

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. IPR2024-01493
Patent No. 10,680,167

**DECLARATION OF CAROLINE A. ROSS, PH.D.
IN SUPPORT OF PATENT OWNER'S RESPONSE**

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I, Caroline A. Ross, Ph.D., declare as follows:

I. INTRODUCTION

1. I have been retained by Wolf, Greenfield & Sacks, P.C., counsel for Patent Owner GODO KAISHA IP BRIDGE 1 (“IP Bridge”), to provide my opinions concerning a Petition for *inter partes* review (IPR) filed by Petitioner Western Digital Corp. (“Western Digital”) challenging claims 1-15 (“Challenged Claims”) of U.S. Patent No. 10,680,167 (“the ’167 patent”). I am being compensated for my time at my standard rate plus actual expenses. My compensation is not dependent in any way upon the outcome of the *inter partes* review of the ’167 patent.

II. PERSONAL AND PROFESSIONAL BACKGROUND

2. I have over 30 years of experience in the fields of magnetic materials, magnetic nanostructures, ferroelectricity, magnetoresistance, thin film deposition, fabrication of spin-valve structures, including magnetic and spintronic devices. In my research, I have investigated the structure, crystallographic and magnetic properties of thin films, giant magnetoresistance metal layered structures, micromagnetic structures and the fabrication of such structures. A copy of my curriculum vitae is provided as EX2054.

3. I have extensive experience with magnetic recording media including magnetoresistive read/write heads; magnetic multilayer stacks including

magnetoresistive and exchange bias layers; thin film oxide deposition; electrical measurements of magnetoresistance; and characterization of microstructure, epitaxy and composition of thin film stacks.

4. I hold a B.A. and a Ph.D. in the field of Materials Science and Metallurgy, which I received from Cambridge University in 1985 and 1988, respectively. From 1989-1990, I was a Post-doctoral Fellow at Harvard University.

5. From 1991 to 1997, I was employed as an Engineer at Komag Inc., a manufacturer of hard disks, that was acquired by Western Digital in 2007. As part of my employment, I conducted research into hard disks and recording heads, including studies of thin film growth, magnetic and mechanical properties, patterning of thin films, and microstructural characterization.

6. Since 1997, I have been a Professor in the Department of Materials Science and Engineering at the Massachusetts Institute of Technology (MIT), appointed as assistant professor in 1997, associate professor in 2000 and full professor in 2004. I was the Associate Head of MIT's Department of Materials Science and Engineering for over 10 years before becoming Interim Department Head in 2023-2024. MIT's Department of Materials Science and Engineering is ranked as #1 by both US News and World Report 2024-25 and the QS World University Rankings 2025-6 for its undergraduate and graduate programs.

7. Throughout the course of my career, I have been invited to give over 170 lectures at conferences, laboratories, and universities. I have authored over 475 peer-reviewed articles, edited two books, and I have been awarded 22 U.S. patents. My publications include studies on magnetic tunnel junctions. In 2011, I was selected as one of the “Top 100 Materials Scientists of the Past Decade.”

8. Six of my papers that specifically address magnetic tunnel junctions are: Conductive Atomic Force Microscopy of Small Magnetic Tunnel Junctions with Interface Anisotropy, Stephan K. Piotrowski, Mukund Bapna, Hamid Almasi, Wei-Gang Wang, Larysa Tryputen, Caroline A. Ross, Mingen Li, Chia-Ling Chien, and Sara A. Majetich, IEEE Trans. Magn. 51(11) 4400504 (2015) 10.1109/TMAG.2015.2434798; Logic circuit prototypes for three-terminal magnetic tunnel junctions with mobile domain walls, J. A. Currivan-Incorvia, S. Siddiqui, S. Dutta, E. R. Evarts, J. Zhang, D. Bono, C. A. Ross, and M. A. Baldo, Nat. Commun. 7 10275 pp1-7 (2016) <DOI: 10.1038/ncomms10275>; Patterning of sub-50 nm Perpendicular CoFeB/MgO-based Magnetic Tunnel Junctions, Larysa Tryputen, Kun-Hua Tu, Stephan K. Piotrowski, Mukund Bapna, Sara A. Majetich, Congli Sun, Paul Voyles, Hamid Almasi, Weigang Wang, Patricio Vargas, Jason S. Tresback, Caroline A. Ross, Nanotechnol. 27 185302 (2016) (7pp) doi:10.1088/0957-4484/27/18/185302; Magnetic reversal and thermal stability of CoFeB perpendicular magnetic tunnel junction arrays patterned by

block copolymer lithography, Kun-Hua Tu, Eduardo Fernandez, Hamid Almasi, Weigang Wang, David Navas Otero, Konstantinos Ntetsikas, Dimitrios Moschovas, Apostolos Avgeropoulos and Caroline A Ross, *Nanotechnology* 29 (2018) 275302 (12pp), <https://doi.org/10.1088/1361-6528/aabce8>; Spintronic logic circuit and device prototypes utilizing domain walls in ferromagnetic wires with tunnel junction readout, J. A. Currivan-Incorvia; S. Siddiqui; S. Dutta; E. R. Evarts; C. A. Ross; M. A. Baldo, 2015 IEEE International Electron Devices Meeting (IEDM) Pages: 32.6.1 - 32.6.4, DOI: 10.1109/IEDM.2015.7409817 IEEE Conference Publications; and A Logic-in-Memory Design with 3-Terminal Magnetic Tunnel Junction Function Evaluators for Convolutional Neural Networks, Sumit Dutta, Saima A. Siddiqui, Felix Büttner, Luqiao Liu, Caroline A. Ross, and Marc A. Baldo, 2017 IEEE/ACM International Symposium on Nanoscale Architectures (NANOARCH). p83-88 doi.ieeecomputersociety.org/10.1109/NANOARCH.2017.8053724

9. Some of my other papers that are particularly relevant to the Yuasa patents are those that address growth and structure of ultra-thin layers of oxides and metals such as: Ross, C.A., “Electrodeposited multilayer thin films,” *Annual Review of Materials Science*, 24 159-188 (1994); C.A. Ross, S. Haratani, F.J. Castaño, B. Vogeli, S. Sumita, “Fabrication of MRAM structure and their magnetic properties”, *J. of the Society of Materials Engineering for Resources of*

Japan 14 p43-51 (2001); F.J. Castaño, Y. Hao, C.A. Ross, B. Vogeli, Henry I. Smith, S. Haratani, “Switching field trends in sub-100 nm pseudo spin valve arrays”, J. Appl. Phys. 91 7317-9 (2002); M. Shima, T. Tepper, C.A. Ross, “Magnetic properties of chromium oxide and iron oxide films produced by pulsed laser deposition J. Appl. Phys. 91 7920-22 (2002); C.A. Ross, F.J. Castaño, E. Rodriguez, S. Haratani, B. Vögeli and Henry I. Smith, “Size-dependent switching of multilayer magnetic elements”, J. Applied Physics 97, 053902 (2005); Magnetic structure and anisotropy of [Co/Pd]5/NiFe multilayers, Larysa Tryputen, Feng Guo, Frank Liu, T. N. Anh Nguyen, Majid S. Mohseni, Sunjae Chung, Yeyu Fang, Johan Akerman, R. D. McMichael, and Caroline A. Ross, Phys. Rev. B 91, 014407 p1-6 (2015); Rare-Earth Iron Garnet Superlattices with Sub-unit Cell Composition Modulation, B Khurana, A.C. Kaczmarek, C.T. Chou, T. Su, K. Lasinger, T. Grossmark, D.C. Bono, L. Liu, C.A. Ross, ACS Nano 18 (52), 35269–35275 (2024); those that describe magnetoresistive measurements such as: Walsh M., Y. Hao, C.A. Ross, H.I. Smith, “Optimization of a lithographic and ion beam etching process for nanostructuring magnetoresistive thin film stacks”, J. Vac. Sci. Technol. B18 3539-3543 (2000); F.J. Castaño, S. Haratani, Y. Hao, C.A. Ross, H.I. Smith, “Giant Magnetoresistance in 60 – 150 nm wide pseudo spin-valve nanowires”, Appl. Phys. Letts. 81 2809-11 (2002); F. J. Castaño, D. Morecroft, W. Jung and C. A. Ross “Spin-dependent scattering in multilayered magnetic rings”,

Phys. Rev. Letts. 95 137201 1-4 (2005); D. Morecroft, F. J. Castaño, W. Jung, C. A. Ross, Angular dependence of the giant magnetoresistance in multilayer rings with different contact configurations, J Appl. Phys. 99 08T104 1-3 (2006); Jeong Dae Suh, C. A. Ross, Dependence of the giant magnetoresistance ratio on the nano-oxide layer position in NiFe/Cu/Co pseudo-spin valve films, Phys. Stat. Sol. (b) 244 4474-7 (2007); F.J. Castaño, B.G. Ng, I.A. Colin, D. Morecroft, W. Jung, C.A. Ross, Magnetoresistance of submicron multilayer Wheatstone bridges as a probe of magnetic reversal mechanism, J. Phys. D 41 132005 (2008) and those that address structural and compositional characterization such as: T J Bromwich, A. Kohn, A K Petford-Long, T Kasama, R Dunin-Borkowski, S Newcomb, C A Ross, “Remanent magnetization states and interactions in square arrays of 100 nm cobalt dots measured using transmission electron microscopy”, J. Appl. Physics 98 053909 1-8 (2005) These examples are not a complete list of my relevant publications.

10. At Komag, my work included development of thin film media consisting of sputtered thin films of magnetic materials, underlayers, and overlayers; studies of epitaxial, polycrystalline and amorphous layers in thin films and multilayers; and the analysis of materials for read/write heads including magnetic pole piece materials, magnetoresistive elements and overcoat materials.

III. MATERIALS REVIEWED AND CONSIDERED

11. In addition to the Petition (Paper 1), the Board's Institution Decision (Paper 9), and any other documents cited or referenced herein, Appendix A provides a list of materials that I have considered in forming the opinions set forth in this Declaration.

IV. LEGAL PRINCIPLES

12. In developing my opinions, I discussed various relevant legal principles with Petitioners' attorneys. I understood these principles when they were explained to me and have relied upon such legal principles, as explained to me, in the course of forming the opinions set forth in this declaration. My understanding in this respect is as follows:

13. I understand that "*inter partes* review" (IPR) is a proceeding before the United States Patent & Trademark Office for evaluating the patentability of an issued patent's claims based on prior-art patents and printed publications.

14. I understand that, in this proceeding, Petitioner has the burden of proving that the challenged claims of the '167 patent are unpatentable by a preponderance of the evidence. I understand that "preponderance of the evidence" means that a fact or conclusion is more likely true than not true.

15. I understand that, in IPR proceedings, claim terms in a patent are given their ordinary and customary meaning as understood by a person of ordinary

skill in the art (“POSA”) in the context of the entire patent and its prosecution history. If the specification or prosecution history provides a special definition for a claim term that differs from the meaning the term would otherwise possess, that special definition applies. I have applied these standards in preparing the opinions in this declaration.

16. I understand that for an invention claimed in a patent to be patentable, it must be, among other things, not obvious from the prior art. My understanding of that standards is set forth below.

A. Obviousness

17. I understand that a patent claim may be unpatentable if it would have been obvious in view of a single prior-art reference or a combination of prior-art references.

18. I understand that a patent claim is obvious if the differences between the subject matter of the claim and the prior art are such that the subject matter as a whole would have been obvious to a person of ordinary skill in the relevant field at the time the invention was made. Specifically, I understand that the obviousness question involves a consideration of:

- the scope and content of the prior art;
- the differences between the prior art and the claims at issue;
- the knowledge of a person of ordinary skill in the pertinent art; and

- objective factors indicative of non-obviousness, sometimes referred to as “secondary considerations.”

19. I understand that in order for a claimed invention to be considered obvious, a POSA must have had a reason for combining teachings from multiple prior-art references (or for altering a single prior-art reference) in the fashion proposed.

20. I understand that obviousness is determined in light of all the facts and that in evaluating alleged reasons to combine references the references must be considered for all their teachings. Furthermore, I understand that the teachings of references or the knowledge of a person having ordinary skill in the art (as discussed below) is understood to teach away from forming a combination achieving a claimed invention if it would have discouraged a person of ordinary skill in the art from forming a combination or would have caused a person having ordinary skill in the art to follow a path that diverged from path taken by the inventor.

21. I understand that obviousness requires that a person of ordinary skill in the art would have had a reasonable expectation of success that a purported combination would have achieved an intended result that meets the claim limitations.

22. I understand that for a single reference or a combination of references to render the claimed invention obvious, a POSA must have been able to arrive at the claimed invention by modifying, implementing, or combining the teachings of the applied references.

B. Claim Interpretation

23. I understand that determining whether a claimed invention is novel and non-obvious requires comparing the prior art to the claims. In this section, I discuss the interpretations I have applied to certain claim terms in my analysis.

24. I have been informed that patent claims are construed from the viewpoint of a person of ordinary skill in the art at the time of the alleged invention. I have been informed that patent claims generally should be interpreted consistent with their plain and ordinary meaning as understood by a person of ordinary skill in the art in the relevant time period (at the time of the purported invention, or the so called “effective filing date” of the patent application), after reviewing the patent claim language, the specification, and the prosecution history (the intrinsic record).

25. I have further been informed that a person of ordinary skill in the art must read the claim terms in the context of the claim itself, as well as in the context of the entire patent specification. I understand that in the specification and prosecution history, the patentee may specifically define a claim term in a way that

differs from the plain and ordinary meaning. I understand that the prosecution history of the patent is a record of the proceedings before the U.S. Patent and Trademark Office and may contain explicit representations or definitions made during prosecution that affect the scope of the patent claims. I understand that an applicant may, during the course of prosecuting the patent application, limit the scope of the claims to overcome prior art or to overcome an examiner's rejection, by clearly and unambiguously arguing to overcome or distinguish a prior art reference, or to clearly and unambiguously disavow claim coverage.

26. In interpreting the meaning of the claim language, I understand that a person of ordinary skill in the art may also consider "extrinsic" evidence, including expert testimony, inventor testimony, dictionaries, technical treatises, other patents, and scholarly publications. I understand this evidence is considered to ensure that a claim is construed in a way that is consistent with the understanding of those of skill in the art at the time of the alleged invention. This can be useful for technical terms whose meaning may differ from its ordinary English meaning. I understand that extrinsic evidence may not be relied on if it contradicts or varies the meaning of claim language provided by the intrinsic evidence, particularly if the applicant has explicitly defined a term in the intrinsic record.

27. I understand that determining whether a claimed invention is novel and non-obvious requires comparing the prior art to the challenged claim. In this

Declaration, I apply the above standards to the terms in the challenged claims. The meanings of specific terms are discussed below in connection with evaluating the disclosure in the priority documents.

V. PERSON OF ORDINARY SKILL IN THE ART (“POSA”)

28. I have been informed and understand a patent and prior-art references must be assessed from the perspective of a person having ordinary skill in the art (“POSA”) to which the patent is related, based on the understanding of that person at the time of the patent claim’s priority date. I have been asked to provide my opinions as to the state of the art in the 2004 timeframe.

29. When I refer to a POSA, I am referring to one of ordinary skill in 2004 unless specified otherwise, even if I do not say so specifically in each case. I have applied this standard throughout my declaration.

30. I understand that Petitioner and Petitioner’s expert Dr. Bokor have proposed that a POSA as of 2004 would be someone that would have had a Ph.D. in electrical engineering, physics, materials science, or a related field, and at least one year of experience in the research, design, and/or development of magnetic/spintronic devices, or the equivalent, or a Master’s degree in electrical engineering, physics, materials science, or a related field, and four years of experience in the research, design, and/or development of magnetic/spintronic

devices, or the equivalent. Less work experience may be compensated by a higher level of relevant education, and vice versa. EX1024 ¶25.

31. My opinions set forth in this declaration are from the perspective of that POSA. In 2004, I held a Ph.D. in Materials Science and Metallurgy from Cambridge University, held a Postdoctoral Fellowship in the Engineering and Applied Sciences department at Harvard University, held a Professorship at Massachusetts Institute of Technology, had 7 years of experience as an engineer at Komag Inc. (purchased by Western Digital) and had more than a decade of experience in magnetic materials and devices, including spintronics. Therefore, I was a person of more than ordinary skill in the art during the relevant timeframe.

32. I have worked with and trained many people who fit the characteristics of the POSA, and I am familiar with their level of skill. When developing the opinions set forth in this declaration, I assumed the perspective of a person having ordinary skill in the art, as set forth above. My opinions are from that perspective even when I do not specifically say so.

VI. '167 PATENT¹

A. Overview

33. The '167 patent concerns magnetic tunnel junction (“MTJ”) devices—magnetoresistive solid state devices having a tunnel barrier layer between two ferromagnetic electrodes. While an MTJ device has many applications, one use is in persistent non-volatile storage devices like a solid-state memory such as magnetoresistive random access memory (“MRAM”).

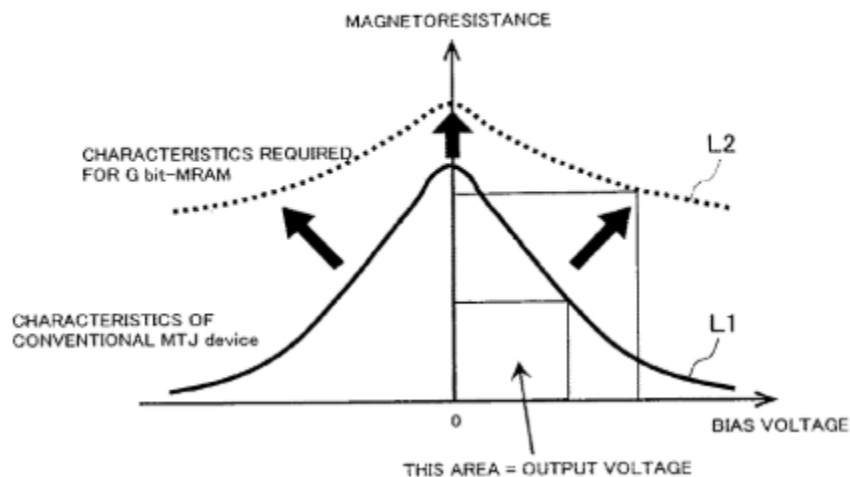
34. The '167 Patent recognized that while “MRAMs with capacities on the order of 64 Mbits” could be achieved using then-current technologies, “the characteristics of the MTJ device [] needs to be improved if higher levels of integration are to be achieved.” EX1013, 2:32-53. This required smaller MRAM cell sizes which would make it more challenging to accurately detect the signal indicating whether the MTJ was in its parallel or antiparallel state given the circuit’s noise. *Id.*

35. FIG. 10 illustrates TMR characteristics of conventional MTJ devices as of the filing date. As shown by line L1, conventional MTJs had a “small” TMR that “drastically decrease[s] upon application of bias voltage” which rendered those MTJ devices unsuitable for MRAM devices. *Id.*, 2:39-47. As shown by the

¹ Unless otherwise indicated all emphases in quoted language is added.

line dotted line L2, an MTJ with a higher peak TMR and slower decay with increasing bias voltage would be needed to support a Gigabit MRAM.

FIG. 10

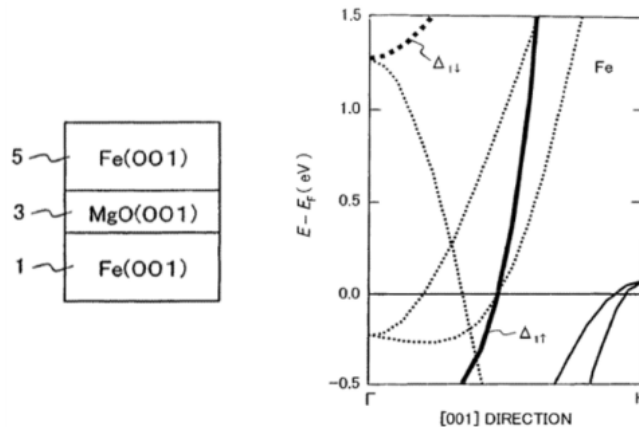


36. As a result of the low peak TMR and its rapid decay, conventional MTJs had small output voltages (a voltage signal representative of the MTJ's magnetic state) of 200 mV that would not be able to support higher-capacity MRAMs. *Id.*, 2:47-53, 8:21-36 (discussing output voltages). The inventor sought to increase TMR and decrease its bias voltage dependency to address the problem of conventional MTJs that, as the level of integration in MRAM increases, "signals are increasingly lost in noise and cannot be read." *Id.*, 2:36-53. The inventor explained that "Julliere's formula predicts a highest estimated MR ratio of about 70%." *Id.*, 4:62-5:24. The inventor noted that although this approximately 70% TMR had been obtained with "an amorphous Al-O tunnel barrier and polycrystalline electrodes, it has been difficult to obtain the output voltage of 200

mV ... thereby preventing the realization of MRAM.” *Id.*, 4:62-5:24; *see also id.*, 2:47-57.

37. The '167 Patent recognized that conventional aluminum oxide (Al_2O_3)-based MTJs would not exhibit the TMR characteristics needed for use in practical applications such as large capacity MRAM where the increased density of the circuits would make it difficult to distinguish the TMR signal from the noise. *Id.*, 2:32-53. The '167 Patent also explained that Julliere's equation predicted limits on the TMR achievable from electrode spin polarization alone and that, even with “the highest estimated MR ratio of about 70%” for ferromagnetic transition metals and alloys, conventional MTJs “using an amorphous Al—O tunnel barrier and polycrystalline electrodes,” the low achievable output voltages would prevent realization of high-capacity MRAM. *Id.*, 5:18-24.

38. The '167 Patent recognized the benefit of using “a single-crystal (001) of magnesium oxide (MgO) or a polycrystalline MgO in which the (001) plane is preferentially oriented” as the tunnel barrier in an MTJ device because, unlike amorphous aluminum oxide, “the electrons are not scattered and the coherent states of the electrons are conserved during the tunneling process. *Id.*, 5:25-33. FIG. 1(B) (below left) illustrates one embodiment of an MgO-based MTJ device structure and FIG. 1(A) (below right) shows the energy band structure of the ferromagnetic Fe(001) in that structure. *Id.*, 5:33-44.



39. As shown in FIG. 1(A), the “majority spin $\Delta 1$ band (solid line) has states at the Fermi energy E_F , whereas the minority spin $\Delta 1$ band (broken line) does not have state at the Fermi energy E_F .” *Id.*, 5:62-65. Because of this characteristic in the Fe(001) electrode, “there is the possibility that a very high MR ratio can be obtained in a coherent spin polarized tunneling.” *Id.*, 5:65-6:1. The ’167 Patent explains that since in a “single-crystal” or “(001) oriented polycrystal” MTJ device (such as FIG. (1A)’s MTJ above) the scattering of electrons is suppressed during the tunneling process, it provides an ideal MTJ structure for “realizing the aforementioned coherent tunneling.” *Id.*, 6:1-5.

40. The inventor of the ’167 Patent, Dr. Shinji Yuasa, recognized that this ideal MTJ structure could be manufactured by growing a single-crystal MgO(100) seed layer, followed by growth of an epitaxial Fe(001) lower electrode. *Id.*, 6:6-34. This was followed by forming a Fe(001) upper electrode on the MgO(001) barrier layer. *Id.*, 6:44-47. Last, “[a] Co layer was provided [on the Fe(001) upper

electrode] to increase the coercive force of the upper electrode so as to realize the antiparallel magnetization alignment.” *Id.*, 6:47-54.

41. As the '167 Patent recognized, Fe(001) could be interchanged with Fe alloys, such as Fe–Co alloy, Fe–Ni alloy, or Fe–Pt alloy. *Id.*, 8:37-42. The '167 Patent further recognized that “an amorphous ferromagnetic alloy, such as CoFeB” could also be used for the electrodes. *Id.*, 9:6-19. The '167 Patent discloses that “an anneal process after the preparation of the MTJ device might cause the amorphous magnetic alloy in the electrode layers to be partially or entirely crystallized,” which “would not lead to a significant deterioration of the MR ratio.” *Id.*, 9:20-25. The '167 Patent discloses that “such a crystallized amorphous magnetic alloy may be used in the electrode layers.” *Id.*, 9:26-27.

42. Dr. Yuasa’s efforts then led to the discovery that the same ideal MTJ device could be made starting from amorphous MgO. *Id.*, 8:43-60. In this second method of manufacturing, Dr. Yuasa discovered that amorphous MgO could be deposited and then annealed “such that a poly-crystal in which the (001) crystal plane is preferentially oriented or a single-crystal is obtained.” *Id.*, 8:45-51. As the '167 Patent explains, Dr. Yuasa realized that his ground-breaking method of manufacturing MTJs, including “an annealing process []carried out for crystallization after an amorphous MgO has been deposited by sputtering,” “eliminat[ed] the need for large-sized equipment.” *Id.*, 9:1-5.

43. Dr. Yuasa also confirmed that while “an anneal process after the preparation of the MTJ device might cause the amorphous magnetic alloy in the electrode layers to be partially or entirely crystallized, this would not lead to significant deterioration of the MR ratio.” *Id.*, 9:20-25. This further discovery led Dr. Yuasa to the realization that “a crystallized amorphous magnetic alloy may be used in the electrode layers,” including amorphous CoFeB crystallized by annealing. *Id.*, 9:6-27.

44. EX2008 (“Yuasa NM paper”) is Dr. Yuasa’s October 2004 paper describing his work on Fe/MgO/Fe MTJs described in the ’167 Patent, which was published in Nature Materials journal shortly after filing the two Japanese patent applications to which the ’167 Patent claims priority. EX1013, Patent Face at (30). He also published his work on Fe/MgO/Fe MTJs in the Japanese Journal of Applied Physics (“Yuasa JJAP paper”) in April of 2004 (EX2007) and published his work on CoFeB/MgO/CoFeB MTJs described in the ’167 Patent in Applied Physics Letters (“Yuasa APL paper”) on February 23, 2005 (EX2013). These are prominent peer-reviewed journals.

B. Challenged Claims

45. Claims 1-15 (“Challenged Claims”) each recite a method of manufacturing a MTJ device. A claim list is provided at Appendix B.

46. Independent claims 1 and 11 recite four steps: (1) **forming** a “first” amorphous CoFeB layer; (2) **forming** a MgO layer “over the first CoFeB layer”; (3) **forming** a “second” amorphous CoFeB layer; and (4) **annealing** the three MTJ layers such that the two CoFeB layers are “crystallized.”

47. The claims require that the manufacturing process results in the MgO layer and the two CoFeB layers having certain crystalline properties. Independent claims 1 and 11 require that annealing “crystallize[s]” the first and second CoFeB layers. All claims require the MTJ to have polycrystalline MgO with a preferentially-oriented (001) crystal plane, while claim 11 requires “forming” the MgO layer to have this microstructure.

48. A polycrystalline microstructure refers to the structure of a material composed of many small, differently oriented crystal grains (also called crystallites) separated by grain boundaries. These materials lack the long-range order of a single crystal. The grain boundaries demarcate regions of different crystal orientation, and atoms at the grain boundaries lack the nearest neighbor coordination found in the ideal crystal. In a polycrystalline film with a (001) preferential orientation, the grains are not randomly oriented but instead their (001) crystal planes are approximately parallel to the plane of the film.

49. Limitation 1[e] requires “the MgO layer is poly-crystalline in which a (001) crystal plane is preferentially oriented,” while Limitation 11[b] requires “a

barrier layer including a magnesium oxide (MgO) layer to have a poly-crystalline state in which a (001) crystal plane is preferentially oriented over the first ferromagnetic layer.”

50. In this Declaration, I refer to these limitations on the polycrystalline MgO having a preferentially-oriented (001) crystal plane at 1[e] and 11[b] as “the claimed microstructure” or “the claimed MgO microstructure.” Because this limitation appears in the two independent claims 1 and 11, I understand that every Challenged Claim requires a barrier layer meeting this MgO microstructure limitation.

VII. REFERENCES

51. I understand that each reference used in the grounds was before the Examiner. EX1013, Patent Face at (56) (listing U.S. Patent No. 7,270,896 (Parkin), U.S. Application Publication No. 2004/0144995 (Nagahama), JP Publication No. 2002-204004 (Sunai), and Bowen’s publication “Large Magnetoresistance in Fe/MgO/FeCo(001) Epitaxial Tunnel Junctions on GaAs(001)”).

A. MTJ References Using Crystalline Electrodes to Match a Crystalline MgO Layer.

1. Bowen (EX1026)

52. Bowen describes a Fe(001)/MgO(001)/FeCo(001) tunnel junction on MgO(001)-buffered GaAs(001). EX1026, 1655-1656. This conventional notation

of materials separated by “/” reflects the order in which the individual layers are formed.

53. Bowen’s MTJ is an entirely single-crystal structure epitaxially grown on GaAs (001). EX1026, 1655. Notably, the MgO buffer layer offers “an appropriate symmetry and lattice match for the epitaxy of Fe on top” of the buffer layer. *Id.*

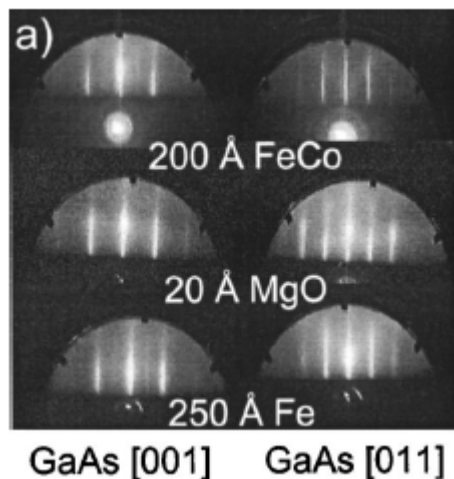
54. The bottom Fe electrode is deposited at room temperature and annealed at 400 °C for optimal “crystallinity, continuity, and interface sharpness.” *Id.*, 1655-1656.

55. A 20 Å thick MgO barrier layer is then epitaxially grown at 400 °C on the bottom Fe electrode. *Id.* An Angstrom (Å) is 10 nanometers (“nm”), so 20 Å is a thickness of 2 nm.

56. And finally a top CoFe electrode is epitaxially grown at room temperature. *Id.* Thus, Bowen describes MgO(001) as being epitaxially grown as a single crystal from a compatibly-oriented single crystal electrode and a substrate underlying the tunnel barrier.

57. Bowen specified a particular fabrication process, under “optimized growth conditions,” achieving “entirely epitaxial samples of high crystalline quality with flat sharp interfaces.” EX1026, 1657. Figure 1(a) shows electron diffraction from the crystalline Fe(001)/MgO(001)/FeCo(001) trilayers for

Bowen's MTJ grown epitaxially on MgO(001)-buffered GaAs(001) which supports Bowen's interpretation of the films being epitaxial. EX1026, 1656, Fig. 1(a) (below).



58. Bowen's process steps used prior work by Bowen's coauthors that developed a new way to grow epitaxial MgO(001) on a semiconductor substrate (GaAs) and provided the MgO buffer, bottom Fe electrode, and epitaxial MgO growth portions of Bowen's manufacturing method. EX1026, 1655, n.8 (citing EX1084); EX2018 [6/25/25], 144:17-22; EX1084, 224 ("very few works have reported on... the epitaxy of MgO on Fe(001)"), 229.

59. Specifically, Boubeta reported a new method where "Fe/MgO heterostructures on GaAs(001) substrates [were] achieved by combined use of sputtering and laser ablation deposition techniques." EX1084, 223. For this method, Boubeta utilized MgO as a "buffer layer," which served to function as an interdiffusion barrier and to "offer[] an appropriate symmetry and lattice match for

the epitaxy of bcc Fe(001) layers.” *Id.*, 224. Thus, Boubeta devised a method to obtain Fe(001) on crystalline MgO for the purpose of layering Fe/MgO on GaAs(001). *Id.*

60. Focusing on Bowen’s MTJ layers:

61. **First**, Bowen deposited Fe on an MgO buffer layer by triode sputtering at room temperature (RT). EX1026, 1655 (“Fe layers were deposited... from individual Fe... targets by triode sputtering[.]”).

62. **Second**, Bowen annealed the uncapped Fe layer at 400°C to achieve crystalline bcc-structured Fe(001). EX1026, 1655 (“Optimal deposition temperatures were... RT **plus annealing at 400°C** for the Fe bottom electrode.”), 1655-1656, Fig. 1(a). “This low-temperature deposition and **subsequent annealing** process leads to **an optimal Fe electrode in terms of crystallinity, continuity, and interface sharpness.**” EX1026, 1655; EX1084, 228 (“Fe films were grown at RT and annealed at 400°C[.]”).

63. **Third**, Bowen grew single-crystal epitaxial bcc-structured MgO(001) at 400°C on the Fe(001) bottom electrode. EX1026, 1655-1656 (“Optimal deposition temperatures were 400°C for the MgO[.]”); EX1084, 228 (“MgO layers were grown 400°C”), 229 (“[E]pitaxy of MgO thin films on the previously deposited Fe layers is also demonstrated, opening new directions for the

fabrication of fully epitaxial metal/insulator heterostructures on semiconductor substrates.”).

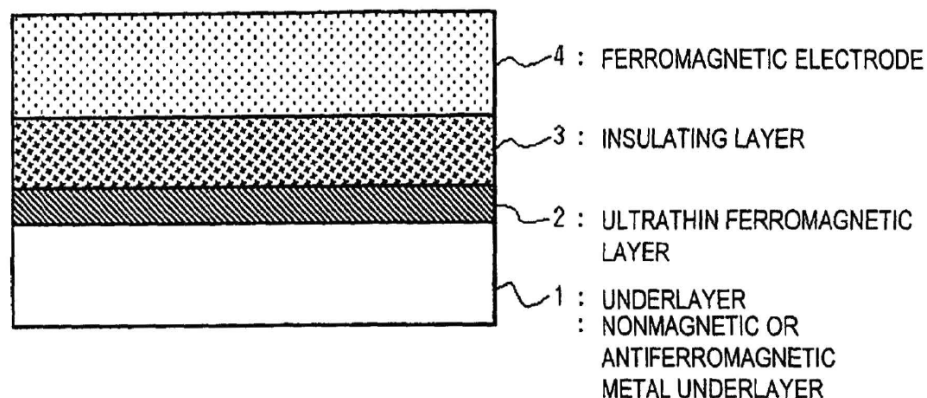
64. **Fourth**, Bowen deposited $\text{Fe}_{50}\text{Co}_{50}$ at room temperature on the epitaxial $\text{MgO}(001)$ layer, achieving a bcc-structured $\text{FeCo}(001)$ top electrode. EX1026, 1655 (“ $\text{Fe}_{50}\text{Co}_{50}$ layer[] [was] deposited from individual Fe and Co targets by sputtering.... Optimal deposition temperatures were... RT for the FeCo top electrode[.]”), 1656, Fig. 1(a).

65. The **only** annealing step that Bowen applies to the MTJ layers is when Bowen anneals the Fe layer at 400°C **before** epitaxially growing the $\text{MgO}(001)$ on it. At no point does Bowen anneal the top FeCo electrode, or the entire MTJ structure.

2. Nagahama (EX1027)

66. Nagahama describes an MTJ comprising a tunnel barrier layer sandwiched between two ferromagnetic layers. EX1027, [0021]-[0022], Fig. 3 (reproduced below).

FIG. 3



67. Nagahama describes providing a “larger magnetoresistive effect” in the MTJ by “varying only the thickness of a known material” layer “to increase spin polarization without changing the chemical composition of the material.” *Id.*, [0015]. Nagahama provides this result by, among other things, controlling the thickness of a lower ferromagnetic material layer. *Id.*, [0023].

68. Specifically, Nagahama describes forming ferromagnetic layer 2 from iron (Fe). *Id.*, [0024]-[0025], [0028]-[0029]. Nagahama explains that for thin iron (Fe) ferromagnetic material layers, the magnetoresistance depends on the layer thickness. *Id.*, [0028], Fig. 4.

69. Nagahama achieves “a large magnetoresistive effect” by making the lower ferromagnetic layer ultrathin, *e.g.*, setting the thickness of the ultrathin ferromagnetic layer 2 “in the range of 1 to 15 atomic layers.” *Id.*, [0022]-[0023],

[0029] (“The magnetoresistive effect is substantially two times increased by setting the thickness of the Fe layer in the range of 4 to 10 atomic layers.”).

70. Nagahama describes using iron (Fe) (*e.g.*, *id.*, [0028], [0061]) and CoFe (*id.*, [0068]) for the ferromagnetic layer. Nagahama does not disclose using boron in the ferromagnetic layer.

71. A “third group” of embodiments is represented by the cross-sectional view of Figs. 12-13. *Id.*, [0060]. “[R]eference numeral 211 designates a Si substrate with an oxide film; 212, a MgO layer (10 nm); 213, Fe(001) layer (20 nm); 214, an amorphous Al-O layer; 215, an upper electrode (polycrystalline Ni-Fe) layer; and 216, an Au cap layer.” *Id.*, [0061].

FIG. 12

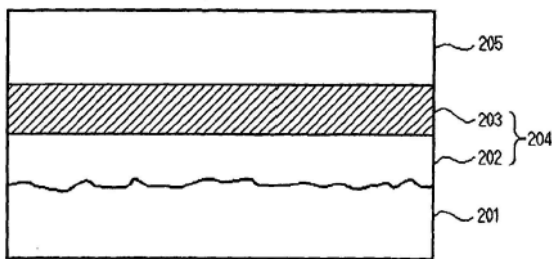
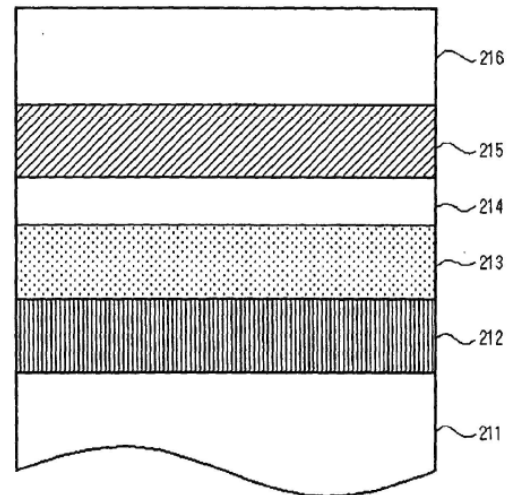


FIG. 13



72. Nagahama describes making the above embodiment by first cleaning the Si wafer with water, removing the water, and then depositing the “MgO 212

(10 nm) by sputtering.” *Id.*, [0057]. Nagahama teaches that “[o]nly through these steps, MgO grows amorphous to be the amorphous MgO layer 202 in the early stage and, then, to be the MgO(001)-oriented highly oriented crystal layer 203.” *Id.*, [0058].

73. Nagahama discloses another embodiment in the “third group” that “includes a (001)-highly-oriented lower ferromagnetic electrode layer, a (001)-highly-oriented MgO barrier layer, and a (001)-highly-oriented upper ferromagnetic electrode layer on the MgO double underlayer.” *Id.*, [0073].

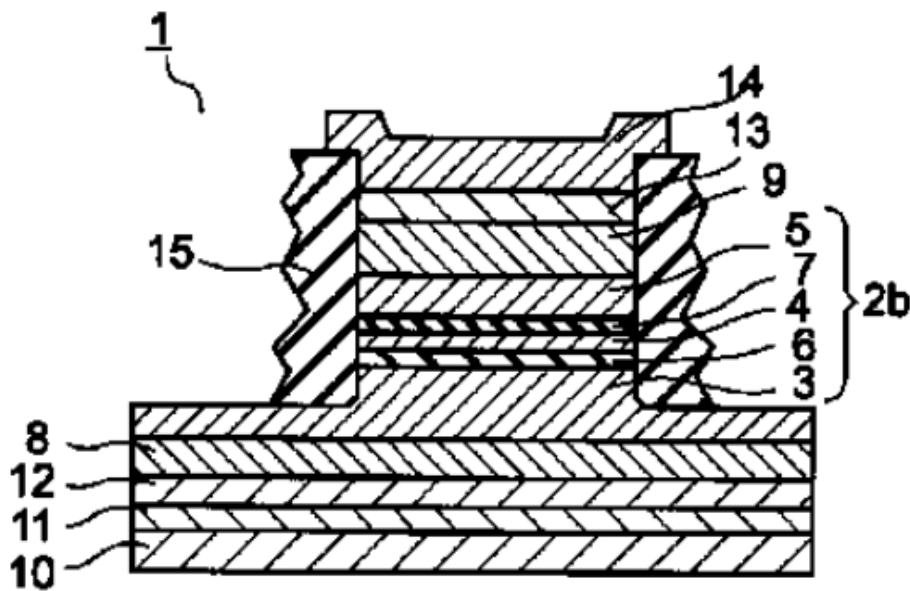
74. Nagahama teaches several benefits to using the MgO double underlayer (i.e. amorphous MgO layer 202 and MgO(001) crystal layer 203), including higher TMR. For example, Nagahama teaches “by forming an even ferromagnetic electrode layer with a thickness of 15 atomic layers or less using the MgO double underlayer, a magnetoresistive effect larger than ever was produced.” *Id.*, [0069]. Nagahama teaches “a larger tunnel magnetoresistive effect of more than 90% was produced by combining heat treatment” but “by preparing a tunnel magnetoresistive element including the (001)-highly-oriented MgO barrier layer overlying the MgO double underlayer, a still larger magnetoresistive effect was produced.” *Id.*, [0074].

B. MTJ References Using Electrodes with Boron to Achieve Amorphous Electrodes

1. Sunai (EX1030)

75. Sunai teaches using elements such as boron to produce a thin amorphous storage electrode. EX1030, [0021]-[0030], Fig. 2 (below).

Sunai Fig. 2



76. Sunai discloses that its “first ferromagnetic layer 3” is the reference layer because it “maintains the direction of magnetization when no external magnetic field is applied” and “in a predetermined external magnetic field.” *Id.*, Abstract; *see also id.* [0019] (“the magnetization direction of the ferromagnetic layer 3 does not change even when the external magnetic field is applied.”). Sunai discloses that the reference electrode, layer 3, is made of “CoFe,” without any

boron. *Id.*, [0050] (“ferromagnetic layer 3 consisting of a 3 nm thick CoFe were sequentially deposited”).

77. Sunai’s “second ferromagnetic layer 4” is the storage layer because that is the layer “that can change the direction of magnetization.” *Id.*, Abstract; *see also id.*, [0019] (“the magnetization direction of the ferromagnetic layer 4 can basically rotate freely depending on the external magnetic field”). Sunai discloses using boron in the storage layer 4. *Id.*, [0026]-0029]. Specifically, Sunai discloses the ferromagnetic layer 4 is represented by the general formula $(\text{CoFe})_{100-x} \text{Y}_x$ or the general formula $(\text{CoFeNi})_{100-x} \text{Y}_x$,” where “Y is at least one element selected from the group consisting of B, Si, Zr, P, Mo, Al, and Nb.” *Id.*, [0024].

78. Sunai discloses the reason such elements as boron are used for the storage electrode is to “reduce[]” the “reversal magnetic field,” that is to say the magnetic field that can change the magnetization direction of the storage electrode. *Id.*, [0025].

79. Sunai teaches that “[i]n a normal film formation method at room temperature, the lower limit of the film thickness at which a Co_9Fe film that does not contain B can be formed as a continuous film is about 1.5 nm.” *Id.*, [0027].

80. Attempts at thinner films result in “a discontinuous film,” which disadvantageously “loses its ferromagnetism at room temperature.” *Id.* “[W]hen B

is added,” however, “a continuous film can be formed up to a film thickness of about 0.5 nm.” *Id.*, [0028].

81. Sunai discloses “[t]he reason that an extremely thin continuous film can be formed when the element Y is added is that the addition of the element Y suppresses the diffusion or movement of atoms that reach the film formation surface during the film formation process, thereby suppressing crystallization.” *Id.*, [0030].

82. Sunai thus teaches adding elements such as boron in order to keep the storage electrode amorphous, to suppress crystallization, in order to “reduce[]” the “reversal magnetic field,” and to allow for thinner continuous films to be formed.

83. Sunai’s barrier layer 6 is made from aluminum oxide (Al_2O_3) by depositing an Al_2O_x layer that is subsequently oxidized. *Id.*, [0051].

2. Parkin (EX1062)

84. Parkin also teaches the benefits of a magnetic tunnel barrier with an amorphous storage electrode of CoFeB. EX1062, 1:18-21, Fig 3A (annotations original to the Petition).

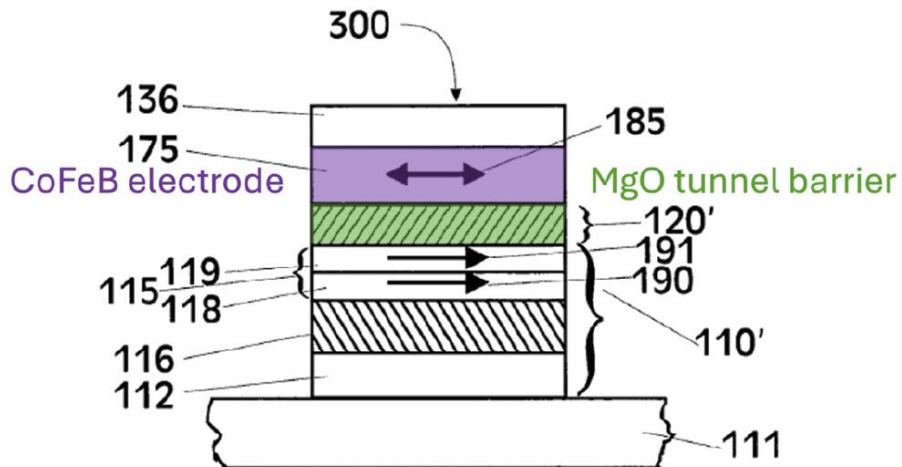


FIG. 3A

85. Parkin teaches a preference for *amorphous*, not *crystallized*, CoFeB for a storage electrode, that is, layer 175 in Fig. 3A. Parkin discloses that the “bulk” of the storage layer 175 “remains amorphous” even after annealing. *Id.*, 18:59-60.

86. Parkin discloses the “substrate 111 is formed from an amorphous layer of SiO₂ formed on a silicon substrate” with a “Ta” “underlayer... 100” and an “antiferromagnetic layer 116 of IrMn.” *Id.*, 17:11-18. These are standard layers in a MTJ.

87. Parkin forms a crystalline bcc(001) layer 115 as a lower ferromagnetic electrode by depositing a “35A Co₇₀Fe₃₀” “layer 115 [that] may be formed from one or more ferromagnetic layers 118 and 119.” *Id.*, 17:19-20.

88. Parkin disclosed that the “layer 115 is preferably formed from a bcc alloy formed from one or more of Co and Fe.” *Id.*, 13:10-11. Parkin teaches that

“the crystallographic texture of these layers can be controlled by suitable choice of the underlayers.” *Id.*, 13:11-15. Specifically, Parkin discloses “forming highly oriented crystalline MgO tunnel barriers by forming the MgO barrier on a ferromagnetic electrode comprised of electrode comprised of a Co-Fe alloy, which is bcc and (100) textured.” *Id.*, 3:34-37. As the ’167 patent explains, “because MgO has a cubic crystal structure (NaCl structure), the (001) plane, the (100) plane, and the (010) plane are all equivalent.” EX1013, 4:39-41.

89. Parkin’s description of the Co-Fe alloy being “bcc and (100) textured” is equivalent to describing a layer as having a bcc structure and a (001) texture or preferred orientation. This numeric index, i.e. (001), describes which plane of the crystal lattice is preferentially oriented parallel to the substrate surface. In cubic materials, planes (100), (010) and (001) are identical so any of these indices can be used to describe the texture. As explained above, a polycrystalline microstructure refers to the structure of a material composed of many small, differently oriented crystal grains (also called crystallites) separated by grain boundaries. In a polycrystalline film with a (001) preferential orientation, the grains are not randomly oriented but instead their (001) crystal planes are approximately parallel to the plane of the film.

90. Parkin discloses forming (001)-oriented MgO on top of the bcc (001) CoFe electrode. Specifically, Parkin discloses “[a]n MgO tunnel barrier 120' is

then formed on top of the lower ferromagnetic electrode 110'." *Id.*, 17:21-22.

Parkin discloses that the MgO layer was "highly textured (100)." *Id.*, 18:50.

91. Parkin discloses it is the underlayer that allows the MgO to grow in the (100) orientation. Specifically, Parkin discloses "forming highly oriented crystalline MgO tunnel barriers by forming the MgO barrier on a ferromagnetic electrode comprised of electrode comprised of a Co-Fe alloy, which is bcc and (100) textured." *Id.*, 3:34-37. Parkin discloses this method equally applies to both polycrystalline MgO formation and "the growth of epitaxial single crystalline film structures." *Id.*, 9:60-67 ("[T]unnel barrier described herein can also be applied to the growth of epitaxial single crystalline film structures, wherein the structures are prepared on a face of a single crystalline substrate chosen so that the crystalline spacing and crystalline cell is compatible with the growth of a bcc ferromagnetic metal layer oriented in the (100) growth direction and the subsequent growth of a MgO.").

92. Parkin discloses "the MTJ device shown in FIG. 3A is completed by forming the top ferromagnetic electrode which is the storage layer," "comprised of an amorphous ferromagnetic layer 175," such as " $(\text{Co}_{73}\text{Fe}_{27})_{74}\text{B}_{26}$." *Id.*, 17:40-44. After a capping layer is formed, Parkin discloses annealing the structures "in a high vacuum anneal furnace at a series of increasing temperatures of 260, 300, 340, 380 and 400° C." *Id.*, 17:60-66.

93. Parkin discloses that “[c]ross-section transmission electron microscopy reveals that a portion of the storage layer 175 adjacent to the MgO tunnel barrier 120’ has crystallized and is, moreover, textured in the same orientation as the crystalline MgO tunnel barrier,” but “the bulk of the storage layer 175 remains amorphous, providing considerable improvement in the magnetic switching properties of arrays of MTJ devices.” *Id.*, 18:51-62.

94. Parkin hypothesized that the “simple cubic crystalline MgO layer” “provides a template for the formation of a thin crystalline ferromagnetic layer which has the bcc structure of CoFe and is oriented in the same (100) direction as the MgO layer.” *Id.*

VIII. A POSA HAD NO REASONABLE EXPECTATION OF ACHIEVING AN MTJ WITH THE CLAIMED PROPERTIES BECAUSE PETITIONER’S EXPERT ADMITTED THAT A POSA HAD NO IDEA WHAT WOULD HAVE HAPPENED IF THE PROCESS ALLEGED IN EACH GROUND WERE ACTUALLY USED.

95. At deposition Petitioner’s expert Dr. Bokor could not explain what would have happened if a POSA had replaced an iron bottom electrode (as taught in both Bowen and Nagahama) with amorphous CoFeB and then annealed it (as taught in both Bowen and Nagahama) before forming an MgO barrier layer on top of it.

Q So in Bowen’s device now, if we modified Bowen’s process, its fabrication method, and instead of depositing iron at room temperature for the bottom electrode, we deposited cobalt iron boron

for the bottom electrode, what would happen when you then annealed that layer at 400 Celsius?

THE WITNESS: Right off the top of my head, *I can't answer that question*. We would – I would have to go look through -- I don't – if you -- if you are aware of a -- somewhere in all of the literature where somebody did that, we could -- I would be happy to look at that. But *I can't -- I'm unwilling to speculate just off the top of my head what would happen*. ... I don't know -- *I don't know what -- what -- what that might -- what might happen in that situation. I can't speculate*.

EX2018, 169:16-170:12.

96. With no knowledge or expectation what surface conditions that bottom CoFeB layer would have provided for the subsequent MgO deposition, a POSA had no reasonable expectation that the alleged manufacturing process in Grounds 1 or 2 would achieve a polycrystalline MgO with a preferentially-oriented (001) crystal plane (e.g., the claimed MgO microstructure) as the claims require (1[e], 11[b]).

97. With no reasonable expectation of success in achieving the claimed invention, the grounds fail to establish that any of the Challenged Claims are obvious as it is my understanding that it is the Petition's burden to establish a reasonable expectation of success.

A. The Manufacturing Methods in Petitioner's Grounds Expressly Rely on Annealing the Bottom Electrode Before Forming the MgO Barrier Layer.

98. Bowen and Nagahama both describe annealing a bottom Fe electrode after deposition, providing a crystalline Fe(001) layer.

99. After depositing the bottom Fe electrode (at room temperature) Bowen anneals it at 400°C (a step that the Petition repeatedly cites), forming a high-quality crystalline Fe(001) layer that crucially provides a lattice match for Bowen to thereafter epitaxially grow its single-crystal MgO(001) barrier layer (which the Petition also relies upon to meet Limitations 1[b] and 11[b]). *Supra* §VII.A.1 (discussing Bowen's process steps); EX1026, 1655-1656; EX1084, 225.

100. Nagahama also specifies depositing Fe bottom layer 213 by sputtering (EX1027, [0062], step 6), then annealing it (*id.*, [0062], step 7), resulting in "high quality crystals... grown in the (001) direction," e.g., Fe(001). *Id.*, [0065].

1. Petitioner Relies on Bowen's and Nagahama's Fe Bottom Electrode Annealing to Meet 1[pre] (and 11[pre]).

a) Bowen

101. In mapping the claimed "method of manufacturing" (1[pre]) in Ground 1, Petitioner explicitly recites Bowen's *specific* process steps of (1) depositing iron (Fe) at room temperature (RT); *then* (2) annealing the Fe bottom electrode at 400°C; *then* (3) epitaxially growing a single-crystal MgO barrier layer on the annealed Fe bottom electrode "at 400°C in order to obtain good

crystallinity.” Petition, 21, citing EX1026, 1655; Petition, 46, relying on 1[pre] mapping to meet 11[pre].

102. When Bowen anneals the lower Fe electrode at step (2), that Fe layer is exposed to the reaction chamber and is not covered by any other material layer. EX1026, 1655-1656.

103. Bowen’s reliance on steps (1) and (2) was central to achieving “optimal Fe electrode” crystallinity. Bowen’s explained that “[t]his low-temperature deposition [e.g., (1)] and subsequent annealing process [e.g., (2)] leads to *an optimal Fe electrode* in terms of crystallinity, continuity, and interface sharpness.” EX1026, 1655; EX2018, 151:6-153:24 (discussing Bowen steps (1)-(3)).

b) Nagahama

104. Nagahama’s manufacturing process also includes annealing a lower ferromagnetic electrode deposited on a crystalline substrate before depositing a barrier layer.

105. In mapping the claimed “method of manufacturing” (1[pre]) in Ground 1, Petitioner explicitly cites Nagahama’s manufacturing method in EX1027, [0062], reciting step 6 (EX1027, [0062], deposit Fe layer 213) and step 7 (*id.*, [0062], “[a]nnealing” the bottom ferromagnetic Fe layer 213) that occur before step 8 (forming barrier layer). Petition, 50, (citing EX1027, [0062]), 57

(“Nagahama taught [] annealing” and relying on Ground 1 analysis for 1[d], which relies on Bowen’s annealing step).

2. Petitioner Relies on Bowen and Nagahama Each Annealing the Fe Bottom Electrode as a Predicate to Meeting 1[b] and 11[b] in Each Ground.

a) Bowen

106. Petitioner expressly relies on Bowen’s epitaxially growing MgO(001)—which relies on having previously formed the Fe(001) crystalline electrode with Bowen’s 400°C annealing step (2)—to meet Limitation 1[b] “forming a [MgO] layer over the first CoFeB layer.” Petition, 28 (“the *MgO barrier* is grown at 400°C in order to obtain good crystallinity’ above the ‘Fe bottom electrode’”), quoting EX1026, 1655, and citing EX1026, 1656; EX1024, ¶139; EX1024, ¶139 (discussing Bowen’s fabrication process); Petition, 33 (relying on 1[b] mapping to meet 1[e]), 47 (citing EX1026, 1655 and relying on 1[b] mapping to meet 11[b]).

107. Petitioner’s expert agreed that Bowen’s epitaxial MgO layer growth step (3) *depended* on the presence of Bowen’s crystalline (001) Fe layer, as formed by Bowen’s deposition step (1) and annealing step (2). EX2018, 73:24-76:21, 159:1-4 (discussing Bowen’s process as described in EX1084, “[I]f you grow iron at room temperature and then anneal you get Fig. 4b... a nice continuous flat uniform thickness layers.”), 159:10-161:22 (POSA “in general” could not be

assured of achieving Bowen's result for crystalline Fe and MgO if "growth conditions" were changed from steps (1)-(3)), 162:18-23 ("So Boubeta and Bowen describe a set of growth conditions that leads to continuous and good crystal quality MgO films with sharp interfaces, all the way down to the thinnest oxide layer. And iron MgO indicative of the crystallinity and high quality of the structure.").

108. In short, Bowen's step (3) epitaxial growth of single-crystal MgO(001) depended on the presence of a near-lattice match provided by the single-crystal Fe(001) bottom electrode—which Bowen only achieved because of the 400°C annealing on the room temperature Fe deposition. EX1026, 1655; EX1084, 224-225; EX2018, 73:24-76:21, 159:1-4, 159:10-161:22.

109. Petitioner further cites Boubeta's discussion of the same process steps that Bowen uses for its step (3) epitaxial single-crystal MgO growth on the crystalline Fe bottom electrode, which Bowen fabricated with steps (1) and (2) above providing the "appropriate growth conditions" for Bowen's crystalline Fe (001) bottom layer and single-crystal MgO (001) barrier layer. Petition, 21 (citing EX1084, 228-229); EX2018, 144:17-145:13, 145:18-148:9, 148:15-149:2, 153:25-155:18, 167:10-15 (Bowen's epitaxial MgO growth in step (3) achieves "a near perfect single-crystal" MgO(001)). Boubeta explains that achieving that epitaxial MgO layer depended crucially on the Fe deposition (1) and anneal (2) steps.

EX1084, 229 (requiring “appropriate growth conditions” to achieve the “fully epitaxial metal/insulator heterostructures”).

b) Nagahama

110. Like Bowen, Nagahama describes its annealing the bottom electrode resulting in “high quality crystals... grown in the (001) direction,” e.g., Fe(001). EX1027, [0065]. The Petition relies on Nagahama’s embodiment at [0073] describing “a *(001)-highly-oriented lower ferromagnetic electrode layer*, a *(001)-highly-oriented MgO barrier layer*, and a (001)-highly-oriented upper ferromagnetic electrode layer” on the MgO(001) “double underlayer of the present invention,” to meet 1[b], 1[e], and 11[b]. EX1027, [0073]; Petition, 54 (quoting EX1027, [0073] to map 1[b]), 57-58 (1[e], citing EX1027, [0073] and relying on 1[b] mapping), 67 (11[b], citing EX1027, [0073] and relying on 1[b] mapping).

111. A POSA understood that Nagahama’s Fe(001) bottom layer *was critical* to templating the MgO(001) layer that Nagahama describes achieving in the [0073] embodiment that Petitioner relies upon, for the same reasons that Bowen’s Fe(001) bottom layer was critical to templating the epitaxial MgO(001) layer growth.

3. Petitioner Relies on Annealing the Fe Bottom Electrode Annealing to Meet 1[d] (and 11[d]).

a) Bowen

112. Petitioner further expressly relies on Bowen's anneal step (2) to meet Limitations 1[d] "annealing the first... CoFeB layer." Petition, 30 ("Bowen taught or suggesting [sic] annealing at 400°C its first ferromagnetic layer ('Fe bottom electrode')[.]" (citing and quoting EX1026, 1655)); Petition, 47 (relying on 1[d] mapping to meet 11[d]).

113. Although Petitioner argues that Bowen also taught annealing its "MgO barrier layer," Petition, 30, this misrepresents Bowen's disclosure. Bowen *epitaxially grows* MgO on the Fe(001) crystal layer; it *does not anneal* the MgO layer. EX1026, 1655; Petition, 30 (quoting EX1026, 1655). Bowen's *only* annealing step is for the Fe(001) electrode, which happens *before* growing the MgO barrier layer. EX1026, 1655-1656; EX2018, 163:24-165:15. Moreover, Petitioner's expert admits that Bowen's *epitaxial growth* achieves a near-perfect crystalline MgO layer (EX2018, 167:10-15), which made annealing that MgO layer pointless.

114. Petitioner expressly quotes Bowen's description of "low-temperature deposition and subsequent annealing process lead[ing] to an optimal Fe electrode in terms of crystallinity, continuity, and interface sharpness" (Petition, 31, quoting EX1026, 1655), and describes Bowen's annealing step as part of Bowen's

“optimized growth conditions” for, in Petitioner’s words, “optimizing the interface between the barrier [e.g., MgO layer] and metal electrode [e.g., bottom Fe electrode]” that Bowen “touted” (Petition, 31).

115. Petitioner cites EX1045 as teaching that “‘nearly perfect crystalline MgO(001) films on high-quality single crystals of Fe’ were effective in improving TMR.” Petition, 32, quoting EX1045, 1. Petitioner argues that EX1045 teaches that where an “‘entire Fe layer has crystalline structure’”—e.g., the Fe(001) achieved by Bowen’s annealing step *before* forming any layer on top of the Fe(001) layer—that this “improves tunneling” and “TMR.” Petition, 32, quoting EX1045, 6.

b) Nagahama

116. In Ground 2 the Petition relies on Nagahama’s “annealing” step in “preparing” its MTJ “including the (001)-highly-oriented MgO barrier layer overlying the MgO double underlayer” (EX1027, [0074]), which describes the MgO(001) layer formed on top of the Fe(001) bottom electrode 213 (*id.*, [0073]), which was formed by Nagahama’s annealing (*id.*, [0062]-[0065]). Petition, 57. Petitioner further relies on its analysis for Ground 1 (and 1[d]) that relies, in turn, on *Bowen’s* epitaxial MgO(001) growth on Bowen’s Fe(001) crystalline bottom electrode, to meet 1[d] in Ground 2. Petition, 56-57.

4. Petitioner Never Modified Bowen or Nagahama's Process to Alter or Exclude the Step of Annealing the Lower Fe Electrode.

117. As the Petition's repeated reliance in its claim mapping on Bowen's step (2) of annealing the lower Fe electrode at 400°C suggests, and Nagahama's process ([0062], step 7) of annealing the lower Fe 213 layer before forming a barrier layer, the Petition never describes modifying Bowen's or Nagahama's teachings to alter or exclude the annealing step.

118. Petitioner's expert admits that he never "explicitly" suggested modifying Bowen to skip Bowen's annealing step—which, had he done so, would have been inconsistent with the Petition's invalidity argument. EX2018, 172:18-24 ("Q: [W]here do you describe modifying Bowen to avoid the anneal step after the room temperature deposition of the bottom electrode? A: So I don't have explicit discussion of that."), 180:24-181:8 (similar); *see also id.*, 172:18-182:11.

B. Petitioner's Expert Admitted That He Did Not Know What Would Have Happened If a POSA Annealed an Amorphous CoFeB Bottom Layer as Bowen and Nagahama Each Teach For Preparing the Bottom Electrode.

119. At deposition, Petitioner's expert could not explain what would have happened if a POSA had followed the process in the grounds and annealed an uncapped amorphous CoFeB layer:

Q So in Bowen's device now, if we modified Bowen's process, its fabrication method, and instead of depositing iron at room

temperature for the bottom electrode, we deposited cobalt iron boron for the bottom electrode, what would happen when you then annealed that layer at 400 Celsius?

THE WITNESS: Right off the top of my head, ***I can't answer that question.*** We would -- I would have to go look through -- I don't -- if you -- if you are aware of a -- somewhere in all of the literature where somebody did that, we could -- I would be happy to look at that. But ***I can't -- I'm unwilling to speculate just off the top of my head what would happen.*** You're talking about a cobalt iron boron layer with nothing else on top of it. Is that right?

Q Yes.

A Yeah. I don't know -- ***I don't know what -- what -- what that might -- what might happen in that situation. I can't speculate.***

EX2018, 169:16-170:12.

Petitioner's expert continued,

Q And what would a person of ordinary skill in the art in 2004 have expected to have [happened] if in Bowen's process they deposited amorphous cobalt iron boron at room temperature on that magnesium oxide buffer layer and then annealed at 400 Celsius?

THE WITNESS: I want to make sure that I got the scenario. You're saying that you deposit cobalt iron boron on MgO?

Q I'm saying that we follow Bowen's fabrication process exactly as we just discussed. And when we reach the step when he deposits the iron bottom electrode at room temperature, we modify that to deposit cobalt iron boron at room temperature, and then take the next step in Bowen's process of annealing at 400 Celsius.

THE WITNESS: I don't recall anywhere right off the top of my head as I sit here any references that describe a process like that. And I think it's -- I -- *I'm unwilling to try to predict.* An uncapped cobalt iron boron layer that would be annealed -- yeah, that -- *I want to read through the references to see if anybody did that.* Off the top of my head, *I don't recall such a situation.* I'm not saying it's not anywhere in the references. I just don't recall that. And without having something to refer to, I -- *I'm not willing to speculate.*

EX2018, 170:13-171:19.

120. And Petitioner's expert testified that a POSA would have had "a natural reticence to anneal" an amorphous CoFeB layer "without a layer on top."

EX2018, 173:2-5.

121. In short, not only was Dr. Bokor unable to explain what would have happened if a POSA, having replaced Bowen's bottom Fe layer with amorphous

CoFeB as the Petition argues in Ground 1, thereafter annealed it at 400°C (as Bowen teaches), but contrary to the Petitioner's alleged combinations Petitioner's expert testified that a POSA would not have done it.

122. Dr. Bokor's testimony concerning the result of the process in Ground 1 applies with equal force to the result of the process in Ground 2 because Nagahama describes annealing the bottom Fe electrode to form Fe(001) before growing MgO(001) on top of it just like Bowen.

C. A POSA Had No Reasonable Expectation of Success that the Manufacturing Method in Either Ground Would Have Achieved the Claimed Invention.

1. The Grounds Fail to Establish Obviousness Because Dr. Bokor's Testimony Precludes a Reasonable Expectation of Success.

123. Dr. Bokor's testimony means that if the process in each ground were actually followed a POSA would have had *no expectation* and *no information* what surface the bottom CoFeB electrode would have provided for forming the MgO layer on top of it.

124. That means that based on the Petitioner's evidence a POSA could not have had a reasonable expectation that annealing the bottom CoFeB layer as provided in Bowen and Nagahama would have provided a surface for forming the MgO layer that would have allowed achieving polycrystalline MgO with a preferentially-oriented (001) crystal plane as required by the claims.

2. Petitioner’s Evidence Contradicts any Suggestion That A POSA Would Have Had a Reasonable Expectation of Achieving the Polycrystalline MgO with The Claimed Microstructure.

a) Jimbo and Cardoso Gave the POSA an Expectation of Failure.

125. Petitioner relies on Jimbo (EX1060) and Cardoso (EX1061) as evidence that it was “known” to “crystallize” amorphous CoFeB by annealing. Petition, 30-31.

126. But in both references annealing amorphous CoFeB allegedly resulted in a (111)-textured material. EX1060, 308-309 (describing a “fcc(111)” x-ray diffraction peak); EX1061, 2273 (describing “some (111) texturing”). Petitioner’s own evidence makes clear that that MgO(001) cannot be grown on a (111)-oriented surface. EX1057, 47 (“A fundamental problem with this structure is that an NaCl-type MgO(001) tunnel barrier... which [has] fourfold in-plane crystallographic symmetry, *cannot be grown on [a] fcc(111)-oriented... structure*, which has threefold in-plane crystallographic symmetry, *because of the lattice mismatch.*”).

127. Thus, even if Petitioner’s reliance on Jimbo and Cardoso is credited, there would have been no expectation of success in achieving the claimed MgO with (001) orientation because the annealed first CoFeB would have had the wrong crystalline orientation, and MgO(001) would not grow on it.

b) Dr. Bokor Distinguished Parkin's Annealing Step.

128. Parkin does not provide a POSA with a reasonable expectation of success that a MgO layer formed on the lower ferromagnetic electrode would achieve the claimed microstructure in Limitations 1[e] or 11[b] because the only cited embodiment in Parkin formed a “highly (001) textured MgO layer” on layer 115—comprising layer 119—in Fig. 3A, which was a “bcc alloy formed from one or more of Co and Fe” and “textured in the (100) orientation.” EX1062, 13:10-25; Petition, 33, citing EX1062, 18:49-51, 18:63-19:10, discussing Fig. 3A embodiment. Parkin's layer 115 thus provided a template for the MgO layer 120' to form its “highly (001)” texture.

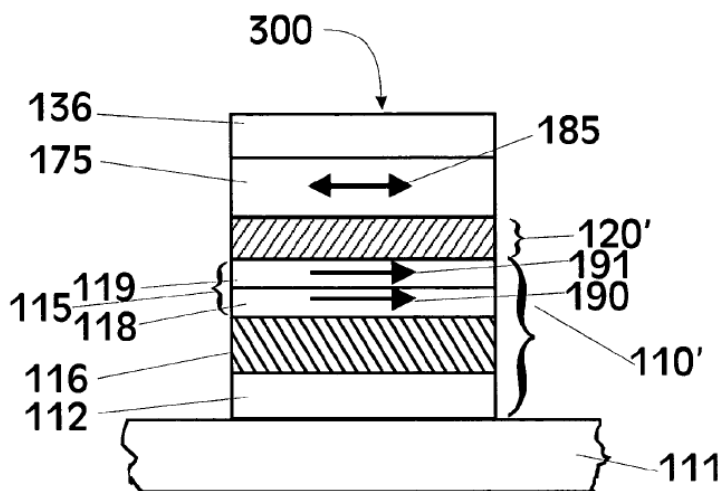


FIG. 3A

129. Moreover, Parkin annealed the *top* amorphous CoFeB layer 175 *after* it was covered with “capping layer 136... comprised of” 10 nm tantalum nitride

(TaN) followed by 7.5 nm rubidium (Ru). EX1062, Fig. 3A, 17:54-59 (describing layer 136), 17:61-18:6 (describing annealing).

130. Unlike Parkin, both Bowen and Nagahama describe annealing the bottom ferromagnetic electrode without a capping layer, a point Dr. Bokor emphasized when refusing to “speculate” what would have happened to the amorphous CoFeB bottom electrode. EX2018, 170:13-171:19 (“*I’m unwilling to try to predict. An uncapped cobalt iron boron layer that would be annealed -- yeah, that -- I want to read through the references to see if anybody did that.* Off the top of my head, *I don’t recall such a situation.* ... [W]ithout having something to refer to, I – *I’m not willing to speculate.*”). By Dr. Bokor’s own testimony, Parkin’s annealing—with the capping layer 136—would not have given a POSA *any* expectation of what would have resulted from annealing the bottom CoFeB layer without a capping layer.

3. A POSA Had No Reasonable Expectation of Achieving an MgO Layer with the Claimed Microstructure if the MgO Layer Were Deposited on an Amorphous First CoFeB Layer.

131. Although Petitioner’s expert could not state what a POSA would have expected to happen following Bowen’s and Nagahama’s annealing the uncapped amorphous CoFeB lower ferromagnetic electrode, the top surface would have either crystallized or stayed amorphous.

132. Petitioner has no evidence that the bottom CoFeB layer's top surface would have crystallized with a (001) texture. Indeed, Petitioner's expert *quotes* the very sentence in EX1057 that states "the stable structure of Co₆₀Fe₂₀B is not bcc but fcc [citing Yuasa's EX2008]." EX1024, ¶61 (cited Pet., 11), quoting EX1057, 48 (but *omitting* the last half of the sentence stating that the stable structure is fcc); *accord* EX1061, 2272 (describing CoFeB with a "strong (111) texture" after annealing); *see also* EX2018, 93:3-97:16 (Petitioner's expert admitting he had no evidence disputing that "the stable structure of Co₆₀Fe₂₀B" is fcc).

133. Thus based on Petitioner's evidence a POSA would have had a reasonable expectation that if the lower CoFeB layer crystallized, it would have crystallized as fcc(111).

134. A POSA would never have combined the references in the manner alleged or used a process yielding a lower CoFeB electrode with fcc(111) because this was incompatible with subsequent steps of the alleged process yielding MgO (100) with the claimed microstructure.

135. At worst, like Petitioner's expert, based on Petitioner's evidence a POSA would have had no idea what would have resulted, and thus no reasonable expectation that the alleged processes would succeed, and thus no reason to combine the references in the manner alleged.

136. Even if it were assumed that Petitioner's process deposited MgO on an amorphous surface, which Petitioner's expert could not say would have happened, there is no evidence that a POSA would have had a reasonable expectation that the alleged processes in Grounds 1 or 2 would have resulted in an MTJ with the MgO layer having the claimed microstructure.

a) Petitioner's Explicit Reliance on Epitaxial MgO Growth to Meet the Claims Fails with an Amorphous CoFeB Bottom Layer.

137. *First*, Ground 1 expressly relies on Bowen's process of *epitaxially growing* MgO on the Fe(100) bottom electrode to meet 1[b] and 1[e]. Petition, 28-29, 33. But Petitioner's expert admits that a POSA would have had no reasonable expectation of epitaxially growing MgO on an amorphous surface. EX1057, 47; EX2018, 72:11-13 ("there's no epitaxy from amorphous substrates"); EX1055, 2270 ("amorphous CoFeB does not support any crystalline grain growth").

138. Therefore, a POSA had no reasonable expectation that the process that the Petition alleges a POSA would have used in Ground 1 would have achieved MgO with structure meeting 1[e] or 11[b].

139. For Ground 2 Petitioner relies on Nagahama's description of an embodiment with a "(001)-highly-oriented MgO barrier layer" on a "(001)-highly-oriented lower ferromagnetic layer" (EX1027, [0073]) to meet 1[b] and 1[e]. Petition, 54-55, 57-58.

140. While Nagahama is ambiguous on how it achieved the MgO(001) layer in [0073], it was unambiguously formed *only* in the presence of the Fe(001) lower ferromagnetic layer, which Nagahama formed by annealing the Fe deposited on the MgO(001) substrate specifically provided by its “double underlayer.” EX1027, [0062], [0065].

141. Thus, just like with Bowen, replacing Nagahama’s Fe(001) bottom electrode with amorphous CoFeB left a POSA with no reasonable expectation that the process alleged in Ground 2 would have achieved MgO with a microstructure meeting 1[e] or 11[b].

b) Petitioner Does Not Explain the “Contemplated Workings of the Combination” and Does Not Even Allege that MgO Deposited on Amorphous CoFeB Would Achieve the Claimed Microstructure.

142. *Second*, even if the grounds were read to encompass depositing (rather than epitaxially growing) MgO on an amorphous first CoFeB layer (they do not), the Petition does *not even allege* that that forming MgO on an amorphous material (e.g., the assumed CoFeB surface) would have achieved polycrystalline MgO with a (001) preferential crystal orientation meeting 1[e] (or 11[b]).

143. The Petition does not provide an evidence-supported account of the contemplated workings of the combination in either Ground 1 or 2 that would support a conclusion that a POSA would have been motivated to make the combination and reasonably expect success in doing so.

144. In Ground 1 Petitioner's 1[b] analysis recites *epitaxially growing* MgO(001) using Bowen's process, which was not possible on an amorphous CoFeB layer. Petition, 28-29.

145. Petitioner's 1[e] analysis asserts only that it "would have been obvious to use" polycrystalline MgO with a preferentially-oriented (001) crystal plane without saying *how* a POSA would have expected to achieve it using the alleged process, let alone on an amorphous CoFeB layer. Petition, 33-35 (discussing 1[e]), 47 (discussing 11[b]).

146. In Ground 2, Petitioner's 1[b] analysis quotes Nagahama's description of forming a "(001)-highly-oriented MgO barrier layer" over a "(001)-highly-oriented lower ferromagnetic electrode layer" without explaining how the modified process in Ground 2 would achieve the claimed polycrystalline MgO, then cites its Ground 1 analysis of Limitation 1[b]. Petition, 54-55, citing Nagahama, [0073] and Petition "§VI.A.3" (e.g., Ground 1, 1[b]).

147. Petitioner's 1[e] analysis simply asserts that Nagahama described achieving polycrystalline MgO with a preferentially-oriented (001) crystal plane but never explains why a POSA would have expected this result after replacing Nagahama's (001) textured lower ferromagnetic layer with amorphous CoFeB. Petition, 57-58 (Limitation 1[e]).

148. Petitioner's Ground 2 analysis for Limitation 11[b] relies on the 11[b]/11[e] analysis. Petition, 67.

149. In short, nowhere does Petitioner explain how depositing MgO on amorphous CoFeB would have achieved the MgO with the claimed microstructure (e.g., (001) texturing). And nowhere does Petitioner explain why a POSA would have had a reasonable expectation that the process in either ground would have achieved the claimed MgO microstructure.

150. The Petition cites Yoon (EX1040), p. 2842, in Ground 2 (but nowhere in Ground 1) for the proposition that "MgO 'polycrystalline structures' have 'preferred orientation.'" Petition, 57 (Limitation 11[e]).

151. This discussion in Yoon concerned "MgO films *grown on GaAs (100)*" (EX1040, 2842), which is crystalline with the desired preferential orientation rather than amorphous, and this teaching thus gave a POSA no expectation that MgO deposited on *amorphous* CoFeB would form the claimed microstructure.

c) Dr. Bokor's Discussion of Wulff and Yoon Adds Nothing.

152. Petitioner's expert declaration cites Wulff (EX1036) p. 148 and Yoon p. 2840 in two paragraphs for the proposition that MgO films achieved a (100) texture even when deposited on an amorphous substrate. EX1024, ¶¶70, 175. But

this testimony fails to show a POSA would have had a reasonable expectation of success using the alleged manufacturing processes.

153. Neither Wulff nor Yoon investigated the microstructure of MgO films on the order of 2 nm thickness that would be used in an MTJ. EX1013, 6:37-41.

154. Wulff described the behavior of MgO films with thicknesses exceeding 100 nm (e.g., 0.1 μm). EX1036, 150 (“MgO films of about 0.1, 0.5, and 1 μm thickness were deposited[.]”).

155. Yoon does not report the thickness of films formed on an amorphous substrate, although Yoon reports having investigated 50 nm thick MgO films grown on crystalline Si(001). EX1040, 2841, Fig. 3(a) (thinnest film was 50 nm on Si(001)). Moreover, Yoon explained that “the giant magnetoresistance effect in magnetic multilayer depends on the interface roughness. Reduction of roughness is desirable for the buffer layer.... [L]ittle is known about the evolution of the interface and its effect on subsequent film growth process.” EX1040, 2839. And Yoon explained that the 50 nm film grown on Si(001) had a “rougher” “surface morphology” than other films. EX1040, 2841, Fig. 2.

156. When there is no epitaxy from a lattice match the factors affecting orientation of grains in thin films on the order of 15-20 atomic layers thick, e.g., a 2 nm MgO barrier layer in an MTJ, are significantly different from the factors

relevant to the orientation of films that are much thicker like those in Yoon and Wulff.

157. Wulff and Yoon did not investigate the dependency of crystal structure on film thickness. A POSA would be aware that the grain size, orientation, and texture of a polycrystalline film evolves with increasing film thickness as the grains grow. For example, favorably oriented grains grow faster so an initially random (untextured) polycrystalline film may develop a texture as it grows thicker, or the texture of a film may change from one orientation to another with increasing thickness. Therefore the texture measured in a 50 nm or 100 nm thick film is not necessarily representative of the texture of a 2 nm thick film.

158. When Wulff and Yoon did their work it was not even possible to use X-ray diffraction to determine the crystal orientation of an MgO film of a thickness useful for tunnel barrier layers (i.e., on the order of 2 nm thick). The x-ray diffraction peaks of films on the order of 2 nm thick are much weaker and broader than those of thicker films, and additional techniques would likely be used by a POSA to fully analyze the structure of such thin films.

159. Contrary to Petitioner's suggestion that Wulff or Yoon's results were indicative of MgO microstructure in films under 10 nm thick, POSAs knew that MgO films formed on amorphous substrates "possessed a crystal orientation which varied with film thickness" and films thinner than 50 nm "showed a random

orientation.” EX2062, 621. EX2062 reported that when thickness increased above 50 nm MgO would form a (111) preferred orientation. *Id.* The conflicting results between EX2062, EX1036, and EX1040 meant that the POSA’s expectations for even MgO thick-film orientation were uncertain.

160. POSAs knew that film texture evolves with thickness, and crystal morphology is impacted by the deposition conditions, which can be expressed in a ‘zone diagram’ as shown below for evaporated metals. Texture means “the preponderance of one (or more) crystallographic planes oriented parallel to the film surface compared with the case of randomly oriented planes.” EX2048, 566.

161. The differences in MgO thickness between what Wulff and Yoon disclose and the thickness necessary for making an MTJ as claimed means that they did not provide a POSA with a reasonable expectation that depositing MgO on amorphous CoFeB would produce a MgO barrier layer with the claimed microstructure.

162. A POSA knew that the initial crystal formation (e.g., nucleation stage) of film growth accounted for “the first few hundred angstroms of film thickness”—a range larger than ultrathin films (on the order of 20-100 angstroms) used in MTJs. EX2048, 195-197. POSAs knew that nucleation on amorphous substrates resulted in *randomly oriented* or weakly textured islands of crystals that could

develop a preferred texture with increasing film thickness. EX2060 (Petrov), S118, S126.

163. A POSA would have expected this to result in “*randomly oriented* islands” of crystal grains for “low temperature deposition on amorphous substrates” as used in Bowen and Nagahama. EX2060, S117; EX1026, 1655 (room temperature Fe deposition); EX1027, [0062] (step 6 Fe 213 deposition by sputtering before step 7 annealing). Petrov states “[n]ear the substrate, the microstructure consists of randomly oriented small grains” and that “[o]rientation selection during coarsening is incomplete, thus crystallites are nearly random or only weakly textured.” EX2060, S119-20.

164. A POSA knew that without a lattice match providing epitaxy the MgO nucleation at the amorphous surface interface would most likely have resulted in random grain orientation in the MgO. The process of MgO nucleation and grain growth depended crucially on multiple factors including the materials, surface morphology, deposition technique, deposition temperature, substrate temperature, deposition rate, and growth time. EX2048, 203. Atoms arrive on the surface, move on the surface by diffusion, and eventually form a nucleus or are incorporated into a growing grain. EX2048, 199. The sticking probability of atoms on a pre-existing nucleus depends among other factors on the orientation of the nucleus. Thus nuclei with different orientations grow at different rates and the

texture of the film can evolve with thickness as the grains grow. The initial texture (if any) and the final texture depend on multiple growth and substrate factors.

POSAs could not predict what crystal orientations would form on an amorphous CoFeB layer in the thicknesses typical for an MTJ barrier (i.e., less than 10 nm), or even within the first 30 nm of the film.

165. Yoon deposited the MgO films by techniques that a POSA would not use for forming MTJs. EX1040, 2839 (deposition by aerosol-assisted chemical vapor deposition). Aerosol-assisted chemical vapor deposition uses a precursor material (in this case, using magnesium ethoxide dissolved in 2-methoxyethanol as a source material). Film deposition is accomplished by spraying an aerosol, produced by ultrasonication of a liquid precursor, onto a heated substrate (300-450°C), by a stream of nitrogen at atmospheric pressure. The precursor (magnesium ethoxide, $\text{Mg}(\text{OC}_2\text{H}_5)_2$) decomposes on the surface to yield an MgO film. Yoon then crystallizes the resulting film: “The films were finally annealed at 500–800 °C for 1 h in a preheated furnace to enhance crystallinity of the films.” This process involves very different conditions and would not be expected to produce MgO with the same stoichiometry or microstructure. Moreover, it is less readily incorporated in a multilayer manufacturing process in which the metallic electrodes are formed by sputter deposition.

166. Wulff and Yoon used deposition rates that were inapplicable to MTJ fabrication. For example, Wulff uses a higher MgO deposition rate (1.6-2 nm/s, *see* EX1036, 150) than would be used in making an MTJ (e.g. 0.02 nm/sec, *see* EX1013, 6:23-26). Yoon utilizes a deposition rate of 5 nm/min (EX1040, 2840), over four times the rate that would be used in a method of making an MTJ as claimed. A POSA would have expected this to result in significantly different ultrathin film morphology at 2 nm, as would be relevant to an MTJ, than at the thick films Wulff and Yoon made, because the growth rate is a highly influential parameter in determining film microstructure. For example, growing at higher rate allows less time for the grains to grow and often yields a smaller grained or even amorphous film.

167. These differences would have precluded a POSA from forming any expectation of success based on Wulff or Yoon's thick-film results. In short, Wulff and Yoon would not have given a POSA any reasonable expectation that the processes alleged in Grounds 1 or 2 would achieve the claimed MgO microstructure.

d) Petitioner's Only Evidence that Annealing a CoFeB/MgO/CoFeB Trilayer Would Achieve the MgO Microstructure as Claimed Is Dr. Yuasa's Post-Dated Work Describing the Claimed Invention.

168. The Petition's *only cited evidence* that annealing a CoFeB/MgO/CoFeB trilayer (with amorphous CoFeB) would *actually achieve* the

claimed MgO structure is Petitioner’s 2017 “textbook”—*citing Dr. Yuasa’s famous post-filing publication from 2005*—that describes the result as “surprising.” EX1057, 47 (“[Yuasa] developed a new MTJ structure, CoFeB/MgO/CoFeB, by using a sputtering deposition technique [citing EX2006][.]... **Surprisingly**, the MgO layer grown on the amorphous CoFeB is (001)-oriented polycrystal (textured structure).”).

169. EX2006—coauthored by Dr. Yuasa—has been cited at least 1269 times since its publication in 2005. EX2052. *See also* EX1057, 46-48 (citing EX2006 and EX2013); Petition, 10 (citing EX1024, ¶¶60-61), 11 (citing EX1024, ¶¶60-61 and EX1057, 47), 31 (citing EX1024, ¶60); EX1024, ¶¶60 (citing EX1057, 47), 61 (citing EX1057, 48), 283 (citing EX1057, 46).

170. Dr. Bokor described EX1057 as “a well-known textbook” and “very good comprehensive text” that is “a comprehensive book... intending to be a comprehensive sort of treatise” that Dr. Bokor himself uses “as a reference source” that “is relatively up to date.” EX2017, 138:23-140:11.

171. In other words, Petitioner’s expert’s *own* “**very good comprehensive**” *treatise on MTJs* shows—at the portions Petitioner cites and relies upon—that *even in 2017 the field continued to regard* Dr. Yuasa’s achieving “(001)-oriented polycrystal (textured structure)” by annealing CoFeB/MgO/CoFeB—as described in a famous 2005 paper published after the critical date—*as a surprising result*.

172. Thus, Petitioner’s only actual evidence of achieving MgO with the claimed structure by annealing a CoFeB/MgO/CoFeB trilayer sandwich is a citation to a comprehensive treatise describing Dr. Yuasa’s own work in his famous post-dated publications.

173. Dr. Bokor and the Petition thus fail to show that a POSA would have had a reasonable expectation of success in achieving the MgO layer with the structure required by the independent claims.

IX. A POSA WOULD NOT HAVE COMBINED THE REFERENCES IN THE MANNER ALLEGED IN THE GROUNDS.

A. A POSA Would Not Have Combined Bowen With Sunai or Parkin In the Manner Alleged.

1. Bowen Went To Heroic Efforts to Achieve Single-Crystal Epitaxial Fe(001)/MgO(001)/FeCo(001) MTJs.

174. Bowen was specifically focused on *experimentally testing* Butler’s “first-principles based calculations of the tunneling conductance and magnetoconductance of epitaxial Fe(100)/MgO(100)/Fe(100)” MTJ “sandwiches.” EX1044 (Butler), 1 (Abstract).

175. Bowen explained that “numerical calculations of spin-dependent tunneling and TMR have been developed for *single crystal MTJs* such as... Fe/MgO(100),” citing Butler (EX1044) and Mathon (EX1046), and that Butler’s model could be tested “on single-crystal epitaxially-grown structures.” EX1026,

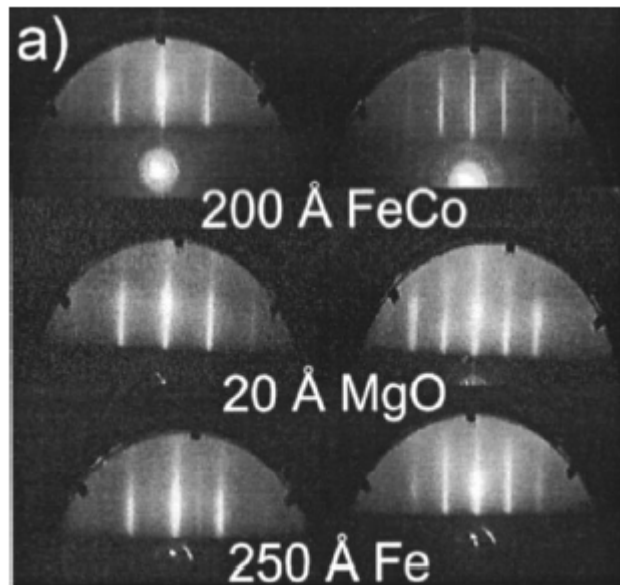
1655. Bowen's group went to extraordinary efforts to form a single-crystal MTJ precisely to test Butler's first-principles theory of spin dependent transport in MTJs with single-crystal MgO barriers.

176. Indeed, Bowen describes continuing its experimental evaluation of Butler's theory in future work testing Butler's explicit prediction that TMR in Fe(001)/MgO(001)/Fe(001) MTJ would increase with barrier thickness (e.g., the width of the MgO barrier layer). EX1026, 1657; EX1044, 1 (predicting "a large magnetoresistance that increases with barrier thickness.").

177. In order to test Butler's theory Bowen made an epitaxially-grown single-crystal MTJ under "optimized growth conditions" that resulted in "*entirely epitaxial* samples of *high crystalline quality* with flat, sharp interfaces." EX1026, 1657. Bowen's MTJ comprised a crystalline iron (Fe) (001) bottom ferromagnetic (FM) electrode, single-crystal magnesium oxide (MgO) (001), and a crystalline iron-cobalt (FeCo) (001) top FM electrode. EX1026, 1655-1656. The notation (001) denotes the orientation of each crystal layer, and Bowen's layers matched the orientation that Butler's model used and which he theorized would provide high TMR. EX1044, 1 (Abstract), 2 (describing DFT on "15 atom/supercell").

178. Bowen's Figure 1(a) shows a reflection high-energy electron diffraction (RHEED) pattern for "typical FeCo/MgO/Fe epitaxial structure" wherein the "Fe₅₀Co₅₀ and Fe layers are bcc structured with sharp diffraction

lines[.]”² EX1026, 1655-1656, Fig. 1(a) (detail below). RHEED is a technique that determines the surface structure of a film by imaging the diffraction of an electron beam incident at glancing angle on the surface. The presence of spots or streaks in the RHEED image are characteristic of the surface structure, crystal orientation, and roughness. The RHEED data of Bowen’s Fig. 1a indicate the relative orientation between the crystal structures of the different layers, Fe (001), MgO (001) and FeCo (001).



179. Bowen explains that its fabrication process achieved an epitaxial MTJ wherein *the MTJ itself* comprised *a single crystal* and not just three separate crystalline layers stacked on top of each other. Bowen, 1655 (“[X]-ray diffraction

² “BCC” or bcc means a body-centered cubic lattice structure. EX013, 4:44-47.

symmetric and asymmetric scans confirm that *the whole structure is epitaxial* with lattice parameters close to bulk values.”), 1657 (“optimized growth conditions result in *entirely epitaxial samples of high crystalline quality* with flat, sharp interfaces”).

180. Epitaxy in thin films refers to the existence of a relationship between the crystal lattices of two materials when one material is grown on the other. For example, if we grow a layer of Ni on a Cu crystal, the Ni can grow epitaxially on Cu such that the Ni crystal planes match exactly those of the Cu. This is possible because Ni and Cu have the same crystal structure (face centered cubic) and very similar lattice parameter (the length of the side of the cubic unit cell). For the case of MgO and bcc-Fe, these two materials are both cubic but they have different crystal structures (MgO is a rock-salt fcc structure whereas Fe is bcc) and different lattice parameters. However, an epitaxial relationship is possible because the lattice parameter of MgO is a good match to the diagonal of the unit cell of bcc-Fe. Therefore MgO can grow with a 45 degree rotation on the (001) surface of bcc-Fe, and bcc-Fe can grow with a 45 degree rotation on the (001) surface of MgO. This relationship in principle enables formation of an epitaxial bcc-Fe/MgO/bcc-Fe multilayer, but the growth conditions must be selected to promote the epitaxial growth.

181. To achieve this result, Bowen's coauthors Boubeta et al. developed an *entirely new process* for epitaxially growing MgO(001) on a crystalline Fe(001) thin film. EX1084, 223, 224 (“very few works have reported on the epitaxy of MgO on Fe(001) or of Fe/MgO/Fe trilayered structures. The aim of the present work is to present results on the study of the epitaxy of metal/insulator Fe/MgO heterostructures on MgO buffered GaAs(001) semiconductor substrates[.]”), 228-229; EX2018, 144:3-148:14; Petition, 21 (citing EX1084, 228-229), EX1024, ¶¶115 (discussing EX1084). Boubeta used an innovative combination of substrate materials and growth processes to form an epitaxial MgO(001) buffer layer using pulsed laser deposition on a pre-treated GaAs substrate with an oxidation barrier, then formed bcc-Fe(001) on the MgO by normal incidence triode sputtering, and a Pt protective layer. Boubeta went to great lengths to characterize the structure and epitaxy of the stack using multiple methods including RHEED, TEM, x-ray diffraction and atomic force microscopy. Developing the MgO buffer layer was critical to forming epitaxial bcc-Fe because the buffer layer, among other functions, blocked diffusion of As into the Fe.

182. Bowen optimized each step in its fabrication process, and each step was crucial to the result. EX1026, 1655-1656, 1657 (“optimized growth conditions result in entirely epitaxial samples of high crystalline quality with flat, sharp interfaces”). Bowen placed the highest importance on obtaining the best

possible quality epitaxial bcc-Fe/MgO/bcc-Fe(001) because such a structure was necessary to test Butler's predictions of TMR. The films needed to avoid having surface and interface roughness or grains of varying orientation because all these imperfections would scatter electrons and make it harder to compare the results to Butler's theory. Selecting non-optimum deposition would lead to an undesirable structure and reduce the scientific value of Bowen's work.

183. Each crystalline layer in the structure depended on achieving the correct crystalline form for the layer beneath it. The single-crystal epitaxial device required achieving single-crystal MgO(001). EX1026, 1655-1656. Achieving Bowen's MgO(001) depended on achieving and providing the Fe(001) bottom layer. EX1026, 1655-1656.

184. As Dr. Bokor agreed, the lattice match between Bowen's crystalline Fe(001) bottom electrode and the single-crystal MgO(001) was crucial to Bowen achieving its epitaxial single-crystal device. EX2018, 74:6-9, 74:19-24; EX1026, 1655-1656; EX1084, 228-229. As mentioned above, an epitaxial relationship is possible because the lattice parameter of MgO is a good match to the diagonal of the unit cell of bcc-Fe, therefore MgO can grow with a 45 degree rotation on the (001) surface of bcc-Fe.

185. Bowen's process of depositing iron at room temperature then annealing at 400°C—before growing MgO(001)—was the reason Bowen achieved

“continuous and flat interfaces” between the bottom Fe electrode and the MgO barrier. EX1026, 1655-1656. Dr. Bokor agreed. EX2018, 160:8-161:16.

186. In short, Bowen went to heroic efforts to achieve single-crystal epitaxial MTJs precisely because this was the device that Butler’s calculations modeled, whose predictions Bowen wanted to test. EX1026, 1655; EX1044, 2. A structure with rough interfaces, imperfect crystallinity, grain boundaries and other microstructural defects would not have provided as good a comparison to Butler’s theory.

2. Bowen’s Teachings Diverge From the Claimed Invention And The Path Taken By Dr. Yuasa.

187. The carefully optimized process and heroic efforts that Bowen made to achieve MTJs with “*entirely epitaxial samples of high crystalline quality* with flat, sharp interfaces” (EX1026, 1657), to test Butler’s theory of spin-dependent tunneling in entirely crystalline “epitaxial Fe(100)/MgO(100)/Fe(100) sandwiches” (EX1044, 1), teach away from the claimed invention.

188. **First**, Bowen explained that “numerical calculations of spin-dependent tunneling and TMR” were developed for *single-crystal* Fe/MgO(001) MTJs, and that testing these models required “*single-crystal epitaxially grown structures.*” EX1026, 1655 (citing Butler EX1044). This diverges from the path taken by Dr. Yuasa and teaches away from the invention, which *precludes* a single-crystal MgO barrier such as Butler modeled and requires a *polycrystalline*

MgO barrier layer. *E.g.*, Limitations 1[e], 11[b]. Replacing Bowen’s single-crystal epitaxial MgO(001) barrier layer with polycrystalline MgO would frustrate Bowen’s purpose of creating a single-crystal epitaxial Fe(001)/MgO(001)/FeCo(001) MTJ.

189. ***Second***, as noted above, Petitioner’s expert agrees that achieving Bowen’s near-perfect single-crystal MgO(001) barrier required the lattice match provided by the high-quality crystalline Fe(001) bottom electrode. EX2018, 74:6-9, 74:19-24; EX1026, 1655-1656; EX1084, 228-229. This diverges from the path taken by Dr. Yuasa and teaches away from the invention, which required forming “a first CoFeB layer that is ***amorphous***” (Limitations 1[a], 11[a]) and—contrary to Bowen’s detailed and carefully optimized process for epitaxial growth—forming a MgO layer over the ***amorphous*** first CoFeB layer (Limitations 1[b], 11[b]). Replacing Bowen’s Fe(001) FM electrode with amorphous CoFeB would frustrate Bowen’s purpose of creating a single-crystal epitaxial Fe(001)/MgO(001)/FeCo(001) MTJ. It would not be possible to grow a single-crystal MgO (001) film on top of an amorphous CoFeB layer.

190. While Bowen’s epitaxial growth was critical to achieving its MTJs, a POSA would have known that an amorphous substrate like the amorphous “first CoFeB” layer in the claims did not provide a lattice that supported epitaxial MgO growth on top of it.

191. Petitioner’s expert admits that “there’s no epitaxy from amorphous substrates” like amorphous CoFeB. EX2018, 72:12-13, 77:4-7 (“if you have an amorphous layer and you try to grow a crystalline on it, there is no epitaxy, there is no templating”), 76:4-21 (explaining epitaxy). A POSA would have agreed.

192. Thus, no POSA reading Bowen would have modified it to replace Bowen’s Fe(001) bottom FM electrode with amorphous CoFeB, a POSA looking to use boron to make CoFeB amorphous would not have looked to Bowen for fabrication process steps, because Bowen was focused solely on forming crystalline layers for a single-crystal device. Bowen’s processes would not be relevant for amorphous CoFeB because they are directed towards maximizing crystallinity.

193. **Third**, Bowen demonstrates that “the spin polarization of tunneling electrodes... depends on the actual electronic structure of *the entire electrode/barrier system*”—including the Fe(001) FM layer and the MgO(001) barrier. EX1026, 1655. Bowen tested Butler’s “first-principles [theory], which used an ideal *crystal Fe(001)* bottom electrode with *a near-perfect MgO(001)* barrier.” EX1044, 1-2. Butler’s theory did not consider an amorphous electrode, and did not consider a polycrystalline MgO barrier layer.

194. Bowen’s approach diverges from the path taken by Dr. Yuasa and teaches away from the invention, which—as noted above—required forming “a

first CoFeB layer that is amorphous” and polycrystalline MgO. Limitations 1[a]-1[b], 11[a]-11[b].

195. Replacing Bowen’s Fe(001) FM electrode with amorphous CoFeB (a different material and phase), and replacing Bowen’s MgO(001) with polycrystalline MgO (a different microstructure), would have fundamentally changed Bowen’s process, changed Bowen’s resulting MTJ, and frustrated Bowen’s purpose of creating a single-crystal epitaxial Fe(001)/MgO(001)/FeCo(001) MTJ to test Butler’s theory.

196. Bowen’s coauthors also included Albert Fert, a future Nobel laureate in Physics for spintronics. EX1057, 7; EX2018, 187:20-190:24. Bowen’s coauthors, in short, had exceptional skill in the art.

197. If the Petition’s alleged reasons to modify Bowen’s process were genuine, rather than hindsight reconstruction, Bowen would have tried it. The fact that they did not speaks volumes, confirms that Bowen led in a path divergent from the claimed invention, and refutes the Petition’s reasons to combine.

3. Petitioner’s Own Evidence Disparaging Bowen’s Process Confirms that a POSA Would Not Have Used Bowen to Make MTJs with “Improved TMR.”

198. Petitioner ignores the teachings in its own references that explain Bowen was not suitable for “fabricating MTJs with improved TMR” for

“improving MRAM”—the very reason that Petitioner alleges a POSA would have combined Bowen with Sunai (Petition, 25) or Parkin (Petition, 27).

199. Dr. Bokor admits that MTJ design required a POSA to make tradeoffs, and that a POSA would have regarded MTJ *manufacturability* as an important consideration in identifying a process for making an MTJ. EX2017, 77:10-79:14. A POSA would have agreed.

200. Parkin explicitly states that “[e]xotic techniques, such as... epitaxy and deposition at elevated temperatures on single crystalline substrates, are *not useful* for the mass-manufacturing of cheap devices for MRAM and other applications[.]” EX1062, 15:38. Bowen anneals the bottom Fe FM electrode and epitaxially grows MgO(001) at 400°C (EX1026, 1655-1656)—conditions that Petitioner’s expert admits is an “elevated temperature.” EX2018, 79:15-18.

201. Bowen grows MgO on a “single crystalline substrate[.]” provided by the bottom Fe(001) after Bowen’s annealing. EX1026, 1655-1656. Bowen’s requirement for a single-crystal substrate to support an epitaxial film on top is a significant manufacturing burden, particularly for a semiconductor industry that is built around processing silicon rather than exotic single crystalline substrates of other materials to support single-crystal MgO growth. Semiconductor manufacturing processes have been developed around Si as a substrate and the industry is generally resistant to the introduction of exotic substrates which require

different handling and process conditions. High temperature processes are generally disfavored because they can cause reactions, diffusion and degradation of structures present on the wafer.

202. In short, Bowen uses precisely the “exotic techniques” that Parkin describes as “*not useful*” for MTJ fabrication. Parkin’s disparagement provides yet another reason that a POSA would not have used Bowen in a combination, or to achieve the alleged motivation of “fabricating MTJs” with “improved TMR” for MRAM.

203. Nagahama similarly disparages Bowen’s process. Citing Bowen, Nagahama states “In this instance, a single-crystal substrate is necessary to form an element [e.g., MTJ]. This however makes it difficult to form the element on a silicon LSI, and thus a challenge for realizing a magnetic random access memory has not yet overcome.” EX1027, [0014].

204. A POSA reading Nagahama would therefore have been discouraged from using Bowen’s process to fabricate an MTJ.

205. Several other references likewise explain the problems with Bowen’s manufacturing process that would have discouraged a POSA from using Bowen as alleged. EX2038, 7 (“MgO barriers [that are] fully epitaxial grown on single-crystal substrates [are] incompatible with read-head manufacturing where junctions are grown by sputtering on plated magnetic shields.”); EX2005, 39 (“[I]t has

proven difficult to grow bcc Co or bcc Fe with (001) texture directly by any practical physical vapor deposition technique without a single crystal substrate (the use of which would vastly limit commercial applications).”).

206. Indeed, the ’167 Patent’s invention was praised as having “significant technology importance for the magnetic recording head industry” specifically because its manufacturing method used “a conventional sputtering method instead of an MBE system” and achieved “a giant TMR ratio with simple amorphous CoFeB ferromagnetic electrodes, instead of strenuously high temperature deposition with single crystal structures” like Bowen. EX2023, 2; EX2024, 2-3 (Yuasa “developed a process that enabled device fabrication on arbitrary underlying layers. This structure and process enabled mass production on large-diameter wafers by room-temperature sputter deposition, which opened the door to industrial applications of MgO MTJ devices.”); *infra* §XI.A.

207. POSAs knew that Bowen did not teach a manufacturable solution, which taught away from the claimed invention.

B. A POSA Would Not Have Combined Nagahama with Sunai or Parkin in the Manner Alleged.

208. Nagahama invented detailed steps to form a “MgO double underlayer.” E.g., EX1027, [0055]-[0059], [0067] (describing MgO double underlayer 212), Fig. 12 (layer 204 comprising amorphous MgO 202 and crystalline MgO 203), Fig. 13 (layer 212).

209. The double underlayer comprised an amorphous MgO (202, 212-1) covered by a “(001)-oriented highly oriented” crystal MgO layer (203, 212-2). EX1027, [0058], [0067].

210. This double underlayer provided a way to form MTJs with crystalline ferromagnetic layers “on an amorphous substrate, such as SiO₂, and polycrystalline wires.” EX1027, [0059]. Nagahama’s MgO double underlayer was thus similar to Bowen’s MgO buffer layer and provided a template for forming (001) ferromagnetic lower electrodes for an MTJ.

211. Nagahama’s process forming a crystalline (001) ferromagnetic lower electrode on a double underlayer diverges from the path taken by Dr. Yuasa and teaches away from the invention, which forms an amorphous first CoFeB layer. Limitations 1[a], 11[a].

212. A POSA would not have added boron to the lower ferromagnetic electrode because it would have inhibited crystallization, and the purpose of the double underlayer that Nagahama went to heroic lengths to fabricate was to provide a (001) crystalline surface that would encourage lattice-matched crystalline (001) growth of a lower ferromagnetic electrode.

C. Petitioner’s Combinations Would So Fundamentally Change the Basic Principles Under Which Bowen and Nagahama Were Designed to Operate as to Render Those References Unrecognizable.

213. By replacing the crystalline lower electrode with amorphous CoFeB in Bowen and Nagahama, Petitioner’s combinations would discard the very feature and process step—forming a crystalline lower electrode to template the epitaxial growth of an MgO barrier layer—that Bowen and Nagahama went to heroic efforts to accomplish by inventing their entirely new processes of forming a MgO(001) buffer layer on GaAs(001) (in Bowen) and a MgO double underlayer (in Nagahama). Petitioner’s combinations would so alter the processes in Bowen and Nagahama, contrary to their principle of operation, as to make them unrecognizable.

D. Sunai Teaches Away from the Claimed Invention.

214. Petitioner alleges that a POSA would have modified Bowen’s Fe(001) FM bottom layer with Sunai’s teachings to replace Bowen’s Fe(001) bottom FM electrode with an amorphous CoFeB FM bottom layer to “increase TMR, and lower H_f and H_c , of Bowen’s MTJ.” Petition, 24. Petitioner alleges that a POSA would have replaced Nagahama’s lower Fe(001) layer 213 with amorphous CoFeB based on Sunai for the same reasons. Petition, 51. A POSA would have disagreed with this reasoning on multiple levels.

215. **First**, Petitioner argues that “CoFeB was known to increase TMR compared to CoFe,” citing Sunai ¶¶27-28. Petition, 24-25. But Bowen used Fe(001) for the bottom electrode, not CoFe; as Petitioner’s expert realized at deposition, nothing in Sunai makes a relevant comparison of TMR achieved with amorphous CoFeB to TMR achieved with Fe(001). EX2018, 184:10-15 (“Q: Where does Sunai describe [CoFeB] as superior to [Fe]? A:... Okay. I’m having trouble finding that.”). Nagahama’s Fe 213 was also the bottom electrode. EX1027, [0060]-[0062], Fig. 13 (layer 213 on MgO “double underlayer” 212), [0064], [0066] (“By using the MgO double underlayer of the present invention, the plane orientation of the ferromagnetic electrode layer can be aligned at angles of $\pm 1^\circ$ from (001) planes.”).

216. **Second**, a POSA would not have looked to Sunai to improve Bowen’s TMR because Sunai’s TMR of less than 25% with an amorphous CoFeB bottom electrode was *inferior* to the TMR that Bowen achieved. EX2018, 182:23-183, 11; EX1030, [0026], Fig. 3. Nagahama achieved TMR exceeding 90% and a POSA had even less reason to look to Sunai, with its inferior TMR below 25%, to improve Nagahama.

217. Petitioner’s reliance on EX1055 and EX1056 as supporting the alleged reason to replace Bowen’s Fe(001) with amorphous CoFeB is likewise misplaced because those references each used an amorphous Al_2O_3 barrier, not

Bowen's single-crystal MgO(001), Nagahama's "(001)-highly-oriented MgO," or the invention's polycrystalline MgO. EX1055, 2269 ("Al₂O₃ tunnel barrier."), 2270; EX1056, [0112] (barrier is Al₂O₃). Butler showed that the mechanisms that lead to TMR in an amorphous barrier like Al₂O₃ are different from the mechanisms at work in crystalline MgO(001). Indeed, Butler's calculations showed that high TMR should be achievable in crystalline MgO with a (001) orientation but not with a (111) orientation. In other words, even a different crystalline orientation of the same material was expected to have different effects on TMR.

218. Petitioner's own expert expressly *rejected* the suggestion that a POSA would have considered TMR data from MTJs with an Al₂O₃ barrier—like EX1055 and EX1056—as indicative of what would have happened to TMR in an MTJ with an MgO barrier. EX2017, 200:16-19 ("Bowen uses MgO. *The whole point about using MgO for a tunnel barrier is because it has special properties, unique properties about how the -- what happens to the TMR.*"), 203:12-19 ("What makes Bowen special... is the single crystal electrodes and the single crystal MgO barrier.... [I]t made a significant jump in the field by going to the MgO—single crystal MgO barrier."), 201:3-17 ("I reject the hypothetical that... a POSA would look at [EX2058] and have... *I don't see how a POSA has a reasonable expectation to accept any of this for the Bowen MTJ... [b]ecause it's for—it's for an aluminum oxide barrier.*"), see also *id.*, 199:23-203:24. Under Dr. Bokor's

analysis, a POSA would not have looked to EX1055 or EX1056 for reasons to modify the cited Bowen or Nagahama embodiments.

219. *Third*, Petitioner’s alleged combinations disregard that Sunai specifically teaches the importance that the bottom CoFeB layer be ***amorphous***. Sunai describes the amorphous CoFeB alloy as having a “smaller saturated magnetization M_s ” than alloys that form crystalline films. EX1030, [0025]. Using the amorphous CoFeB alloy facilitates maintaining “the reversal magnetic field of the ferromagnetic layer 4... at a sufficiently small value[.]” EX1030, [0025]; *see also* EX2018, 204:21-206:7 (citing Sunai and explaining benefit of lower power consumption using a smaller reversal magnetic field).

220. Petitioner’s corroborating references EX1055 and EX1056 likewise each used MTJ with an ***amorphous*** CoFeB electrode, not the “crystallized” CoFeB of the invention (e.g., 1[d], 11[d]). EX1055, 2269 (“High-resolution transmission electron microscopy (HRTEM) reveals that the CoFeB has an amorphous structure[.]”), 2270; EX1056, [0036] (“information recording layer”—e.g., the “free” or storage layer—is amorphous CoFeB alloy), [0038] (same).

221. In contrast, Sunai found that crystallizing the electrode results in unstable magnetization and ***reduces*** TMR. Sunai explains that crystalline CoFe forms a “discontinuous film composed of aggregate fine particles” that each “loses its ferromagnetism at room temperature, and the magnetization direction becomes

unstable, becoming so-called superparamagnetic,” causing the TMR to “drop significantly.” EX1030, [0027]; *id.*, [0030] (crystalline FM thin films formed “island structures” that “exhibit superparamagnetism, in which magnetization direction fluctuates, resulting in a significantly low magnetoresistance change rate.”).

222. Sunai’s motivation for using amorphous CoFeB to replace crystalline CoFe is to avoid the tendency of films of CoFe to aggregate into small particles or islands when the film thickness is very small, especially when grown on an oxide. This is a problem because the magnetization of small particles can flip spontaneously at room temperature leading to loss of the data that they represent, and degrading the TMR because the magnetization of the electrode constantly fluctuates. This superparamagnetism limits how thin the magnetic layer can be made, and hence limits the scalability of MRAM. Amorphous CoFeB is less prone to aggregation so can be made thinner without suffering from superparamagnetism.

223. In short, Sunai’s emphasis on the importance of keeping the lower CoFeB layer amorphous *diverges* from the path taken by Dr. Yuasa and *teaches away* from the invention, which requires that the CoFeB layers be “crystallized” (1[d], 11[d]) or “entirely crystallized” (claims 2, 4 (4[a]), 6 (6[a]), 12, 13 (13[a])). Even apart from Bowen’s teaching away, Sunai’s divergent teachings alone would have prevented a POSA from relying on Sunai to achieve the claimed invention.

E. Parkin Teaches Away from the Claimed Invention.

224. Parkin's disparagement of Bowen's techniques, as explained above, would have specifically discouraged a POSA from combining Parkin with Bowen.

225. Furthermore, Petitioner alleges that a POSA would have replaced Bowen's lower Fe(001) layer with Parkin's amorphous CoFeB to "lower H_f and H_c ." Petition, 27. Petitioner argues that a POSA would have replaced Nagahama's lower Fe(001) layer 213 with Parkin's amorphous CoFeB for the same reasons—to provide "desirable improvement to TMR, H_c , and H_f ." Petition, 53-54.

226. The coercive field H_c is the magnetic field needed to be applied to switch the magnetization. H_c of the storage layer of an MRAM needs to be small enough that the data can be written using as low a field as possible, which for an MRAM means using as low an energy as possible. (In contrast, the reference layer needs a high H_c to avoid its magnetization being inadvertently changed, which is why it is often pinned with an antiferromagnet layer.) The coupling field H_f is the interaction field that the reference layer exerts on the storage layer. It is generally desirable to minimize H_f because it can raise H_c of the storage layer and make the response asymmetric, i.e. switching from parallel to antiparallel vs. antiparallel to parallel states require different switching fields.

227. Parkin teaches that "reducing the variation in [MTJ] magnetic switching fields" would have been a benefit of using *amorphous* CoFeB

(“*amorphous magnetic materials*”) for MTJ storage layer 175 (EX1062, 5:48-51) because “the use of *amorphous* [FM] layers... would likely give rise to smaller variations in magnetic switching fields” (EX1062, 6:9-13). This is because amorphous materials, lacking the magnetocrystalline anisotropy and the heterogeneity of polycrystalline materials, intrinsically have very low H_c .

228. Parkin teaches that the “strong (100) crystallographic texture of the MgO layer will likely lead to significant variations in the orientation and strength of the magnetocrystalline anisotropy field” between MTJ devices that is “mitigated” by using FM storage layers “*formed from materials that have no preferred crystallographic orientation*” such as “*amorphous magnetic materials*” (e.g., amorphous CoFeB). EX1062, 15:62-16:4. A POSA would have been very well aware of the low anisotropy and therefore low H_c of amorphous materials compared to crystalline materials.

229. Thus, adding “glass forming elements” like boron to CoFe “*causes the crystalline structure to be eliminated*” or results in the crystalline grains being very small” such that “the ordered arrangement of atoms within the [FM material] is also destroyed even on an atomic scale. Thus, *there is no longer any crystallographic orientation along which the magnetic moments prefer to align, so the magnetic switching characteristics of such devices are much more*

uniform than crystalline devices.” EX1062, 16:35-40, *see also id.*, 18:49-62. I agree with Parkin’s comment, as would a POSA.

230. In short, Parkin explains—at length—that the *amorphous* nature of the CoFeB layer is *critical* to the improving the MTJ magnetic switching properties, which the Petition calls “lowering H_f and H_c .”

231. Parkin’s teaching on the importance of the CoFeB layer being amorphous *diverges* from the path taken by Dr. Yuasa and *teaches away* from the invention, which requires that the CoFeB layers be “crystallized” (1[d], 11[d]) or “entirely crystallized” (claims 2, 4 (4[a]), 6 (6[a]), 12, 13 (13[a])), depriving the combination of the very benefit that Parkin attributes to the amorphous state of the CoFeB and that the Petition alleges was a reason to replace Bowen’s Fe(001) or Nagahama’s Fe(001) lower electrode with amorphous CoFeB.

232. Thus, even apart from Bowen’s and Nagahama’s teaching away, Parkin’s divergent teachings alone would have prevented a POSA from relying on Parkin to achieve the claimed invention.

F. The Petitioner Provides No Credible Reason that a POSA Would Have Modified Bowen or Nagahama by [1] Replacing the Bottom Fe Electrode with Amorphous CoFeB, then [2] Crystallized that Amorphous Layer.

233. The Petition alleges that a POSA would have modified Bowen’s process to deposit an *amorphous* CoFeB bottom (Petition, 23 (discussing 1[a] first CoFeB layer) and top layer (Petition, 30 (discussing 1[c] second CoFeB layer).

The Petition then alleges that a POSA would have *crystallized* each amorphous CoFeB layer (Petition, 31 (discussing 1[d])).

234. But the Petition never identifies a coherent reason *why* a POSA, having modified Bowen to use *amorphous* CoFeB rather than crystalline Fe, would then *go right back to Bowen's starting point* and crystallize those amorphous CoFeB layers.

1. The Petition's Reasons to Combine Are Incoherent and Internally Inconsistent.

235. To meet Limitation 1[a] (and 11[a], Petition, 46) concerning a “first CoFeB layer that is amorphous,” the Petition argues that a POSA would have had reasons to replace Bowen's Fe(001) bottom electrode with *amorphous* CoFeB as taught in Sunai or Parkin in order to “increase TMR.” Petition, 23 (“[A POSA] would have found it obvious to replace Bowen's Fe layer with an *amorphous ferromagnetic CoFeB layer* as taught by Sunai.”), 24 (“[A POSA] would have been motivated to substitute Sunai's CoFeB electrode for either or both of Bowen's electrodes *to increase TMR*, and lower H_f and H_c , of Bowen's MTJ.”), 27 (similar), 26 (“Parkin taught forming an ‘amorphous ferromagnetic layer 175’” from CoFeB), 27 (“[A POSA] would have found it obvious to use Parkin's CoFeB layer in place of Bowen's electrodes *to increase TMR*.”).

236. To meet Limitation 1[c] (and 11[c], Petition, 47) concerning the “second CoFeB layer that is amorphous,” the Petition relies on the same arguments

it made for Limitation 1[a]. Petition, 29-30 (“[A POSA] would have been motivated to replace Bowen’s top FeCo electrode layer with an amorphous CoFeB layer from Sunai or Parkin for the same reasons as explained for Claim [sic] 1[a].”).

237. Then to meet Limitation 1[d] (and 11[d], Petition, 47) concerning annealing MTJ layers “wherein the first and second CoFeB layers are crystallized by the annealing,” the Petition alleges that a POSA would have annealed the amorphous CoFeB layers to “*improve TMR*” and “*crystallize the CoFeB electrodes*.” Petition, 31 (“[A POSA] reading Bowen and Sunai would have been motivated to anneal the CoFeB layers... *to increase TMR* and *crystallize* the CoFeB layers.”), 33 (“[A POSA] would have been motivated to anneal the CoFeB layers and crystallize the CoFeB layers by annealing *because Parkin taught it improved TMR*.”).

238. The Petition thus argues that in order to improve Bowen’s TMR a POSA would have used CoFeB electrodes that were *simultaneously amorphous* (to purportedly meet Limitations 1[a] and 1[c]) and *crystalline* (to purportedly meet Limitation 1[d]). While MTJs use quantum mechanical tunneling, they do not exist in a macroscopic superposition of being simultaneously amorphous and crystalline.

239. The failures in the Petition’s reasons to combine are not a question of degree on the meaning of “crystallized” in 1[d] or 11[d]. At Institution the Board relied on differentiation from the “**entirely** crystallized” limitation in claim 2 to conclude that “we view claim 1 as not requiring that **the entirety** of the first and second CoFeB layers be crystallized.” Paper 9, 20. The Board thus agreed that “entirely crystallized” means that “the entirety of the first and second CoFeB layers be crystallized.”

240. Notwithstanding the Petition’s improper hindsight reconstruction that defines the Bowen and Suani or Parkin combination in terms of claim limitations, the law requires a POSA to have had reasons to form the combination **without reference** to claim language. Claims 2, 4, 6, and 12-13 require that the CoFeB layers be “entirely crystallized,” *infra* §X, and the Petition relies on the **same combination** of Bowen in view of Sunai or Parkin to meet claims 2 as it does to meet 1[d] (and 11[d]). Petition, 35-38. (The Petition relies on its claim 2 analysis to meet “entirely crystallized” in claims 4, 6, and 12-13. Petition, 39-40, 47-48.)

241. At minimum an “entirely crystallized” CoFeB layer has **no** amorphous portion, and forming such a layer would have deprived the combination of the beneficial consequences of the CoFeB electrode being amorphous in order to reduce the MTJ’s magnetic switching field that Parkin describes at length and that

the Petition argues would have motivated replacing Bowen's Fe(001) with *amorphous* CoFeB for 1[a] (and 11[a]). *Supra* §IX.

242. Petitioner's modifications to Nagahama in Ground 2 have the same defects and fail for the same reasons.

2. The Petition Never Identifies a Reason to "Crystallize" the CoFeB Layers.

243. The Petition contends that a POSA "would have been motivated to ... crystallize the CoFeB layers" (Petition, 31) but never gives an evidence-based reason *why* a POSA would have done this.

244. The Petition states that "[a]nnealing CoFeB electrodes to crystallize them was... known," citing EX1060 at 311, EX1061 at 2273-2273, and EX1062 at 7:53-59. But whether it "was known" that annealing amorphous CoFeB would "crystallize" it does not provide a POSA *with a reason to have done it*, particularly where the Petition specifically argues elsewhere that a POSA would had reasons *to do the exact opposite* and *replace Bowen's crystalline Fe(001) electrode with amorphous CoFeB* to, among other things, *improve TMR* and *reduce the magnetic coupling and switching fields* (H_f , H_c) for a ferromagnetic storage layer *by destroying any crystalline order* in the electrode. *Supra* §IX. (discussing consequences of the electrode's *amorphous* state).

245. The same defects apply to the Ground 2 arguments involving Nagahama.

a) EX1060 Does Not Support Petitioner's Alleged Reasons to Combine.

246. The Petition cites EX1060 as showing “[i]t was known that TMR was ‘enhanced by... annealing’ [] which was likely attributed to ‘structural change of the interface’ between the CoFeB and adjoining layers.” Petition, 31, citing EX1060, 311. This argument fails for several reasons.

247. *First*, the Petition's argument rests on a false premise. There is *no TMR* in the EX1060 devices. EX1060 studied *spin valves*, not MTJs. EX1060's spin valves disposed a copper (Cu) film between CoFeB electrodes. EX1060, 308, 310. Copper is a conductor, i.e., the “barrier height” is zero. Current instead flows through a Cu layer via the conduction electrons. There is *no tunneling* through copper, let alone spin-dependent tunneling that Butler describes as the basis for TMR in MTJs (like Bowen's) using crystalline MgO(001). This is explicit in the rudimentary Simmons model for tunneling current density that expresses tunneling current as a function of a fitted parameter called barrier height and the thickness of an insulator layer. Dr. Bokor describes a low voltage bias approximation for that tunnel current density that is relevant to MTJ tunneling current in his declaration. EX1024, ¶¶49 (tunnel current density (J or J_c) is directly proportional to barrier height $(\varphi_0)^{\frac{1}{2}}$, so that tunneling current density is zero for $\varphi_0=0$), 45-49 (describing tunneling); EX1031, 1797.

248. In other words, the spin valves in EX1060 *had no tunneling magnetoresistance*. Their magnetoresistance arises from a completely different physical mechanism, giant magnetoresistance. The Petition's reliance on EX1060 to show that "TMR was enhanced by annealing" thus rests on a false premise that fundamentally misunderstands and misrepresents the teachings in EX1060.

249. *Second*, even if EX0160's devices provided TMR (they did not), the Petition does not identify any reason that EX1060's suggestion of "structural change of the interface" between CoFeB (with unspecified Co and Fe content) and Cu would have had any bearing on the "structural changes" of an interface between such an amorphous CoFeB alloy and an adjoining MgO deposition with unspecified microstructure and orientation. The CoFeB/Cu interfaces in the EX1060 devices, in short, were fundamentally different from the MTJs allegedly being made using the Bowen with Sunai or Parkin combination, and EX1060 would not have given a POSA any motivation to do anything to modify Bowen's MTJ fabrication process.

250. *Third*, contrary to the Petition's suggestion (Petition, 30-31), a POSA would have understood that EX1060 does *not* teach that CoFeB crystallizes when annealed. EX1060 provided X-ray diffraction patterns for devices with a gold (Au) layer. EX1060, 309.

251. Gold—including which has a fcc(111) gold structure—has a (200) diffraction peak at 44 degrees, precisely where EX1060 labels a “CoFe fcc(111)” peak. When interpreting x-ray diffraction scans a POSA would consider possible diffraction peaks from all the components of the sample. It happens, due to the crystal structure and lattice parameter of Au, that there is a strong Au peak from the fcc Au(200) crystal planes at a very similar diffraction angle to the peak from fcc CoFe (111) planes. In a sample with both Au and fcc-CoFe, these peaks would be very hard to distinguish. Therefore a perfectly reasonable interpretation of the peak at 44 degrees is that it comes from Au (which is present in the sample and is known as a strong scatterer due to its high atomic number). Indeed, given the strong Au(111) peak at 38 degrees, it would be surprising if there were not an Au(200) peak. Therefore Jimbo is in error by attributing this peak solely to CoFe, and his deductions from this peak are dubious. The positions of peaks from a wide range of materials are, and were in 2004, readily available from the Powder Diffraction file (EX2059), which shows what angle the peaks are expected to appear and how strong they are expected to be relative to other peaks from the material. For fcc Au, the (200) peak is the second strongest. To disambiguate the source of the peak, Jimbo would have needed to measure the diffraction over a much wider range of angles to capture additional peaks from CoFe.

252. EX1060 never even compared its data to the expected diffraction pattern from gold and does not appear to have even recognized that a peak at 44 degrees should have been present *regardless* of any CoFe layer. EX1060 did not show any data that would have allowed a POSA to conclude that even CoFe fcc(111) was present rather than the expected diffraction from Au(200).

253. A POSA would have recognized that this the presence of crystalline CoFe was unlikely because EX1060 did not include tantalum (Ta) or an oxide that could have drawn boron out of the CoFeB layer to facilitate the CoFe crystallization. EX1060, 309.

254. Finally, if the Petition's reason to "crystallize" CoFeB was "enhance" TMR, then as explained below this is inconsistent with relying on "increasing TMR" as a reason to replace Bowen's crystalline Fe(001) and FeCo(001) with amorphous CoFeB as alleged for Limitation 1[a].

b) EX1061 Does Not Support Petitioner's Alleged Reasons to Combine.

255. Moreover, EX1061 does not show "crystallized CoFeB" as the petition alleges. Petition, 37. The Petition's quoted language (*id.*, citing EX1061 at 2273) shows *only* that post-annealing films were "not amorphous."

256. EX1061 provides no explanation of what happened to the CoFeB film, or any explanation of the material content of any grain or microstructure that might have nucleated in the CoFeB layer whose description the Petition quotes.

257. EX1061 also does not support any assertion that annealing CoFeB would increase TMR in Bowen's modified MTJ because EX1061's MTJs used an amorphous Al₂O₃ barrier. Petitioner's own expert plainly testified that MgO's "special properties" governed and explained Bowen's TMR. "[I]t was understood that *MgO was a special -- had special properties with regard to MR that depended on the detailed band structure of the MgO.*" EX2017, 62:20-23; *see also id.*, 124:7-8 ("MgO [] *has this very special preference* for parallel versus antiparallel tunneling"), 200:16-19 ("The *whole point about using MgO for a tunnel barrier* is *because it has special properties, unique properties about* how the -- *what happens to the TMR.*"), 203:12-14 ("What makes Bowen special is the M -- *is the single crystal electrodes and the single crystal MgO barrier.*"). Based on Dr. Bokor's own explanation, a POSA would not have considered EX1061's results as a reason to modify Bowen's fabrication process.

c) Bowen Does Not Support Petitioner's Alleged Reasons to Combine.

258. The Petition's reliance on Bowen as motivating "crystallizing" the amorphous CoFeB electrodes is absurd given that the Petition just finished arguing that a POSA would have modified Bowen to use amorphous (not crystalline) electrodes.

259. The Petition states that "Bowen touted crystalline layers" and describes Bowen's process step of annealing the bottom Fe electrode in order to

provide a template for epitaxially growing MgO(001) (Petition, 31-32), but the Petition ignores that Bowen never used any amorphous material, let alone amorphous CoFeB, in its MTJ. Nor does the Petition explain how **Bowen** could motivate crystallizing the amorphous CoFeB while at the same time arguing that a POSA would have *modified Bowen* to *replace* Bowen's crystalline Fe with amorphous CoFeB. A POSA would have regarded the two arguments are inconsistent and self-defeating.

**d) EX1045 Does Not Support and Contradicts
Petitioner's Alleged Reasons to Combine.**

260. The Petition's reliance on EX1045 for the proposition that “‘nearly perfect crystalline MgO(001) films on high-quality single crystals of Fe’ were effective in *improving TMR*” and touting the benefits of an MTJ wherein an “entire Fe layer has crystalline structure” (Petition, 32, quoting EX1045, 1, 6) is likewise misplaced.

261. EX1045 provides *no reason* for a POSA to anneal and “crystallize” amorphous CoFeB because (1) EX1045 (and the quoted language) describes *precisely* the structure in Bowen *that the Petition contends a POSA would have modified with amorphous CoFeB*, (2) EX1045 started with crystalline Fe electrodes; and (3) EX1045 has nothing to say about the effect of annealing an MTJ with amorphous CoFeB electrodes. EX1045, 1 (“*Single-crystal* epitaxial MgO thin films *were grown directly onto high-quality Fe single crystal*[.]”).

262. Indeed, Bowen's *only* annealing was to anneal to lower Fe electrode that the Petition argues a POSA would have replaced with amorphous CoFeB. EX1026, 1655; *supra* §VII.A.1. To the extent that EX1045 gave a POSA a reason to do anything, it would have been to leave Bowen's fabrication process *unchanged*.

e) Parkin Does Not Support Petitioner's Alleged Reasons to Combine.

263. Petitioner's reliance on EX1062, 7:53-59 for annealing increasing TMR (Petition, 30-31) is likewise misplaced because unlike the three MTJ layers that the Petition purports to "anneal," the cited passage in EX1062 describes an MTJ in which one FM electrode is crystalline—not amorphous—and "has a [bcc] structure... preferably oriented in the (100) direction" and "in proximity with the tunnel barrier[.]" EX1062, 7:15-22, 7:51-53.

264. The Petition's contention that "Parkin taught" that "anneal[ing] the MTJ layers and crystal[lizing] the CoFeB electrodes" would have "improved TMR" likewise misrepresents the cited teachings in Parkin's Fig. 3A embodiment that the Petition relies upon. Petition, 32-33.

265. In Parkin's Fig. 3A embodiment, a single amorphous CoFeB storage layer was deposited on a "highly textured (100) MgO tunnel barrier[.] 120' that itself was formed on a *crystalline* "ferromagnetic layer 115" that was "preferably formed *from a bcc alloy* formed from one or more of Co and Fe" and was

“textured in the (100) orientation.” EX1062, 13:10-25. Thus, the Parkin embodiment that the Petition relies upon had a bcc (001) crystalline ferromagnetic electrode, which templated a “highly textured” MgO (001) barrier layer, which was already textured when it was covered with an amorphous CoFeB storage layer 175.

266. The Parkin embodiment that the Petition relies upon did not teach annealing an amorphous lower reference electrode 115 (as required for 1[d] and 11[d]); that was already bcc CoFe(001) when the MgO was deposited on it. Contrary to the Petition’s allegations, Parkin would not have motivated a POSA to anneal the top and bottom amorphous CoFeB electrodes in the BSO process.

X. THE PETITION FAILS TO ESTABLISH THAT CLAIMS 2, 4, 6, 12, AND 13 ARE OBVIOUS

A. Ground 1 Fails to Establish Claims 2, 4, 6, 12, and 13 Are Obvious.

267. In its Institution Decision, the Board relied on the “entirely crystallized” limitation in claim 2 to conclude that “we view claim 1 as not requiring that the entirety of the first and second CoFeB layers be crystallized.” Paper 9, 20. The Board thus agreed that “entirely crystallized” means that “the entirety of the first and second CoFeB layers be crystallized.” A POSA would have agreed that this was the plain and ordinary meaning of “entirely crystallized” in the art.

268. Claims 2, 4, 6, and 12-13 each require CoFeB layers that are “entirely crystallized” after annealing. The Petition argues that claim 2 is “obvious over Bowen in view of Sunai or Parkin” (Petition, 35-38) and only cross-references its claim 2 analysis for claims 4, 6, 12, and 13 (*id.*, 39, 40, 47, 48).

269. The Petition, however, fails to identify any prior art that discloses a CoFeB layer that is “entirely crystallized” as required by those claims and fails to cite any evidence that the alleged combination of Bowen in view of Sunai or Parkin would have resulted in an entirely crystallized CoFeB layer.

1. The Petition Fails to Cite Any Prior Art Disclosing an MTJ with an “Entirely Crystallized” CoFeB Layer

270. The Petition fails to identify prior art reference that discloses an MTJ with an entirely crystallized CoFeB layer as claimed. The Petition cross references its prior sections on limitations 1 [a], 1[c], and 1[d] (Petition, 35-36) but only alleges that those sections addressed that the “CoFeB layers are crystallized by the annealing,” as opposed to “*entirely* crystallized” as specifically required by claims 2, 4, 6, 12, and 13. *Id.*

271. Indeed, those three cross-referenced sections identify no prior art MTJ with an “entirely crystallized” CoFeB layer.

272. The Petition cites Patent Owner’s infringement contentions (EX1072), which in turn cites several of Petitioner’s patents, but the Petition does not allege that any of them are prior art to the ’167 Patent. Indeed, none of Petitioner’s cited

patents (EX1081-1083) are prior art at least because they were all filed after March 10, 2004, which the Petition admits is the critical date for the '167 Patent. Petition, 18.

273. The Petition cites the file history of the '138 Patent (*see* Petition, 36), but there the Examiner found that “*Parkin fails [to] explicitly disclose the first and second ferromagnetic material layers [are] entirely crystallized.*” EX1012, 119.

274. The Petition cites Cardoso and Parkin as allegedly disclosing crystallized CoFeB, but neither reference discloses a layer of CoFeB that is “entirely crystallized” as claimed.

275. Cardoso only discloses “nanocrystalline CoFeB” and disclosed testing of its CoFeB electrodes that showed they were “not amorphous.” EX1061, 2272-2273. An electrode being “not amorphous” just means that there is some order to the layer and does not amount to it being “entirely crystallized” as claimed.

276. Parkin discloses that only “a portion of the [CoFeB] storage layer 175... has crystallized” EX1062, 8:51-55. A layer of which only a “portion” is crystallized does not have “the entirety” of the layer “crystallized” and thus is not “entirely crystallized” under the usage adopted by the Board and the ordinary meaning in the art.

277. The disclosure that a “portion” of the storage layer 175 crystallized is not tantamount to the disclosure of a layer being “entirely crystallized” as claimed

because a “portion” may take on many forms that are not layers. For example, there could be islands of crystallized material in a sea of amorphous material. *Id.* Indeed, the Examiner of the related ’138 Patent found that “Parkin fails [to] explicitly disclose ... layers [that are] entirely crystallized.” EX1012, 119.

278. Despite citing that prosecution history, the Petition does not even allege that Examiner erred in that finding. Parkin discloses that its MgO layer provides a “template” for crystal formation (Petition, 37), but Parkin’s testing showed that only a “portion” of the storage layer above the MgO actually crystallized. Parkin discloses that the “bulk” of the storage layer 175 “remains amorphous” even after annealing. EX1062, 18:59-60. Thus, Parkin’s disclosure that a “portion” of the storage layer 175 crystallized does not disclose that the “portion” was itself a layer as the Petition speculates.

279. In sum, the Petition fails to cite a single prior art reference that discloses a CoFeB layer that is “entirely crystallized” as required by claims 2, 4, 6, 12, and 13.

2. The Petition Fails to Cite Any Evidence that the Alleged Combination Would Have Resulted in an “Entirely Crystallized” CoFeB Layer.

280. In addition to failing to cite any prior art reference that discloses an “entirely crystallized” CoFeB layer in an MTJ, the Petition also fails to cite any

evidence to establish that the alleged combination would have resulted in an entirely crystallized CoFeB layer.

281. The Petition's cross reference to its prior sections on claim limitations 1[a], 1[c], and 1[d] (Petition, 35-36, cross-referencing §§VI.A.2, VI.A.4-VI.A.5) fails to show that the combination would have resulted in a CoFeB layer that was "entirely crystallized," as claimed.

282. Indeed, nowhere does the Petition in those prior sections ever allege that the Bowen-Sunai-Parkin combination would have resulted in an *entirely* crystallized CoFeB layer. *Id.*, 22-28, 29-33. The cross-referenced sections are therefore insufficient to establish the alleged combination would have resulted in an entirely crystallized CoFeB layer.

B. Ground 2 Fails.

283. The Petition alleges in Ground 2 that claim 2 is "obvious over Nagahama in view of Sunai or Parkin" (Petition, 58) but largely relies on its Ground 1 analysis, which fails as explained above. See *supra* §X.A. The only new allegation for Ground 2 is that "Nagahama taught annealing," but the Petition does not even allege that Nagahama discloses a CoFeB layer that is "entirely crystallized." *Id.* Nagahama has no such disclosure.

284. The Petition's analysis for claims 4, 6, 12, and 13 merely cross-reference the Petition's claim 2 analysis and thus fail to establish the obviousness of those claims for the same reasons as claim 2 fails. Petition, 59, 61, 67-68.

XI. SECONDARY CONSIDERATIONS DEMONSTRATE NON-OBVIOUSNESS OF EACH CHALLENGED CLAIM.

285. In this section I evaluate secondary considerations of non-obviousness including industry praise, the recognition of contemporaries, failure of others, and solving a long-felt but unmet need. Even if the combinations in the Petition did not have the problems I discussed above, these secondary considerations would still compel a conclusion that the claims are non-obvious.

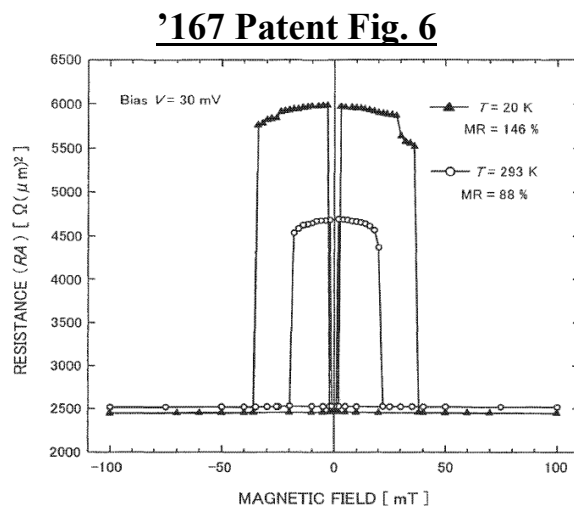
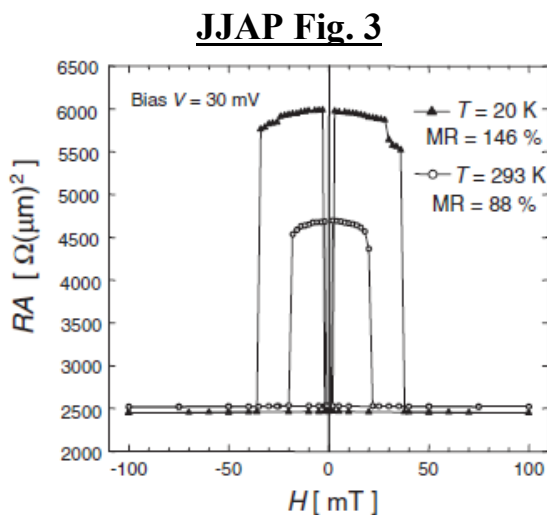
286. I understand that certain secondary considerations can include evidence of how others reacted to Dr. Yuasa's invention and, therefore, such evidence is sometimes dated after the date of invention for the Challenged Claims. I understand that this evidence is highly relevant to evaluating the nonobviousness of the invention in the Challenged Claims because it objectively demonstrates the reactions of those in the field who were most familiar with Dr. Yuasa's work and how it impacted the art.

287. The objective indicia discussed below are reasonably commensurate with the scope of the claims for aspects that were not in the prior art, and taken individually or as a whole plainly show the invention in the Challenged Claims

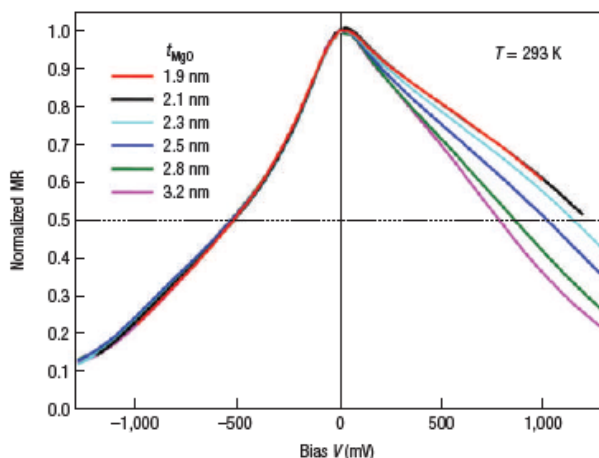
was non-obvious over the alleged combinations of Bowen in view of Sunai or Parkin (Ground 1), and Nagahama in view of Sunai or Parkin (Ground 2).

A. The Claimed Technology Received Widespread Praise from Industry and Academia.

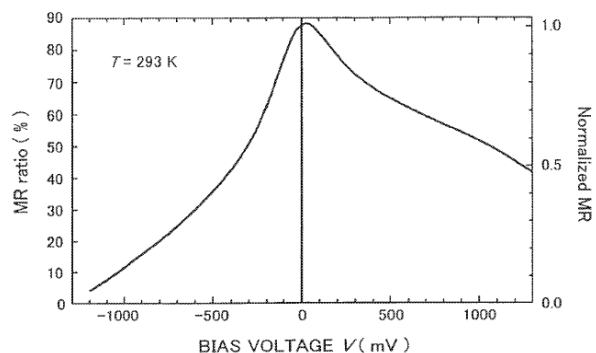
288. Shortly after filing the two Japanese patent applications to which the '167 Patent claims priority, Dr. Yuasa publicly disclosed the '167 Patent's embodiments that use Fe electrodes through articles in the Japanese Journal of Applied Physics ("JJAP," EX2007) and in Nature Materials ("Nature," EX2008). Indeed, versions of the '167 Patent's figures appear in JJAP and Nature as shown below. *Id.*



Nature Fig. 3a



'167 Patent Fig. 7(A)



289. Albert Fert—a Nobel laureate in physics for his work in spintronics, and notably a co-author on Petitioner’s primary reference Bowen—when providing a historical overview of spintronics in a 2012 textbook, specifically referred to Dr. Yuasa’s work in his famous 2004 Nature Materials paper (EX2008) as an “important breakthrough” in “the most important step [of] the transition from MTJ with amorphous tunnel barrier (alumina) to single-crystal MTJ and especially MTJ with MgO barrier.” EX2020, 8; EX1026, 1655; EX1057, 7; EX2018, 187:20-190:24. The Nature Materials article (EX2008) has been cited at least 4216 times. EX2057.

290. Dr. Yuasa also disclosed the results achieved by the claimed methods of the '167 Patent in Applied Physics Letters (EX2006, “Yuasa-APL2005”). For example, Yuasa-APL2005 discloses a method of manufacturing an MTJ (Limitation 1[pre]) by disclosing “[t]hin films for MTJs were deposited onto thermally oxidized Si wafer (100) using magnetron sputtering system.” EX2006, 1.

291. Yuasa-APL2005 disclosed that “CoFeB was deposited” for both the “reference and free layers (each 3 nm),” and that the CoFeB was “amorphous,” thus meeting Limitations 1[a] and 1[c]. EX2006, 1.

292. Yuasa-APL2005 disclosed “grow[ing]” an “MgO layer” “sandwiched” in-between the “amorphous CoFeB ferromagnetic electrodes,” thus meeting Limitation 1[b]. EX2006, 1.

293. Yuasa-APL2005 disclosed “annealing” that “caused” at least “partial crystallization” of the “CoFeB layers,” thus meeting Limitation 1[d]. EX2006, 2.

294. Yuasa-APL2005 disclosed that “the MgO layer [had] (001) fiber texture” that was “polycrystalline,” thus meeting Limitations 1[e] and 11[b].

295. Yuasa-APL2005 also disclosed “a possibility of local crystallization of a few monolayers of CoFeB at the electrode/barrier interfaces.” EX2006, 2.

296. A POSA would have recognized that the crystalized “*monolayers*” of CoFeB met the claimed first and second CoFeB layers that “are entirely crystallized” “after the annealing,” thus meeting, e.g., independent claims 1 and 11 and the “entirely crystallized” limitations in claims 2, 4, 6, and 12-13. In sum, Yuasa-APL2005 disclosed the claimed methods of the ’167 Patent.

297. Dr. Yuasa’s public disclosure of the claimed methods drew immediate and sustained attention and praise from across the industry and research community, including from Petitioner’s own employees. Indeed, according to

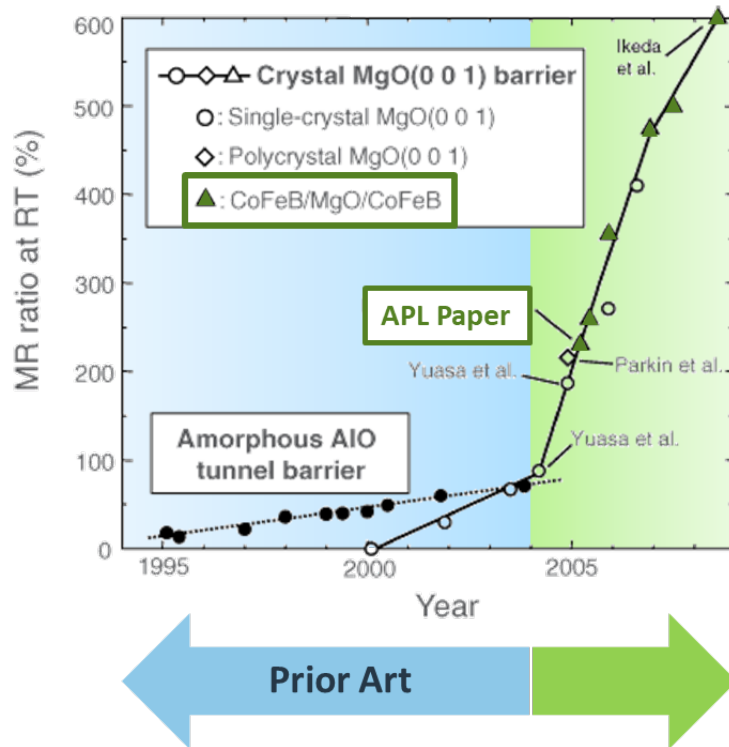
Google Scholar, Dr. Yuasa's Yuasa-APL2005 paper has been cited more than 1,200 times. EX2052.

298. As one example, a 2005 review explained "In the past year unprecedentedly large TMR ratios have been reported..." citing Dr. Yuasa's Yuasa-APL2005 paper. EX2019, 591, 592 (citing [43]), 694 ([43] is EX2006).

299. EX2019 praised the claimed methods that achieved a "230% room temperature magnetoresistance," EX2019, 592. Because Yuasa-APL2005 disclosed the claimed methods that directly resulted in the "unprecedentedly large" 230% TMR, the praise is directly connected to the claimed invention.

300. As another example, Petitioner cites a 2017 book chapter, Petition, 6-7, 11-12, 14, citing EX1057, that discusses the Yuasa-APL2005 paper disclosing the claimed invention. EX1057, 46-47 (citing [33]), 52 ([33] is EX2006). Figure 2.21 shows graphically how the claimed methods disclosed in Yuasa-APL2005 unleashed a new era of skyrocketing TMRs. EX1057, 46.

Figure 2.21 (Annotated)



301. EX1057 explains that a “fundamental problem” with the prior art was “a problem concerning crystal growth.” EX1057, 46-47. It credits the claimed method disclosed by Yuasa-APL2005 as “solv[ing] this problem” “by using a sputtering deposition technique” to make a “CoFeB/MgO/CoFeB” “MTJ structure,” where the “as-grown state” of the CoFeB was “amorphous.” *Id.*, 47. EX1057 explains that “[s]urprisingly” the MgO barrier became “a (001)-oriented polycrystal” despite being grown on an “amorphous CoFeB” underlayer. *Id.*

302. The “problem concerning crystal growth,” EX1057, 46-47, describes the problem that the materials used for the reference layer, consisting of an antiferromagnet such as PtMn or IrMn coupled to a magnetic layer of CoFe or a

multilayer “SAF” (synthetic antiferromagnet) structure of CoFe/Ru/CoFe, grow with a (111) texture. The (111) surface with its 3-fold symmetry does not provide a template for forming MgO(001) with its 4-fold symmetry. This prevented manufacturing of the desirable CoFe/MgO/CoFe (001) – the only solution would have been to discard the known, reliable antiferromagnet/CoFe/Ru/CoFe(111) structure and look for another materials stack to form the reference layer which was compatible with the (001)-textured tunnel barrier stack. As stated in EX1057, 47, this solution “is not generally acceptable to the electronics industry because it has spent more than a decade in developing the reliable pinned layer structure.”

303. Yuasa’s MTJ structure “solve[d] this problem” EX1057, 47 by using an amorphous CoFeB/MgO/amorphous CoFeB structure which was then crystallized, leading to the desirable (001) orientation of the tunnel stack while preserving the use of the well-established and reliable antiferromagnet/SAF structure. Moreover, Yuasa’s stack is deposited using a sputtering technique, which is well suited to incorporation into the semiconductor manufacturing process. The importance of this innovation cannot be overstated, in particular leading to a dramatic increase in readback signal for hard disk drives (HDDs) and hence an increase in the trend in data density. For example, “By using ultralow-resistance CoFeB/MgO/CoFeB MTJs [], HDD manufacturers were able to commercialize TMR read heads for ultrahigh-density HDDs in 2007 [.]”, EX1057, 49.

304. As Figure 2.21's triangle icons show, others then applied the claimed methods, "known as solid-phase epitaxy," to achieve increasingly higher TMRs of "up to 600%." EX1057, 48.

305. Significant industry praise came from Petitioner itself. For example, Chando Park co-authored a 2006 review on MTJs. EX2005, 36. The review article lists Mr. Park as working for "Western Digital Corporation." *Id.* It asserts, "[t]he development of CoFeB/MgO/CoFeB tunnel junctions" disclosed by the Yuasa-APL2005 paper "provides a practical solution to overcome this difficulty [of crystal growth]" that using amorphous CoFeB as-deposited solved. EX2005, 39 (citing [21]), 45 ([21] is EX2006 Yuasa-APL2005).

306. As another example, "Zheng Gao, Recording Head Development Group, Western Digital Corporation" co-authored a 2018 paper that not only credited the "even higher TMR ratio of 230%" disclosed by Yuasa-APL2005, but credited the "significance" of method of making that MTJ through "a fully integrated film directly produced from sensor deposition sputtering" using "amorphous (*a*)-CoFeB ... to promote strong (001) MgO texture in the as-deposited state" where "post annealing transforms" the CoFeB layer to a polycrystalline layer. EX2022, 107 (citing [10]), 110 ([10] is EX2006).

307. Petitioner’s employees have thus recognized the difficulty of crystal growth using prior art methods and credited the claimed methods as solving those challenges.

308. Employees of TDK, a competitor to Petitioner, more recently authored a 2023 paper that recognized the importance of the claimed methods of the ’167 Patent in the development of MTJs. EX2023, 1. The TDK paper states the claimed method was significant because it “used a conventional sputtering system instead of an MBE system... [to] achieve a giant TMR ratio with simple amorphous CoFeB ferromagnetic electrodes, instead of strenuously high temperature deposition with single crystal structures.” EX2023, 2 (citing reference [20], i.e., EX2006). While the claimed methods may seem “conventional” and “simple” in 2023, such an achievement of using such methods that resulted in a 230% TMR at room temperature was extraordinary in 2004.

309. Dr. Yuasa has been awarded many prizes recognizing his groundbreaking work related to the invention of the ’167 patent. In 2022, Dr. Yuasa was awarded the “Japan Society of Applied Physics Achievement Award,” for his “invent[ion] of MTJs combining MgO and cobalt iron boron (CoFeB) alloys,” including his “*process* that enabled [MTJ] device fabrication on arbitrary underlying layers,” which “enabled mass production on large-diameter wafers by room-temperature sputter deposition, which opened the door to industrial

applications of MgO MTJ devices.” EX2024, 2-3. In 2021, he was made an “IEEE Fellow” for his “contributions to MgO-based magnetic tunnel junctions.” EX2026, 1. Also in 2021, Dr. Yuasa was awarded the “Future Creative Invention Prize” for his “invention... of [JP] patent no. 5120680” (EX2055) which is a foreign equivalent of the ’167 Patent. EX2027.

310. In 2016, Dr. Yuasa won the “Science and Technology Prize” for his “new type of tunnel magnetoresistance element ... using crystalline magnesium oxide (MgO) as the tunnel insulating film,” for which “*a giant tunnel magnetoresistance effect of approximately 200% at room temperature was realized for the first time in the world.*” EX2029, 2. The award noted that “mass production technology was developed that combines MgO and the magnetic alloy CoFeB, making industrial applications of MgO tunnel magnetoresistance elements possible.” *Id.*

311. IEEE named Dr. Yuasa a Magnetics Society Distinguished Lecturer in 2012, noting his work with “MTJs with a CoFeB/MgO/CoFeB structure were developed for practical application and found to have MR ratios of above 200% and other practical properties.” EX2030, 3. The IEEE Magnetics society profile notes that “[Dr. Yuasa’s] most important scientific achievements are the development of MgO-based MTJs including CoFeB/MgO/CoFeB-type MTJs and their applications to read heads of hard disk drives and STT-MRAM.” EX2031.

312. Dr. Yuasa was awarded the Tsukuba Prize in 2009, which included a monetary award of 5 million yen, his development of an MTJ using a crystalline MgO tunnel barrier that “achieved a huge MR ratio of 180% at room temperature” and for his work “developing mass production technology for crystalline MgO-MTJ elements.” EX2032, 1; *see also* EX2033. In the same year, he was awarded the “Inoue Harushige Prize” for his invention of “an original method of growing a crystalline layer [MgO] on an amorphous layer [CoFeB].” EX2034, 1; *see also* EX2035.

313. Dr. Yuasa has received numerous other awards for his work on MTJs, including the JSPS Prize in 2010 for the “Development of High Performance Magnetic Tunnel Junction Devices,” the Asahi Award in 2008 for his “Studies on development and application of tunnel magnetoresistive effect,” the IBM Japan Science Prize in 2007 for “Studies on tunnel magnetoresistive effects and their application,” the Tokyo Techno Forum 21 Gold Medal Prize in 2006 for “Study on spintronics technology for MRAM,” the Marubun Science Prize in 2006 for the “Study on tunnel magnetoresistance effect,” and the Ichimura Science Prize in 2005. EX2028, 4.

314. In sum, Dr. Yuasa has been repeatedly praised for his development of the method for making MTJs disclosed and claimed in the '167 Patent.

B. The Claimed Technology Solved a Long-Felt but Unmet Need

315. The claimed methods also satisfied a long-felt, but unmet need for commercially manufacturable processes providing MTJs with high room temperature TMR for mass MRAM production, further confirming their nonobviousness.

316. Yuasa's MTJ structure could be deposited using a sputtering technique, which is highly advantageous in semiconductor manufacturing compared to other processes used to make thin layers. Sputtering is used to make other metal and oxide layers in semiconductor devices and is familiar to the industry, and equipment is readily available. Sputtering can deposit uniformly over large areas which is critical for successful manufacturing considering the very thin and uniform layers required for MTJs. Thus Yuasa's MTJ deposition process dramatically increased the TMR, satisfying a long felt need in improving hard drive readback heads.

317. In 1995 an MTJ with a 10% TMR was achieved in 1995. EX2039, 846. By the late 1990s, MTJ devices were considered the "most viable" MRAM technology (EX1039, 2819) but commercialization was not feasible because TMR was too low and manufacturing techniques were incompatible with large scale manufacturing (EX2038, 6-7). Ross, ¶XX. There was a need to achieve TMRs

using manufacturing method to make MTJs in mass quantities and rather than one single crystal at a time. EX2056, 8; Ross, ¶XX.

318. Researchers undertook extensive experimental effort from 1995 to 2000 to make MTJs using an amorphous alumina tunnel barrier layer, but the resulting 10-70% TMRs were still “lower than those needed for many applications of spintronic devices.” EX1057, 9; EX2056, 6, 7; EX1011, 2:42-56.

319. In 2001, Butler and Mathon speculated that higher TMRs could be obtained using crystalline MgO tunnel barriers with epitaxially grown crystalline Co or Fe electrodes. EX1057, 16. These theoretical predictions “led to numerous experimental studies to explore the possibility of high TMR in epitaxial (100) oriented Fe/MgO/Fe tunnel junctions”—i.e., MTJs with purely crystalline layers. EX2056, 11.

320. Early attempts at making MTJs using crystalline MgO tunnel barriers failed to achieve the theoretical predictions and such epitaxially grown single crystal structures were unsuited to mass production.

321. One well-known example was Bowen, Petitioner’s base reference in ground 1, which was the “first report of significant tunneling magnetoresistance through epitaxially grown MgO tunnel barriers,” but whose 27% TMR was lower than was achieved with conventional amorphous alumina tunnel barriers. EX2056, 10, EX1057, 45.

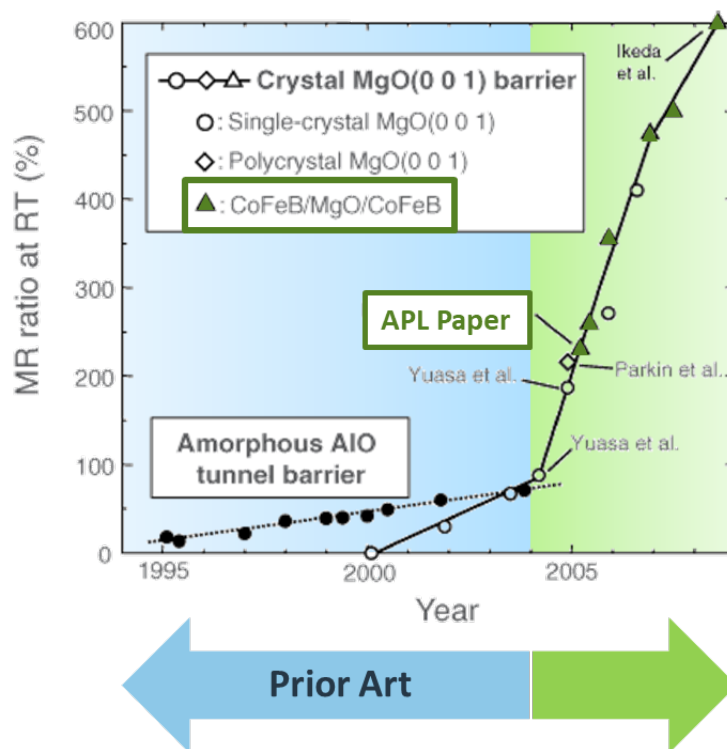
322. Early attempts also failed to address the problem of manufacturability, as the MgO barriers “were either very thick resulting in high resistance-area (RA) values or fully epitaxial grown on single-crystal substrates, which is incompatible with read-head manufacturing.” EX2038, 7. Even Petitioner’s employees recognized that such single crystal approaches “vastly limit commercial applications.” EX2005, 39.

323. The ’167 Patent’s claimed invention solved these long-felt but unmet needs. The ’167 Patent provided a breakthrough for commercially manufacturing MTJs by avoiding “strenuously high temperature deposition with single crystal structures.” EX2023, 2. Because the claimed method used amorphous CoFeB, it allowed for the use of “conventional sputtering system instead of an MBE system.” *Id.*, 1. Indeed, this ease of manufacturing formed the basis of many of the awards that the ’167 Patent’s inventor, Dr. Yuasa, received in recognition of his achievements. *Supra* §XI.B; EX2024, 2-3.

324. The specific methods claimed by the ’167 Patent using CoFeB electrodes achieved even higher 230% room temperature TMR. EX2006, 1-2; *see also supra* §XI.A (comparing the claimed method published by EX2006 with the claimed method and finding them identical); EX1013, 8:4-20, 9:6-27 (describing resulting characteristics of MTJs made by claimed method).

325. This immediately shifted the focus of industrial and academic MTJ research and development efforts. As Figure 2.21 shows, after the pioneering Yuasa-APL2005 published—describing the '167 Patent's invention—skyrocketing TMR improvements focused almost entirely on CoFeB/MgO/CoFeB MTJs as claimed. EX1057, 46.

Figure 2.21 (Annotated)



EX1057, 46.

326. In short, industry praise, the recognition of contemporaries, failure of others, and solving a long-felt but unmet need, compel a conclusion that the claims are non-obvious over the alleged combinations.

XII. CONCLUSION

327. I declare that all statements made herein of my own knowledge are true, that all statements made on information and belief are believed to be true, and that these statements were 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.

328. I declare under penalty of perjury that the foregoing is true and correct.

Date: 7/12/2025

By: 
Caroline A. Ross, Ph.D.

APPENDIX A: MATERIALS CONSIDERED

Exhibit	Description
1011	U.S. Patent No. 10,367,138 (“’138 Patent”)
1012	File History for U.S. Patent No. 10,367,138
1013	U.S. Patent No. 10,680,167 (“’167 Patent”)
1024	Declaration of Jeffrey Bokor, Ph.D.
1026	Bowen et al., <i>Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions on GaAs(001)</i> , 79 Appl. Phys. Letters 1655-1657 (2001) (“Bowen”)
1027	European Patent Application No. EP1391942A1 to Nagahama et al. (“Nagahama”)
1030	Certified English Translation (with Translator Declaration) of Japanese Patent Application Publication No. JP2002204004A to Sunai et al. (“Sunai”)
1031	Simmons, <i>Generalized Formula for the Electric Tunnel Effect between Similar Electrodes Separated by a Thin Insulating Film</i> , 34 J. Appl. Phys. 1793-1803 (1963)
1036	Wulff et al., <i>Characterization of MgO Layers on Different Alumina and Glass Substrates by Grazing Incidence Diffractometry and Grazing Incidence X-ray Reflectometry</i> , 23 Surface & Interface Analysis 148-154 (1995)
1039	Tehrani et al., <i>Progress and Outlook for MRAM Technology</i> , 35 IEEE Trans. Magn. 2814-2819 (1999)
1040	Yoon et al., <i>Growth characteristics and surface roughening of vapor-deposited MgO thin films</i> , 60 Phys. Rev. 2839-2843 (1999)
1044	Butler et al., <i>Spin-dependent tunneling conductance of Fe MgO Fe sandwiches</i> , 63 Phys. Rev. B 054416 (2001)

Exhibit	Description
1045	Klaauw et al., <i>Growth, structure, electronic, and magnetic properties of MgO/Fe(001) bilayers and Fe/MgO/Fe(001) trilayers</i> , 64 Phys. Rev. B. 134411 (2001)
1046	Mathon et al., <i>Theory of tunneling magnetoresistance of an epitaxial Fe/MgO/Fe(001) junction</i> , 63 Phys. Rev. 220403 (2001)
1055	Wang et al., <i>70% TMR at Room Temperature for SDT Sandwich Junctions With CoFeB as Free and Reference Layers</i> , 40 IEEE Trans. Magn. 2269-2271 (2004)
1056	U.S. Patent Publication No. 2004/0136232A1 (“Hosomi”)
1057	Dieny et al., <i>Introduction to Magnetic Random-Access Memory</i> (IEEE Press 2017) (excerpts)
1060	Jimbo et al., <i>Thermal stability of spin valves using amorphous CoFeB</i> , 165 J. Magnetism & Magnetic Materials 308-311 (1997)
1061	Cardoso et al., <i>Ferromagnetic Coupling Field Reduction in CoFeB Tunnel Junctions Deposited by Ion Beam</i> , 40 IEEE Trans. Magn. 2272-2274 (2004)
1062	U.S. Patent No. 7,270,896 (“Parkin”)
1072	Claim Chart for ’138 Patent, Exhibit EE to First Amended Complaint, <i>Godo Kaisha IP Bridge 1 v. Western Digital Corporation</i> , Case No. 24-cv-00342-RGA (D. Del. July 8, 2024)
1081	U.S. Patent No. 7,751,156 (’156 Patent)
1082	U.S. Patent No. 8,427,791 (’791 Patent)
1083	U.S. Patent No. 8,914,970 (’970 Patent)
1084	Boubeta et al., <i>Epitaxial Fe/MgO heterostructures on GaAs(001)</i> , 226 J. of Crystal Growth 223-230 (2001)
2001	Kittel, C., <i>Introduction to Solid State Physics</i> , 6th Edition, 1986, pgs. 13-15, 18, 23 (“Kittel”)

Exhibit	Description
2002	Duke, C.B., <i>Tunneling in Solids</i> , Solid State Physics: Advances in Research and Applications, 1969, pgs. 1, 6-7, 34-35, 78-79 (“Duke”)
2003	Definition of “ferromagnetism,” Oxford English Reference Dictionary, Second Edition, pg. 513 (“Oxford English Reference Dictionary”)
2004	“Ferromagnetism,” The New Encyclopedia Britannica: Volume 4, 15th Edition, 2003, pgs. 748-749 (“Britannica”)
2005	J-G Zhu and C. Park. “Review Feature: Magnetic tunnel junctions,” <i>Materials Today</i> , vol. 9, no. 11, 2006, pp. 36-45 (“Zhu”)
2006	Djayaprawira, D. et al. “230% room-temperature magnetoresistance in CoFeB/MgO/CoFeB magnetic tunnel junctions,” <i>Applied Physics Letters</i> , vol. 86, no. 9, 2005, pp. 092502-1 to -3
2007	Yuasa, S., et al. “High Tunnel Magnetoresistance at Room Temperature in Fully Epitaxial Fe/MgO/Fe Tunnel Junctions due to Coherent Spin-Polarized Tunneling,” <i>Japanese Journal of Applied Physics</i> , vol. 43, no. 4B, 2004, p. L588
2008	Yuasa, S., et al. “Giant room-temperature magnetoresistance in single crystal Fe/MgO/Fe magnetic tunnel junctions,” <i>Nature Materials</i> , vol. 3, no. 12, 2004, pp. 868-871
2009	Callister, W.D., <i>Fundamentals of Materials Science and Engineering, An Integrated Approach</i> , Department of Metallurgical Engineering, The University of Utah, Second Edition, 2005, pgs. 36-37, G1 (“Callister”)
2010	U.S. Patent No. 6,590,803 to Saito et al. (“the ’803 Patent”)
2011	U.S. Patent Application Publication No. 2002/0036877 to Sakakima et al. (“Sakakima”)
2012	U.S. Patent No. 6,917,492 to Matsukawa et al. (“the ’492 Patent”)

Exhibit	Description
2013	S. Yuasa et al. “Characterization of growth and crystallization processes in CoFeB / MgO / CoFeB magnetic tunnel junction structure by reflective high-energy electron diffraction,” <i>Applied Physics Letters</i> , vol. 87, no. 24, p. 242503, 2005.
2014	Definitions of “crystalline” and “crystallize,” Webster’s Encyclopedic Unabridged Dictionary of the English Language (1989)
2015	Definitions of “anneal”, “crystalline” and “crystallized,” Webster’s Ninth New Collegiate Dictionary (1984)
2016	Gleiter, H. “Nanostructured Materials: Basic Concepts and Microstructure,” <i>Acta Materialia</i> , vol. 48, no. 1, pp. 1-29, 2000
2017	Deposition of Jeffrey Bokor, Ph.D. (June 24, 2025)
2018	Deposition of Jeffrey Bokor, Ph.D. (June 25, 2025)
2019	Marrows, C.H. “Spin-polarised currents and magnetic domain walls,” <i>Advances in Physics</i> , vol. 52, no. 8, 2005, pp. 585-713
2020	Tsymbal, E., et al., <i>Handbook of Spin Transport and Magnetism</i> , 2012
2021	RESERVED
2022	Nakatani, T., et al. “Read sensor technology for ultrahigh density magnetic recording,” <i>MRS Bulletin, Materials Research Society</i> , vol. 43, no. 2, 2018, pp. 106-111
2023	Jiang, B., et al. “Tunneling magnetoresistive devices as read heads in hard disk drives,” <i>Journal of Magnetism and Magnetic Materials</i> , vol. 571, 2023, p. 170546
2024	The 23rd (FY2022) Japan Society of Applied Physics Achievement Award Recipients (with English translation), The Japan Society of Applied Physics, <i>available at</i> https://www.jsap.or.jp/outstanding-achievementaward/recipients/recipients23
2025	RESERVED

Exhibit	Description
2026	2021 New Fellows, IEEE Japan Council, <i>available at</i> https://ieeejp.org/en/kaiin/fellow/fellow21.html
2027	JST owned patent wins Future Creative Invention Prize at the National Invention Award 2021, Japan Science and Technology Agency, <i>available at</i> https://www.jst.go.jp/report/2021/210525_e.html
2028	Dr. Shinji Yuasa profile, <i>available at</i> https://www.jst.go.jp/impact/sahashi/en/system/index.html
2029	AIST wins three Science and Technology Awards in the 2016 Minister of Education, Culture, Sports, Science and Technology Commendation for Science and Technology, <i>available at</i> https://www.aist.go.jp/aist_j/news/prize/pr20160412_3.html
2030	Yuasa, S., “IEEE Magnetics Society Distinguished Lecturers for 2012: Magnetoresistance and Spin-Transfer Torque in Magnetic Tunnel Junctions,” <i>IEEE Transactions on Magnetics</i> , vol. 48, no. 1, 2012, p.3
2031	Shinji Yuasa – IEEE Magnetics Society, <i>available at</i> https://ieeemagnetics.org/contact/shinji-yuasa#biography
2032	AIST, “Winner of the 20th Tsukuba Award,” <i>available at</i> 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), <i>available at</i> https://www.tsukuba-sci.com/cms/?p=9853
2034	AIST: 34th Inoue Harunari Prize, <i>available at</i> https://www.aist.go.jp/aist_j/news/prize/itemid025-000082.html
2035	Technological seeds that overcome the valley of death (Shinji Yuasa/Head of the Spintronics Group, National Institute of Advanced Industrial Science and Technology), <i>available at</i> https://scienceportal.jst.go.jp/explore/highlight/20090717_01/

Exhibit	Description
2036-2037	RESERVED
2038	Maat, S., et al. “Physics and Design of Hard Disk Drive Magnetic Recording Read Heads,” <i>Handbook of Spintronics</i> , 2014
2039	Butler, et al. “ <i>Magnetic Memory A signal boost is in order,</i> ” <i>Nature Materials</i> , vol. 3, December 2004, pp. 845-847
2040-2047	RESERVED
2048	M. Ohring, <i>The Materials Science of Thin Films</i> , Academic Press (1992).
2049-2051	RESERVED
2052	Google Scholar data page for Djayaprawira, D. et al. “230% room-temperature magnetoresistance in CoFeB/MgO/CoFeB magnetic tunnel junctions,” <i>Applied Physics Letters</i> , vol. 86, no. 9, 2005, pp. 092502-1 to -3
2053	RESERVED
2054	CV of Caroline A. Ross, Ph.D.
2055	Japanese Patent No. JP 5120680 B2 with certified English translation
2056	File History of U.S. Patent Application No. 10/824835 (EX1092 in <i>Western Digital v. IP Bridge</i> , IPR2025-00701)
2057	Google Scholar data page for Yuasa, S., et al. “Giant room-temperature magnetoresistance in single crystal Fe/MgO/Fe magnetic tunnel junctions,” <i>Nature Materials</i> , vol. 3, no. 12, 2004, pp. 868-871
2058	Saito, Y., et al., “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>Jpn. J. Appl. Phys.</i> , vol. 39 (2000), pp. L 1035–L 1038.

Exhibit	Description
2059	Powder diffraction file for Au, from Joint Committee of Powder Diffraction Standards (JCPDS), The International Centre for Diffraction Data, icdd.com
2060	I. Petrov et al. “Microstructural evolution during film growth,” <i>Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films</i> , vol. 21, no.5, 2003, pp. S117-S128 (“Petrov”)
2061	E. Krikorian and R.J. Sneed. “Nucleation, Growth and Transformation of Amorphous and Crystalline Solids Condensing From the Gas Phase,” <i>Astrophysics and Space Science</i> , vol. 65, 1979, pp. 129-154 (“Krikorian”)
2062	M.O. Aboelfotoh. “Crystal Structure of Evaporated MgO Films on Amorphous and Polycrystalline Substrates,” <i>Journal of Vacuum Science and Technology</i> , vol. 10, no. 5, 1973, pp. 621-625

APPENDIX B: U.S. PATENT NO. 10,680,167 CLAIM LIST

This claim list uses Petitioner's taxonomy for marking claim limitations as provided in the Petition's List of Challenged Claims. Petition, xvii-xix.

Ref	Limitation
1[pre]	A method of manufacturing a magnetic tunnel junction (MTJ) device, comprising:
1[a]	forming a first CoFeB layer that is amorphous;
1[b]	forming a magnesium oxide (MgO) layer over the first CoFeB layer;
1[c]	forming a second CoFeB layer that is amorphous over the MgO layer; and
1[d]	annealing the first and second CoFeB layers and the MgO layer, wherein the first and second CoFeB layers are crystallized by the annealing, and
1[e]	wherein the MgO layer is poly-crystalline in which a (001) crystal plane is preferentially oriented.
2	The method of claim 1, wherein after the annealing, the first and second CoFeB layers are entirely crystallized.
3	The method of claim 1, wherein after the annealing, each of the first and second CoFeB layers is poly-crystalline in which a (001) crystal plane is preferentially oriented.
4[pre]	The method of claim 1, wherein
4[a]	after the annealing, the first and second CoFeB layers are entirely crystallized, and
4[b]	each of the first and second CoFeB layers is poly-crystalline in which a (001) crystal plane is preferentially oriented.

Ref	Limitation
5	The method of claim 1, wherein after the annealing, each of the first and second CoFeB layers is poly-crystalline in which a (001) crystal plane is preferentially oriented and each of the first and second CoFeB layers includes a BCC (body-centered cubic) structure.
6[pre]	The method of claim 1, wherein
6[a]	after the annealing the first and second CoFeB layers are entirely crystallized, and
6[b]	each of the first and second CoFeB layers is poly-crystalline in which a (001) crystal plane is preferentially oriented and each of the first and second CoFeB layers includes a BCC (body-centered cubic) structure.
7	The method of claim 1, wherein in the forming the MgO layer, the MgO layer is formed as a MgO_x ($0 < x < 1$) layer.
8	The method of claim 1, wherein in the forming the MgO layer, the value of x in MgO_x for the MgO layer is greater than 0 and less than 1.
9	The method of claim 1, wherein in the forming the MgO layer, the MgO layer is formed directly on the first CoFeB layer.
10[pre]	The method of claim 1, wherein
10[a]	in the forming the MgO layer, the MgO layer is formed directly on the first CoFeB layer, and
10[b]	in the forming the second CoFeB layer, the second CoFeB layer is formed directly on the MgO layer.
11[pre]	A method of manufacturing a magnetic tunnel junction (MTJ) device, comprising:
11[a]	forming a first ferromagnetic layer including a first CoFeB layer that is amorphous;
11[b]	forming a barrier layer including a magnesium oxide (MgO) layer to have a poly-crystalline state in which a (001) crystal plane is preferentially oriented over the first ferromagnetic layer;

Ref	Limitation
11[c]	forming a second ferromagnetic layer including a second CoFeB layer that is amorphous over the barrier layer; and
11[d]	annealing the first and second ferromagnetic layers and the barrier layer, to crystallize the first and second CoFeB layers.
12	The method of claim 11, wherein after the annealing, the first and second CoFeB layers are entirely crystallized.
13[pre]	The method of claim 11, wherein
13[a]	the first and second CoFeB layers are entirely crystallized, and
13[b]	each of the first and second CoFeB layers is poly-crystalline in which a (001) crystal plane is preferentially oriented and each of the first and second CoFeB layers includes a BCC (body-centered cubic) structure.
14	The method of claim 11, wherein in the forming the barrier layer, the MgO layer is formed as a MgO_x ($0 < x < 1$) layer.
15[pre]	The method of claim 11, wherein
15[a]	in the forming the barrier layer, the barrier layer is formed directly on the first ferromagnetic layer, and
15[b]	in the forming the second ferromagnetic layer, the second ferromagnetic layer is formed directly on the barrier layer.