in paragraph 18 of my First Declaration, I understand that the obviousness analysis must include, to the extent there are any, secondary considerations of non-obviousness, such as unexpected results, industry praise,

commercial success, long-felt but unmet need, failure of others, copying by others, and skepticism of experts. EX1024 (First Declaration) ¶18. Sometimes secondary considerations are referred to as secondary or objective indicia of non-obviousness. I understand that for any secondary considerations of non-obviousness to be afforded substantial weight in the obviousness analysis, the evidence must have a “nexus” to the claims. Nexus requires a legally and factually sufficient connection between the evidence and the patented invention. I understand that in the circumstance where the offered secondary consideration results from something other than what is both claimed and novel in the claim, there is no nexus to the merits of the claimed invention. I also understand that if the secondary consideration evidence relates to a limitation disclosed in the prior art, then this evidence cannot be used to show non-obviousness.

IV. ONE OF SKILL WAS MOTIVATED TO EXPERIMENT WITH LOWER BARRIER HEIGHTS

7. I was asked to respond to Dr. Ross’ opinions regarding how one of ordinary skill in the art would understand Butler’s teachings to be pertinent to the effect of barrier height on TMR. Dr. Ross has extensive testimony on this point, and I was asked to respond only to the following points:

- “Butler’s model predicts nothing about the effect of lowering the barrier height on TMR—nor could it.” EX2053 (Ross Decl.) ¶92; *see also* ¶85

(“I disagree that a POSA would have drawn any conclusions from Butler about the impact of lowering the barrier on TMR.”).

- “Butler does not provide any data for any structure other than the one the authors modeled and a POSA would not have drawn any conclusions beyond those reached by Butler, let alone any conclusion that would have motivated a POSA to lower the barrier height in Bowen’s or Nagahama’s MTJs.” EX2053 (Ross Decl.) ¶96.

8. I disagree with Dr. Ross. In my opinion, Butler would have motivated one of skill to explore lower barrier heights to improve TMR, and Butler provides ample data to support such reasoning to one of skill with ordinary creativity.

9. It was well known to one of skill that oxygen vacancy defects would cause the Fermi energy of the electrode to increase at the electrode-barrier layer interface, thus lowering the barrier height. For example, Giordano investigated the adsorption energies of palladium (Pd) deposited on an MgO(001) surface. EX1106 (Giordano) at Abstract. As part of the analysis, Giordano calculated the density of states (DOS) for a Pd monolayer on MgO(001). EX1106 (Giordano) at pages 4-5, Fig. 3. Giordano shows that the Fermi energy level is elevated where the Pd electrode interfaces with an oxygen-deficient MgO(001) surface (Fig. 3(b)) compared to interfacing with an MgO(001) surface lacking oxygen vacancies (Fig. 3(a)).

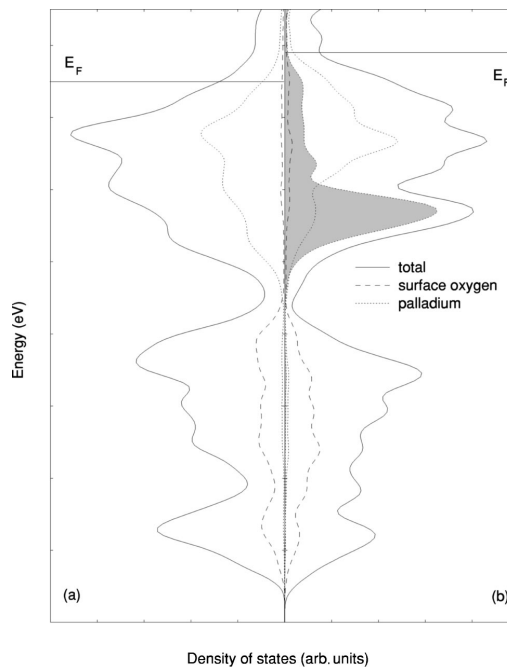


FIG. 3. DOS for a Pd monolayer adsorbed on the regular (a) and on the oxygen-deficient (b) MgO(100) surface. Total DOS and projections on the surface oxygen and on the Pd atom at the regular (clear) and at the vacancy (shaded) sites are plotted. All DOS have been convoluted by a 0.1-eV-wide Gaussian function.

EX1106 (Giordano) at Fig. 3. Giordano is representative of one of skill's knowledge in 2004 that introducing oxygen vacancy defects in the MgO(001) barrier layer would, among other things, increase the height of the Fermi energy in the adjoining electrode, thus decreasing the barrier height, which depends on the Fermi energy.

10. Butler taught that a change in barrier height was expected to affect majority and minority channel tunneling. This effect can be seen in Butler's Figure 3. EX1044 (Butler) at page 3, Fig. 3. There, Butler shows the density of states in the Fe(001) layers adjacent to and near the Fe(001)|MgO(001) interface. Butler calculates DOS for various energy levels. DOS represents the number of quantum states available for electrons to occupy at a certain energy level and thus acts as a

proxy for electrical conduction at that energy. The Fermi energy level is indicated by the solid black line drawn at 0.35 Hartree. EX1044 (Butler) at page 6, Fig. 8 (teaching that the Fermi energy (E_F) is at 0.35 Hartree.) One can see in the top and bottom sub-figures that changing the Fermi energy would affect, respectively, the DOS (and hence conductance) of the majority and minority tunneling channels. Figure 4 shows the same phenomena for the MgO layers adjacent to and near the Fe(001)|MgO(001) interface.

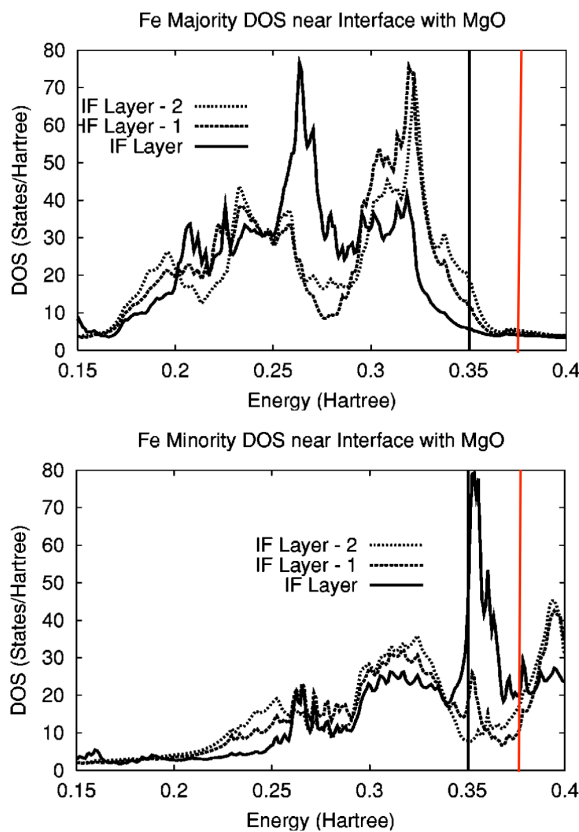


FIG. 3. Density of states for each atomic layer of Fe(100) near an interface with MgO. One hartree equals 27.2 eV.

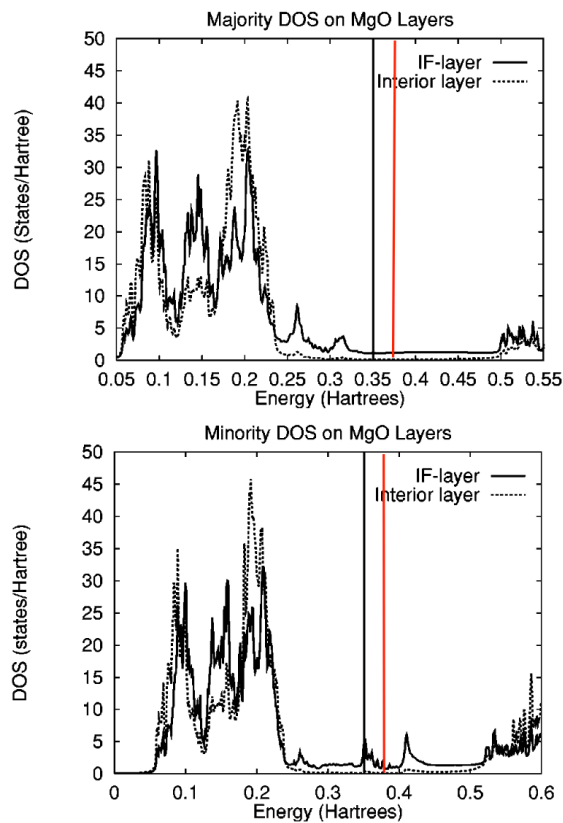


FIG. 4. Density of states for each of the atomic layers of MgO near an interface with Fe(100).

EX1044 (Butler) at Figs. 3-4 (annotations in red).

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.

12. Butler does therefore contain data that a minimally creative person of ordinary skill in the art would understand connects changing barrier height to changing TMR.

V. THERE WAS NO TEACHING IN THE ART THAT LOWER BARRIER HEIGHTS SHOULD BE AVOIDED FOR MgO

13. I was also asked to respond to the following opinions of Dr. Ross related to the Slonczewski model and what one of skill in the art understood about that model in 2004:

- “[I]t 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.” EX2053 (Ross Decl.) ¶82; *see also* ¶¶68-82.
- “The expectation at the time was that lowering the barrier height would decrease TMR as it was known to do for Al₂O₃-based MTJs.” EX2053 (Ross Decl.) ¶57.

A. One Of Skill Understood That Crystalline MgO(001) Barrier Layers Are Fundamentally Different Than Amorphous Alumina Barriers

14. Contrary to Dr. Ross’ opinion, one of skill in the art was well informed as of 2004 that MTJs with MgO(001) barrier layers behave fundamentally different than MTJs with amorphous alumina barrier layers. Given this understanding, one

of skill would not assume that any relationship between barrier height and TMR observed in the context of MTJs with simple amorphous alumina barrier layers would apply to MTJs with crystalline MgO(001) barrier layers.

15. To put Dr. Ross' opinion into perspective, one must first recall that Butler's and Mathon's papers in 2001 were the first to predict that MTJs with crystalline MgO(001) barrier layers would exhibit "large magnetoresistance," EX1044 (Butler) at page 1, "in excess of 1000%" TMR, EX1046 (Mathon) at page 1. As Dieny reports, the MTJs in use in 2001 had amorphous alumina barrier layers and exhibited at most only about 50% TMR. EX1057 (Dieny) at page 46.

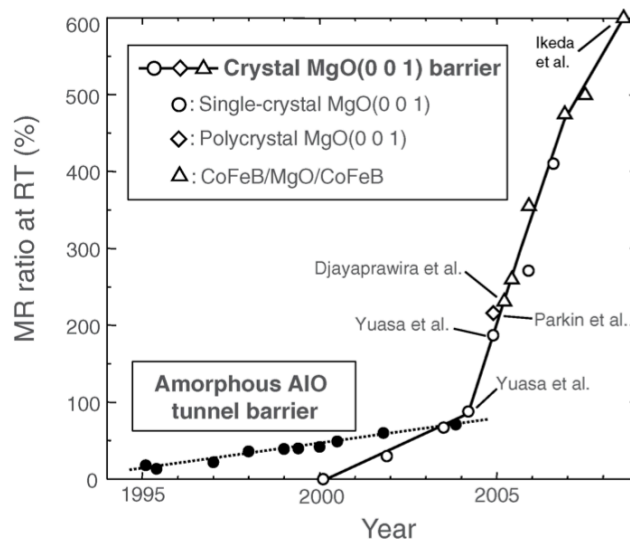


Figure 2.21 History of improvement in MR ratio at RT for MTJs with amorphous AlO barrier (solid circles) or crystalline MgO(001) barrier (open symbols). Data are shown for work by Yuasa et al. (22,23), Parkin et al. (24) Djayaprawira et al. (33), and Ikeda et al. (36).

EX1057 (Dieny) at Fig. 2.21.

16. Butler's and Mathon's collective predictions of an order of magnitude increase in TMR represented a very significant step forward from MTJs with

amorphous alumina barrier layers. Such a significant improvement in performance indicated to one of skill in 2004 that MTJs with crystalline MgO(001) operate and behave in ways fundamentally different than extant MTJs with amorphous alumina barrier layers.

1. Butler (EX1044)

17. Butler confirms this. EX1044 (Butler). Butler presented a model of MTJ behavior specific to MTJs with ferrous(001) electrodes and MgO(001) barrier layers. *Id.* at page 1. As was widely understood at the time, in ferrous(001) electrodes, the electrons involved in conduction are organized in quantum band structures referred to as “Bloch states,” which exhibit certain quantum “symmetr[ies].” *Id.* at Abstract. For example, Butler identified band structures with Δ_1 , Δ_5 , Δ_2 , and Δ_2' symmetries in the electrodes. *Id.* at pages 5-6, Fig. 7.

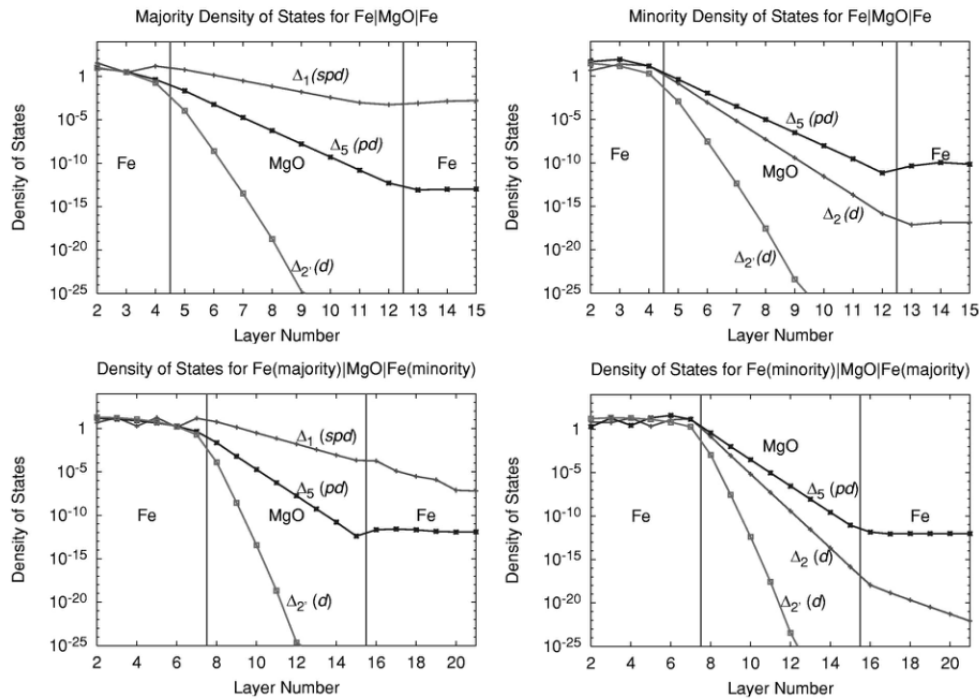


FIG. 7. Tunneling DOS for $k_{\parallel}=0$ for Fe(100)|8MgO|Fe(100). The four panels show the tunneling DOS for majority (upper left) minority (upper right), and antiparallel alignment of the moments in the two electrodes (lower panels). Additional Fe layers are included in the lower panels to show the TDOS variation in the Fe. Each TDOS curve is labeled by the symmetry of the incident Bloch state in the left Fe electrode.

EX1044 (Butler) at Fig. 7.

18. Butler recognized that in an MgO(001) barrier layer these wave functions would decay as evanescent states with certain symmetries. EX1044 (Butler) at page 6. An “evanescent state” is a wave function that decays exponentially with distance. In quantum mechanics, electron wave functions are not permitted to be discontinuous—for example, to immediately stop at the boundary between a conductor and insulator. Instead, the wave function must continue from the conductor into the insulator while decaying towards a near zero-probability state, even if over only a very short distance.

19. Butler taught that conduction from an electrode to the barrier layer and from the barrier layer to an electrode in a ferrous(001)|MgO(001)|ferrous(001) MTJ would depend on the compatibilities of these symmetries:

- “(1) Tunneling conductance depends strongly on the symmetry of the Bloch states in the electrodes and of the evanescent states in the barrier layer.” EX1044 (Butler) at Abstract.
- “[W]e shall show that the symmetry of both the propagating states in the electrodes and of the evanescent states in the barrier material are crucial to determining the tunneling conductance.” *Id.* at page 1.
- “(1) The symmetry of the Bloch states at the Fermi energy and their relationship to the symmetry of the slowly decaying evanescent states in the barrier layer are crucial to understanding tunneling conductance.” *Id.* at page 11.

20. More specifically, Butler taught that certain band structure symmetries in the electrodes “couple” with certain evanescent state symmetries in the MgO(001) barrier:

- “One particular state with Δ_1 symmetry is able to effectively couple from the Fe into the MgO and also out of the MgO into the Fe electrode on the other side.” EX1044 (Butler) at page 1.

- “Both majority and minority Fe channels have a Δ_2' state that couples to a Δ_2 state in the MgO where it decays very rapidly...” *Id.* at page 7.
- “Finally there is a minority Fe Δ_2 state that couples to a Δ_2' state in the MgO...” *Id.*

21. This coupling is significant because evanescent states with different symmetries decay at different rates in the MgO(001) barrier:

- “(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.” EX1044 (Butler) at Abstract.
- “It can be seen that the slowest decay rate is for states with Δ_1 symmetry... The next slowest decay rate is for states with Δ_5 symmetry.” *Id.* at pages 5-6.
- “The decay rates for each of the Fe(100) Bloch states within the MgO can be determined by inspection of a band structure plot as is illustrated in Fig. 8.” *Id.* at page 5. As seen in Figure 8, the decay rates at E_F (the Fermi energy of the electrodes, at which the electrons involved in tunneling are found) are different for the Δ_1 , Δ_5 , and Δ_2' symmetries. The ordinate for the Δ_2 band is -31.5—off the chart and different from Δ_1 , Δ_5 , and Δ_2' . *Id.* at page 5 (“The nearest complex band with

symmetry Δ_2 would cross the Fermi energy with a value of $-(k\Delta z)^2$ of approximately 31.5.”).

- Figure 7, showing calculations of Density of States for the Δ_1 , Δ_5 , Δ_2 , and Δ_2' symmetries and different rates of decay of those densities in the MgO barrier layers (from layers 7 to 15). *Id.* at page 6, Fig. 7.

22. Of particular importance here is the Δ_1 state that Butler found to decay most slowly. The Δ_1 state fortuitously is found only in the “majority channel.” EX1044 (Butler) at pages 6 (“Only the majority channel has the slowly decaying Δ_1 state.”), 9 (“The Δ_1 electrons readily enter the MgO... On the right-hand side of the barrier however these states cannot propagate because there are no minority Δ_1 propagating states at the Fermi energy.”). The “majority channel” here refers to conduction of electrons that are magnetically aligned with the magnetic moments of the electrodes when the magnetic moments of the electrodes are parallel. Butler accordingly observed that “[a]s the barrier becomes thicker the majority channel conductance for parallel moment alignment dominates the conductance because of the slow decay of the Δ_1 state in the MgO.” *Id.* at page 1. This behavior is visually observed in Figure 7, where the other band structures (Δ_5 , Δ_2 , and Δ_2' symmetries) decay much more quickly than the Δ_1 majority state when moving from left to right in the direction of conduction through the MgO layer to the opposite electrode.

23. Thus, Butler made clear to one of skill that ferrous(001)|MgO(001)|ferrous(001) MTJs would exhibit “a large magnetoresistance” because of (1) coupling between band structures in the electrodes and evanescent states in the MgO of compatible symmetries and (2) the difference in decay rates between these different symmetries. EX1044 (Butler) at Abstract.

24. Butler explicitly criticized earlier models of tunneling conductance that failed to appreciate this “crucial” behavior as “completely inadequate”:

- “Most previous theories of tunneling conductance and magnetoconductance have emphasized the density of states of the electrodes. The tunneling matrix elements are almost always neglected or treated as inert factors. One of our conclusions is that this approach is *completely inadequate* for understanding tunneling. The nature of the states both in the electrodes and in the barrier layer are extremely important in determining the tunneling conductance. Specifically we shall show that the symmetry of both the propagating states in the electrodes and of the evanescent states in the barrier material are crucial to determining the tunneling conductance.” EX1044 (Butler) at page 1 (emphasis added).

- “In calculating the tunneling conductance we encountered the following results which we believe to apply rather generally to tunneling in epitaxial systems and to be contrary to the simple barrier model that is typically used to describe electron tunneling: (1) The symmetry of the Bloch states at the Fermi energy and their relationship to the symmetry of the slowly decaying evanescent states in the barrier layer are *crucial* to understanding tunneling conductance.” *Id.* at page 11 (emphasis added).
- “It is generally believed that the simple barrier model is appropriate for describing the tunneling of electrons through insulating barriers. In the preceding section we showed contrary to that model, that states with different symmetry decay at different rates as they tunnel through the barrier.” *Id.* at page 7.

25. As seen above, Butler explicitly distinguished its MgO(001)-specific model from “simple barrier model[s]” that preceded it. I will explain further below that such “simple” models included that of Slonczewski and its progeny, which Dr. Ross relies upon.

2. Slonczewski And Its Progeny

a) Slonczewski (EX2041)

26. Dr. Ross relies on several prior art references—Moodera-1995 (EX1035), Moodera-1996 (EX1038), and Saito (EX2037)—that make various pronouncements about the effect on TMR of barrier height. EX2053 (Ross Decl.) ¶¶68-82. All of these rely directly or indirectly on Slonczewski (EX2041) or comparably simplistic models.

27. Slonczewski was an early attempt to model the behavior of MTJs before the groundbreaking discoveries of Butler in 2001. Slonczewski modeled the behavior of MTJs assumed to have two generic ferromagnetic layers separated by a generic tunneling barrier. EX2041 (Slonczewski) at page 6995 (“This paper treats three related phenomena involving two ferromagnets separated by a nonmagnetic tunneling barrier.”). In particular contrast to Butler, Slonczewski does not assume that its barrier layer is MgO(001).

28. This is unsurprising because, at the time of Slonczewski in 1989, it was yet to be proven that an operationally successful MgO(001) barrier layer in an MTJ even could be fabricated. Butler itself suggests that the first successful fabrication of an MgO(001)-based MTJ did not occur until the work of Heinrich, Wulfskel, and Klaua, et al. approximately contemporaneous to Butler:

Recently Heinrich *et al.* have grown Fe(100)|MgO(100)|Fe(100) magnetic tunnel junctions by depositing MgO epitaxially onto Fe whiskers and then depositing another Fe electrode epitaxially on top of the MgO.

EX1044 (Butler) at page 1. This research was first published in 2000.

- **Heinrich (2000):** “We have grown single crystal epitaxial Magneto Tunneling Junctions using Fe whisker substrates, MgO(001) oxide spacers and Fe/Ni/Au(001) top electrodes.” EX1043 (Henrich) at page 1.
- **Wulfhekel (2001):** “We have grown epitaxial single-crystal magnetotunnel junctions using Fe(001) substrates, MgO(001) spacers and Fe top electrodes.” EX1047 (Wulfhekel) at Abstract.
- **Klaua (2001):** “Single-crystal epitaxial MgO thin films were grown directly onto high-quality Fe single crystal and Fe whisker substrates and covered with Fe/Au layers.” EX1045 (Klaua) at Abstract.

29. Slonczewski’s early simple model focused on generic MTJs, and Butler’s relatively sophisticated model focused on MgO(001)-based MTJs, resulting in several significant differences between the models.

30. First, Slonczewski failed to account for the crystallinity and composition of an MgO(001) barrier. Butler, in contrast, recognized that a reliable physical model of an MgO(001)-based MTJ, including its barrier layer, was necessary to truly understand its behavior:

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.

EX1044 (Butler) at page 1. For example, Butler's analysis of the MgO(001) barrier layer determined that the Fe-O distance is 2.169 Å. *Id.* at page 2. Butler input this distance (truncated to 2.16 Å) into its subsequent layer Korringa-Kohn-Rostoker analysis of the transmission and reflection of Bloch waves in Fe incident on the MgO layer. *Id.* This permitted calculation of the electronic density of states (DOS) for each layer of Fe or MgO atoms in Butler's model. *Id.* at pages 2-3 ("The electronic density of states (DOS) was calculated for each layer and for the majority and minority spin channels."). The eventual results of these DOS calculations, as shown in Butler's Figure 7, supports Butler's conclusion that different symmetries have different decay rates, a foundational finding underlying Butler's conclusion that MgO(001)-based MTJs would exhibit "large magnetoresistance." *Id.* at Abstract ("(1) Tunneling conductance depends strongly on the symmetry of the Bloch states in the electrodes and of the evanescent states in the barrier layer... We predict a large magnetoresistance..."), page 6 (Figure 7).

31. Second, and relatedly, Slonczewski failed to account for the distinct evanescent states that exist in MgO(001) barrier layers. As I discussed above, Butler recognized that distinct evanescent states have different decay rates that are

responsible for the Δ_1 symmetry (which exists only in the majority state) dominating conductance in the parallel alignment.

One particular state with Δ_1 symmetry is able to effectively couple...
As the barrier becomes thicker the majority channel conductance for parallel moment alignment dominates the conductance because of the slow decay of the Δ_1 state in the MgO.

EX1044 (Butler) at page 1. This is a further foundational finding supporting Butler's conclusion that MgO(001)-based MTJs would exhibit "large magnetoresistance." *Id.* at Abstract ("(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... We predict a large magnetoresistance...").

b) Butler's Critique Of Simple Models Like Slonczewski

32. Butler's detailed modeling specific to MTJs with MgO(001) barrier layers constituted a significant advance in one of skill's understanding of how such MTJs function and directly led to Butler's accurate prediction that they would achieve "large magnetoresistance." EX1044 (Butler) at page 1.

33. The Butler paper recognized itself as constituting a paradigm shift in the art's understanding of MgO(001)-based MTJs.

34. For example, Butler taught that prior models that failed to accurately account for the barrier layer were "completely inadequate" for understanding tunneling conductance. EX1044 (Butler) at page 1. Slonczewski falls within the

scope of such “previous studies” that failed to account for the “tunneling matrix,” as I discussed above.

35. Moreover, and as I also discussed above, Butler distinguished between “simple” models and its MgO(001)-specific model. Butler explained that a “simple model” assumes:

[A] free electron incident on a square barrier of height V_b and thickness d for which the transmission probability contains a factor $\exp(-2d\kappa)$ where $\kappa^2 = (2m/\hbar^2)(V_b - E_f) + k_{\parallel}^2$.

EX1044 (Butler) at page 5. Above, d is distance, κ is the decay rate coefficient, m is the mass of an electron, $\hbar$ is Planck’s constant, V_b is the barrier height, E_f is the electrode’s Fermi energy (because in a metal it is those electrons that are involved in conduction), and $k_{\parallel}^2$ is the electron’s wave vector in the direction parallel to the interface between the electrode and the barrier layer. Butler uses a slightly different notation in its Equation 9:

According to the theory for tunneling through a *simple barrier* the transmission should vary with $k_{\parallel}$ as $\exp(-2d\kappa)$ where d is the thickness of the barrier and κ is given by

$$\kappa^2 = \frac{2m^*}{\hbar^2} (E_b - E) + k_{\parallel}^2 = \kappa_0^2 + \kappa_{\parallel}^2.$$

Id. at page 7 (emphasis added).

36. Slonczewski is just such a “simple model” with a “simple barrier.” The later Dieny reference explains that Slonczewski utilized the same expression for κ

(decay rate) that Butler classified as “simple,” excepting that the $k_{\parallel}$ term is assumed to be zero. Slonczewski assumes that the electrons involved in tunneling primarily are those that travel perpendicular to the interface; hence, $k_{\parallel} \cong 0$. EX2041 (Slonczewski) at page 6997 (“In the limit of a small barrier factor $e^{-2\kappa d}$, a narrow distribution of electrons near normal incidence... carry most of the current.”). As Dieny says:

1.2.3.1 The Model In Slonczewski model, several assumptions are made, similar to those of Jullière’s model. First, the tunneling barrier is simply described as a square potential (energy height Φ and thickness d) above the Fermi level of the two ferromagnetic electrodes, considering the *free-electron approximation*. Second, the two ferromagnetic electrodes are taken to be identical. Finally, the model assumes that only electrons propagating perpendicular to the layers ($\vec{k} \approx \vec{k}_{\perp}$, $k_{\parallel} \approx 0$) can efficiently tunnel through the barrier. Indeed, if we consider electrons propagating in another direction, with $k_{\parallel} \neq 0$, then the decay coefficient inside the insulating layer becomes $\kappa(E) = \sqrt{k_{\parallel}^2 + (2m_e/\hbar^2)(\Phi - E)}$. Then, the higher the parallel wave vector,

EX1057 (Dieny) at page 14. Dieny’s equation here, which he attributes to Slonczewski, is equivalent to Butler’s Equation 9 for “the simple barrier model”/“a simple barrier.” EX1044 (Butler) at page 7. At the time of the ’909 Patent, one of skill understood that Slonczewski recognized and adopted the same decay rate relationship that Dieny characterizes Slonczewski as using, which was the understanding of decay rate for a simple barrier possessed by one of skill at the time.

37. Butler explains that such a simple barrier model is not appropriate for understanding tunneling in an MgO(001)-based MTJ. For one, the simple barrier

model assumes that all quantum states decay at the same rate, whereas Butler found that band structures with distinct symmetries decay at different rates:

It is generally believed that the *simple barrier model* is appropriate for describing the tunneling of electrons through insulating barriers. In the preceding section we showed *contrary to that model, that states with different symmetry decay at different rates as they tunnel through the barrier*.

EX1044 (Butler) at page 7 (emphases added). Moreover, Butler found that simple barrier models failed to account for how tunneling current changes with the wave vector:

In this section we address the variation of the tunneling current with $k_{\parallel}$ and show that *the [simple] barrier model fails for this aspect of tunneling as well*.

Id. (emphasis added). Butler's Figure 9 shows the differences in predicted transmission for the majority channel between a simple barrier model and its MgO-specific model.

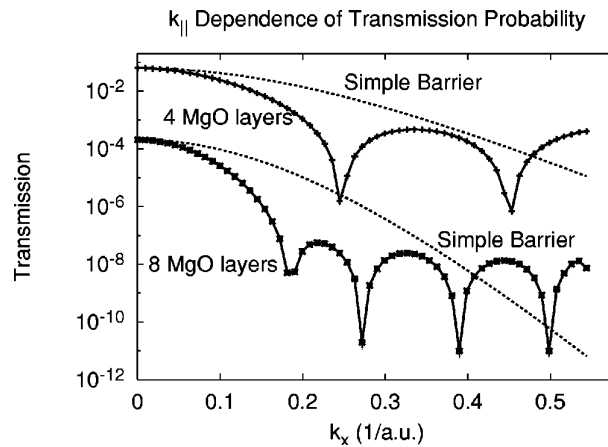


FIG. 9. Majority transmission probability as a function of $k_{\parallel}$ for $k_y=0$ for 4 and 8 layers of MgO. The curves end before the zone boundary is reached because there are no states for $k_x > 0.55 \text{ (a.u.)}^{-1}$. Smooth curves show the expected behavior of the transmission probability from Eq. (9).

EX1044 (Butler) at page 7, Fig. 9. Slonczewski, with its assumption that $k_{\parallel} \cong 0$, would be even less predictive than the simple barrier model presented in Butler, since Slonczewski does not permit any wave vector other than one perpendicular to the interface between the electrode and barrier layer.

38. Thus, not only did one of skill at in 2004 recognize that Slonczewski failed to account for the primary factual findings of Butler, one of skill also was explicitly taught by Butler that predecessor models such as that of Slonczewski were “completely inadequate” and not appropriate for understanding MgO(001)-based MTJs.

39. For at least these reasons, one of skill knew that any predictions about trends between barrier height and TMR arising from Slonczewski’s model would be

“completely inadequate for understanding tunneling” in MgO(001)-based MTJs like those of Bowen and Nagahama.

c) Moodera-1995 (EX1035)

40. Dr. Ross cites Moodera-1995 (EX1035) and contends that it teaches that lowering barrier height would decrease TMR. EX2053 (Ross Decl.) ¶¶68-74; *id.* ¶¶69 (“Moodera is not saying that lowering barrier height would increase TMR... Moodera in fact teaches the opposite.”), 74 (“Moodera’s understanding of lower barrier height yielding lower TMR.”). Dr. Ross contends that such a teaching from Moodera-1995 is derived from, and consistent with, Slonczewski. *Id.* ¶¶70-74

41. As I explained in my First Declaration (EX1024), Moodera-1995 teaches that TMR can be expressed in terms of the difference between parallel and antiparallel resistance in MTJs, EX1024 ¶¶37-38, 169, 276, and teaches the use of CoFe alloys in electrodes to increase TMR, *id.* ¶¶187, 189, 192, 293. I do not rely upon Moodera-1995’s characterization of Slonczewski that Dr. Ross cites. Nor would one of skill rely upon Moodera-1995’s characterization of Slonczewski by 2004, as such a person would be armed with knowledge of the interceding teachings of Butler that superseded “simple” models like Slonczewski for MgO-based MTJs.

42. Moodera-1995 suffers from the same defects vis-à-vis MgO(001)-based MTJs as does Slonczewski. Like Slonczewski, Moodera-1995 is not specific to MTJs with MgO barrier layers. The MTJs studied in Moodera-1995 all used

amorphous alumina barrier layers. EX1035 (Moodera-1995) at Abstract. Like Slonczewski, Moodera-1995 does not recognize the existence of distinct band structures in the electrodes, distinct evanescent states in the barrier layer, or different decay rates for the distinct evanescent states. Butler explained that its recognition of these phenomena led to its conclusion that MgO(001)-based MTJs would exhibit “large magnetoresistance,” EX1044 (Butler) at Abstract, and that models lacking this understanding are “completely inadequate for understanding tunneling,” *id.* at page 1.

43. Additionally, Moodera-1995 itself found Slonczewski’s model is not reliable. Slonczewski predicted TMR values of less than 1% for the MTJs that Moodera-1995 studied. EX1035 (Moodera-1995) at page 3276. However, Moodera-1995 measured TMR values of 11.8%, 20%, and 24%. *Id.* at Abstract. The significant difference between the TMR values predicted by Moodera-1995’s application of Slonczewski and the actual TMR values measured taught one of skill that Slonczewski’s predictive capabilities are limited or non-existent. Given this limitation, Moodera-1995 does not teach one of skill to increase barrier height to increase TMR, as Dr. Ross contends, and certainly would not do so after Butler was published in 2001.

d) Moodera-1996 (EX1038)

44. Dr. Ross cites Moodera-1996 (EX1038) and contends that it also teaches that lowering barrier height would decrease TMR. EX2053 (Ross Decl.) ¶74 (“Moodera’s understanding of lower barrier height yielding lower TMR. Moodera confirmed that understanding in a subsequent paper (EX1038) for MgO barriers.”).

45. Moodera-1996 does not purport to study the effect of barrier height on TMR. Instead, Moodera-1996 studied the effect on tunneling current of the relative magnetic orientations of electrodes in an MTJ. EX1038 (Moodera-1996) at Abstract (“Tunnel current was observed to be dependent on the relative orientation of the magnetization (M).”). With respect to the foregoing purpose, Moodera-1996 studied MTJs with Al_2O_3 and with MgO barrier layers. *Id.* at Abstract. However, Moodera-1996’s studies of MgO barrier layers were “limited.” *Id.* at page 4725. Indeed, none of the 5 figures presented in Moodera-1996 concern MTJs with MgO barrier layers. And Moodera-1996 presents virtually no data concerning MTJs with MgO barrier layers other than to say that in its “limited studies done with MgO barriers,” the barrier height was about 0.9 eV. *Id.*

46. Moodera-1996 makes the following observation with respect to the effect of DC bias on tunneling, which Dr. Ross relies upon, EX2053 (Ross Decl.) ¶74:

the decrease in $\Delta R/R$. With the increase in dc bias, the effective barrier height decreases. MgO, with its smaller barrier height, is affected more than the Al_2O_3 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.⁴

EX1038 (Moodera-1996) at page 4728. Dr. Ross appears to be of the opinion that this statement, standing alone, teaches one of skill that a decrease in barrier height leads to a decrease in spin polarization and thus TMR.

47. However, one of skill by 2004 understood this statement in the context of Butler's teachings. Like Moodera-1995, Moodera-1996 suffers from the same defects vis-à-vis MgO(001)-based MTJs as does Slonczewski. Although Moodera-1996 purports to have conducted "limited studies" of MgO barrier layers, Moodera-1996, like Slonczewski, does not recognize the existence of distinct band structures in the electrodes, distinct evanescent states in the barrier layer, or different decay rates for the distinct evanescent states. Butler explained that its recognition of these phenomena led to its conclusion that MgO(001)-based MTJs would exhibit "high magnetoresistance," EX1044 (Butler) at Abstract, and that models lacking this understanding are "completely inadequate for understanding tunneling," *id.* at page 1. Thus, even though Moodera-1996 nominally studied MgO-based MTJs, it did not undertake the probative analysis of such barrier layers that Butler did.

e) Saito (EX2037)

48. Dr. Ross cites Saito (EX2037) and contends that it too teaches that lowering barrier height would decrease TMR. EX2053 (Ross Decl.) ¶¶75-80; *id.* ¶¶76 (“Saito’s assessment of the results obtained from the experiment was that the ‘TMR ratio increased with increasing barrier height.’”), 78 (“Both the predicted value of TMR calculated from the theoretical model and Saito’s measured data demonstrate that a POSA would not have expected Bowen’s TMR to increase if its barrier height were lowered...”).

49. Saito suggests that its predictions and measured values are consistent with those of Slonczewski. EX2037 (Saito) at pages 1036 (“This suggests that the result is roughly consistent with the free electron model; that is, transmission coefficients of up and down spin depend on the barrier height for the STJs¹⁹.”), 1038 n.19 (citing Slonczewski (EX2041)). Although Saito’s predictions of TMR were not based on Slonczewski, they suffer from the same defects vis-à-vis MgO(001)-based MTJs as does Slonczewski. Like Slonczewski, Saito is not specific to MTJs with MgO barrier layers. The MTJs studied in Saito all used amorphous alumina barrier layers. *Id.* at Abstract. Like Slonczewski, Saito does not recognize the existence of distinct band structures in the electrodes, distinct evanescent states in the barrier layer, or different decay rates for the distinct evanescent states. Butler explained that its recognition of these phenomena led to its conclusion that

MgO(001)-based MTJs would exhibit “large magnetoresistance,” EX1044 (Butler) at Abstract, and that models lacking this understanding are “completely inadequate for understanding tunneling,” *id.* at page 1. In sum, Saito’s model is a simple model for tunneling, like Slonczewski’s simple model that Butler criticized.

50. Dr. Ross particularly relies on Saito’s measurements of barrier height and TMR. EX2053 (Ross Decl.) ¶¶75-76. However, all of these measurements were for amorphous alumina-based MTJs, not crystalline MgO(001)-based MTJs. Unlike a periodic insulator (e.g., MgO(001)), an amorphous insulator (e.g., alumina) does not present evanescent states of distinct symmetries or distinct decay rates. This is illustrated, for example, in Dieny:

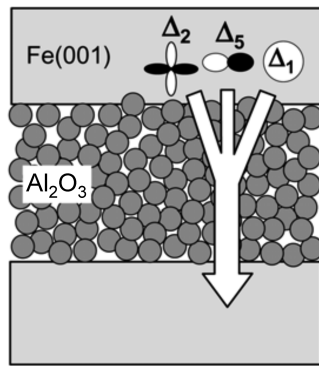
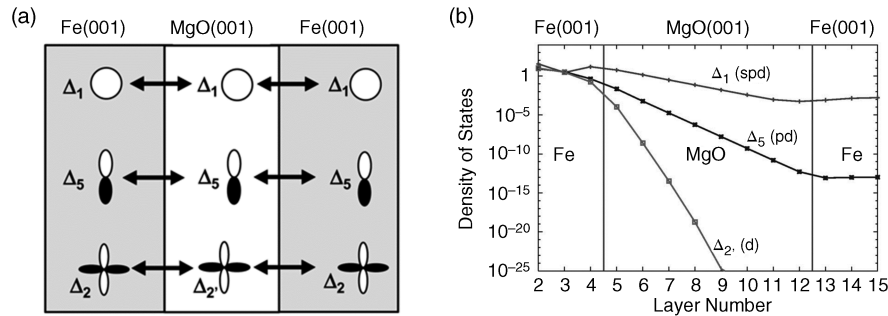


Figure 1.6 Schematic illustration of electrons tunneling through an amorphous (Al₂O₃) barrier. (From Ref. 17.)

EX1057 (Dieny) at page 17. As seen above, the distinct band structures in the crystalline Fe(001) electrode tunnel through the amorphous barrier using a common mechanism regardless of their original symmetry.

51. This is in stark contrast to Butler’s later discovery that band structures of different symmetries “couple” with evanescent states of compatible symmetries when tunneling through an MgO(001) barrier layer. This also is illustrated in Dieny:



EX1057 (Dieny) at page 18; *see also id.* page 44.

52. Given the intervening teachings of Butler, one of skill in 2004 appreciated that studies of alumina-based MTJs such as Saito could not accurately predict the behavior of MgO(001)-based MTJs, given the fundamental differences in tunneling between amorphous alumina and crystalline MgO(001) barriers.

3. Yuasa *Nature Materials* (EX2017)

53. Dr. Ross also cites to Yuasa’s 2004 paper published in *Nature Materials* (EX2017), arguing that it too conveys the understanding of one of skill in 2004 that a decrease in barrier height was expected to result in a decrease in TMR. EX2053 (Ross Decl.) ¶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.”).

54. I disagree with Dr. Ross’ opinion because Yuasa’s 2004 *Nature Materials*, which Dr. Ross cites for support of this opinion, in turn relies on Saito: “It should also be noted that for an Al-O tunnel barrier, a lower barrier height yields a lower MR ratio¹⁷.” EX2017 (Yuasa NM) at pages 869, 871 n.17 (citing Saito (EX2037)). As I explained above, Saito could not inform the understanding of one of skill concerning the behavior of crystalline MgO(001)-based MTJs given that Saito (published 2000) analyzed and tested only amorphous alumina-based MTJs, and one of skill understood from Butler’s later paper (published 2001) that MgO(001)-based MTJs behave fundamentally different than alumina-based MTJs.

4. Mitani (EX1053)

55. Dr. Ross finally cites Mitani’s 2003 paper, which according to Dr. Ross suggested that “TMR in MgO based MTJs depend[s] on the barrier like it does for alumina-based MTJs.” EX2053 (Ross Decl.) ¶81. Dr. Ross’ opinion is based on the following statement in Mitani:

This value of TMR is 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.

EX1053 (Mitani) at page 8043 (emphasis added).

56. I disagree with Dr. Ross that Mitani taught one of skill that TMR in crystalline MgO(001)-based MTJs would be affected by changes in barrier height in the same way that TMR is affected by changes in barrier height in amorphous alumina-based MTJs. The passage in Mitani that Dr. Ross cites does not refer to barrier *height*. Rather, it refers to barrier *structure* (and interface structure) for the purpose of explaining why Mitani's observed TMR for its MgO(001)-based MTJs was smaller than expected. Mitani's statement here stands for the uncontroversial proposition that TMR can be affected by barrier *structure* and interface *structure*. It says nothing regarding the effect of barrier *height* on TMR.

5. Dr. Ross' Cited Exhibits Would Not Have Dissuaded A Skilled Artisan From Experimenting With Lower Barrier Heights

57. Slonczewski (EX2041), Moodera-1995 (EX1035), Moodera-1996 (EX1038), Saito (EX2037), Yuasa NM (EX2017), and Mitani (EX1053) all fail to recognize the "crucial" discoveries of Butler that led Butler to accurately predict "large magnetoresistance" for MgO(001)-based MTJs: band structures and evanescent states with different symmetries and decay rates. By the time of the '909 Patent—after Butler—one of skill understood by way of Butler that Slonczewski, Moodera-1995, Moodera-1996, Saito, Yuasa NM, and Mitani could not accurately predict the behavior of MgO(001)-based MTJs like those of Bowen and Nagahama because Butler explicitly taught them as much: "Most previous theories of tunneling

conductance... [are] completely inadequate for understanding tunneling.” EX1044 (Butler) at page 1.

58. Accordingly, none of this art that Dr. Ross relies upon would have dissuaded one of skill from experimenting with lower barrier heights, including the barrier heights of Soukup, in Bowen and Nagahama, both of which taught MgO(001)-based MTJs.

VI. SOUKUP IS ANALOGOUS ART

59. I was also asked to respond to the following opinions of Dr. Ross about whether the Soukup reference (EX1028) constitutes analogous art to the '909 Patent:

- “[A]ll of the sources that I have been told are used to identify a patent’s field of endeavor convey that the '909 Patent’s field is MTJ devices.” EX2053 (Ross Decl.) ¶117.
- “Soukup’s study of *non-magnetic* devices in which the dominant current-flow mechanism was found not to be tunneling is not in the same field (*magnetic tunnel* junction devices) as the '909 Patent.” EX2053 (Ross Decl.) ¶121 (emphases in original).
- “The problem the inventor sought to solve was improving ‘the characteristics of the MTJ device’ to support MRAMs with greater capacities than the 64 Mbits achievable with then-current technologies. EX1017, 2:45-49. the [sic] inventor recognized that ‘the

magnetoresistance [TMR] must be increased and the bias voltage characteristics must be improved’ for an MTJ device to be viable for higher capacity MRAMs. EX1017, 2:49-52.” EX2053 (Ross Decl.) ¶122 (alteration in original).

- “A POSA would not have understood Soukup to be reasonably pertinent to the problem of increasing the TMR and reducing TMR dependency on bias voltage in an MTJ device.” EX2053 (Ross Decl.) ¶128.
- “A POSA thus would not have found anything about Soukup’s study of the electron transport mechanisms through an MgO layer in Au-MgO-Au devices reasonably pertinent to any problem the ’909 Patent was involved with, nor to ways in which the inventor solved them.” EX2053 (Ross Decl.) ¶131.

60. I disagree with Dr. Ross’ opinions that Soukup is not within the same field as the ’909 Patent and that Soukup is not reasonably pertinent to the problem the ’909 Patent sought to solve.

A. Soukup Is In The Same Field As The ’909 Patent

61. As Dr. Ross acknowledges, the Field of the Invention section of the ’909 Patent describes itself as related to “a magnetic tunnel junction device with a high magnetoresistance.” EX2053 (Ross Decl.) ¶114; EX1017 (’909 Patent) at col.

1:37-40. But more specifically, the '909 Patent says that it concerns MTJs with MgO barrier layers, *e.g.*, EX1017 ('909 Patent) at Abstract, cols. 3:5-4:8, 10:6-7 (Claim 1), 10:32-34 (Claim 9), 10:53-54 (Claim 15), Figs. 1B, 11, because MTJs with amorphous Al-O barrier layers failed to provide sufficiently high TMR, *id.* at col. 2:52-61. Thus, the '909 Patent is directed to high-magnetoresistance devices that use MgO barrier layers to achieve that high magnetoresistance.

62. Soukup's relationship to the '909 Patent is easily apparent to one of skill: Soukup evaluates mechanisms of current flow in MgO barriers, including tunneling. EX1028 (Soukup) at Abstract ("voltage-current characteristics of Au-MgO-Au thin-film emission diodes"), page 3229 ("The simple band picture was used by Simmons to analyze the electron injection process in terms of tunneling...") (citations omitted). With respect to the mechanisms of current flow, Soukup describes changing the barrier height of an MgO film by altering the number of oxygen vacancies in the barrier. *Id.* at page 3232. The '909 Patent also describes changing the barrier height of an MgO film by altering the number of oxygen vacancies in the barrier. EX1017 ('909 Patent) at cols. 3:5-61 ("MgO_x (0<x<1)"), 10:6-7 (same), 7:19-23 (oxygen vacancy defects lower barrier height). In fact, the '909 Patent Claims 1-4 expressly recite some level of oxygen vacancy defects in the MgO barrier layer. EX1017 ('909 Patent) at cols. 10:6-7 (Claim 1), 10:8-9 (Claim 2), 10:10-11 (Claim 3), 10:12-13 (Claim 4). To the extent the structure and function

of the claims are considered in determining the field of the invention as I understand they are, Soukup is within the same field as the '909 Patent.

63. It is therefore my opinion that the '909 Patent includes within its field other art that describes voltage-current characteristics of MgO barrier layers, especially those that expressly describe the effect of oxygen vacancy defects in MgO barrier layers, such as Soukup.

64. Dr. Ross' opinion that Soukup is not in the same field as the '909 Patent rests in part on her observation that Soukup's devices are not MTJs. EX2053 (Ross Decl.) ¶119. I disagree with this logic because it would necessitate concluding that the Simmons paper (EX1031) on barrier height, which the '909 Patent relies upon, EX1017 ('909 Patent) at col. 8:3-9, and which was published in 1963, EX1031 (Simmons), is not in the same field as the '909 Patent because it also does not discuss or describe MTJs. This makes no sense at all given the '909 Patent's express reliance on Simmons. Additionally, Dr. Ross' observation misses the mark because it fails to account for the myriad ways in which the '909 Patent's and Soukup's devices are similar.

- **Sandwiches:** The '909 Patent's devices are sandwiches of MgO barrier layers between metallic electrodes. EX1017 ('909 Patent) at cols. 1:51-58, 5:51-56. Soukup's devices also are MgO barrier layers

sandwiched between metallic electrodes. EX1028 (Soukup) at page 3229 (“metal-insulator-metal sandwich devices”).

- **Barrier height:** The '909 Patent discusses barrier height of conductor-insulator junctions in its devices. EX1017 ('909 Patent) at cols. 3:24-28, 4:2-6. Soukup also discusses barrier height of conductor-insulator junctions in its devices. EX1028 (Soukup) at pages 3229 (“[T]he insulator presents a potential barrier to conduction electrons in the metals.”), 3232 (“interfacial barrier height”).
- **Tunneling:** The '909 Patent discusses tunneling of electrons through its MgO barrier. EX1017 ('909 Patent) at cols. 5:39-6:18 (references to “the tunneling process”). Soukup also discusses tunneling of electrons through MgO. EX1028 (Soukup) at pages 3229 (“A number of other people have also analyzed the current flow mechanism in terms of tunneling.”), 3232 (“[I]t can be seen that the injection mechanism could now be tunneling...”).
- **Effect of oxygen vacancies on barrier height in MgO:** The '909 Patent purports to be based in part on the use of oxygen vacancy defects in the MgO barrier layer to lower the barrier height. *E.g.*, EX1017 ('909 Patent) at col. 7:19-31 (“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.”). Soukup also addresses the use of oxygen vacancy defects to lower barrier height. EX1028 (Soukup) at Abstract (“The apparent barrier height determined from the zero-field intercept went up for increasing oxygen pressure...”), pages 3232 (“In order to determine the effect of nonstoichiometry on the device characteristics a number of devices were fabricated by depositing the oxide film with oxygen gas present in the vacuum system.”), 3236 (“If the emission is Schottky emission the barrier height was a function of the amount of oxygen present in the vacuum system during deposition of the MgO film with a higher barrier for larger amounts of oxygen present.”).

65. Dr. Ross’ opinion that Soukup is not in the same field as the ’909 Patent further rests on her observation that Soukup was published before the Jullière paper in 1970. EX2053 (Ross Decl.) ¶119. I disagree for the same reasons I discussed above regarding Soukup’s failure to describe MTJs, which is effectively the same point Dr. Ross is making regarding the Jullière paper.

66. It therefore is my opinion that one of skill at the time of the ’909 Patent, exercising ordinary creativity, would have considered Soukup to be in the same field of art as the ’909 Patent and therefore analogous to the ’909 Patent.

B. Soukup Is Reasonably Pertinent To The Problem The '909 Patent Sought To Solve

67. It also is my opinion that Soukup is reasonably pertinent to the problem that the '909 Patent sought to solve. Again, the '909 Patent sought to improve magnetoresistance by adopting MgO barrier layers in its conductor-oxide-conductor sandwich devices and even to improve magnetoresistance by lowering barrier height using oxygen vacancy defects in MgO barriers. EX1017 ('909 Patent) at cols. 2:52-61 (improve MR), 1:51-58 (sandwich), 5:53-56 (same); *see also id.* at Abstract (MgO(001) barrier layer), cols. 3:5-4:8 (“In a preferred embodiment... the height of the tunnel barrier... is smaller than an ideal value... These features increase magnetoresistance.”), 10:6-7 (Claim 1), 10:32-33 (Claim 9), 10:53 (Claim 15), Figs. 1B, 11. Soukup similarly taught the use of MgO barrier layers in conductor-insulator-conductor sandwiches and specifically taught the effect on barrier height of oxygen vacancy defects in MgO barriers. EX1028 (Soukup) at page 3229. Accordingly, Soukup is reasonably pertinent to the problem to be solved.

VII. SOUKUP'S THESIS (EX2039)

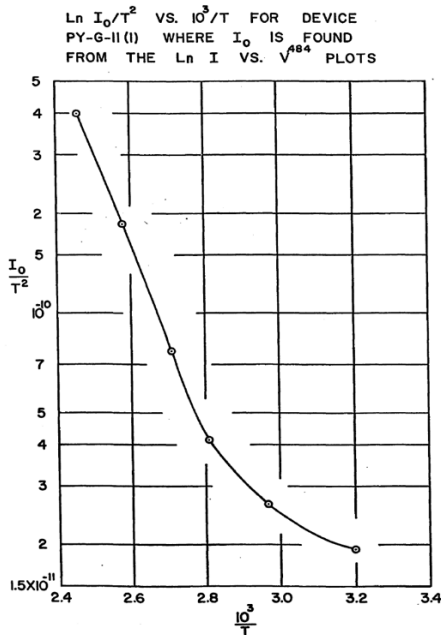


Figure 33

Figure 33
Soukup's 1969 Thesis (EX2039)

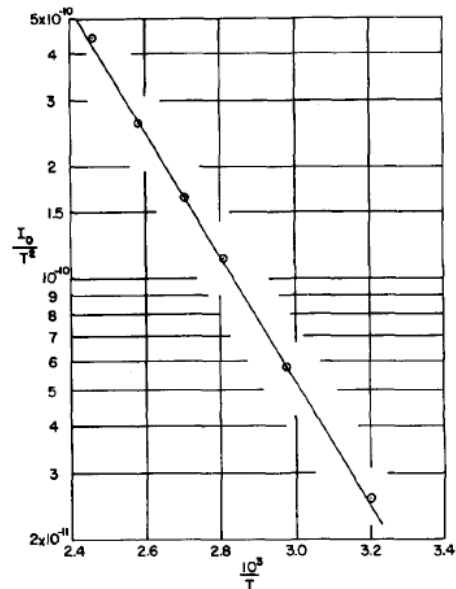


FIG. 5. $\text{Ln}(I_0/T^2)$ vs $10^3/T$ for device PY-G-11, overlayer 1.

Figure 5
Soukup's 1970 Paper (EX1028)

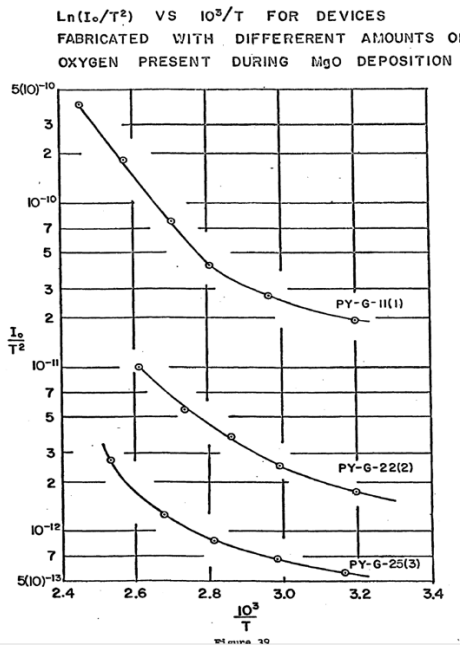


Figure 39

Figure 39
Soukup's 1969 Thesis (EX2039)

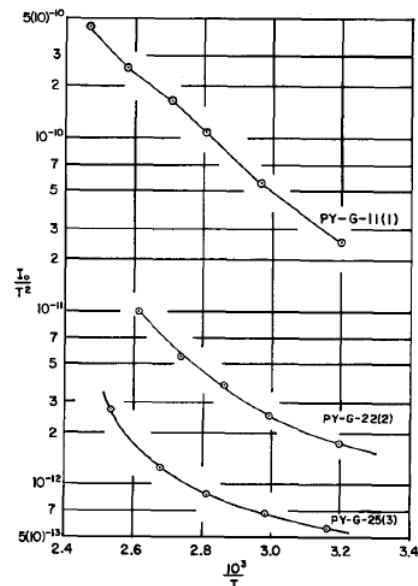


FIG. 12. $\text{Ln}(I_0/T^2)$ vs $10^3/T$ for devices fabricated with different amounts of oxygen present during MgO deposition.

Figure 12
Soukup's 1970 Paper (EX1028)

68. I was asked to respond to Dr. Ross’ reliance on Figures 33 and 39 in the Soukup thesis, reproduced above (EX2039). EX2053 (Ross Decl.) ¶108. Dr. Ross assumes that “[t]he Soukup article [EX1028] is based on the investigation Soukup performed for his doctoral dissertation (EX2039) that describes this study in greater detail.” *Id.* In fact, it appears that the data for sample PY-G-11(1) in Figures 33 and 39 of the Soukup thesis are different than what is reported for the same sample in Figures 5 and 12 of the Soukup article. Similarly, that traces back to the differences for PY-G-11(1) in Figure 32 of the Soukup thesis versus Figure 4 of the Soukup article. Those differences are due to the x-axis data being plotted as $V^{0.484}$ in Figure 32 of the thesis versus $V^{0.5}$ in Figure 4 of the paper. It appears that the change in data for sample PY-G-11(1) between publication of the earlier thesis (EX2039) and the later, peer-reviewed article (EX1028) that I rely upon stems from Soukup’s abandonment of his attempt to “correct” the Richardson-Schottky equation. *E.g.*, EX2039 (Soukup thesis) at pages 74-78 (discussing corrections of Richardson-Schottky in Appendix I and the impact of those corrections). One of skill at the time of the ’909 Patent would have understood this and would have credited the authoritative data in the later, peer-reviewed article over the data in the earlier thesis.

69. The difference in these values seen in the y-intercepts (I_0) in Figure 32 of the thesis versus Figure 4 of the published paper are readily apparent. For example, at 337 K, the thesis shows a y-intercept of approximately 3×10^{-6} whereas the paper shows around 6×10^{-6} for the same sample. One of skill reviewing Soukup's paper and thesis would conclude that the peer-reviewed paper abandoned the proposed correction of Richardson-Schottky in favor of the established formula resulting in the difference in reported reliability of the data for PY-G-11(1) between Soukup's thesis and paper. *E.g.*, EX1028 (Soukup) at page 3232 ("A plot of this type is made in Fig. 5. It can be seen that the plot is a straight line although most of these plots were not. The slope of the straight line drawn in the figure gives a barrier of $\phi_R^* = 0.33$ eV."). I disagree with Dr. Ross' election to rely on the data reported in the thesis over the data reported in the peer-reviewed paper without acknowledging there is a difference, much less addressing the reason for the difference.

VIII. THE PURPORTED SECONDARY EVIDENCE OF NON-OBVIOUSNESS DOES NOT CHANGE MY OPINIONS

70. When I prepared my First Declaration, IP Bridge had not provided its evidence pertaining to secondary considerations of non-obviousness. EX1024 (First Declaration) ¶331. I was asked to respond to Dr. Ross' opinion that "secondary considerations... compel a conclusion that the claims are non-obvious." EX2053 (Ross Decl.) ¶149. My First Declaration set forth a straightforward obviousness case

where each and every limitation was described in the prior art, and one of skill would have combined them with a reasonable expectation of success. As explained in Paragraph 6 of this Declaration, I understand that evidence unrelated to the specific claimed subject matter at issue, or relating to limitations of those claims already disclosed in the prior art, does not provide evidence of non-obviousness. I reviewed Dr. Ross' opinions on secondary considerations of non-obviousness, and in my view they are not sufficient to change my opinion that the '909 Patent claims are obvious.

71. I have considered the exhibits Dr. Ross cites, and I disagree that they suggest non-obviousness of the '909 Patent. None of the purported secondary evidence cited by Dr. Ross alters my opinions that the '909 Patent is obvious in view of the prior art. Even if Dr. Ross had established nexus, I believe that the prior art provides clear teachings leading one of skill to the conclusion that the claims would have been obvious. However, as explained below, I also disagree that there is any nexus between any allegedly novel aspects of the claims and the cited secondary considerations evidence. Dr. Ross relies on a common set of exhibits to argue secondary considerations of the tunnel barrier height claims in this '909 IPR and for its CoFeB-MgO claims in the '134 and '167 IPRs. As shown in the table below, the numbering is different between the IPRs, but the exhibits are the same:

'909 Patent IPR	'134/'167 Patent IPRs	Description
EX2005	EX2005	Zhu et al., <i>Magnetic tunnel junctions</i> , 9 Materials Today 36-45 (2006)
EX2008	EX2057	Yuasa citations, Google Scholar
EX2009	EX2052	Yuasa citations 2, Google Scholar
EX2015	EX2006	Djayaprawira et al., <i>230% room-temperature magnetoresistance in CoFeB/MgO/CoFeB magnetic tunnel junctions</i> , 86 Appl. Phys. Letters 092502 (2005)
EX2016	EX2007	Yuasa et al., <i>High Tunnel Magnetoresistance at Room Temperature in Fully Epitaxial Fe/MgO/Fe Tunnel Junctions due to Coherent Spin-Polarized Tunneling</i> , 43 Japanese J. Appl. Phys. L588 (2004)
EX2017	EX2008	Yuasa et al., <i>Giant room-temperature magnetoresistance in single crystal Fe/MgO/Fe magnetic tunnel junctions</i> , 3 Nature Materials, 868-871 (2004)
EX2019	EX2019	Marrows, <i>Spin-polarised currents and magnetic domain walls</i> , 54 Advances in Physics 585-713 (2005)
EX2020	EX2020	Tsymbal et al., <i>Handbook of Spin Transport and Magnetism</i> (Tsymbal et al. eds. 2012)
EX2022	EX2022	Nakatani et al., <i>Read sensor technology for ultrahigh density magnetic recording</i> , 43 MRS Bulletin 106-111 (2018)
EX2024	EX2024	<i>The 23rd (FY2022) Japan Society of Applied Physics Achievement Award Recipients</i> (with English translation), The Japan Society of Applied Physics
EX2026	EX2026	2021 New Fellows, IEEE Japan Council
EX2028	EX2028	Dr. Shinji Yuasa profile, Japan Science and Technology Agency
EX2029	EX2029	<i>AIST wins three Science and Technology Awards in the 2016 Minister of Education, Culture, Sports, Science and Technology Commendation for Science and Technology</i>
EX2032	EX2032	AIST: 20th Tsukuba Prize winner

'909 Patent IPR	'134/'167 Patent IPRs	Description
EX2033	EX2033	Announcing the winners for “Tsukuba Prize,” “Esaki Leona Prize,” and “Tsukuba Encouragement Prize,” Ibaraki Prefectural Science and Technology Promotion Foundation (with English translation), https://www.tsukuba-sci.com/cms/?p=9853
EX2038	EX2038	Maat et al., <i>Physics and Design of Hard Disk Drive Magnetic Recording Read Heads</i> , Handbook of Spintronics (2014)
EX1039	EX1039	Tehrani et al., <i>Progress and Outlook for MRAM Technology</i> , 35 IEEE Trans. Magn. 2814-2819 (1999)
EX1057	EX1057	Dieny et al., <i>Introduction to Magnetic Random-Access Memory</i> (IEEE Press 2017) (excerpts)

A. Praise By Others

72. Dr. Ross opined that “Dr. Yuasa has been repeatedly praised for his development of the method for making MTJs disclosed and claimed in the ’909 Patent. These awards were directly linked to the inventive MTJs claimed in the ’909 Patent.” EX2053 (Ross Decl.) ¶162; *see also id.*, ¶¶152-62. I disagree.

73. Dr. Ross cites several papers to argue Yuasa received industry praise. However, many of these papers were authored or co-authored by Yuasa himself, including Yuasa’s paper with Djayaprawira in Applied Physics Letters (EX2015), Yuasa’s paper in the Japanese Journal of Applied Physics (EX2016), Yuasa’s paper in Nature Materials (EX2017), Yuasa’s paper with Nagamine in Applied Physics Letters (EX2021), and Yuasa’s chapter in the Dieny textbook (EX1057). EX2053

(Ross Decl.) ¶¶152-57. One of skill would not have viewed Yuasa's own publications to constitute industry praise or praise by *others*.

74. Dr. Ross also opines that publications by Zhu/Park (EX2005), Marrows (EX2019), Tsymbal/Fert (EX2020), and Nakatani/Gao (EX2022) constitute praise by others of Yuasa's purported invention. EX2053 (Ross Decl.) ¶¶155, 157. Each of these papers describes Yuasa's contribution to the art as the application of MgO barrier layers in MTJs (replacing Al-O barrier layers in use at the time) to achieve improved TMR, in accordance with Butler's and Mathon's predictions. EX2005 (Zhu/Park) at page 38 (molecular beam epitaxy used to grow Fe/MgO/Fe MTJ); EX2019 (Marrows) at page 591 (MTJ with "MgO barriers" and "pure Fe electrodes grown by MBE"); EX2020 (Tsymbal/Fert) at page 8 (achieving "MgO [] of very high structural quality"); EX2022 (Nakatani/Gao) at page 107 (achieving MTJs "based on [the] theoretical prediction" of Butler and Mathon of "a TMR sensor with low resistance and high MR ratio" using coherent tunneling). I have seen nothing in these publications that praises what is claimed in the '909 Patent: ***MTJs with specific barrier heights***.

75. Dr. Ross also cites Dr. Yuasa's various awards and prizes. EX2053 (Ross Decl.) ¶¶158-61. Again, I see nothing about these awards that concern what is claimed in the '909 Patent: ***MTJs with specific barrier heights***. *Id.*

- **JSAP Award** (EX2024 at pages 2-3): “MTJs combining MgO and cobalt iron boron (CoFeB) alloys in collaboration with Canon ANELVA.” I saw nothing about this award mentioning barrier height.
- **IEEE Fellow** (EX2026 at page 1): “for contributions to MgO-based magnetic tunnel junctions.” I saw nothing about this award mentioning barrier height.
- **Yuasa JST profile** (EX2028 at page 4): variously referencing TMR and MgO-based MTJs. I saw nothing about this award mentioning barrier height.
- **S&T Prize** (EX2029 at page 2): “a new type of [MTJ]... using crystalline magnesium oxide (MgO) as the tunnel insulating film.” I saw nothing about this award mentioning barrier height.
- **Tsukuba Prize** (EX2032 at page 1): “experiments based on the theory that a very large MR ratio could be obtained by using crystalline magnesium oxide [] instead of the conventional amorphous aluminum oxide.” I saw nothing about this award mentioning barrier height.
- **Tsukuba Prize** (EX2033 at page 1): “for the first successful creation of a three-layer [MTJ]... composed of iron and MgO.” I saw nothing about this award mentioning barrier height.

B. Long-Felt But Unmet Need

76. Dr. Ross opines that there was a need for improved TMR in the industry that Yuasa’s purported inventions allegedly satisfied. EX2053 (Ross Decl.) ¶¶163-

66. Dr. Ross is wrong because it was Butler and Mathon who satisfied the need for improved TMR by proposing the adoption of MgO barrier layers in MTJs, not Yuasa. Butler and Mathon accurately predicted that adopting MgO barrier layers would result in “large magnetoresistance,” EX1044 (Butler) at page 1, “in excess of 1000%” TMR, EX1046 (Mathon) at page 1. Dr. Ross does not cite any evidence that there was a need for MTJs with barrier heights in the claimed range, the purported invention of the ’909 Patent. Dr. Ross also opines that the ’909 Patent “surprisingly and unexpectedly achieved the highest MR ratio MTJs seen [sic] at that time.” EX2053 (Ross Decl.) ¶167. But the ’909 Patent did not in fact provide the highest TMR at that time because Parkin achieved a higher TMR of 220% at room temperature before the ’909 Patent. EX1062 (Parkin) at col. 18:45-47. Nor does Dr. Ross explain why the 88% TMR at room temperature (293 K) that the ’909 Patent reported, EX1017 at col. 8:17, was surprising or unexpected in view of Butler’s and Mathon’s predictions of “large magnetoresistance,” EX1044 (Butler) at page 1, “in excess of 1000%,” EX1046 (Mathon) at page 1.

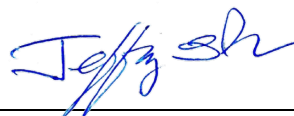
IX. CONCLUSION

77. In signing this Declaration, I recognize that the Declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be called upon to testify in deposition or before the Patent Trial and Appeal Board. If called upon to testify, I would testify truthfully and competently to all matters stated in this Declaration.

78. I reserve the right to supplement my opinions in the future to respond to any arguments that Patent Owner raises and to take into account new information as it becomes available to me.

79. I hereby declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true and that such statements are made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: October 8, 2025



Jeffrey Bokor