

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
U.S. Patent No. 10,680,167

DECLARATION OF JEFFREY BOKOR, PH.D.

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I, Jeffrey Bokor, hereby declare as follows:

I. INTRODUCTION

1. I have prepared this Declaration in connection with Western Digital Technologies, Inc.’s Petition for *Inter Partes* Review of U.S. Patent No. 10,680,167 (“the ’167 Patent”) (EX1013).

2. In the course of preparing this Declaration, I reviewed the ’167 Patent and its prosecution file history, as well as the other documents listed in Section III and/or discussed in this Declaration.

3. I have been retained by Western Digital Technologies, Inc. (“Western Digital” or “Petitioner”) as an expert in the field of integrated circuit device technologies, including magnetic devices, device physics, nanomagnetism, and spintronics. I am being compensated at my normal consulting rate for my time. My compensation is not dependent on, and in no way affects, the substance of my statements in this Declaration. I have no financial interest in Western Digital, the ’167 Patent, or the owner of the ’167 Patent.

II. BACKGROUND AND QUALIFICATIONS

4. I have over 35 years of experience in the fields of integrated circuit device technologies, including magnetic devices, device physics, nanomagnetism, and spintronics. I received a Bachelor of Science degree in Electrical Engineering from the Massachusetts Institute of Technology in 1975, a Master of Science in

Electrical Engineering from Stanford University in 1976, and a Ph.D. in Electrical Engineering from Stanford University in 1980.

5. From 1980 until 1993, I was employed at AT&T Bell Laboratories, where I worked on semiconductor physics, laser physics, optoelectronics, and integrated circuit technology, among other topics. In particular, I worked on semiconductor surface and interface physics, CMOS device physics, advanced lithography for integrated circuit manufacturing, and integrated circuit process technology.

6. From 1993 until July 1, 2024, I was a Professor of Electrical Engineering and Computer Sciences (“EECS”) at the University of California (UC), Berkeley, with a joint appointment as a Faculty Scientist in the Materials Science Division at the Lawrence Berkeley National Laboratory (“LBNL”). At UC Berkeley, I held the National Semiconductor Distinguished Professorship in Engineering (an endowed Chair) from 2006-2015 and then the Paul Gray Distinguished Professorship in Engineering from 2015-2024. In 2008, I was appointed as a Senior Faculty Scientist at LBNL. On July 1, 2024, I retired from the University and LBNL with the title of Professor Emeritus. From 2012-2017, I served as Associate Dean for Research in the College of Engineering at UC Berkeley. In 2017, I was appointed as Chair of the Electrical Engineering Division in the EECS Department at UC Berkeley, and Associate Chair of the Department.

In July 2019, I was appointed as Chair of the EECS Department, and I served in that capacity until June 2021.

7. As Principal Investigator, I led the Nanoelectronics and Nanostructures research group at UC Berkeley, which focused on a wide range of topics, including magnetic tunnel junctions, voltage control of magnetism, spintronics, spin-based quantum computing, and ultrafast magnetism. Among my various major research accomplishments over the years, I demonstrated a nanoscale magnetic recording system using spin transfer torque switching from a scanned spin-polarized nanoprobe tip across a tunnel gap to a magnetic recording medium and magnetoresistive magnetic tunnel junction readout using the same probe. I also demonstrated spin transfer torque switching in sub-10 nm size magnetic tunnel junctions and ultrafast spin-orbit torque based magnetic switching using current pulses of only 9 picosecond duration.

8. I have been elected Fellow of the Institute for Electrical and Electronic Engineers (“IEEE”), the American Physical Society (“APS”), and the Optical Society of America (“OSA”). During my career, I served on numerous program committees, scientific advisory committees, and technical advisory boards. I have also served as Chair or Co-Chair of numerous technical conferences, published over 330 articles in scientific and technical literature, including at least 90 papers relating to magnetic and/or spin-based devices dating back to 2002, and been awarded 12

patents in the areas of electronic devices, nanofabrication technologies, including 5 patents on magnetic memory and magnetic/spin-based devices.

9. For further details regarding my qualifications, including my employment and academic history, please refer to my curriculum vitae, which accompanies this declaration as Exhibit 1025 (EX1025).

III. MATERIALS CONSIDERED

10. In addition to any other documents cited or referenced herein, I have reviewed the following materials in preparing this Declaration:

Exhibit No.	Description
1001	U.S. Patent No. 7,884,403 (“’403 Patent”)
1002	File History for U.S. Patent No. 7,884,403
1003	U.S. Patent No. 8,319,263 (“’263 Patent”)
1004	File History for U.S. Patent No. 8,319,263
1005	U.S. Patent No. 8,405,134 (“’134 Patent”)
1006	File History for U.S. Patent No. 8,405,134
1007	U.S. Patent No. 9,123,463 (“’463 Patent”)
1008	File History for U.S. Patent No. 9,123,463
1009	U.S. Patent No. 9,608,198 (“’198 Patent”)
1010	File History for U.S. Patent No. 9,608,198
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”)
1014	File History for U.S. Patent No. 10,680,167
1015	U.S. Patent No. 11,737,372 (“’372 Patent”)
1016	File History for U.S. Patent No. 11,737,372

Exhibit No.	Description
1017	U.S. Patent No. 11,968,909 (“’909 Patent”)
1018	File History for U.S. Patent No. 11,968,909
1019	Patent Family Tree
1020	Japanese Patent No. JP2004071186
1021	English Translation of Japanese Patent No. JP2004071186, from ’372 Patent File History (EX1016)
1022	Japanese Patent Application No. JP2004313350
1023	Certified English Translation (with Translator Declaration) of Japanese Patent Application No. JP2004313350
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”)
1028	Soukup et al., <i>Voltage-Current Characteristics for Electrical Conduction Through Thin MgO Films</i> , 41 J. Appl. Phys. 3229-3236 (1970) (“Soukup”)
1029	Japanese Patent Application Publication No. JP2002204004A to Sunai et al. (“Sunai”)
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)
1032	Trasatti, <i>Electronegativity, Work Function, and Heat of Adsorption of Hydrogen on Metals</i> , 67 J. Chem. Soc. 229-236 (1972)
1033	Jullière, <i>Tunneling between ferromagnetic films</i> , 54A Phys. Letters 225-226 (1975)

Exhibit No.	Description
1034	Miyazaki et al., <i>Giant magnetic tunneling effect in Fe / Al₂O₃ / Fe junction</i> , 139 J. Magnetism & Magnetic Materials L231-L234 (1995)
1035	Moodera et al., <i>Large Magnetoresistance at Room Temperature in Ferromagnetic Thin Film Tunnel Junctions</i> , 74 Phys. Rev. Lett. 3273–3276 (1995)
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)
1037	Castanier et al., <i>Oxygen vacancies on MgO(100)</i> , 364 Surf. Sci. 1-16 (1996)
1038	Moodera et al., <i>Ferromagnetic–insulator–ferromagnetic tunneling: Spin-dependent tunneling and large magnetoresistance in trilayer junctions (invited)</i> , 79 J. Appl. Phys. 4724-4729 (1996)
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)
1041	Wollschläger et al., <i>Stoichiometry and morphology of MgO films grown reactively on Ag(100)</i> , 142 Appl. Surface Science 129-134 (1999)
1042	Pacchioni, <i>Ab initio theory of point defects in oxide materials: structure, properties, chemical reactivity</i> , 2 Solid State Scis. 161-179 (2000)
1043	Heinrich et al., <i>Single Crystal Tunnel Junctions</i> , IEEE (2000)
1044	Butler et al., <i>Spin-dependent tunneling conductance of Fe MgO Fe sandwiches</i> , 63 Phys. Rev. B 054416 (2001)
1045	Klaui 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)

Exhibit No.	Description
1047	Wulfhekel et al., <i>Single-crystal magnetotunnel junctions</i> , 78 Appl. Phys. Letters 509-511 (2001)
1048	Bogicevic et al., <i>Effect of oxide vacancies on metal island nucleation</i> , 515 Surf. Sci. L481-486 (2002)
1049	Kim et al., <i>MRAM Technology for High Density Memory Application</i> , 2 J. Semicond. Tech. Sci. 185-196 (2002)
1050	Yuasa et al., <i>A large quantum-well oscillation of the TMR effect</i> , 35 J. Phys. D. 2427-2431 (2002)
1051	Meyerheim, et al., <i>Geometrical and Compositional Structure at Metal-Oxide Interfaces: MgO on Fe(001)</i> , 87 Phys. Rev. Letters 076102 (2001)
1052	Faure-Vincent et al., <i>High tunnel magnetoresistance in epitaxial Fe/MgO/Fe tunnel junctions</i> , 82 App. Phys. Letters 4507-4509 (2003)
1053	Mitani et al., <i>Fe/MgO/FeCo(100) epitaxial magnetic tunnel junctions prepared by using in situ plasma oxidation</i> , 93 J. Appl. Phys. 8041-8043 (2003)
1054	Goniakowski et al., <i>Electronic States and Schottky Barrier Height at Metal/MgO(100) Interfaces</i> , 12 Interface Science 93–103 (2004).
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)
1058	Amodeo et al., <i>Dislocations and Plastic Deformation in MgO Crystals: A Review</i> , 8 Crystals 240 (2018)
1059	Matthews et al., <i>Comment: “Generalized formula for the electric tunnel effect between similar electrodes separated by a thin insulating film,”</i> 123 J. Appl. Phys. 136101 (2018)

Exhibit No.	Description
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”)
1063	Complaint, <i>Godo Kaisha IP Bridge 1 v. Western Digital Corporation</i> , Case No. 24-cv-00342-RGA (D. Del. Mar. 15, 2024) (without exhibits)
1064	Claim Chart for ’403 Patent, Exhibit D to Complaint, <i>Godo Kaisha IP Bridge 1 v. Western Digital Corporation</i> , Case No. 24-cv-00342-RGA (D. Del. Mar. 15, 2024)
1065	Claim Chart for ’263 Patent, Exhibit E to Complaint, <i>Godo Kaisha IP Bridge 1 v. Western Digital Corporation</i> , Case No. 24-cv-00342-RGA (D. Del. Mar. 15, 2024)
1066	Claim Chart for ’372 Patent, Exhibit F to Complaint, <i>Godo Kaisha IP Bridge 1 v. Western Digital Corporation</i> , Case No. 24-cv-00342-RGA (D. Del. Mar. 15, 2024)
1067	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)
1068	Amended Claim Chart for ’403 Patent, Exhibit AA 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)
1069	Amended Claim Chart for ’263 Patent, Exhibit BB 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)
1070	Amended Claim Chart for ’372 Patent, Exhibit CC 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)

Exhibit No.	Description
1071	Claim Chart for '909 Patent, Exhibit DD 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)
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)
1073	Claim Chart for '198 Patent, Exhibit FF 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)
1074	Claim Chart for '463 Patent, Exhibit GG 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)
1075	Claim Chart for '167 Patent, Exhibit HH 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)
1076	Claim Chart for '134 Patent, Exhibit II 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)
1077	Docket, <i>Godo Kaisha IP Bridge 1 v. Western Digital Corporation</i> , Case No. 24-cv-00342-RGA (D. Del. Mar. 15, 2024)
1078	U.S. District Courts – Combined Civil and Criminal Federal Court Management Statistics (Dec. 31, 2023), https://www.uscourts.gov/statistics-reports/federal-court-management-statistics-december-2023 (excerpts)
1079	Microsoft Computer Dictionary (5th ed. 2002) (excerpts)
1084	Boubeta et al., <i>Epitaxial Fe/MgO heterostructures on GaAs(001)</i> , 226 J. of Crystal Growth 223-230 (2001)

IV. RELEVANT LAW

11. I am not an attorney. For the purposes of this Declaration, I have been informed about certain aspects of the law that are relevant to my opinions. My understanding of the relevant law is summarized below.

12. I have been informed and understand that determining whether a patent claim is valid requires a two-step analysis. First, the claim must be construed. Second, the properly construed claim must be compared to the prior art.

13. I have been informed and understand that claim construction is a matter of law and that the final claim constructions for this proceeding will be determined by the Patent Trial and Appeal Board.

14. I have been informed and understand that in the context of an *inter partes* review, claims are construed from the perspective of a person of ordinary skill in the art at the time of the purported invention (which is approximated based on the earliest priority date of the patent). I understand that absent disclaimer or express definition, claim terms are given their plain and ordinary meaning to a person of ordinary skill in the art in view of the specification, file history, and knowledge of a person of skill in the art.

15. I have been informed and understand that a patent claim is invalid if it is anticipated by the prior art (*i.e.*, lacks novelty). I understand that anticipation

requires the disclosure in a single prior art reference of every limitation of the claim, expressly or inherently, with the limitations arranged as specified in the claim.

16. I have been informed and understand that, although not expressly disclosed, subject matter may be inherently disclosed in a prior art reference where that subject matter is necessarily present in the expressly disclosed subject matter and would be understood to be so by those of ordinary skill in the art. I understand that the fact that a certain result or characteristic may occur or be present in the prior art is not sufficient to establish the inherency of that result or characteristic.

17. I have been informed and understand that a patent claim is obvious and therefore invalid if the claimed subject matter as a whole would have been obvious to a person of ordinary skill in the art as of the priority date of the patent based on one or more prior art references and/or the knowledge of one of ordinary skill in the art.

18. I understand that an obviousness analysis must consider (1) the scope and content of the prior art, (2) the differences between the claims and the prior art, (3) the level of ordinary skill in the pertinent art, and (4) secondary considerations, if any, of non-obviousness (such as unexpected results, industry praise, commercial success, long-felt but unmet need, failure of others, copying by others, and skepticism of experts).

19. I understand that a prior art reference may be combined with other references to disclose each element of the invention under 35 U.S.C. § 103. I understand that a reference may also be combined with the knowledge of a person of ordinary skill in the art, and that this knowledge may be used to combine multiple references. I further understand that a person of ordinary skill in the art is presumed to know the relevant prior art. I understand that the obviousness analysis may take into account the inferences and creative steps that a person of ordinary skill in the art would employ.

20. In determining whether a prior art reference would have been combined with other prior art or other information known to a person having ordinary skill in the art, I understand that the following principles may be considered:

- a. A combination of familiar elements according to known methods is likely to be obvious if it yields predictable results;
- b. The substitution of one known element for another is likely to be obvious if it yields predictable results;
- c. The use of a known technique to improve similar items or methods in the same way is likely to be obvious if it yields predictable results;
- d. The application of a known technique to a prior art reference that is ready for improvement to yield predictable results;

- e. Any need or problem known in the field and addressed by the reference can provide a reason for combining the elements in the manner claimed; and
- f. The proper analysis of obviousness requires a determination of whether a person of ordinary skill in the art would have a “reasonable expectation of success”—not an “absolute predictability” of success—in achieving the claimed invention by combining prior art references.

21. I am informed that whether a prior art reference invalidates a patent claim as obvious is determined from the perspective of a person of ordinary skill in the art. While there is no requirement that the prior art contain an express suggestion to combine known elements to achieve the claimed invention, a suggestion to combine known elements to achieve the claimed invention may come from the prior art as a whole or individually, as filtered through the knowledge of one skilled in the art. In addition, the inferences and creative steps a person of ordinary skill in the art would employ are also relevant to the determination of obviousness.

22. When a work is available in one field, design alternatives and other market forces can prompt variations of it, either in the same field or in another. If a person of ordinary skill in the art can implement a predictable variation and would see the benefit of doing so, that variation is likely to be obvious. In many fields, there may be little discussion of obvious combinations, and in these fields market

demand – not scientific literature – may drive design trends. When there is a design need or market pressure and there are a finite number of predictable solutions, a person of ordinary skill in the art has good reason to pursue those known options.

23. It is my understanding that there is no rigid rule that a reference or combination of references must contain a “teaching, suggestion, or motivation” to combine references. But, I understand that the “teaching, suggestion, or motivation” test can be a useful guide in establishing a rationale for combining elements of the prior art. This test poses the question as to whether there is an express or implied teaching, suggestion, or motivation to combine prior art elements in a way that realizes the claimed invention, and it seeks to counter impermissible hindsight analysis.

V. PRIORITY DATE

24. I have been asked to assume that 2004 is the priority date for the '167 Patent and thus the relevant date for determining the level of ordinary skill in the art. Throughout this declaration, when I refer to one of ordinary skill, I am referring to one of ordinary skill in the art as of 2004 unless otherwise specified. My opinions would be the same if the '167 Patent priority date were around the March 12, 2004 date of the first Japanese priority application to the '167 Patent, the October 28, 2004 date of the second Japanese priority application to the '167 Patent, or the March 10, 2005 PCT filing date of the '403 Patent from which the '167 Patent claims priority.

VI. LEVEL OF ORDINARY SKILL IN THE ART

25. Based on my review of the '167 Patent and my background and experience in the field of electrical engineering and magnetic/spintronic device physics, it is my opinion that one of ordinary skill in the art as of the 2004 priority date (see paragraph 24) would be someone with:

- 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. My opinion would be the same for a different date in the 2004-2005 timeframe than the 2004 priority date, as explained in paragraph 24 of this Declaration.

26. The '167 Patent generally relates to “a magnetic tunnel junction device and a method of manufacturing the same.” EX1013 ('167 Patent) at col. 1:27-28.

27. Based on my education and experience, I am familiar with the level of knowledge that one of ordinary skill would have possessed during the relevant period of time.

28. In reaching this opinion as to the qualifications of the hypothetical person of ordinary skill in the art, I have considered the types of problems encountered in the art, the prior art solutions to those problems, the rapidity with which innovations are made, the sophistication of the technology, and the educational level of active workers in the field.

29. By the 2004 priority date of the '167 Patent (see paragraph 24 of this Declaration), I was a person who had more than ordinary skill in the art. Nevertheless, the opinions I express in this Declaration are from the perspective of a person of ordinary skill in the art as I have defined it above.

VII. TECHNOLOGY BACKGROUND

A. Conventional Magnetic Memory

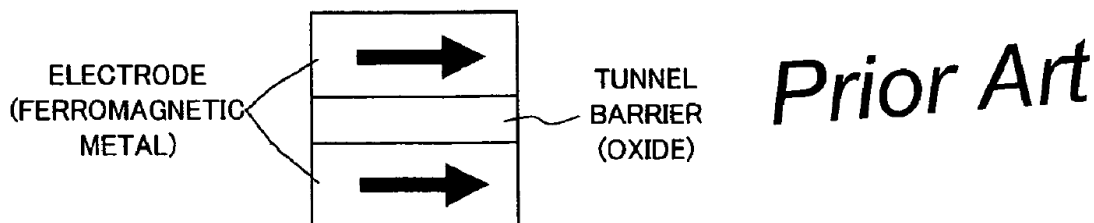
30. This IPR is related to magnetic memory technology. Magnetic memory operates differently than semiconductor-based memories like DRAM and EEPROM that store data as electrical charges. EX1057 (Dieny textbook) at page 1. Magnetic memory, including magnetoresistive random access memory (MRAM), uses magnetic tunnel junctions (MTJs) and is based on spintronics. EX1057 (Dieny textbook) at pages 1-2, 9.

B. Magnetic Tunnel Junctions (MTJs) And Spintronics

31. MTJs are “of high interest in the research field of magnetic nanostructures” because they “play a significant role in the development of non-volatile magnetic random access memories (MRAM’s).” EX1045 (Klaauw) at page 1.

32. Each electron has an elementary magnetic moment, or spin, which is explained by quantum mechanics. EX1057 (Dieny textbook) at pages 1-3. In a ferromagnetic metal (such as Fe or Co), quantum mechanics assigns different densities for “spin-up” and “spin-down” state electrons. The state (spin-up or spin-down) that has the greater density in the metal is known as the majority spin and the state with the smaller density is known as the minority spin. EX1057 (Dieny textbook) at pages 11-13.

33. As illustrated in the “Prior Art” Figure 8 from the ’167 Patent below, showing the prior art, a magnetic tunnel junction (MTJ) consists of a tunnel junction with ferromagnetic metal layers (electrodes) on either side of an insulating layer (tunnel barrier layer).

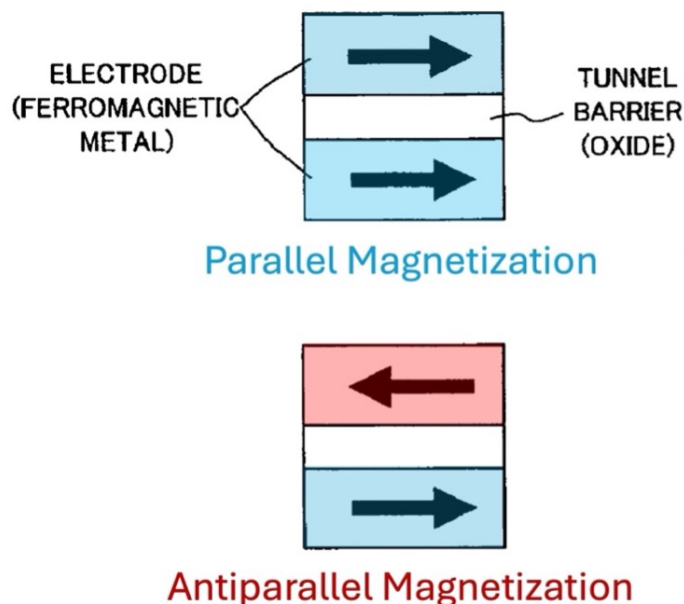


EX1013 (’167 Patent) at Fig. 8(A); *see also id.* at Fig. 8(B), col. 1:39-64; EX1057

(Dieny textbook) at page 9.

34. In MRAM, one of the MTJ's electrodes is set to a particular polarity and is often called the "fixed layer." The other electrode's magnetization can be changed by an external electric field. It is called the "free layer," and its state is used to store binary information, e.g. a "0" or "1." EX1057 (Dieny textbook) at page 29; EX1030 (Sunai) ¶19.

35. "Parallel" aligned electrodes have the same majority spin direction for their electrodes, while in the case of "antiparallel" alignment the majority spin directions of the two electrodes are opposite. EX1057 (Dieny textbook) at pages 11-13; EX1013 ('167 Patent) at col. 1:48-59. The parallel magnetization has a lower electrical resistance than antiparallel, allowing the magnetization state (parallel or antiparallel) to be sensed with an electrical circuit. EX1057 (Dieny textbook) at pages 11-13; EX1013 ('167 Patent) at col. 1:48-64.



EX1013 ('167 Patent) at Figs. 8(A)-8(B) (excerpted, annotated).

C. Tunnel Magnetoresistance Ratio

36. The tunnel magnetoresistance ratio (“TMR”) has been called “the most important parameter” for magnetic tunnel junction devices. EX1055 (Wang) at page 2269.

37. The TMR is equal to the difference in the resistance between the antiparallel (R_{ap}) and parallel states (R_p), divided by the parallel state resistance:

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

EX1035 (Moodera 1995) at page 3273; EX1027 (Nagahama) ¶2; EX1013 ('167 Patent) at cols. 4:62:5:3 (TMR equation); EX1057 (Dieny textbook) at page 13. A high anti-parallel resistance R_{ap} compared to lower parallel resistance R_p results in

high TMRs. Put another way, the TMR characterizes the effectiveness of the junction at passing parallel electrons while inhibiting antiparallel electron tunneling.

38. In 1995, Miyazaki and Moodera demonstrated the tunneling effect at room temperature, each by separately measuring TMR over 10%. EX1034 (Miyazaki) at Abstract (18% TMR at 300K); EX1035 (Moodera 1995) at Abstract (11.8% TMR at 295K).

39. Kim explained in 2002 that for conventional MRAM, “low MR ratio is a big issue for [a] high density device, and this makes the device slow.” EX1049 (Kim) at page 185. As a result, the price of (low MR ratio) MRAM “is quite higher than other competing [memory] devices, and the application has been limited.” EX1049 (Kim) at page 185.

40. Higher TMRs were necessary to improve MTJ performance, and thereby achieve commercially viable MRAM.

41. The higher the TMR, the larger the resistance difference between the parallel and antiparallel electrode configurations, which increases the signal to noise ratio for electrical detection of the magnetization state. EX1055 (Wang) at page 2269 (“A high TMR value is desirable because it leads to greater signal level...”); EX1055 (Wang) at page 2271 (“[A] functioning junction with high TMR value means high signal level, high sensitivity, high speed, and lower power consumption

for devices based on tunnel junctions.”); EX1056 (Hosomi) ¶26 (When “the TMR ratio is higher, a memory device having a... low error rate can be realized.”).

42. Tunneling MRAM devices “promise[d] huge enhancement of the density, speed, reliability and power consumption of solid-state memory.” EX1049 (Kim) at page 185. Wang explained many benefits stemming from a high TMR value: “A high TMR value is desirable because it leads to greater signal level, lower power consumption, higher speed, and larger design margin for devices such as MRAM....” EX1055 (Wang) at page 2269; *see also* EX1049 (Kim) at page 186 (“[L]arger MR ratio is the [sic] another important issue for the high speed MRAM operations.”).

43. Higher TMR allowed lower voltages (and smaller currents) to determine the MTJ’s resistance and thus lowered power consumption. EX1055 (Wang) at page 2271; *see also* EX1055 (Wang) at page 2269 (“A high TMR value is desirable because it leads to... lower power consumption” for MRAM.).

44. Higher TMRs paved the way for higher speed and smaller, denser MRAMs. EX1049 (Kim) at pages 194-95 (“[W]e may require new MR device with over 100% MR ratio in the future.... The key issues of MRAM technology as a future memory candidate are resistance control and low current operation for small enough device size.”); EX1057 (Dieny textbook) at page 9 (“[L]arger TMR ratios... enabled new types of MRAM that could be scaled down in size and ramped up in

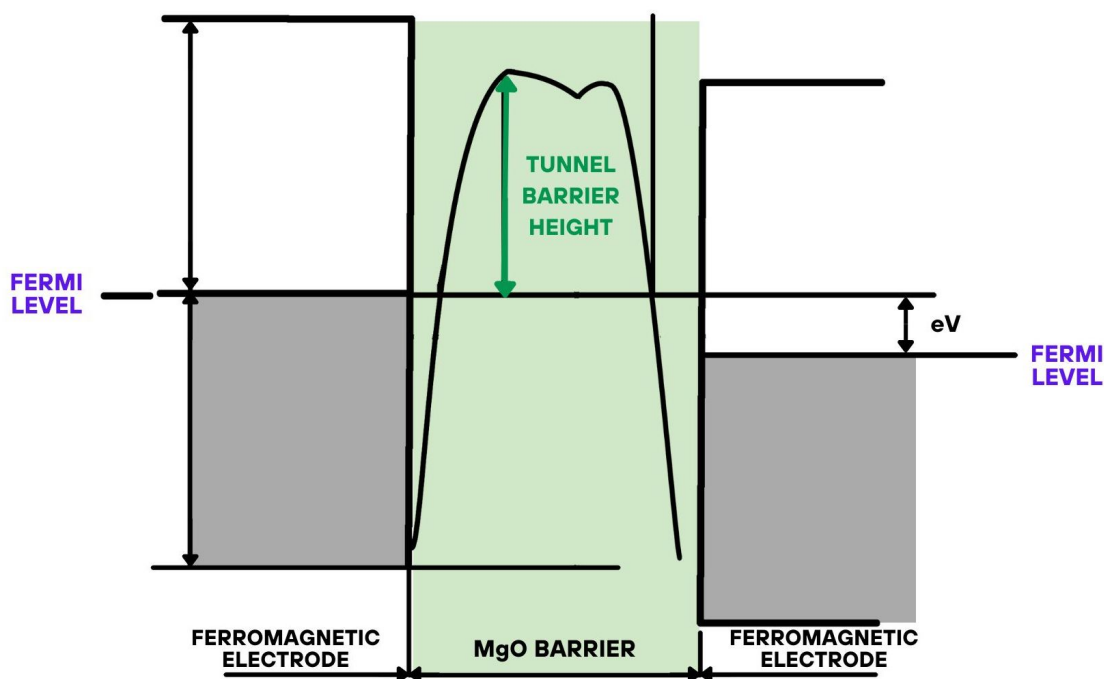
density.”); EX1055 (Wang) at page 2269 (“A high TMR value is desirable because it leads to... higher speed....”). Hosomi explained that when “the TMR ratio is higher, a memory device having a high speed and a high degree of integration... can be realized.” EX1056 (Hosomi) ¶26. Hosomi contrasted MRAMs with high TMRs with existing MRAM designs where it was “difficult to downsize the MRAM, namely, increase the degree of integration of the MRAM.” EX1056 (Hosomi) ¶23.

D. Quantum Tunneling

45. MTJs operate based on tunneling. The “tunnel effect” is a quantum mechanical phenomenon where current (electrons) flows between two electrodes separated by a very thin insulating layer or barrier. EX1057 (Dieny textbook) at page 10.

46. Electrons that participate in tunneling from the injector to the collector lie at or near the **Fermi level**, E_F , of the injector, which corresponds to the highest energy level in the injector occupied by electrons at 0 K. EX1052 (Faure-Vincent) at page 4508 (tunneling “electrons [are] injected from the Fermi level in one side of the barrier”); EX1057 (Dieny textbook) at page 4. At zero bias voltage, also known as equilibrium, the Fermi levels of the two electrodes (**gray**) align so that the same number of electrons are tunneling in both directions across the barrier (**green**), such that there is no net flow of electrons or current across the barrier. EX1057 (Dieny textbook) at page 11; EX1031 (Simmons) at page 1794, Fig. 3. When a bias

voltage, V , is applied, the collector electrode's (right) Fermi level lowers by an energy given by eV (where e is the charge of a single electron), compared to the injector electrode (left), allowing the electrons to tunnel across the barrier from the injector to empty states above the **Fermi level** in the collector. EX1057 (Dieny textbook) at page 11; EX1031 (Simmons) at Fig. 3.



EX1031 (Simmons) at page 1794, Fig. 1 (modified and annotated).

47. This “tunnel effect” of electrons across the barrier is described and illustrated in Simmons’ seminal 1963 paper. EX1031 (Simmons) at pages 1793-94, Fig. 1; *see also* EX1057 (Dieny textbook) at pages 10-11, Fig. 1.4. Shown above is an adapted version of Figure 1 from Simmons’ paper illustrating a tunnel barrier between two ferromagnetic electrodes.

48. The **tunnel barrier height** represents the difference between the bottom of the conduction band of the tunnel barrier layer and the **Fermi level** of electrons in the metal conductor. EX1031 (Simmons) at Fig. 1; EX1047 (Wulfhekel) at page 509 (tunnel barrier height estimated by difference between bottom of the conduction band of the MgO layer and Fermi level of Fe in an Fe/MgO/Fe(100) junction). The patent agrees, explaining that “the height of the tunnel barrier” measures the value “between the bottom of the conduction band of the MgO(001) layer and the Fermi energy of the first or the second ferromagnetic material layer.” EX1013 ('167 Patent) at col. 3:55-59.

49. In his 1963 paper, Simmons provided a mathematical formula, commonly known as Simmons' formula, for calculating the tunnel barrier height at a low-voltage range:

$$J = [3(2m\phi)^{\frac{1}{2}}/2s](e/h)^2 V \times \exp[-(4\pi s/h)(2m\phi_0)^{\frac{1}{2}}].$$

EX1031 (Simmons) at page 1797; *see also id.* at pages 1793-1803. Simmons had a typo (an extra factor of 3/2) in his published formula and the corrected version is below:

$$J_c = \frac{(2m\phi_0)^{\frac{1}{2}}}{s} \left(\frac{e}{h}\right)^2 V \exp \left[-\frac{4\pi s}{h} (2m\phi_0)^{\frac{1}{2}} \right].$$

EX1059 (Matthews) at page 1.

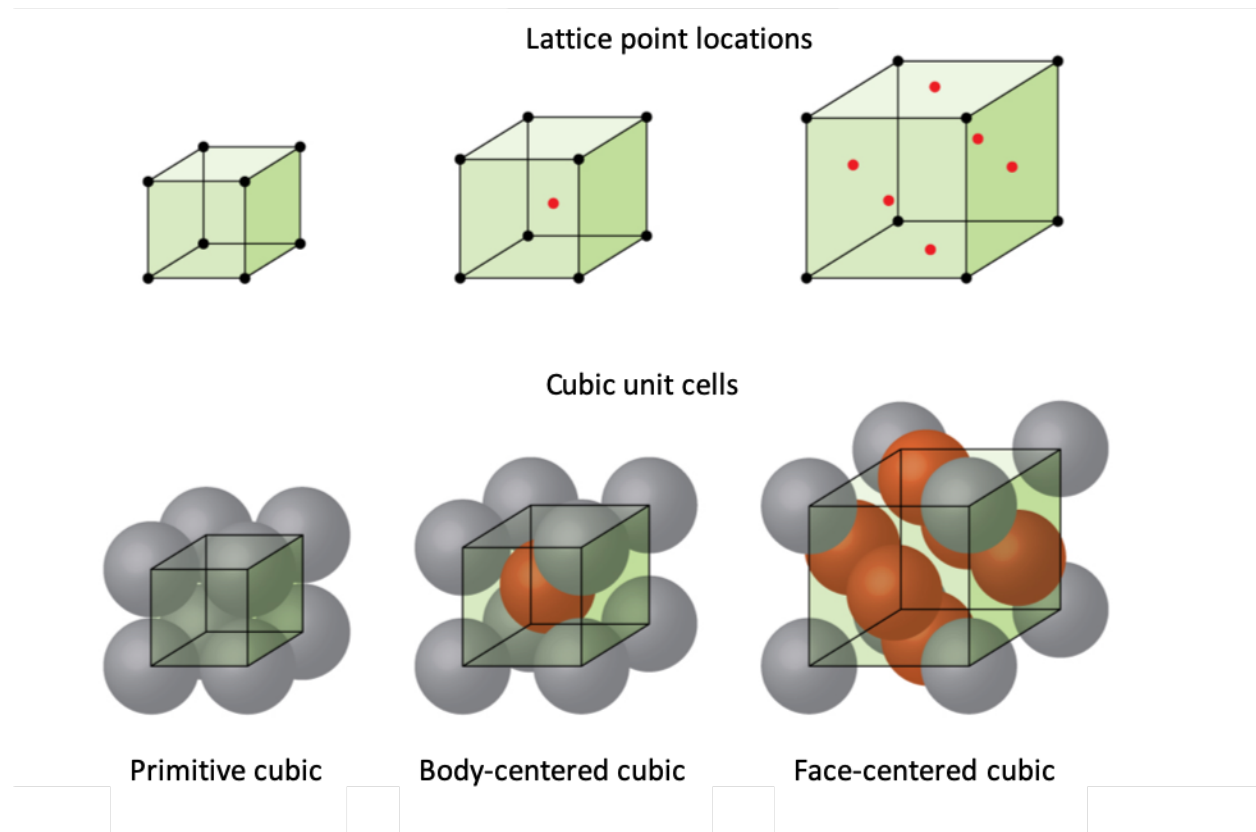
E. MTJ Materials

50. Considerable research has been undertaken to study and improve the materials used in the MTJ barrier layer and electrodes in order to increase TMR. As explained by Wang: “New junction materials have been explored in dozens of laboratories around the world and ever increasing TMR values have been observed.”

EX1055 (Wang) at page 2269.

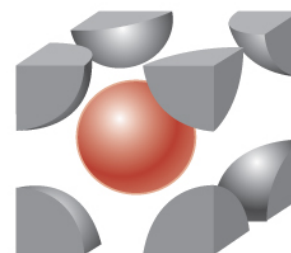
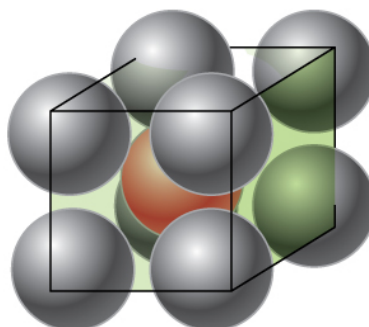
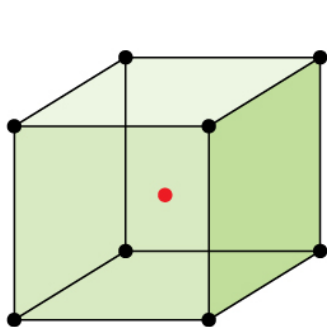
1. Crystalline Structures

51. There are three basic types of cubic crystalline structures for metals, as shown in the below graphic:

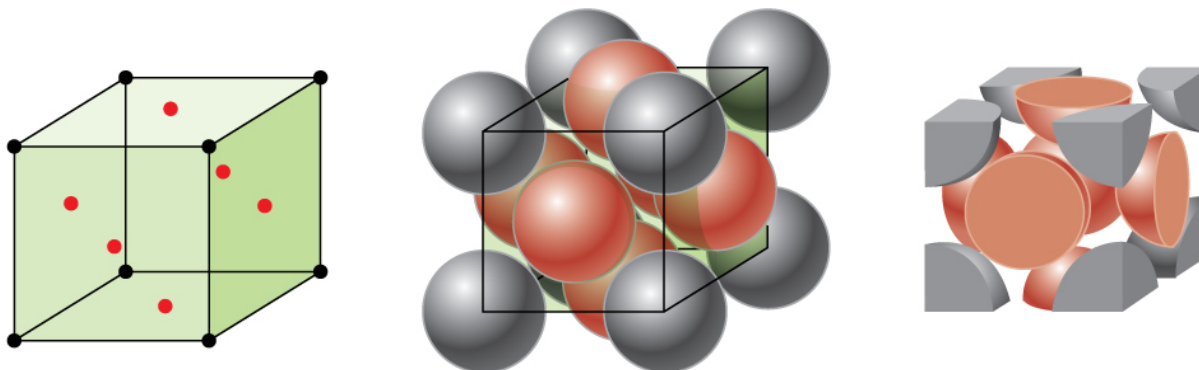


UW Madison Chemistry 103/104 Resource Book (“UW Chemistry Book”), Topic 61, Fig. 1, *available at* <https://wisc.pb.unizin.org/minimisgenchem/chapter/types-of-unit-cells-body-centered-cubic-and-face-centered-cubic-m11q5/>.

52. The simplest unit is the primitive cubic, with metal atoms on each corner. Body-centered cubic cells (BCC), shown in the above middle, have metal ions at all of the corners and in the center. Face-centered cubic cells (FCC), at the above right, crystallize with the metal atoms at all corners and the centers of each face. More detailed cross sections of BCC and FCC crystalline cells are reproduced below:



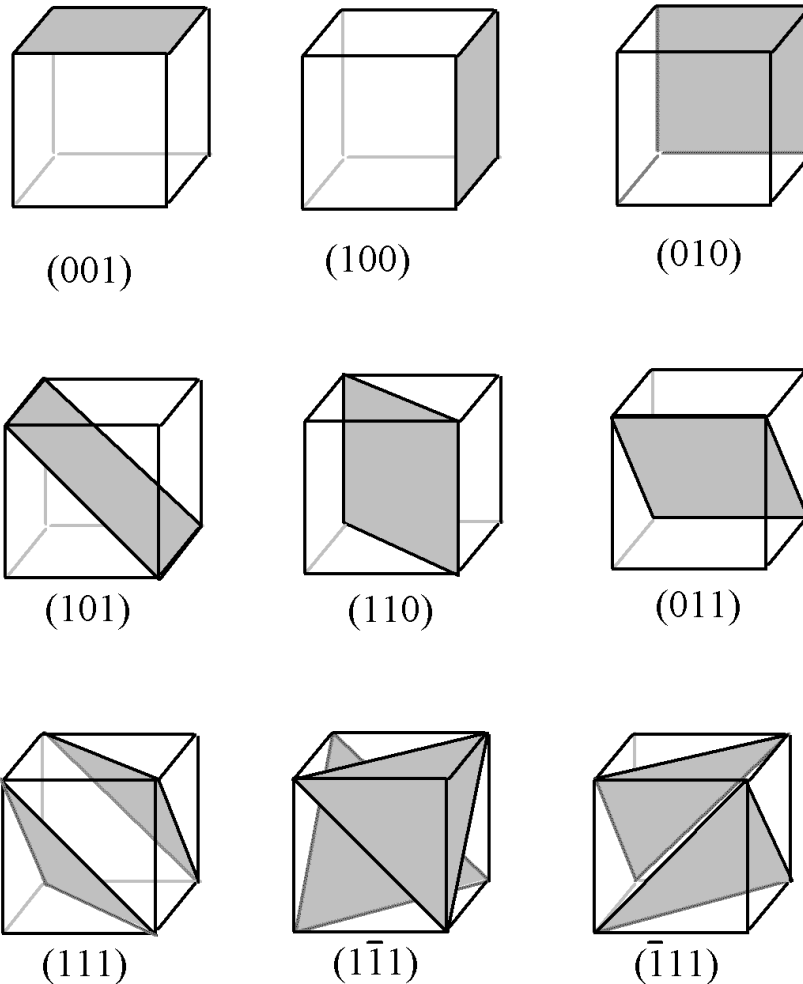
Body-centered cubic structure



Face-centered cubic structure

UW Chemistry Book at topic 61, Figs. 2-3.

53. Cubic crystals can be described by specific planes in three dimensions. As shown below, for a cubic crystalline structure, the (001), (010), and (100) planes are all the same:



WikiMedia Commons graphic, available at:

https://commons.wikimedia.org/wiki/File:Indices_miller_plan_exemple_cube.png.

The '167 Patent agrees. EX1013 ('167 Patent) at col. 4:39-41 (explaining that “because MgO has a cubic crystal structure (NaCl structure), the (001) plane, the (100) plane, and the (010) plane are all equivalent”).

2. Ferromagnetic Materials In MTJs

54. The ferromagnetic layers are comprised of ferromagnetic materials, such as iron (Fe), nickel (Ni), cobalt (Co), or their alloys, which typically have

crystalline structures. EX1030 (Sunai) ¶33 (“[F]erromagnetic materials” include “Fe, Co, Ni, and alloys containing them.”); EX1057 (Dieny textbook) at page 16.

55. Iron is a metal known to have a cubic crystalline structure. Iron typically has a body centered cubic (BCC) structure at room temperature. UW Chemistry Book, Topic 61 (“Isomorphous metals with a BCC structure include K, Ba, Cr, Mo, W, and Fe at room temperature.”); EX1046 (Mathon) at page 1 (analyzing tunneling between “bcc Fe” and MgO barrier); EX1044 (Butler) at page 2 (calculating tunneling for “bcc Fe” and MgO layers). Iron can also have a face-centered cubic (FCC) crystalline structure at higher temperatures.

56. The alignment between the crystal of the ferromagnetic electrodes and the MgO barrier layer facilitates electron tunneling, increasing TMR. EX1044 (Butler) at page 1 (Butler observing that the tunneling across an MgO barrier was facilitated by the “symmetry” between the electrodes and barrier material which “are crucial to determining the tunneling conductance.”); *see also* EX1046 (Mathon) at page 1 (“only a small lattice mismatch of about 3.5%” shows close symmetry between the crystal structures of a thin MgO barrier and Fe electrodes in an MTJ).

57. Electron wave functions in crystalline structures are described by Bloch states, which are wave function solutions of the Schrödinger equation for a perfect, infinite crystalline structure. EX1057 (Dieny textbook) at page 16. The Bloch states

for these ferromagnetic crystals have specific symmetries, particularly for “delta-1” band electrons that allow for higher TMRs. EX1057 (Dieny textbook) at page 16.

58. Researchers found that using alloys of Fe and Co as ferromagnetic electrodes in MTJs improved electron spin polarization (difference between the majority and minority spin densities). Higher spin polarization in the electrodes increases the TMR. EX1057 (Dieny textbook) at pages 1, 18; EX1050 (Yuasa) at page 2428 (study on FeCo electrodes); EX1026 (Bowen) at page 1655 (Fe₅₀Co₅₀ electrode layers); EX1052 (Faure-Vincent) at page 4507 (Fe and Co layers used to achieve the predicted high TMRs).

59. CoFeB ferromagnetic alloys were also known and studied. “Amorphous or nanocrystalline CoFeB films have been previously used in spin valves and tunnel junctions for their soft properties.” EX1061 (Cardoso) at page 2272. Adding boron (B) to FeCo resulted in an amorphous alloy. EX1055 (Wang) at Abstract; EX1030 (Sunai) ¶¶25, 30 (noting “crystallization is inhibited” in CoFeB). Jimbo *et al.* studied amorphous CoFeB electrodes in spin valves and found an improved MR ratio. EX1060 (Jimbo) at Abstract, page 310. Others found a similar result for MTJs: CoFeB electrodes increased TMRs and improved MTJ performance. Unlike FeCo films, which had to be deposited as thicker or discontinuous films, lowering the TMR, EX1030 (Sunai) ¶27, using CoFeB, which can result in a thinner 0.5 nm film, improved TMR. EX1030 (Sunai) ¶28. Cardoso

et al. fabricated CoFeB electrodes and found higher TMRs, particularly after annealing. EX1061 (Cardoso) at pages 2273-74.

60. Because of CoFeB's amorphous properties, a "CoFeB/MgO/CoFeB MTJ can theoretically be grown on all kinds of underlayers." EX1057 (Dieny textbook) at page 47. CoFeB's thinner, smoother interface ultimately produced an improved structure matched to the crystalline structure of the MgO barrier. EX1030 (Sunai) ¶¶24-28; EX1055 (Wang) at Abstract ("CoFeB has an amorphous structure and a smooth interface" with the tunnel barrier.). Without the addition of Boron, CoFe films typically had lower TMRs because they were often deposited as thicker or discontinuous films. EX1030 (Sunai) ¶27.

61. Annealing the amorphous CoFeB electrodes induced formation of a crystalline structure matching an adjoining crystalline layer. One of skill was aware that CoFeB would adopt the crystalline structure of an adjoining layer. Jimbo deposited CoFeB by sputtering, and then "[t]he annealing was performed for 1 hour." EX1060 (Jimbo) at page 308. Jimbo observed that CoFeB started to form a crystalline structure "first after annealing at 250°C and becomes still higher at 300°C." EX1060 (Jimbo) at page 308. The CoFeB adopted the fcc(111) structure of the adjoining Au fcc(111) top layer. EX1060 (Jimbo) at page 308. Jimbo found the MR ratio was "enhanced by the annealing." EX1060 (Jimbo) at page 311. Cardoso also found that CoFeB began to crystallize with annealing, measuring the

lattice and finding “CoFeB films are not amorphous.” EX1061 (Cardoso) at page 2273. A “Co₆₀Fe₂₀B₂₀ layer adjacent to an MgO(001) layer crystallizes in a bcc(001) structure.” EX1057 (Dieny textbook) at page 48. Parkin taught that “[c]ross-section transmission electron microscopy reveals that a portion of the [CoFeB] 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. The simple cubic crystalline MgO layer thus 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.” EX1062 (Parkin) at col. 18:51-59.

62. Researchers extensively studied using CoFeB alloys to improve TMR. EX1030 (Sunai) ¶¶25-29. Wang taught the “benefit of using CoFeB is multifold” including “a higher TMR value.” EX1055 (Wang) at pages 2269-70. Hosomi found a similar result. EX1056 (Hosomi) ¶39 (A ferromagnetic layer “exhibits a larger TMR ratio” when “comprised of a CoFeB alloy.”). Jimbo found the MR ratios increased after annealing the CoFeB layers. EX1060 (Jimbo) at page 310. He noted that “the CoFeB layer is confirmed to be amorphous in the as-deposited state and begin[s] to crystallize after annealing at 250°C. The GMR effect itself is not only stable up to above 300°C but also enhanced by the annealing.” EX1060 (Jimbo) at page 311. Cardoso also found higher TMR values for its CoFeB electrodes after annealing. EX1061 (Cardoso) at pages 2273-74. Parkin similarly observed of his

CoFeB-MgO MTJ that “[t]he TMR of the device of FIG. 3A is nearly two times higher than the highest TMR ever reported in prior art devices using conventional alumina tunnel barriers.” EX1062 (Parkin) at col. 18:63-65.

3. Oxide Layer In MTJs

63. In this section I will discuss two types of oxide layers, aluminum oxide (Al_2O_3) and magnesium oxide (MgO), depicted below:

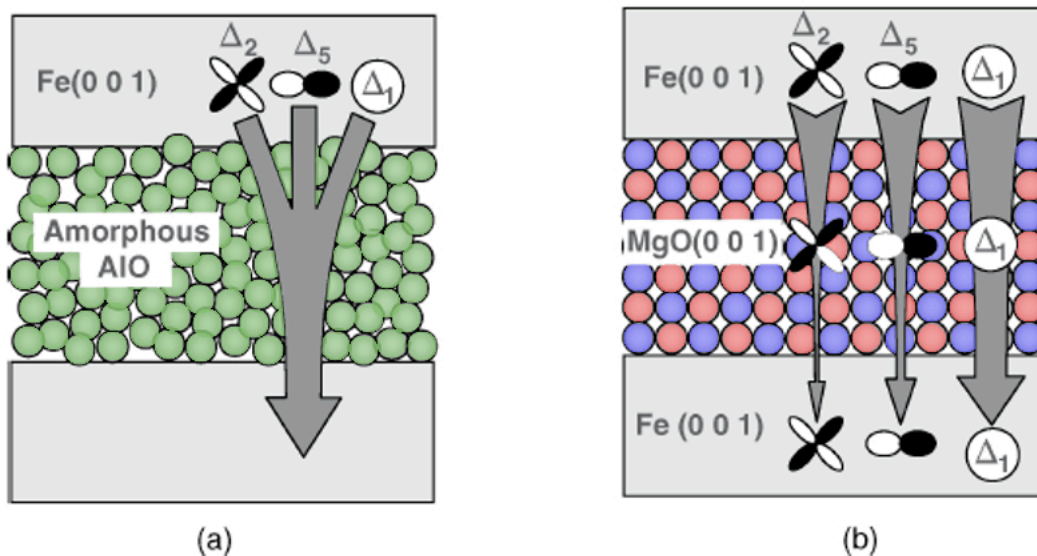


Figure 2.19 Schematic of electron tunneling through (a) an amorphous AlO barrier and (b) a crystalline $\text{MgO}(0\ 0\ 1)$ barrier.

EX1057 (Dieny textbook) at page 44, Fig. 2.19 (annotated).

64. Researchers initially focused their efforts on studying aluminum oxide (Al_2O_3) MTJs. EX1052 (Faure-Vincent) at page 4507. Butler noted this in his research paper, explaining: “There is presently great scientific and commercial interest in spin-dependent tunneling between ferromagnetic electrodes separated by

insulating oxide barriers. Most of the interest for applications currently centers on systems with amorphous aluminum oxide tunneling barriers because of the relative ease of growing adherent aluminum oxide without pinholes.” EX1044 (Butler) at page 1.

65. Aluminum oxide (Al_2O_3) barriers are amorphous. Butler explained they “are difficult to characterize and model because of the noncrystalline nature of the oxide and the lack of any known epitaxial relationship between the oxide and the ferromagnetic electrodes.” EX1044 (Butler) at page 1. As a result, tunneling is incoherent and “complex; it consists of random hopping between oxide resonant states which are created by a number of poorly understood defects.” EX1045 (Klaauw) at page 1. Both parallel and antiparallel spin electrons are randomly scattered. EX1045 (Klaauw) at page 1.

66. Magnesium oxide (MgO) later became commonly used as the insulating or barrier layer. MgO crystals are known for their cubic structure, similar to rock salt (NaCl). EX1040 (Yoon) at page 2839 (“ MgO ... has NaCl structure”); EX1041 (Wollschläger) at page 130 (“ MgO crystallizes in the rocksalt structure”); EX1013 (’167 Patent) at col. 4:39-40 (“ MgO has a cubic crystal structure (NaCl structure)”).

67. As I explained in Section VII.E.1 of this Declaration, MgO ’s cubic crystal structure means the (001), (100), and (010) crystalline planes are the same.

EX1013 ('167 Patent) at col. 4:39-41. The crystal structure of MgO enables well-defined tunneling wave function symmetry for electrons from the ferromagnetic electrodes. EX1057 (Dieny textbook) at page 17.

68. MgO has the special property that tunneling is governed by the majority (parallel) spin electrons. EX1045 (Klauda) at page 1. Research groups led by Butler (EX1044) and Mathon (EX1046) in 2001 “calculated optimistic TMR ratio is in excess of 1000% for an MgO barrier.” EX1046 (Mathon) at Abstract; *see also* EX1044 (Butler) at page 1, Fig. 16; EX1057 (Dieny textbook) at page 16. Their research established that a thin MgO barrier passed delta-1 electrons while largely blocking other electrons having opposite spin—leading the way to high TMRs. EX1044 (Butler) at page 1; EX1046 (Mathon) at page 1. As a 2001 paper by Klauda explained, unlike amorphous Al₂O₃ barriers, for crystalline MgO barriers: “The tunneling resistance for the parallel orientation of the magnetic moments is estimated to be **100 times smaller** than that for the antiparallel orientation of the magnetic moments due to the absence of scattering in the barrier.” EX1045 (Klauda) at page 1 (emphasis added).

69. Mathon observed the symmetry between a thin MgO barrier and Fe electrode, with “only a small lattice mismatch of about 3.5%,” opened the door to high TMRs. EX1046 (Mathon) at page 1. This symmetry between MgO’s and Fe’s body-centered cubic (bcc) structures resulted in a “tunneling resistance for the

parallel” electrons “estimated to be 100 times smaller than that for the antiparallel” electrons, “due to the absence of scattering in the barrier” for Fe/MgO/Fe(001) MTJs. EX1045 (Klaauw) at page 1. This resistance differential resulted in high TMRs.

70. In addition to single-crystal MgO, MgO barrier layers were also fabricated from polycrystalline MgO. Polycrystalline MgO layers are formed from numerous MgO crystals, reminiscent of grains of table salt. Because polycrystalline MgO is formed of many MgO crystals that may have varied planar orientations, the layer is characterized by its predominant planar direction, sometimes referred to as its preferential orientation. The structure of polycrystalline MgO made it well suited to deposition on a variety of surfaces, including amorphous layers. EX1036 (Wulff) at page 148 (studying MgO deposition on both crystalline substrates as well as on amorphous float glass and reporting that “[a]part from epitaxy, MgO grows with strong preferential $\langle 100 \rangle$ orientation regardless of the substrate selection”); EX1040 (Yoon) at page 2840 (similar: studying the deposition of highly (100)-oriented MgO crystalline thin films on Si, GaAs, and fused quartz substrates). It was commonly used with other amorphous materials, including CoFeB.

71. Polycrystalline MgO had other advantages. In 1996, Moodera *et al.* used a “polycrystalline MgO” barrier to obtain a lower barrier height. EX1026 (Bowen) at page 1656 (describing Moodera’s study at EX1038); EX1038 (Moodera

1996) at pages 4725-26. Nagahama also used polycrystalline MgO layers. EX1027 (Nagahama) ¶73 (describing “a (001)-highly-oriented MgO barrier layer”). Likewise, Yoon also grew a polycrystalline MgO barrier. EX1040 (Yoon) at page 2842.

72. After Butler and Mathon, “considerable interest has evolved in both the theoretical and experimental studies of the tunneling magnetoresistance (TMR) effect” because of “its importance [to] the development of” MRAM. EX1051 (Meyerheim) at page 1.

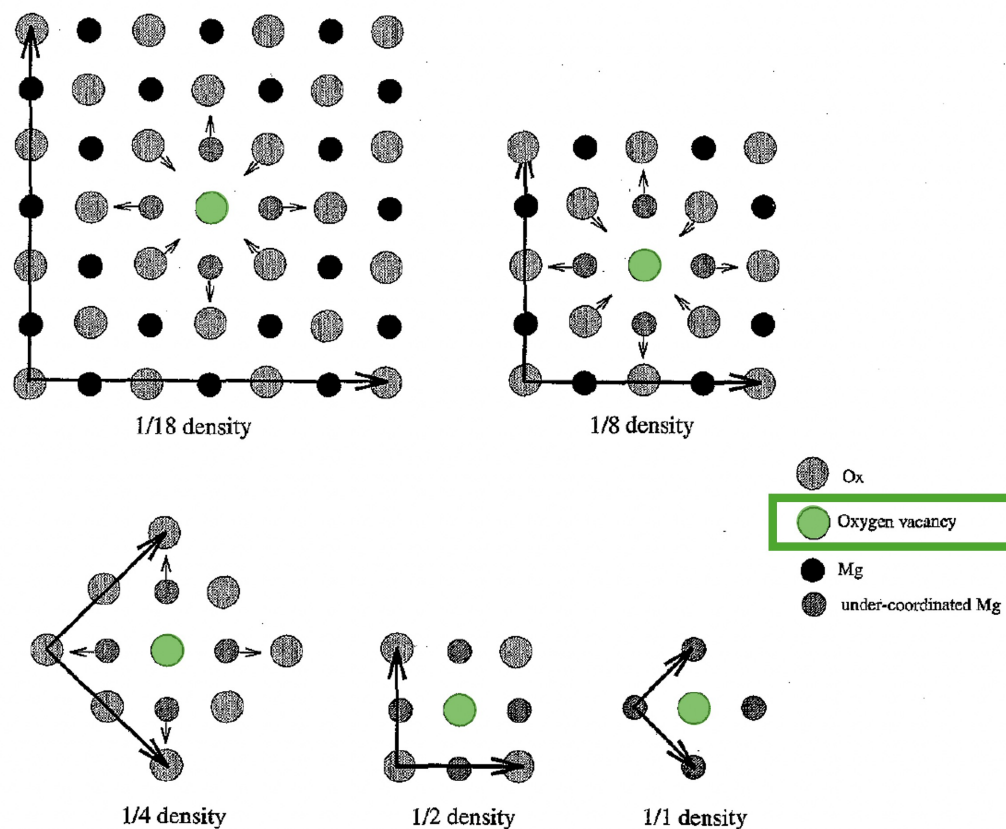
F. Oxygen Vacancy Defects In MgO Thin Films

73. Oxygen vacancies are one of the most important defects that are naturally present in every oxide. EX1042 (Pacchioni) at page 162. In the literature, oxygen vacancy defects in MgO are sometimes referred to as “color centers” or “F centers.” EX1042 (Pacchioni) at page 162; *see also* EX1048 (Bogicevic) at page 482 (studying “the propensity of oxygen vacancies (F_s centers)” in MgO(100) thin films).

74. MgO is a metal oxide with a 1:1 stoichiometric ratio of Mg and O atoms in a perfect crystalline structure. In other words, the MgO crystalline lattice has 1 magnesium atom for every 1 oxygen atom. However, perfect MgO crystal structures don’t exist in nature. In reality, there is always at least some concentration of oxygen vacancies, at least at finite temperature. EX1042 (Pacchioni) at page 162.

75. One way to characterize the level of oxygen vacancies in an MgO crystal is MgO_x , where $x < 1$, describing a sub-stoichiometric composition (e.g. MgO_x). E.g., EX1041 (Wollschlager) at page 132 (“understoichiometric MgO_x ($x < 1$)”). In a perfect, stoichiometric MgO crystal, x would equal 1. This is described in the '167 Patent. EX1013 ('167 Patent) at cols. 7:5-6 (“[T]here is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).”), 7:22-24. The '167 Patent applicant provided this explanation about oxygen vacancy defects: “ MgO_x ($0 < x < 1$)” and “ x is $0 < x < 1$. (Namely, if this is represented as ‘MgO crystals,’ the crystals have oxygen vacancy defects.)” EX1002 ('403 Patent File History) at page 168.

76. Castanier *et al.* described and studied oxygen vacancy defects, providing the following images of different levels of oxygen vacancy defects in **green**:



EX1037 (Castanier) at page 3, Fig. 1 (annotated).

77. Oxygen vacancy defects lowered the barrier height of MgO thin films. Soukup experimentally observed a 0.33 eV barrier height for an MgO thin film, noting that increased oxygen vacancy defects lowered the barrier height of MgO. EX1028 (Soukup) at Abstract, page 3232.

78. Other researchers observed similar behavior. Klaua grew “nearly perfect crystalline MgO(001) films on high-quality single crystals of Fe,” and found they had high purity and “the correct stoichiometry.” EX1045 (Klaua) at pages 1-2. Yet they still had “a low density of local defects.” EX1045 (Klaua) at page 8. Klaua

noticed bright spots of current which they said “may be related to inhomogeneities in the substrate-oxide interface.” EX1045 (Klaau) at page 4. Due to “defect states exist[ing] within the band gap of [the] MgO,... the tunneling probability via these defect states is largely enhanced.” EX1045 (Klaau) at page 4. Yet the defect states were not due to surface errors or irregularities. EX1045 (Klaau) at pages 4-5 (finding “[t]he local defects have dimensions of a few nm. They are not correlated with the surface topography....”). His assessment was that the observed defects in the MgO barrier “are most likely caused by structural defects, which create localized resonant tunneling states in the MgO bandgap.” EX1045 (Klaau) at page 5. He “assume[d] that the observed defects are intrinsic to the MgO layer due to the agglomeration of atomic defects.” EX1045 (Klaau) at page 5. In other words, the tunneling appeared related to oxygen vacancy defects intrinsic in the MgO barrier. Yet when Klaau studied the properties of the MgO barrier, the IV characteristics “give no hint of the presence of any defects in the MgO layer.” EX1045 (Klaau) at page 4. This strongly suggested that the concentration of vacancy defects is very small, perhaps on the order of less than a few percent.

79. Klaau’s collaborators Wulfhekel and Meyerheim confirmed his results. Wulfhekel fabricated a high-quality MTJ where “the concentration of defects in the MTJ structure is low. The structures grown are not only of high crystalline quality but also of high electrical quality.” EX1047 (Wulfhekel) at page 511. Despite

attempting to “minimize the effect of lattice defects on tunneling,” EX1047 (Wulfhekel) at page 509, Wulfhekel found high tunneling current that “are not correlated with the topography” of the MgO film, EX1047 (Wulfhekel) at page 510, finding “small variations of the local barrier height lead to strong variations of the tunneling current,” EX1047 (Wulfhekel) at page 511. “From this we conclude that the spikes are not caused by a thinner oxide film but by a lower tunneling barrier most likely due to localized states in the band gap of the barrier material.” EX1047 (Wulfhekel) at page 510. Wulfhekel noted that a “low tunneling barrier... point[s] [to] a high density of defects in the barrier.” EX1047 (Wulfhekel) at page 509. In other words, despite building a high-quality crystalline MgO MTJ, defects in the MgO resulted in a low tunneling barrier.

80. Meyerheim also observed that “[s]tructural defects strongly influence the electron tunneling in both the majority and the minority channels.” EX1051 (Meyerheim) at page 2.

81. Mitani also observed “the resistance decreases dramatically” for “tunneling transport through the MgO barrier” above 150 K, attributing it to “defects in the MgO barrier.” EX1053 (Mitani) at page 8042.

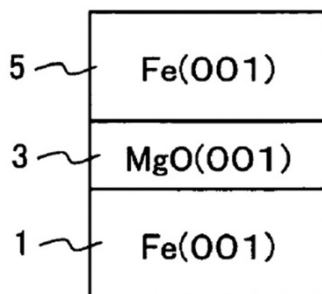
82. Similarly, Bowen observed a lower barrier height for an MgO thin film and hypothesized that it may have resulted from “the presence of stoichiometric and/or thickness inhomogeneities in the insulating film.” EX1026 (Bowen) at

page 1656. As Parkin observed, “[t]he exact composition of the MgO layer may differ from the stoichiometric [sic] composition.” EX1062 (Parkin) at col. 17:37-39. A skilled artisan would have understood from this extensive collection of research, and particularly Soukup’s, Bowen’s, and Parkin’s conclusions, that the “defects” causing MgO’s increased tunneling current were oxygen vacancies in the MgO structure.

VIII. OVERVIEW OF THE ’167 PATENT

83. The ’167 Patent is titled “Magnetic Tunnel Junction Device.” EX1013 (’167 Patent) at [54]. It discloses an MTJ having a structure where “an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal.” EX1013 (’167 Patent) at col. 1:39-46; *see also id.* at col. 1:46-64. As shown in Figure 1(B) below, the ’167 Patent discloses two Fe electrodes surrounding a single-crystalline or polycrystalline MgO barrier layer:

FIG. 1 (B)



EX1013 (’167 Patent) at Fig. 1(B) (modified), col. 5:38-44.

84. The '167 Patent's claims are directed to a method of manufacturing an MTJ device. EX1013 ('167 Patent) at cols. 9:55-11:9. Claim 1 requires, *inter alia*, "annealing the first and second CoFeB layers and the MgO layer" and "wherein the first and second CoFeB layers are crystallized by the annealing." EX1013 ('167 Patent) at col. 9:62-65. Other claims recite additional requirements, including that, after the annealing, "each of the first and second CoFeB layers is poly-crystalline in which a (001) crystal plane is preferentially oriented" and/or "each of the first and second CoFeB layers includes a BCC (body-centered cubic) structure." EX1013 ('167 Patent) at cols. 10:4-7 (Claim 3), 10:15-20 (Claim 5). Further, certain claims require that the MgO layer has oxygen vacancy defects. EX1013 ('167 Patent) at cols. 10:28-35 (Claims 7-8), 11:1-3 (Claim 14).

85. According to the '167 Patent, when fabricating the MgO layer, "separation of oxygen from MgO during the deposition of MgO" means "there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$)." EX1013 ('167 Patent) at cols. 6:66-7:6. The '167 Patent further explains that "[w]hen there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current." EX1013 ('167 Patent) at col. 7:6-10.

86. The '167 Patent also explains that the “basic structure of the MRAM,” as shown in Figure 9, is “Prior Art.” EX1013 ('167 Patent) at col. 1:65-66, Fig. 9. It explains, for example, that in an MRAM device, “the MRAM cell [is] disposed at the intersection of a word line and a bit line” and “comprises a MTJ device and a MOSFET directly connected to the MTJ device.” EX1013 ('167 Patent) at col. 2:5-8; *see also id.* at cols. 1:65-2:26.

IX. CLAIM CONSTRUCTION

87. I have been informed and understand that claim construction is viewed from the perspective of a person of ordinary skill in the art in question at the time of the invention.

88. In my opinion, the claims are obvious in view of the grounds discussed below based on the plain and ordinary meaning of the claim terms in view of the '167 Patent's specification. Where relevant, I have identified teachings in the '167 Patent that inform the plain and ordinary meaning of the claim limitations.

X. PRIOR ART TO THE '167 PATENT

89. I have been asked to assume that each of the references relied upon in my analysis including those covered in detail in this section and those cited throughout my analysis below are prior art to the '167 Patent except for the textbook, *Introduction to Magnetic Random-Access Memory* by Bernard Dieny *et al.* (EX1057), which I reference periodically for definitions and various concepts

without regard to whether that reference itself is prior art. I am familiar with Dieny's textbook, published by Wiley, and understand that it is an authority relied upon in the field.

A. Bowen *et al.*, *Large magnetoresistance in Fe/MgO/FeCo(001) epitaxial tunnel junctions on GaAs(001)*, 79 Appl. Phys. Letters 1655-1657 (2001) (EX1026, "Bowen")

90. In 2001, the journal Applied Physics Letters published experimental results from a group of European researchers on "Fe(001)/MgO(20 Å)/FeCo(001) single-crystal" MTJs. EX1026 (Bowen) at Abstract, page 1655. Guided by calculations from Butler and Mathon, Bowen *et al.* grew "FeCo/MgO/Fe epitaxial structures" (shown below) with "increasingly thin MgO layers" to study their TMR. EX1026 (Bowen) at pages 1655, 1657 nn.5-6, Fig. 1(a). Bowen used "good crystal quality MgO films with sharp interfaces" in its tunneling experiments, resulting in an experimental TMR of 60%. EX1026 (Bowen) at Abstract, pages 1655-56.

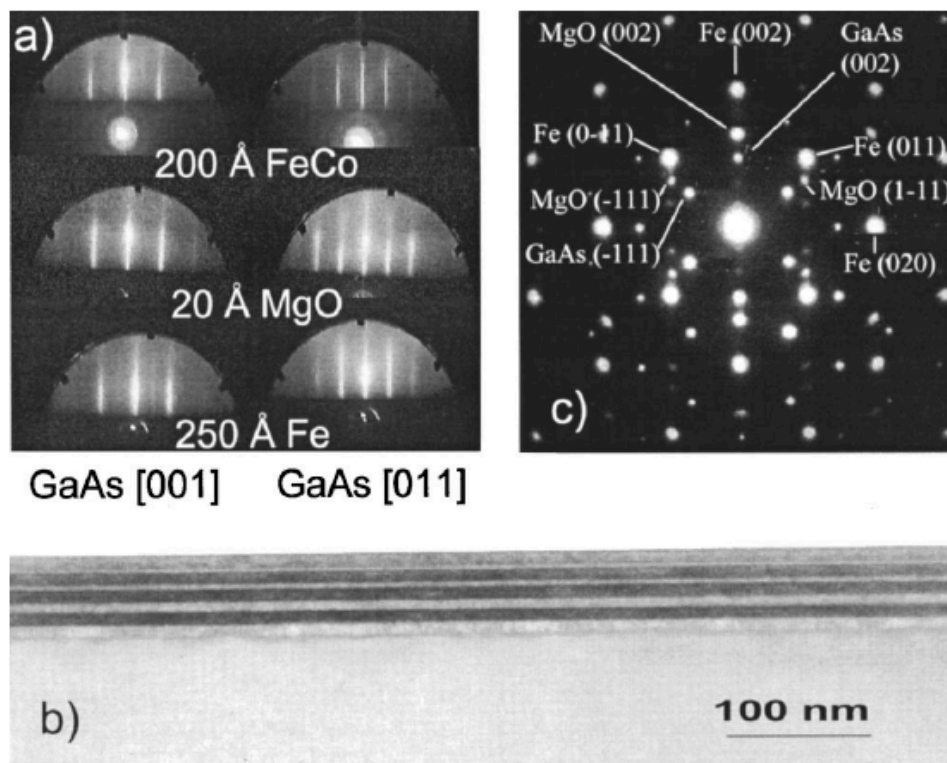


FIG. 1. (a) RHEED patterns along the GaAs [100] and [110] substrate azimuths of a typical FeCo/MgO/Fe epitaxial structure; (b) cross section TEM image of a Fe/MgO(001) multilayer with gradually decreasing MgO layer thickness; (c) TEM electron diffraction pattern.

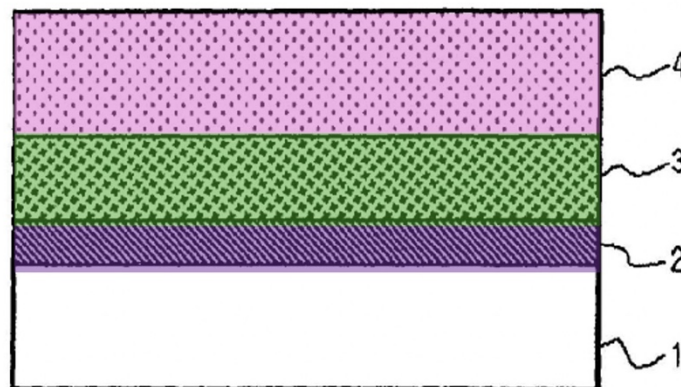
EX1026 (Bowen) at Fig. 1.

91. Bowen noted the TMR values calculated by Butler were higher (2000% for 20 Å MgO) than its experimental value of 60%. EX1026 (Bowen) at page 1657. Bowen stated a goal “to confirm the predicted relative increase of the TMR” in “future experiments.” EX1026 (Bowen) at page 1657. Although Bowen used high-quality MgO films and obtained a 60% TMR, Bowen did not “rule out the presence of stoichiometric and/or thickness inhomogeneities” in its MgO barrier. EX1026 (Bowen) at page 1656.

B. European Patent Application Publication No. EP1391942A1 to Nagahama *et al.* (EX1027, “Nagahama”)

92. Nagahama was a collaboration between the named inventor of the '167 Patent and two other researchers, then at the National Institute of Advanced Industrial Science and Technology in Japan. EX1027 (Nagahama) at page 1. Nagahama disclosed an MTJ having an MgO barrier disposed between two ferromagnetic layers. EX1027 (Nagahama) at page 1, ¶73.

FIG. 3

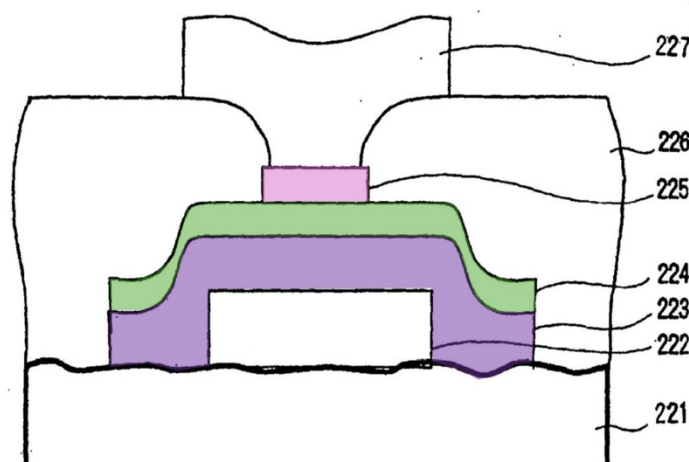


EX1027 (Nagahama) at Fig. 3 (excerpted, annotated).

93. As shown in the excerpted and shaded Figure 3 (reproduced above), Nagahama generally disclosed an MTJ structure with a ferromagnetic electrode 4 [pink], an insulating layer 3 [green], and an ultrathin ferromagnetic layer 2 [purple] on a substrate underlayer 1 [white]. EX1027 (Nagahama) at Abstract.

94. Nagahama further disclosed a polycrystalline MgO thin-film MTJ shown, for example, in Figure 17 reproduced below with a lower ferromagnetic electrode (223) [purple], a barrier layer (224) [green], and an upper ferromagnetic electrode (225) [pink]. EX1027 (Nagahama) ¶76. In another example, Nagahama taught “a (001)-highly-oriented lower ferromagnetic electrode layer, a (001)-highly-oriented MgO barrier layer, and a (001)-highly-oriented upper ferromagnetic electrode layer.” EX1027 (Nagahama) ¶73. Nagahama taught that its invention could be implemented using a “body-centered cubic lattice.” *E.g.*, EX1027 (Nagahama) ¶¶1, 18 (item [20]). Observing that Bowen *et al.* experimentally obtained a TMR of “more than 60%,” EX1027 (Nagahama) ¶14, Nagahama disclosed that its MgO-based MTJ obtained superior results: “a larger tunnel magnetoresistive effect of more than 90%,” *id.* ¶74.

FIG. 17



EX1027 (Nagahama) at Fig. 17 (annotated).

95. Under the heading “Industrial Applicability,” Nagahama taught that its MTJ is “suitably used in a magnetic sensor of a pickup head of a hard disk drive or a ferromagnetic random access memory.” EX1027 (Nagahama) ¶82.

C. Soukup *et al.*, Voltage-Current Characteristics for Electrical Conduction Through Thin MgO Films, 41 J. App. Phys. 3229-3236 (1970) (EX1028, “Soukup”)

96. Published in 1970, and citing Simmons’ seminal 1963 paper on electron tunneling, Soukup was a Journal of Applied Physics article that studied voltage-current characteristics of MgO thin films. Soukup applied a high voltage to create a strong electric field across the barrier. EX1028 (Soukup) at pages 3235-36; *id.* at Abstract, pages 3229, 3236 n.1. Soukup observed at the outset that a “number of possible current flow mechanisms from metal to metal have been proposed for metal-insulator-metal sandwich devices” and that “[t]he simple band picture was used by Simmons to analyze the electron injection process in terms of tunneling, where the insulator presents a potential barrier to conduction electrons in the metals.” EX1028 (Soukup) at page 3229.

97. Soukup studied “Au-MgO-Au thin-film” devices by making “60 thin-film sample sets.” EX1028 (Soukup) at Abstract, page 3230. Soukup reported a barrier height of 0.33 eV for its thin MgO film. EX1028 (Soukup) at Abstract, page 3232.

98. Soukup also sought “to determine the effect of nonstoichiometry” of MgO “on the device characteristics” like barrier height. EX1028 (Soukup) at page 3232. It varied the oxygen level “during deposition of the MgO film” to “determine the dependence of the results on the insulating film composition.” EX1028 (Soukup) at pages 3229, 3232. Soukup conducted experiments with “devices fabricated with more oxygen present during MgO deposition, which could mean more stoichiometric oxide films,” hypothesizing “that admitting oxygen gas during deposition of the MgO film increases the stoichiometry of the film as seen by an increased barrier height.” EX1028 (Soukup) at page 3232. Soukup ultimately documented that “the barrier height was a function of the amount of oxygen present... with a higher barrier for larger amounts of oxygen present.” EX1028 (Soukup) at page 3236. Because a more stoichiometric MgO film means fewer oxygen vacancy defects, Soukup demonstrated that increasing stoichiometry (reducing oxygen vacancy defects) results in higher barrier height and, conversely, that increasing the amount of oxygen vacancy defects lowers the barrier height.

D. Japanese Patent Application Publication No. JP2002204004A to Sunai *et al.* (EX1029/EX1030, “Sunai”)

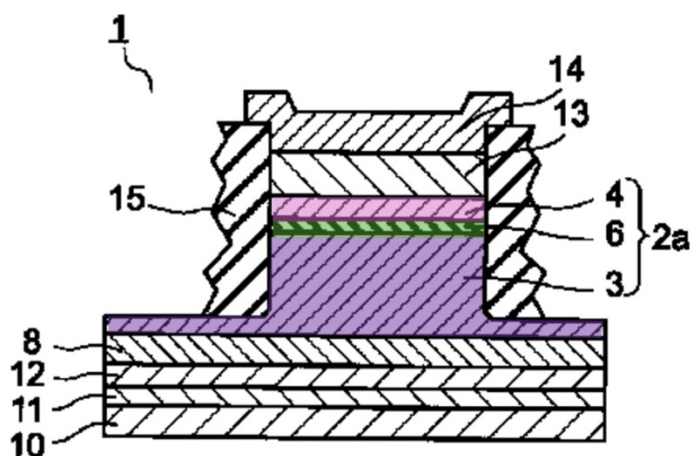
99. Published in 2002, Sunai is a Japanese patent application titled “Magnetoresistance effect element, magnetic memory, magnetic head, and magnetic reproducing device.” EX1030 (Sunai) at page 1.

100. I am informed that EX1029 is a copy of Sunai and EX1030 is a copy of a certified English translation of Sunai. I will reference the English translation in this declaration unless otherwise indicated.

101. Sunai described providing an MTJ for “magnetic memory” that “can maintain a sufficiently high magnetoresistance ratio.” EX1030 (Sunai) at Abstract. Sunai specifically disclosed using its MTJ in a “magnetic random access memory: MRAM.” EX1030 (Sunai) ¶4.

102. As shown in Figure 1 below, Sunai disclosed a conventional 3-layer MTJ with “a first ferromagnetic layer 3” [purple], “a second ferromagnetic layer 4” [pink], and “a first tunnel barrier layer 6 [green] interposed between the first ferromagnetic layer 3 and the second ferromagnetic layer 4.” EX1030 (Sunai) at Abstract, ¶1.

[Figure 1]

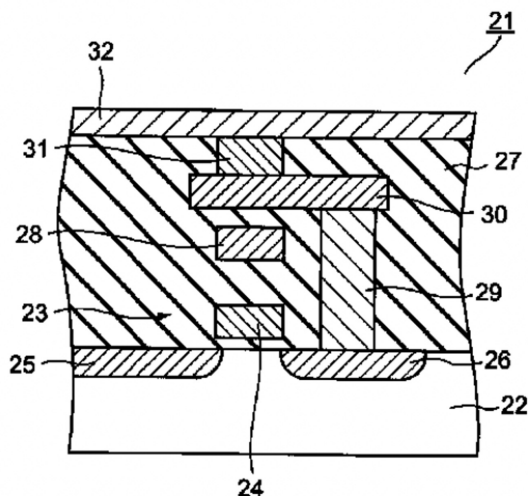


EX1030 (Sunai) at Fig. 1 (annotated).

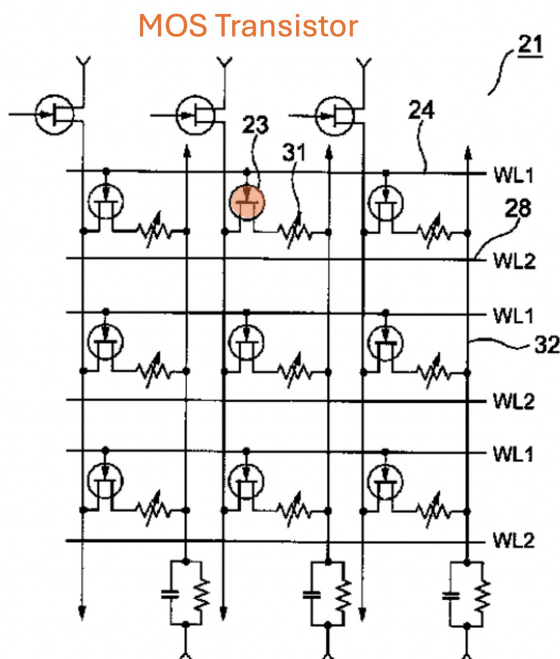
103. Sunai further disclosed that the ferromagnetic layer 4 in its MTJ included a CoFeB alloy. EX1030 (Sunai) ¶24 (“[T]he composition of the ferromagnetic layer 4 is represented by the general formula $(\text{CoFe})_{100-x}\text{Y}_x \dots$ [where] Y is at least one element selected from the group consisting of B” or other elements.); *id.* at Abstract, ¶11.

104. As shown in Figures 4-5 below, Sunai taught and depicted how to use its MTJ in an MRAM:

[Figure 4]



[Figure 5]



EX1030 (Sunai) ¶¶38-40, Figs. 4-5 (Fig. 5 annotated). Figure 4 provides a “cross-sectional view that shows a schematic of a magnetic memory (MRAM) using” Sunai’s MTJ (called “TMR 31” in Sunai), while Figure 5 depicts the “equivalent circuit diagram of the MRAM shown in Figure 4.” EX1030 (Sunai) ¶38. A

transistor (MOS transistor 23) and an MTJ (TMR 31) together form the memory cell in Sunai's MRAM 21. EX1030 (Sunai) ¶¶39, 42.

E. U.S. Patent No. 7,270,896 to Parkin (EX1062, "Parkin")

105. Parkin disclosed MgO-based MTJs with CoFeB electrodes. EX1062 (Parkin) at col. 19:10-19. As shown in Figure 3A below, Parkin's "MgO crystalline layer 120'" [green] is sandwiched between ferromagnetic electrodes. EX1062 (Parkin) at col. 19:16-17. Adjoining the MgO layer is a ferromagnetic "layer 175" [purple] which "may be comprised of 75 Å thick $(\text{Co}_{73}\text{Fe}_{27})_{74}\text{B}_{26}$." EX1062 (Parkin) at col. 17:43-44. Parkin explained that the "highly (100) textured MgO layer is likely to form an excellent template layer for the formation of a thin crystalline layer of CoFeB." EX1062 (Parkin) at col. 19:17-19. Parkin disclosed that the "MTJ device of FIG. 3A may also be inverted, such that the reference ferromagnetic electrode is formed above the tunnel barrier layer and the storage layer is formed beneath the tunnel barrier." EX1062 (Parkin) at col. 17:7-10.

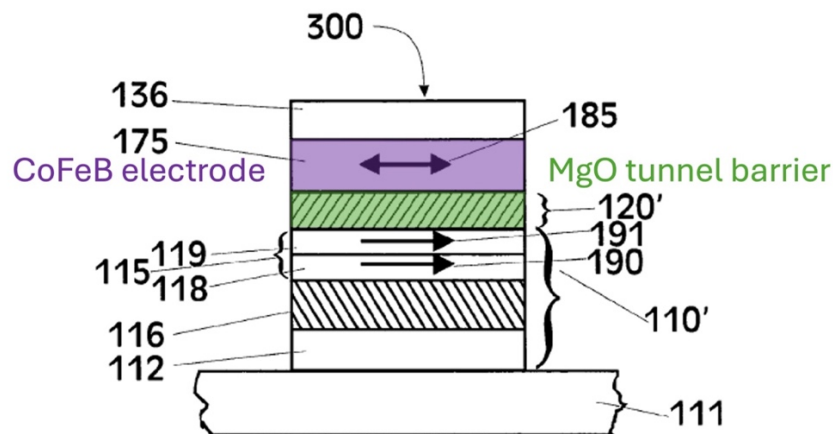


FIG. 3A

EX1062 (Parkin) at Fig. 3A (annotated).

106. According to Parkin, its MTJs were capable of obtaining “very high TMR values,” EX1062 (Parkin) at col. 18:49-51, and “[t]he TMR of the device of FIG. 3A is nearly two times higher than the highest TMR ever reported in prior art devices,” *id.* at cols. 18:63-19:10.

XI. SUMMARY OF OPINIONS OFFERED

107. In my opinion, Claims 1, 3, 5, 7-11, and 14-15 are obvious over the two grounds presented in this Declaration.

XII. GROUND 1: CLAIMS 1, 3, 5, 7-11, AND 14-15 ARE OBVIOUS OVER BOWEN IN VIEW OF SUNAI OR PARKIN (AND SOUKUP)

108. In my opinion, Claims 1, 3, 5, 7-11, and 14-15 are obvious over the prior art. Specifically:

- a. Claims 1, 3, 5, 9-11, and 15 are obvious over Bowen in view of Sunai or Parkin, and

- b. Claims 7-8 and 14 are obvious over Bowen in view of Sunai or Parkin and optionally Soukup.

A. Claim 1: Obviousness Over Bowen In View Of Sunai Or Parkin

1. Claim 1[preamble]: “A method of manufacturing a magnetic tunnel junction (MTJ) device, comprising:”

109. I am informed and understand that claim preambles may or may not limit the claim. I have been asked to assume the preambles of the '167 Patent claims are limiting for purposes of this analysis. Assuming that the preamble of Claim 1 is limiting, it is taught or suggested by Bowen.

110. Claim 1 is directed to a “method of manufacturing.” Claim 1[preamble] does not specify any particular method or process for manufacturing the claimed magnetic tunnel junction (MTJ) device. Thus, for purposes of my analysis in this Declaration, I have assumed that any method of manufacturing an MTJ device satisfies Claim 1[preamble].

111. Bowen taught or suggested a method of manufacturing a magnetic tunnel junction device. Bowen taught epitaxially growing FeCo/MgO/Fe MTJs. EX1026 (Bowen) at Abstract, pages 1655-56, Fig. 1; *see also* Sections XII.A.2-XII.A.7 of this Declaration. Bowen explained that its “Fe(001)/MgO(20 Å)/FeCo(001) single-crystal epitaxial junctions of high quality” were “grown by sputtering and laser ablation.” EX1026 (Bowen) at Abstract.

112. Thin film deposition methods including sputtering, thermal or electron beam evaporation, and molecular beam epitaxy (MBE) were conventional and known manufacturing techniques for MTJs and spintronic devices. *See, e.g.*, EX1026 (Bowen) at page 1655; EX1027 (Nagahama) ¶¶57, 62 (describing MTJ manufacturing techniques including depositing layers and sputtering); EX1030 (Sunai) ¶20 (“The above-mentioned ferromagnetic single tunnel junction 2a and antiferromagnetic layer 8 are usually formed by sequentially depositing various thin films on one main surface of the substrate 10.”); EX1041 (Wollschlager) at page 130 (describing “MgO films deposited” on substrates “either by molecular beam epitaxy (MBE) of the oxide or evaporating Mg in an oxygen atmosphere.”); EX1045 (Klaua) at page 2 (“MgO layers were deposited at 295 K using electron beam evaporation from a 3-mm-diam MgO rod of 99.8% purity.”). Even the ’167 Patent acknowledges that “ferromagnetic alloy[s] can be formed by evaporation or sputtering, for example,” EX1013 (’167 Patent) at col. 9:16-18, and that other deposition methods are “obvious,” *id.* at col. 9:35-38.

113. Bowen describes how his MTJ was fabricated. According to Bowen, its “FeCo/MgO/Fe epitaxial structures were grown on GaAs(001) in a combined sputtering/laser ablation system with a base pressure of 2×10^{-9} mbar as described elsewhere.” EX1026 (Bowen) at page 1655. Bowen explained that it used “a MgO buffer layer as an interdiffusion barrier with good electrical insulation

characteristics” to “prevent[] the incorporation of As from the substrate into the Fe bottom electrode.” EX1026 (Bowen) at page 1655.

114. Bowen went on to explain that “in a subsequent step, the MgO barrier is grown at 400 °C in order to obtain good crystallinity.” EX1026 (Bowen) at page 1655. In Bowen, the “Fe₅₀Co₅₀ and Fe layers were deposited from individual Fe and Co targets by triode sputtering with an Ar pressure of 4×10^{-4} mbar and with deposition rates in the range of 0.1–0.3 Å/s.” EX1026 (Bowen) at page 1655. Bowen further discussed deposition and annealing temperatures it used in building its MTJ:

Optimal deposition temperatures were 400 °C for the MgO, RT for FeCo top electrode, and RT plus annealing at 400 °C for the Fe bottom electrode. This low-temperature deposition and subsequent annealing process leads to an optimal Fe electrode in terms of crystallinity, continuity, and interface sharpness.

EX1026 (Bowen) at page 1655. Bowen’s reference to “RT” means room temperature.

115. Bowen taught that Boubeta provided additional and further details on how Bowen’s epitaxial MTJ structures were grown. EX1026 (Bowen) at page 1657 n.8 (citing EX1084). Bowen’s methods were consistent with those discussed in Boubeta, which studied the “epitaxy of metal/insulator Fe/MgO heterostructures on MgO buffered GaAs(001) semiconductor substrates.” EX1084 (Boubeta) at page

224. Like Bowen, Boubeta explained that its “[s]ubstrates were... loaded in a separate growth chamber with 2×10^{-9} mbar base pressure and combined triode sputtering and laser ablation facilities.” EX1084 (Boubeta) at page 224. Boubeta also used an “MgO buffer layer... grown at 450°C .” EX1084 (Boubeta) at page 224.

Boubeta continued:

The role of this MgO buffer layer is twofold: it first serves as interdiffusion barrier to avoid incorporation of As from the substrate into the sample layers, and secondly, offers an appropriate symmetry and lattice match for the epitaxy of bcc Fe(001) layers. Onto this MgO buffer layer, Fe films were deposited by normal incidence triode sputtering in the same deposition system at 4×10^{-4} mbar Ar pressure to optimize film quality obtaining deposition rates between 0.1 and 0.2 Å/s, similar to those normally used in MBE.

EX1084 (Boubeta) at page 224.

116. Bowen’s disclosed manufacturing methods are also akin or comparable to those described in the ’167 Patent. The ’167 Patent explains that “[t]he amorphous ferromagnetic alloy can be formed by evaporation or sputtering, for example.” EX1013 (’167 Patent) at col. 9:16-18. Similarly, the patent explains that the MgO layer can be “deposited by electron-beam evaporation or sputtering, [and] it should be obvious that other deposition methods are also possible.” EX1013 (’167 Patent) at col. 9:35-38. One of skill would understand from these disclosures that the

methods described in the '167 Patent were not considered inventive, and the '167 Patent did not attribute or highlight anything about its disclosed fabrication methods that are inventive or unexpectedly leading to higher-than-expected performance. Indeed, in another example, the '167 Patent disclosed the conventional method of forming an MTJ, comprising: “depositing a first Fe(001) layer on the substrate; depositing a tunnel barrier layer on the first Fe(001) layer... and forming a second Fe(001) layer on the tunnel barrier layer.” EX1013 ('167 Patent) at col. 3:19-27.

117. As shown, for example, in Figure 1 below, Bowen studied the FeCo/MgO/Fe MTJs that it prepared. EX1026 (Bowen) at pages 1655-57.

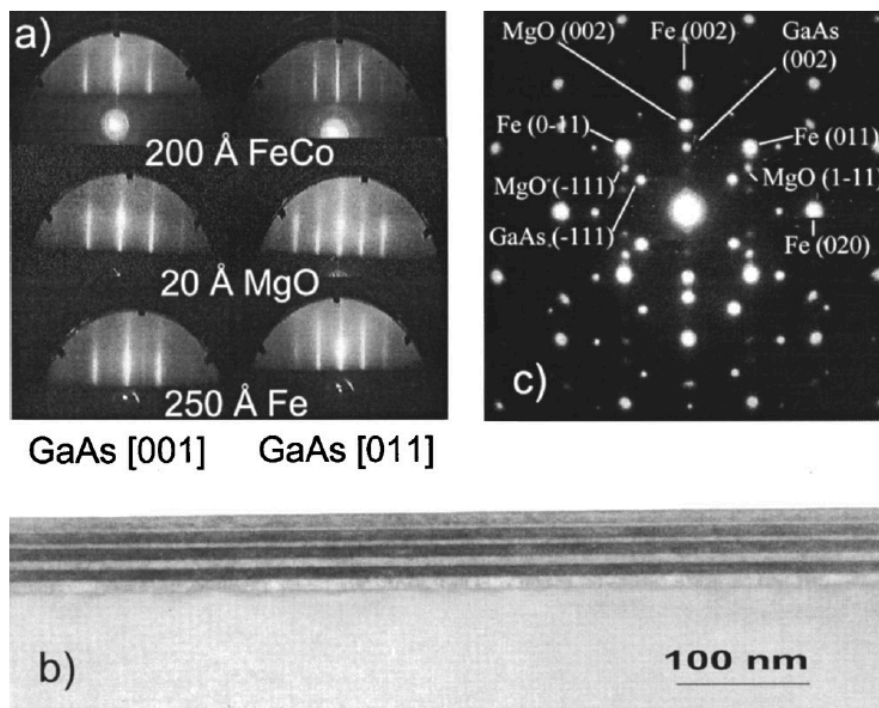


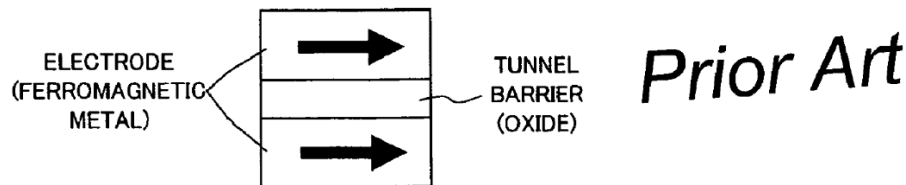
FIG. 1. (a) RHEED patterns along the GaAs [100] and [110] substrate azimuths of a typical FeCo/MgO/Fe epitaxial structure; (b) cross section TEM image of a Fe/MgO(001) multilayer with gradually decreasing MgO layer thickness; (c) TEM electron diffraction pattern.

EX1026 (Bowen) at Fig. 1.

118. In addition, magnetic tunnel junctions (MTJs), including those with a three-layer MTJ structure, and methods of forming them were well known in the art.

119. This is evident from the '167 Patent itself. EX1013 ('167 Patent) at Figs. 8(A)-8(B), col. 1:39-64. For example, Figure 8(A) of the '167 Patent below shows an “MTJ device compris[ing] a tunnelling junction structure in which a tunnel barrier... made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal.” EX1013 ('167 Patent) at col. 1:42-46. The patent correctly identifies and labels this conventional MTJ design as “Prior Art”:

FIG. 8 (A)



EX1013 ('167 Patent) at Fig. 8(A) ("Prior Art" legend in original); *see also id.* at col. 9:35-38.

2. Claim 1[a]: "forming a first CoFeB layer that is amorphous;"

120. Bowen in view of Sunai or Parkin taught or suggested this limitation.

121. Claim 1[a] does not specify the specific molecular composition or stoichiometry of the claimed "CoFeB." EX1013 ('167 Patent) at col. 9:57. Thus, I was asked to assume that any CoFeB alloy satisfies Claim 1[a]. Further, a skilled artisan understood that CoFeB and FeCoB refer to the same alloy.

122. For purposes of this Declaration, "first" will refer to the CoFeB layer that is closest to the substrate, and "second" will refer to the "upper" CoFeB layer. Claim 1 requires "forming a first CoFeB layer that is amorphous" (Claim 1[a]), "forming a magnesium oxide (MgO) layer over the first CoFeB layer" (Claim 1[b]), and "forming a second CoFeB layer that is amorphous over the MgO layer" (Claim 1[c]). EX1013 ('167 Patent) at col. 9:57-61. Thus, one of skill would have understood that the "first" CoFeB layer is the CoFeB layer below the claimed MgO

layer, and the “second” CoFeB layer is the CoFeB layer above the claimed MgO layer.

123. According to Bowen, “FeCo/MgO/Fe epitaxial structures were grown on GaAs(001) in a combined sputtering/laser ablation system....” EX1026 (Bowen) at page 1655; *id.* at Abstract, 1656 (explaining that its “Fe(200 Å)/MgO(20 Å)/FeCo(250 Å) trilayer” was “grown epitaxially” and “processed by optical lithography”), Fig. 1. Bowen described its “Fe” layer as an “Fe bottom electrode,” and explained that it was “deposited from individual Fe... targets by triode sputtering.” EX1026 (Bowen) at page 1655. Bowen thus disclosed forming a first, Fe ferromagnetic layer.

124. Manufacturing MTJs by forming ferromagnetic layers was well known and conventional by 2004, as the ’167 Patent acknowledges. EX1013 (’167 Patent) at col. 1:42-46 (Description of Related Art: “As shown in FIG. 8(A), a MTJ device comprises a tunnelling junction structure in which a tunnel barrier (to be hereafter also referred to as a ‘barrier layer’) made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal.”); *id.* at Figs. 8(A)-8(B) (labeled “Prior Art”).

125. Bowen in view of Sunai. It would have been obvious to replace Bowen’s Fe layer with an amorphous CoFeB layer, as taught by Sunai, including to improve TMR and lower H_f and H_c . EX1030 (Sunai) ¶¶28 (teaching CoFeB

electrode by adding B to Co₉Fe so “a continuous film can be formed”), 24 (teaching “ferromagnetic layer 4 is represented by the general formula (CoFe)_{100-x}Y_x” and specifying Y is an “element selected from the group consisting of B” or other elements); *id.* ¶¶25-29. Iron (Fe) and cobalt (Co) were known ferromagnetic materials, and CoFeB was a known ferromagnetic alloy based on Fe and Co. EX1030 (Sunai) ¶33 (“[F]erromagnetic materials” include “Fe, Co, Ni, and alloys containing them.”); EX1057 (Dieny textbook) at pages 2-3, 18 (“ferromagnetic metals, such as cobalt (Co) and alloys based on Fe and Co”); EX1026 (Bowen) at page 1655.

126. To improve Bowen’s MTJ, one of skill would have looked to Sunai’s teachings. Bowen and Sunai both sought to fabricate thin film structures to improve the TMR of magnetoresistive devices, one of the problems the ’167 Patent claimed to address. EX1026 (Bowen) at Abstract, page 1655; EX1030 (Sunai) at Abstract, ¶¶1, 10; EX1013 (’167 Patent) at Abstract, cols. 1:27-2:26. Like the ’167 Patent, Bowen and Sunai also both discussed improving MRAM memory performance. EX1026 (Bowen) at page 1655; EX1030 (Sunai) at Figs. 4-5, ¶¶1, 4, 38-40; EX1013 (’167 Patent) at cols. 1:32-38, 2:32-36. Further, they both formed an MgO barrier layer and ferromagnetic alloy electrodes. EX1026 (Bowen) at Abstract, page 1655; EX1030 (Sunai) ¶¶24, 35.

127. Sunai explained that CoFeB was a superior material compared to Fe or CoFe electrodes. For example, Sunai taught that CoFeB electrodes improved the TMR of an MTJ compared to CoFe. EX1030 (Sunai) ¶¶27-28 (discussing improved TMR resulting from adding B to CoFe); *see also* EX1061 (Cardoso) at Abstract (“CoFe-based junctions ($R \times A \sim 500 \Omega \cdot \mu m^2$) have lower TMR ($\sim 35\%$) and larger H_f ($\sim 5-6$ Oe) and H_c ($\sim 12-14$ Oe) [compared to CoFeB-based junctions].”). CoFe was also known to increase TMR compared to Fe. EX1035 (Moodera) at page 3274. Other researchers agreed. Wang extolled the “benefit of using CoFeB is multifold,” including “a higher TMR value.” EX1055 (Wang) at pages 2269-70. Hosomi taught that when an MTJ “ferromagnetic layer” is “comprised of a CoFeB alloy,” it “exhibits a larger TMR ratio.” EX1056 (Hosomi) ¶39. Hosomi found “remarkabl[e] increases in the TMR ratio” for certain CoFeB alloys. EX1056 (Hosomi) ¶76.

128. Bowen aimed to increase the TMR in manufacturing its MgO MTJ, EX1026 (Bowen) at pages 1655, 1657, and understood that the properties of the MTJ’s electrodes contributed to improving the tunneling and hence TMR of its device:

As corroborating evidence, Butler *et al.* point out in recently published first principles conductance calculations for Fe(100)/MgO(100)/Fe(100) trilayers that, despite a strongly negative spin polarization on the interfacial Fe layer, the spin polarization of

tunneling electrons should be positive due to wave function *symmetry matching in the Fe electrodes and in the MgO barrier*.

EX1026 (Bowen) at page 1657 (emphasis added). Because TMR was so important to optimizing MTJ design for commercial applications like MRAM, as I explained in detail in Section VII.C of this Declaration, Sunai's and other researchers' teachings about CoFeB would have provided a strong motivation to modify Bowen's method of fabricating an MTJ to include a CoFeB layer to increase the TMR.

129. One of skill would have been motivated to replace either or both of Bowen's MTJ electrodes with a CoFeB layer. Changing up the ferromagnetic materials of the electrodes had long been an area of research to find improvements in TMR. Almost a decade before the '167 Patent, a 1995 paper by Moodera taught forming "FM/I/FM thin film planar tunnel junctions... prepared in a high vacuum (10^{-7} torr) evaporation system," EX1035 (Moodera 1995) at page 3273, and trying different Co, Fe, and CoFe alloys for the top and bottom electrodes:

Co, Fe, and NiFe and CoFe alloys were tried in this study as both bottom and top electrodes. The best results were obtained with a CoFe bottom electrode and a Co or NiFe top electrode. With Fe films as one of the electrodes, for the thickness range of Al used, the junctions were too low in resistance.

EX1035 (Moodera 1995) at page 3274. Others in the literature had already suggested using CoFeB in both the top and bottom electrodes. Wang found "such a

large increase of TMR value by changing the free layer... to CoFeB, it is natural to replace both the free and pinned layers to CoFeB to further increase the TMR value.” EX1055 (Wang) at page 2270. Similarly, Hosomi explained that “both the ferromagnetic layers 5, 7 are made of an FeCoB” to achieve “improvement of the TMR ratio.” EX1056 (Hosomi) ¶¶67-68. Experimenting with different ferromagnetic layers to improve TMR and tunneling was widely known and an obvious modification.

130. As Sunai recognized, it was known that adding boron resulted in an amorphous CoFeB layer. EX1030 (Sunai) ¶¶24-25, 30. Sunai discussed a “normal film formation method” and observed that “crystallization is inhibited according to the above material containing element Y,” where “Y is at least one element selected from the group consisting of B.” EX1030 (Sunai) ¶¶24-25, 27. It similarly explained that B “suppresses the diffusion or movement of atoms that reach the film formation surface during the film formation process, thereby suppressing crystallization.” EX1030 (Sunai) ¶30; *see also* EX1055 (Wang) at Abstract (explaining that “CoFeB has an amorphous structure”); EX1056 (Hosomi) at Abstract (describing CoFeB ferromagnetic layer as having “an amorphous structure”); EX1062 (Parkin) at cols. 17:40-53, 18:49-19:27. According to Sunai, depositing CoFeB resulted in thinner electrode layers with improved quality. EX1030 (Sunai) ¶¶27-28, 30. Sunai explained that an “extremely thin continuous

film can be formed when” B is added to CoFe. EX1030 (Sunai) ¶30; *see also id.* ¶¶27-28 (“[W]hen B is added to Co₉Fe, a continuous film can be formed up to a film thickness of about 0.5 nm,” which was thinner and had better properties than Co₉Fe alone.).

131. Bowen in view of Parkin. Alternatively, in my opinion, Claim 1[a] is also taught or suggested by Bowen in view of Parkin. As shown in Figure 3A below, Parkin taught forming a CoFeB layer. In particular, Parkin taught forming an “amorphous ferromagnetic layer 175” that “may be comprised of 75 Å thick (Co₇₃Fe₂₇)₇₄B₂₆.” EX1062 (Parkin) at col. 17:42-44; *id.* at col. 19:16-17.

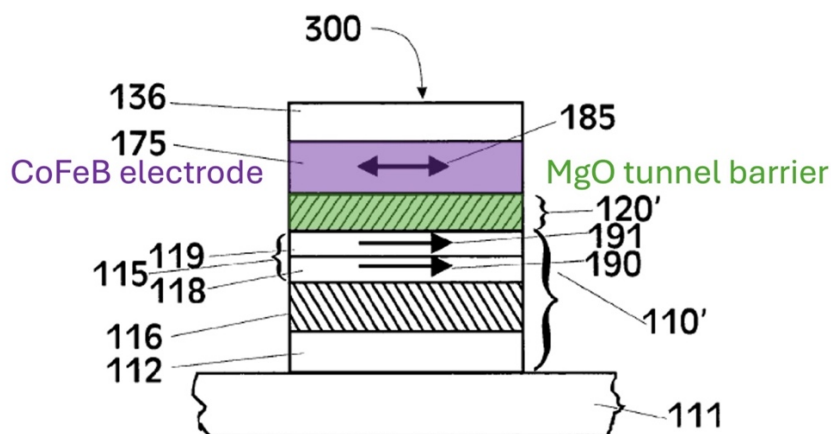


FIG. 3A

EX1062 (Parkin) at Fig. 3A (annotated). Parkin explained that the CoFeB layer 175 is “formed by magnetron sputtering in a pure argon plasma where a target of composition (Co₇₀Fe₃₀)₈₀B₂₀ is used.” EX1062 (Parkin) at col. 17:44-46. As explained, it was known that CoFeB would be deposited as an amorphous layer.

EX1030 (Sunai) ¶¶24-28; EX1055 (Wang) at Abstract; EX1056 (Hosomi) at Abstract.

132. As I explained above for the combination of Bowen and Sunai, a skilled artisan would have been motivated to replace either or both of Bowen's electrodes with CoFeB to increase TMR, as well as lower H_f and H_c . EX1055 (Wang) at page 2270 (“[I]t is natural to replace both the free and pinned layers to CoFeB to further increase the TMR value.”); EX1056 (Hosomi) ¶¶67-68; EX1035 (Moodera 1995) at page 3274; EX1061 (Cardoso) at Abstract (“CoFe-based junctions ($R \times A \sim 500 \Omega \cdot \mu m^2$) have lower TMR ($\sim 35\%$) and larger H_f ($\sim 5-6$ Oe) and H_c ($\sim 12-14$ Oe) [compared to CoFeB-based junctions].”). Further, Parkin taught that the ferromagnetic electrodes shown in Figure 3A may be “inverted” so that “the storage layer is formed beneath the tunnel barrier.” EX1062 (Parkin) at col. 17:7-10. Thus, one of skill would have understood that Parkin's CoFeB layer 175 may be formed as an upper or lower electrode, or both.

133. It would have been obvious to replace Bowen's Fe layer with Parkin's CoFeB layer to improve TMR. Indeed, Parkin taught “[t]he TMR of the device of FIG. 3A is nearly two times higher than the highest TMR ever reported in prior art devices using conventional alumina tunnel barriers... [which] is likely due to the formation of a very thin crystalline ferromagnetic interface layer” at “the boundary between the MgO tunnel barrier 120' and the [CoFeB] layer 175.” EX1062 (Parkin)

at col. 18:63-19:10; *see also id.* at col. 18:49-51 (explaining that “very high TMR values are unexpectedly found for MTJs with highly textured (100) MgO tunnel barriers but with nominally amorphous storage layers”).

134. To improve Bowen’s MTJ, one of skill would have looked to Parkin’s teachings. Both Bowen and Parkin sought to fabricate thin film structures to improve the TMR of magnetoresistive devices, a problem the ’167 Patent claimed to address. EX1026 (Bowen) at Abstract, page 1655; EX1062 (Parkin) at col. 1:18-21 (“[T]his invention relates to an improved MTJ exhibiting high tunneling magnetoresistance....”); EX1013 (’167 Patent) at Abstract, cols. 1:27-2:26. Like the ’167 Patent, Bowen and Parkin also both discussed improving MRAM memory performance. EX1026 (Bowen) at page 1655; EX1062 (Parkin) at cols. 2:65-3:1 (“[F]or non-volatile magnetic memory storage cells, high TMR values are needed for improving the performance of these devices.”); EX1013 (’167 Patent) at col. 2:54-57. Additionally, they both formed an MgO barrier layer and ferromagnetic alloy electrodes. EX1026 (Bowen) at Abstract, page 1655; EX1062 (Parkin) at Abstract, col. 1:18-21 (“[T]his invention relates to an improved MTJ... with one or more electrodes formed from amorphous ferromagnetic materials.”).

135. Because forming CoFeB electrodes in MTJs was already known, one of skill would have found it to be straightforward and predictable to replace Bowen’s Fe layer with CoFeB. MTJs already used CoFeB alloy electrodes successfully to

increase the TMR ratio, as well as lower H_f and H_c . EX1030 (Sunai) ¶¶27-28; EX1062 (Parkin) at cols. 18:49-51, 18:63-19:10; EX1055 (Wang) at pages 2269-70; EX1056 (Hosomi) ¶¶39, 78; EX1061 (Cardoso) at Abstract. Sunai itself taught that “when B is added to Co_9Fe ” alloy, it would improve TMR, EX1030 (Sunai) ¶28, and Parkin touted its “very high TMR values,” EX1062 (Parkin) at col. 18:49-51. Replacing Bowen’s electrode with a CoFeB alloy was a straightforward and desirable improvement that would have predictably succeeded.

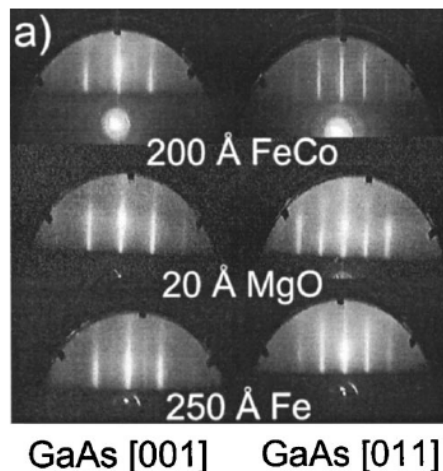
136. In sum, Claim 1[a] was taught or suggested by Bowen in view of Sunai or Parkin.

3. Claim 1[b]: “forming a magnesium oxide (MgO) layer over the first CoFeB layer;”

137. This claim limitation is taught or suggested by Bowen in view of Sunai or Parkin.

138. As I discussed for Claim 1[a] in Section XII.A.2 of this Declaration, Bowen in view of Sunai or Parkin taught or suggested forming a first CoFeB layer. To increase TMR and lower H_f and H_c , it would have been obvious to replace Bowen’s Fe layer with a CoFeB layer as taught by Sunai or Parkin. *Supra* §XII.A.2.

139. Bowen taught growing its MgO MTJs, explaining that “Fe(001)/MgO(20 Å)/FeCo(001) single-crystal epitaxial junctions of high quality” were “grown by sputtering and laser ablation.” EX1026 (Bowen) at Abstract; *id.* at pages 1655-56, Fig. 1. Bowen explained that its “**MgO barrier** is grown at 400 °C” on top of the “Fe bottom electrode.” EX1026 (Bowen) at page 1655 (emphasis added). As shown in Figure 1 (excerpted) on the right, Bowen’s MgO barrier is formed over the Fe bottom electrode that one of skill would have been motivated to replace with a CoFeB layer, as I explained for Claim 1[a]. EX1026 (Bowen) at pages 1655-56, Fig. 1; *supra* §XII.A.2. Thus, Bowen in view of Sunai or Parkin taught or suggested forming an MgO layer over the first or lower CoFeB layer.



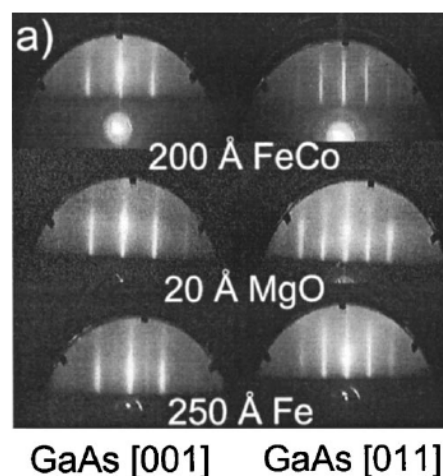
140. Forming an MgO layer over a ferromagnetic layer in an MTJ was conventional by 2004, as the '167 Patent acknowledges. EX1013 ('167 Patent) at col. 1:42-46 (Description of Related Art: “As shown in FIG. 8(A), a MTJ device comprises a tunnelling junction structure in which a tunnel barrier (to be hereafter also referred to as a ‘barrier layer’) made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal.”); *id.* at Figs. 8(A)-8(B) (labeled “Prior Art”).

4. Claim 1[c]: “forming a second CoFeB layer that is amorphous over the MgO layer; and”

141. This claim limitation is taught or suggested by Bowen in view of Sunai or Parkin.

142. As I discussed for Claim 1[a] in Section XII.A.2 of this Declaration, forming a first CoFeB layer that is amorphous was obvious over Bowen in view of Sunai or Parkin. Claim 1[c]’s requirement of forming a second CoFeB layer that is amorphous over the MgO layer was also obvious over Bowen in view of Sunai or Parkin. As I explained above with respect to Claim 1[a], although Claim 1 does not specify which layer is the “second,” for purposes of this Declaration, “second” will refer to the “upper” CoFeB layer.

143. According to Bowen, “FeCo/MgO/Fe epitaxial structures were grown on GaAs(001) in a combined sputtering/laser ablation system....” EX1026 (Bowen) at page 1655; *id.* at Abstract, 1656, Fig. 1. Bowen described its “FeCo” layer as an “FeCo top electrode” in its “trilayer” MTJ structure. EX1026 (Bowen) at pages 1655-56. Bowen thus disclosed forming a second, FeCo ferromagnetic layer over its MgO barrier layer, as shown in Figure 1 (excerpted) on the right.



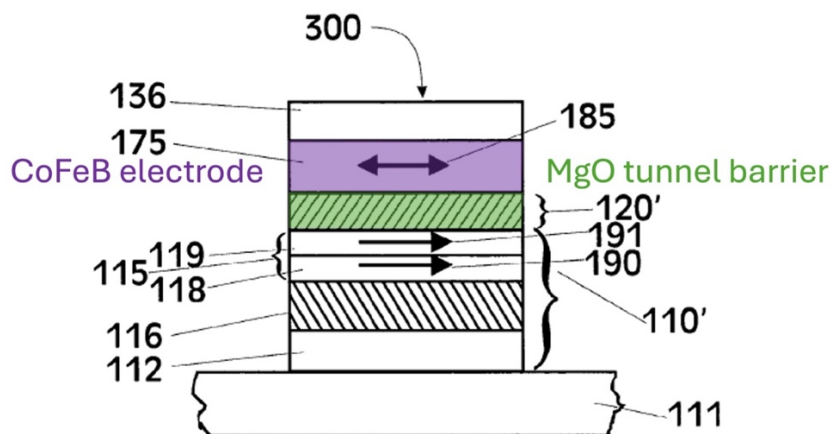
144. As I explained above for Claim 1[a] in Section XII.A.2 of this Declaration, manufacturing MTJs by forming ferromagnetic layers was well known and conventional by 2004, as the '167 Patent acknowledges. EX1013 ('167 Patent) at col. 1:42-46, Figs. 8(A)-8(B).

145. Bowen in view of Sunai. One of skill would have been motivated to replace Bowen's FeCo electrode with an amorphous CoFeB layer, as taught by Sunai, for the same reasons a skilled artisan would have been motivated to replace Bowen's Fe electrode with Sunai's CoFeB layer, as I explained above for Claim 1[a]. *Supra* §XII.A.2. For the reasons I provided with respect to Bowen's lower Fe electrode, replacing Bowen's upper FeCo electrode with a CoFeB layer would have further improved Bowen's device, including improved tunneling and higher TMR, as well as lower H_f and H_c . *Supra* §XII.A.2. Indeed, it was known that "CoFe-based junctions ($R \times A \sim 500 \Omega \cdot \mu m^2$) have lower TMR ($\sim 35\%$) and larger H_f ($\sim 5-6$ Oe) and H_c ($\sim 12-14$ Oe)" compared to CoFeB-based junctions. EX1061 (Cardoso) at Abstract.

146. As explained, it was known that adding boron resulted in an amorphous CoFeB layer. *Supra* §XII.A.2; EX1030 (Sunai) ¶¶24-25, 30; EX1055 (Wang) at Abstract; EX1056 (Hosomi) at Abstract.

147. Bowen in view of Parkin. Alternatively, Claim 1[c] is also obvious over Bowen in view of Parkin. As shown in Figure 3A below, Parkin taught forming

an “amorphous ferromagnetic layer 175” that “may be comprised of 75 Å thick $(\text{Co}_{73}\text{Fe}_{27})_{74}\text{B}_{26}$.” EX1062 (Parkin) at col. 17:42-46; *id.* at col. 19:16-17.



EX1062 (Parkin) at Fig. 3A (annotated).

148. A skilled artisan would have been motivated and found it obvious to replace Bowen’s FeCo layer with Parkin’s second CoFeB layer for the same reasons I explained for Bowen’s Fe layer in Section XII.A.2 of this Declaration, including to improve tunneling and TMR and lower H_f and H_c .

5. Claim 1[d]: “annealing the first and second CoFeB layers and the MgO layer,”

149. Bowen in view of Sunai or Parkin taught or suggested this claim limitation.

150. As I explained for Claims 1[a] and 1[c] in Sections XII.A.2 and XII.A.4 of this Declaration, it would have been obvious to replace Bowen’s lower and upper

ferromagnetic electrode layers with CoFeB layers as taught by Sunai or Parkin to increase TMR and lower H_f and H_c .

151. It was known and conventional to anneal both ferromagnetic electrode layers and MgO barrier layers. Bowen taught “annealing at 400 °C for the Fe bottom electrode.” EX1026 (Bowen) at page 1655. Bowen also taught or suggested annealing the MgO barrier at 400 °C. For example, Bowen taught that “[o]ptimal deposition temperatures were “400 °C for the MgO, RT for FeCo top electrode, and RT plus annealing at 400 °C for the Fe bottom electrode.” EX1026 (Bowen) at page 1655; *see also id.* (“in a subsequent step, the MgO barrier is grown at 400 °C in order to obtain good crystallinity”).

152. Indeed, high-temperature annealing ferromagnetic electrodes in an MTJ was routine and conventional. EX1045 (Klaauw) at page 1 (“Fe(001)... annealed at 1170 K”); EX1047 (Wulfhekel) at pages 509-10 (discussing “sputtering and annealing” of Fe); EX1052 (Faure-Vincent) at page 4507 (“Fe layer is deposited... then annealed at 450°C”).

153. Annealing an MgO barrier layer was also routine and conventional. For example, Wollschläger taught annealing MgO films. EX1041 (Wollschläger) at pages 131-34.

154. Annealing CoFeB electrodes was also well known and conventional. EX1060 (Jimbo) at page 309-11 (annealing “CoFeB layer” at 250°C and also above

300°C); EX1061 (Cardoso) at Abstract, pages 2272-73. Cardoso taught annealing its CoFeB tunnel junction structure, including both upper and lower CoFeB electrodes and barrier layer, at 280°C. EX1061 (Cardoso) at page 2272, Fig. 1 (showing tunnel junction structure with CoFeB electrodes and oxide layers annealed at 280°C).

155. It was obvious and a skilled artisan would have been motivated to anneal the CoFeB and MgO barrier layers to improve TMR and crystallize the layers. *See* Claim 1[e] in Section XII.A.6 of this Declaration. Jimbo observed that the MR effect was “enhanced by the annealing” even “above 300°C.” EX1060 (Jimbo) at page 311. Similarly, Parkin explained that “[t]he tunnel junction may be advantageously annealed to improve its TMR, e.g., at temperature selected to yield a room temperature TMR of greater than 100%, 160%, or even 200%.” EX1062 (Parkin) at col. 7:53-56. Parkin explained that “[t]he junction may be annealed at a temperature greater than 300 °C. or even greater than 340 °C” and that “the junction may be annealed at a temperature in the range of 300 °C. to 400°C.” EX1062 (Parkin) at col. 7:56-59. It touted that “MgO... tunnel barriers... may be improved through annealing” and that “annealing a tunnel barrier improves, in particular, its magneto-tunneling resistance... [and] its spin polarization.” EX1062 (Parkin) at col. 8:50-67; *see also id.* at cols. 17:60-18:48, Figs. 4-5.

156. Bowen too observed that its post-deposition “annealing process leads to an optimal Fe electrode in terms of crystallinity, continuity, and interface sharpness.” EX1026 (Bowen) at page 1655. According to Bowen, its “optimized growth conditions result in entirely epitaxial samples of high crystalline quality with flat, sharp interfaces” resulting in “27% TMR at 300 K which increases to 60% at 30 K.” EX1026 (Bowen) at page 1657. It was understood that annealing was beneficial and led to higher TMRs.

157. Annealing MTJs was known and one of skill would have predictably expected annealing to result in an improved MTJ having higher TMR. Annealing is a routinely used heat treatment process used by researchers in the field. As explained, researchers had successfully annealed both CoFeB and MgO layers, including in an MTJ, and accordingly, one of skill would have reasonably expected success in annealing an MTJ with CoFeB and MgO layers.

6. Claim 1[e]: “wherein the first and second CoFeB layers are crystallized by the annealing, and”

158. Bowen in view of Sunai or Parkin taught or suggested this claim limitation.

159. As I explained for Claims 1[a] and 1[c] in Sections XII.A.2 and XII.A.4 of this Declaration, it would have been obvious to replace Bowen’s lower and upper

ferromagnetic electrode layers with CoFeB layers as taught by Sunai or Parkin to increase TMR and lower H_f and H_c .

160. Further, as I explained for Claim 1[d] in Section XII.A.5 of this Declaration, Bowen in view of Sunai or Parkin taught or suggested annealing both CoFeB layers.

161. Bowen in view of Sunai. One of skill also would have found it obvious to anneal Bowen's MgO MTJ with CoFeB layers to crystallize the CoFeB layers.

162. As explained in Paragraph 154-155 of this Declaration, one of skill knew how to anneal CoFeB layers to crystallize them, and a skilled artisan would have been motivated to crystallize CoFeB electrodes in an MTJ, including to improve tunneling and TMR. EX1060 (Jimbo) at pages 309, 311; EX1061 (Cardoso) at pages 2272-73.

163. It was known to one of skill that annealing CoFeB electrodes resulted in their crystallization. Cardoso described fabricating MTJs with CoFeB electrodes, explaining that "CoFeB films have been previously used in spin valves and tunnel junctions for their soft properties." EX1061 (Cardoso) at page 2272; *id.* at Abstract. Cardoso explained that "[a]fter deposition, the structures were annealed 10 min at 280 °C" and that x-ray measurements "confirmed that the CoFeB films are not amorphous" and had "strong texture enhancement upon annealing." EX1061 (Cardoso) at pages 2272-73. Similarly, Jimbo observed that "the CoFeB layer is

confirmed to be amorphous in the as-deposited state and begin[s] to crystallize after annealing at 250°C,” EX1060 (Jimbo) at page 311, and found that CoFeB had a crystalline structure “[a]fter annealing at 400°C,” *id.* at page 309.

164. Skilled artisans also understood that the magnetoresistive effect was “enhanced by the annealing,” including at temperatures “above 300°C.” EX1060 (Jimbo) at page 311. And one of skill would have understood this to be likely the result of “structural change of the interface” between the CoFeB layer and adjoining layers. EX1060 (Jimbo) at page 311.

165. Skilled artisans would have been motivated to anneal Bowen’s MTJ with its CoFeB electrode to obtain a crystallized ferromagnetic layer. Bowen recognized the importance of creating crystallized electrodes because a high TMR “depends on the actual electronic structure of the barrier/electrode system.” EX1026 (Bowen) at page 1656; *see also id.* at page 1655 (“All emphasize that a correct depiction of the spin-dependent tunneling properties of epitaxial MTJs must transcend the simple potential barrier image and take into account the interplay of electronic structure between metal and insulator.”). It was known that crystallizing led to improved tunneling and TMR, as had been observed for crystallized Fe electrodes. EX1045 (Klaua) at pages 1 (finding that “nearly perfect crystalline MgO(001) films on high-quality single crystals of Fe” improved TMR), 6 (explaining that “the thin Fe film is basically transparent for electrons that tunnel

and that diffuse transport in the Fe film does not play an important role” for an “Fe layer [that] has crystalline structure”).

166. Improved TMR as well as lower H_f and H_c had similarly been observed for crystallized CoFeB electrodes. EX1061 (Cardoso) at Abstract (“CoFe-based junctions ($R \times A \sim 500 \Omega \cdot \mu m^2$) have lower TMR ($\sim 35\%$) and larger H_f ($\sim 5-6$ Oe) and H_c ($\sim 12-14$ Oe) [compared to CoFeB-based junctions].”); EX1062 (Parkin) at cols. 18:49-59 (observing “very high TMR values” where “a portion of the [CoFeB] storage layer 175 adjacent to the MgO tunnel barrier 120’ has crystallized”), 18:63-19:10. In Parkin, this was observed even where “only a very thin crystalline interface layer would need to be formed, perhaps by crystallization of the interface layer of the CoFeB layer 175 on the underlying MgO crystalline layer 120’.” EX1062 (Parkin) at col. 19:10-17.

167. Bowen in view of Parkin. Alternatively, Claim 1[e] is also obvious over Bowen in view of Parkin. As explained in Paragraph 154-155 of this Declaration, annealing CoFeB electrodes was known.

168. As I explained for Claim 1[d] in Section XII.A.5 of this Declaration, Parkin explained that annealing an MgO MTJ with CoFeB electrodes improves tunneling and TMR. EX1062 (Parkin) at cols. 7:53-59, 8:50-67, 17:60-18:48, Figs. 4-5. Parkin explained that “[t]he highly (100) textured MgO layer is likely to form an excellent template layer for the formation of a thin crystalline layer of CoFeB,”

which Parkin explains is “lower in B content” because “the B diffuses away from the interface with the MgO layer, during the thermal anneal treatments.” EX1062 (Parkin) at col. 19:17-22. According to Parkin, after annealing, “a portion of the [CoFeB] 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.” EX1062 (Parkin) at col. 18:51-55; *id.* at col. 19:16-17 (“CoFeB layer 175”).

169. A skilled artisan would have been motivated to anneal Bowen’s MgO MTJ to crystallize the CoFeB electrodes because doing so was known to improve TMR. As Parkin explained, “[t]he TMR of the device of FIG. 3A is nearly two times higher than the highest TMR ever reported in prior art devices using conventional alumina tunnel barriers.” EX1062 (Parkin) at col. 18:63-65. This was “likely due to the formation of a very thin crystalline ferromagnetic interface layer” at “the boundary between the MgO tunnel barrier 120’ and the [CoFeB] layer 175.” EX1062 (Parkin) at col. 19:7-10; *id.* at col. 18:49-51.

170. As I explained for Claim 1[d] in Section XII.A.5 of this Declaration, one of skill would have reasonably expected success in annealing an MTJ with CoFeB layers. In addition, as explained, it was known that annealing CoFeB electrodes resulted in their crystallization. Thus, one of skill would have reasonably

expected success in annealing an MTJ with CoFeB layers to crystallize the CoFeB layers, as researchers had demonstrated in the prior art.

7. Claim 1[f]: “wherein the MgO layer is poly-crystalline in which a (001) crystal plane is preferentially oriented.”

171. This claim limitation was taught or suggested by Bowen.

172. As I explained for Claim 1[b] in Section XII.A.3 of this Declaration, Bowen taught or suggested forming an MgO layer. Bowen disclosed forming a single-crystal MgO(001) tunnel barrier layer. EX1026 (Bowen) at Abstract (“Fe(001)/MgO(20 Å)/FeCo(001) single-crystal epitaxial junctions”), page 1655 (“single-crystal epitaxially grown structures... Fe(001)/MgO(001)/FeCo(001) epitaxial tunnel junctions”). Bowen’s reference to MgO(001) refers to the (001) crystalline plane. EX1026 (Bowen) at page 1655.

173. One of skill would have found it obvious to use a polycrystalline MgO barrier with the (001) crystal plane preferentially oriented in place of Bowen’s single-crystal MgO barrier.

174. Polycrystalline MgO barrier layers were well known. Bowen himself noted Moodera’s 1996 study used a “polycrystalline MgO” barrier to achieve a 0.9 eV barrier height. EX1026 (Bowen) at page 1656 (citing EX1038); EX1038 (Moodera 1996) at pages 4725-26; EX1047 (Wulfhchel) at pages 509 & 511 nn. 5-7 (recognizing that Moodera 1996 and other “[s]tudies using polycrystalline MgO

indicated a low tunneling barrier of ≈ 0.9 eV"). Moodera's 1996 study taught depositing the base electrode and MgO layer on "[g]lass substrates cooled to 77K" and "then warmed to room temperature and subjected to oxygen glow discharge to create an insulating layer of Al_2O_3 or MgO." EX1038 (Moodera 1996) at page 4725. One of skill would understand that Moodera's technique would *not* result in a single-crystalline MgO barrier layer, *see id.*, and Bowen explained that Moodera's MgO barrier was polycrystalline, EX1026 (Bowen) at page 1656 (citing EX1038). Further, one of skill knew polycrystalline MgO was an available and useful barrier layer, capable of achieving low barrier heights and thus high TMRs. EX1026 (Bowen) at page 1656; EX1047 (Wulfhekel) at page 509 (explaining that "[s]tudies using polycrystalline MgO indicated a low tunneling barrier of ≈ 0.9 eV"). One of skill would have been motivated to use polycrystalline MgO with a reasonable expectation of success. EX1026 (Bowen) at page 1656 (citing EX1038); EX1038 (Moodera 1996) at pages 4725-26.

175. Polycrystalline MgO provided its own advantages. It was easily formed on a variety of substrates and other materials, including ones that were not single-crystalline. EX1062 (Parkin) at col. 9:58-60 (describing the "polycrystalline nature of the film structures" as "preferable for ease of manufacturing"). For example, Wulff studied MgO deposition on both crystalline substrates as well as on amorphous float glass, reporting that "[a]part from epitaxy, MgO grows with strong

preferential $\langle 100 \rangle$ orientation regardless of the substrate selection.” EX1036 (Wulff) at page 148. Yoon also studied the deposition of highly (100)-oriented MgO crystalline thin films on Si, GaAs, and fused quartz substrates, reporting: “The growth behaviors of MgO films on GaAs and fused quartz substrates were further investigated. All the films show highly (100)-textured structure regardless of the substrate materials, as shown in Fig. 1(b).” EX1040 (Yoon) at page 2840. As I explained above in Section VII.E.1 of this Declaration, the (100) and (001) planes for an MgO crystal are the same.

176. One of skill knew that using polycrystalline MgO(001) would produce similar results as single-crystal MgO(001). For example, Parkin described the use of polycrystalline MgO methods to prepare “epitaxial single crystalline film structures,” EX1062 (Parkin) at cols. 9:58-10:2, and disclosed good results, EX1062 (Parkin) at cols. 13:3-10 (“high tunneling magnetoresistance” using “the (100) textured MgO tunnel barrier”), 14:35-41, 15:15-18 (“[T]he TMR will be increased to the extent that the film structure is textured” or polycrystalline.), 18:49-51 (“very high TMR values” for “highly textured (100) MgO tunnel barriers”).

177. Because using polycrystalline MgO was a known and available material for the barrier layer and provided its own advantages, one of skill would have found it obvious to form a tunnel barrier layer with polycrystalline MgO having

the (001) crystal plane preferentially oriented, in place of Bowen's single-crystal MgO barrier, to realize its benefits.

178. In addition, if Sunai's or Parkin's CoFeB layers are used as I explained above for Claims 1[a] and 1[c] in Sections XII.A.2 and XII.A.4 of this Declaration, a skilled artisan would have understood that the MgO barrier could be formed as either polycrystalline or single-crystal but would still have the same (001) orientation. EX1062 (Parkin) at cols. 9:58-10:2 (describing use of polycrystalline or single-crystal MgO), 18:38-39, 18:49-51 ("highly textured (100) MgO tunnel barriers" formed by "reactive magnetron sputtering").

B. Claim 3: Obviousness Over Bowen In View Of Sunai Or Parkin

1. Claim 3: "The method of claim 1, wherein after the annealing, each of the first and second CoFeB layers is polycrystalline in which a (001) crystal plane is preferentially oriented."

179. As I explained previously in Section XII.A of this Declaration, Claim 1 is taught or suggested by Bowen in view of Sunai or Parkin. Claim 3 depends from Claim 1 and thus incorporates all of Claim 1's requirements. Claim 3 was taught or suggested by Bowen in view of Sunai or Parkin.

180. A skilled artisan understood that annealing an MgO(001) MTJ with CoFeB layers would result in CoFeB layers having a (001) crystal plane that is preferentially oriented. Bowen taught that its tunnel barrier layer was "MgO(001)." EX1026 (Bowen) at page 1655; *supra* Claim 1[f], §XII.A.7.

181. As Parkin explained, “[t]he highly (100) textured MgO layer is likely to form an excellent template layer for the formation of a thin crystalline layer of CoFeB.” EX1062 (Parkin) at col. 19:17-19. In annealing Bowen’s MgO(001) MTJ with CoFeB layers, it was known that the “MgO layer... provides a template for the formation of a thin crystalline ferromagnetic layer which... is oriented in the *same (100) direction* as the MgO layer.” EX1062 (Parkin) at col. 18:55-59 (emphasis added). Because MgO has a symmetrical cubic structure, MgO(100) is the same as MgO(001). *See* Section VII.E.3 of this Declaration.

182. One of skill also knew that annealing Bowen’s MTJ with CoFeB layers would result in polycrystalline CoFeB layers. After annealing, Cardoso observed from “X-ray measurements of bulk CoFe and CoFeB 200 Å thick films” that “the CoFeB films *are not amorphous*” and that “the spectra show clearly the existence of a peak around 45.3 ° corresponding to a *strong texture enhancement upon annealing*.” EX1061 (Cardoso) at page 2273 (emphases added). Cardoso’s “strong texture enhancement upon annealing” was understood to mean that the CoFeB was polycrystalline. For example, Parkin explained that its “magnetic and tunnel barrier layers are *polycrystalline* and are comprised of grains or crystallites” and that “these layers and the overall film structure are what is commonly referred to as *textured*.” EX1062 (Parkin) at col. 14:46-50 (emphases added); *id.* at col. 15:47-49 (“[T]he

structures produced using the methods described herein are not expected to be single crystalline but rather highly *textured polycrystalline* films.” (emphasis added)).

C. Claim 5: Obviousness Over Bowen In View Of Sunai Or Parkin

- 1. Claim 5: “The method of claim 1, wherein after the annealing, each of the first and second CoFeB layers is polycrystalline 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.”**

183. As I explained previously in Section XII.A of this Declaration, Claim 1 is taught or suggested by Bowen in view of Sunai or Parkin. Claim 5 depends from Claim 1 and thus incorporates all of Claim 1’s requirements. Claim 5 was taught or suggested by Bowen in view of Sunai or Parkin.

184. As I explained for Claim 3 in Section XII.B.1 of this Declaration, Bowen in view of Sunai or Parkin taught or suggested that after the annealing, each of the first and second CoFeB layers is polycrystalline in which a (001) crystal plane is preferentially oriented. As I also explained, MgO(100) is the same as MgO(001), and one of skill would have understood that “[t]he highly (100) textured MgO layer is likely to form an excellent template layer for the formation of a thin crystalline layer of CoFeB.” EX1062 (Parkin) at col. 19:17-19; *supra* §XII.B.1.

185. In annealing Bowen’s MgO(001) MTJ with CoFeB layers, it was understood that the “MgO layer... provides a template for the formation of a thin crystalline ferromagnetic layer which has the *bcc structure* of CoFe....” EX1062

(Parkin) at col. 18:55-59 (emphasis added); EX1026 (Bowen) at page 1655. As I explained in Section VII.E.1 of this Declaration, the term “bcc” refers to “body-centered cubic.” Thus, Bowen in view of Sunai or Parkin taught or suggested that after the annealing, each of the first and second CoFeB layers includes a BCC (body-centered cubic) structure.

D. Claim 7: Obviousness Over Bowen In View Of Sunai Or Parkin And Optionally Soukup

1. Claim 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.”

186. As I explained previously in Section XII.A of this Declaration, Claim 1 is taught or suggested by Bowen in view of Sunai or Parkin. Claim 7 depends from Claim 1 and thus incorporates all of Claim 1’s requirements. Claim 7 was taught or suggested by Bowen in view of Sunai or Parkin and optionally Soukup. As I explained for Claim 1[b] in Section XII.A.3 of this Declaration, Bowen taught or suggested forming an MgO layer.

a) Oxygen vacancy defects

187. Obviousness over Bowen. Bowen also taught or suggested forming an MgO layer as MgO_x where $0 < x < 1$. As I explained in Section VII.F of this Declaration, MgO_x where $0 < x < 1$ refers to a non-stoichiometric MgO crystal where the ratio of oxygen to magnesium atoms is less than 1:1. In other words, there is less than 1 oxygen atom for every 1 magnesium atom. This is due to the presence of

oxygen vacancy defects in the MgO crystal, indicating that an oxygen atom is missing at certain places in the crystalline structure. MgO_x , non-stoichiometric MgO, and oxygen vacancy defects in an MgO layer are interchangeable terminology and all refer to the same phenomenon: missing oxygen atoms in the MgO crystal. *E.g.*, EX1041 (Wollschläger) at page 132 (“understoichiometric MgO_x ($x < 1$)”); EX1037 (Castanier) at page 3, Fig. 1 (showing “sub-stoichiometric $\text{MgO}\{100\}$ surfaces with various densities of oxygen vacancies,” and thus that oxygen vacancy defects were known).

188. The '167 Patent uses this terminology in the same way. For example, the patent contrasts using barrier layers of “MgO of the stoichiometric composition (the ratio of Mg to O is 1:1)” compared to MgO “with oxygen vacancy defects.” EX1013 ('167 Patent) at col. 6:26-33. It explains that when fabricating the MTJ, “there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).” EX1013 ('167 Patent) at col. 7:5-6. The '167 Patent applicant said the same thing to the Patent Office, explaining that “ MgO_x ($0 < x < 1$)” means the MgO “crystals have oxygen vacancy defects.” EX1002 ('403 Patent File History) at page 168.

189. Any oxygen vacancy defects in MgO produce MgO_x ($0 < x < 1$). Said another way, MgO_x ($0 < x < 1$) is inherent in any MgO substance that has oxygen vacancy defects. That is because the ratio of oxygen to magnesium has to be greater

than zero for the substance to constitute MgO. In other words, there must be some oxygen present to have MgO. Otherwise, it would simply be Mg. Similarly, to have oxygen vacancy defects, the ratio of oxygen to magnesium must be less than 1, which simply means less than the stoichiometric ratio of oxygen to magnesium. *See* Section VII.F of this Declaration.

190. Bowen taught or suggested oxygen vacancy defects in its MgO barrier layer. Bowen posited that the 0.9 eV MgO tunnel barrier height he observed may be attributed to a non-stoichiometric MgO barrier, explaining:

This value is lower than half of the 5.5 eV MgO band gap calculated for an ultrathin layer. This difference may be due to metal-induced gap states in the MgO barrier although we cannot completely rule out the *presence of stoichiometric and/or thickness inhomogeneities in the insulating film.*

EX1026 (Bowen) at page 1656 (emphasis added). A skilled artisan understood the use of less than stoichiometric amounts of oxygen in MgO in tunnel barrier layers.

191. Obviousness over Bowen and Soukup. Forming an MgO layer with oxygen vacancy defects was also taught or suggested by Bowen in view of Soukup. As discussed in the preceding Paragraph 190, Bowen stated that the properties of his MgO barrier may be explained by “the presence of stoichiometric and/or thickness inhomogeneities in the insulating film.” EX1026 (Bowen) at page 1656. Soukup also studied the “effect of nonstoichiometry on the device characteristics” on his

MgO thin film. EX1028 (Soukup) at page 3232. Soukup here is referring to oxygen vacancy defects in his MgO barrier. EX1028 (Soukup) at page 3232. He fabricated devices with different levels of nonstoichiometry in the MgO layer and assessed their barrier heights. EX1028 (Soukup) at Abstract, pages 3232-33, Table I.

192. To vary the level of oxygen vacancy defects in the MgO film, Soukup taught adjusting the amount of oxygen present during deposition of MgO. EX1028 (Soukup) at Abstract (“increasing oxygen pressure”), pages 3229 (“oxygen gas was admitted to various pressures during deposition of the MgO film”), 3232 (discussing “devices fabricated with more oxygen present during MgO deposition, which could mean more stoichiometric oxide films” and explaining that “admitting oxygen gas during deposition of the MgO film increases the stoichiometry of the film”), 3236 (same).

193. A skilled artisan would have been motivated to apply Soukup’s teachings about varying the level of oxygen vacancy defects in the MgO barrier to Bowen’s non-stoichiometric MgO barrier. Bowen sought to improve the TMR of its MTJ using an MgO barrier layer. EX1026 (Bowen) at page 1655. One of skill in the art looking to improve the TMR of Bowen’s MTJ would have been motivated to experiment with different levels of oxygen vacancy defects to study their impact on the MgO barrier properties and therefore improve TMR. EX1028 (Soukup) at page 3232.

b) Barrier height

194. Bowen in view of Soukup taught or suggested a tunnel barrier height between 0.2 to 0.5 eV.

195. Bowen disclosed an MTJ with a “barrier height at $\phi = 0.9$ eV” for his MgO barrier. EX1026 (Bowen) at page 1656. Soukup measured a “barrier height” of “about 0.33 eV” for its MgO thin film that is within the ’167 Patent’s disclosed range of 0.2 to 0.5 eV. EX1028 (Soukup) at Abstract, pages 3231-32, Fig. 5, Table I; EX1013 (’167 Patent) at col. 7:6-10 (“When there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current.”).

196. Indeed, oxygen vacancy defects in an MgO barrier impact the barrier height. Soukup investigated the “effect of nonstoichiometry on the device characteristics.” EX1028 (Soukup) at page 3232. Soukup suggested there was a “higher barrier?[] present for the devices fabricated with more oxygen present during MgO deposition, which could mean more stoichiometric oxide films.” EX1028 (Soukup) at page 3232. Said another way, Soukup found that a lower level of oxygen vacancy defects may result in a higher barrier height. This suggested a higher level of oxygen vacancy defects lowered the barrier height. EX1028 (Soukup) at page

3232. In sum, Soukup taught there was an inverse correlation between oxygen vacancy defects and the barrier height of the MgO layer.

197. A skilled artisan would have had a motivation to take Soukup's teachings about forming an MgO thin film barrier with a "barrier height" of "about 0.33 eV" and apply them to Bowen's MgO barrier. EX1028 (Soukup) at Abstract, pages 3232, 3236. As is evident from the TMR equation (reproduced below), lowering the resistance (barrier height) for parallel spin electrons compared to antiparallel improved TMRs:

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

EX1035 (Mooder 1995) at page 3273; EX1027 (Nagahama) ¶2; EX1013 ('167 Patent) at cols. 4:62-5:3 (TMR equation); EX1057 (Dieny textbook) at page 13.

198. The TMR was and is a key parameter for improving MRAM performance. EX1055 (Wang) at page 2269; EX1049 (Kim) at pages 185-88, 194. As explained in Section VII.E.3 of this Declaration, Butler and Mathon taught that MgO barriers would achieve higher TMRs due to improved symmetry matching between the MgO barrier and ferromagnetic electrodes, facilitating tunneling of parallel electrons across the barrier compared to antiparallel tunneling. EX1044 (Butler) at page 1; EX1046 (Mathon) at page 1. Mathon explained that tunneling was enhanced due to "only a small lattice mismatch of about 3.5%" between

electrodes and barrier. EX1046 (Mathon) at page 1. Following this research, Bowen and others were quite interested in increasing TMRs to enable better performing MRAM. *E.g.*, EX1026 (Bowen) at Abstract (showing “[t]unnel magnetoresistance measurements” of 60%), page 1655 (“present[ing] experimental results showing large TMR values in Fe(001)/MgO(001)/FeCo(001) epitaxial tunnel junctions”); EX1055 (Wang) at page 2271. MgO had been extensively studied for decades. One of skill would have been motivated to consult the literature on MgO, including Soukup.

199. To increase TMR of an MgO barrier, skilled artisans would have been motivated to explore lower barrier heights to facilitate tunneling of parallel electrons. One of skill in the art that was interested in improving Bowen’s MgO MTJ would have looked to Soukup’s teachings about forming MgO barriers, and how defects lowered the barrier height. Bowen’s and Soukup’s research dovetailed together. Both Bowen and Soukup studied properties of MgO barriers, including the barrier height, and discussed tunneling, EX1026 (Bowen) at Abstract, pages 1655-57; EX1028 (Soukup) at pages 3229-30, which is a problem also addressed by the ’167 Patent, EX1013 (’167 Patent) at Abstract, cols. 1:27-2:26. Bowen and Soukup discussed Simmons’ seminal 1963 paper and well-known formula for determining barrier height. EX1026 (Bowen) at page 1656; EX1028 (Soukup) at page 3229. A skilled artisan also would have had a reasonable expectation of success in applying

Soukup's teachings to Bowen to achieve oxygen vacancy defects. Soukup had already fabricated an MgO barrier with a tunnel barrier height of 0.33 eV, EX1028 (Soukup) at Abstract, and one of skill in the art would have understood that Soukup's barrier height was obtained by adjusting the level of oxygen vacancy defects in the MgO barrier and thus would have been motivated to predictably do the same.

200. As I mentioned in Paragraph 196 of this Declaration, oxygen vacancy defects impacted the barrier height. Bowen itself hypothesized that the low barrier height he observed, which was "lower than half" of the calculated value for "an ultrathin layer" of MgO, may be due to the "presence of stoichiometric... inhomogeneities in the insulating film." EX1026 (Bowen) at page 1656. Soukup observed a relationship between barrier height and MgO stoichiometry (oxygen vacancy defects). EX1028 (Soukup) at pages 3232, 3236 ("[B]arrier height was a function of the amount of oxygen present... with a higher barrier for larger amounts of oxygen present" and "more stoichiometric" MgO film.). Others in the field also observed a lower tunneling barrier for MgO barriers with defects. *See, e.g.*, EX1043 (Heinrich) at page 1 (noting that the "sharp increases in tunneling current were caused by localized defects in the MgO layer" and "the tunneling barrier is significantly decreased"); EX1045 (Klaua) at page 7 ("[S]mall variations in the electronic structure of the MgO lead to strong variations in the local tunneling current."); EX1053 (Mitani) at page 8042 (reporting "the resistance decreases

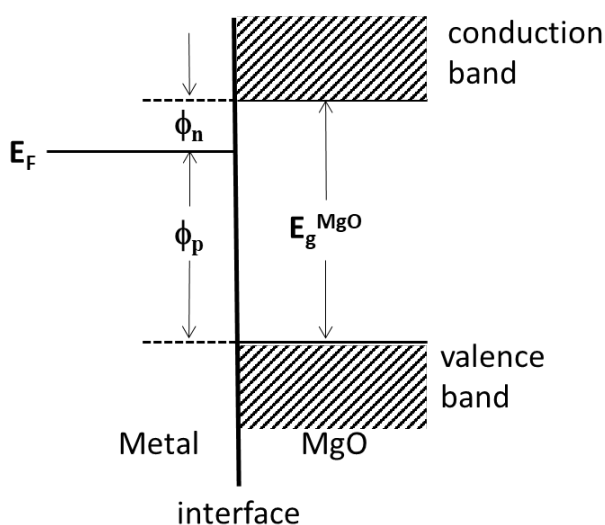
dramatically” for “tunneling transport through the MgO barrier,” attributing it to “defects in the MgO barrier”); EX1047 (Wulfhchel) at page 510 (observing “defects in the MgO barrier” and concluding that spikes in current are likely caused by “a lower tunneling barrier”).

201. According to the '167 Patent, “[w]hen there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of... 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current.” EX1013 ('167 Patent) at col. 7:6-10. Thus, the '167 Patent itself recognized that the tunnel barrier height is lowered when there are oxygen vacancy defects as taught by Bowen and Soukup. EX1026 (Bowen) at page 1656; EX1028 (Soukup) at pages 3232, 3236.

202. One of skill would have been motivated to adjust oxygen vacancy defects to improve TMR by lowering the barrier height.

203. Soukup reported a barrier height of 0.33 eV for his MgO barrier with an Au/MgO interface. EX1028 (Soukup) at pages 3229, 3232. The barrier height is principally driven by the barrier itself, in this case MgO. *E.g.*, EX1054 (Goniakowski) at Fig. 1; *id.* at page 96, Table 2. One of skill would have expected a barrier height for a ferromagnetic/MgO interface to be about the same or even lower than Soukup’s Au/MgO interface.

204. Goniakowski studied barrier heights for a large number of metal/MgO interfaces. In Figure 1, Goniakowski showed experimental data exhibiting a strong trend for p-type Schottky barrier heights, ϕ_p , for many metals on MgO in which the barrier height decreases linearly with the increase of the Pauling electronegativity of the metal. EX1054 (Goniakowski) at Fig. 1; *see also id.* at page 96, Table 2. One of skill would have understood the tunnel barrier height for electrons, ϕ_n , is related to ϕ_p by the relation: $\phi_p + \phi_n = E_g^{\text{MgO}}$, where E_g^{MgO} is the band gap of MgO. This is depicted schematically in the figure at right, where E_F represents the Fermi-level of the metal. Thus,



Goniakowski showed a strong trend for tunnel barrier heights in which the barrier height increases linearly with the increase of the Pauling electronegativity of the metal, or correspondingly decreases with the decrease of the Pauling electronegativity of the metal.

205. Trasatti reported experimental data for the Pauling electronegativity for many metals. EX1032 (Trasatti) at Table 1; *see also id.* at pages 229-31. In Table 1, Trasatti showed two values for the Pauling electronegativity for Au. 2.37 is given as the value by “a number of authors,” but 2.10 is the value given as the “operative”

value “corresponding to the state of the metal as used in electrochemistry or catalysis.” EX1032 (Trasatti) at page 231, Table 1. Trasatti’s Table 1 also showed a value for the Pauling electronegativity of Co as 1.8 and 1.77 for Fe. EX1032 (Trasatti) at Table 1. One of skill would have understood that a thin film of metal deposited on MgO using the techniques disclosed in Bowen (“triode sputtering with an Ar pressure of 4×10^{-4} mbar”) is not consistent with the state of the metal as used in electrochemistry or catalysis. Nevertheless, for either value of Pauling electronegativity cited for Au, the values of the Pauling electronegativity of Co and Fe are each lower. EX1026 (Bowen) at page 1655; EX1032 (Trasatti) at Table 1. Thus, one of skill reading Goniakowski in light of Trasatti would have concluded that a tunnel barrier height for Fe or Co on MgO would be lower than the value found by Soukup for Au on MgO. At a minimum, one of skill would have been aware of the trend for tunnel barrier heights disclosed in Goniakowski and would have understood that there would be a reasonable expectation of success in achieving a low barrier height using Fe or Co, or an alloy of Fe or Co.

206. In sum, Claim 7 was taught or suggested by Bowen in view of Sunai or Parkin and optionally Soukup.

E. Claim 8: Obviousness Over Bowen In View Of Sunai Or Parkin And Optionally Soukup

- 1. Claim 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.”**

207. Claim 8 specifies “the value of x in MgO_x for the MgO layer is greater than 0 and less than 1.” EX1013 (’167 Patent) at col. 10:31-34. That is equivalent to the mathematical notation used in Claim 7 of “ MgO_x ($0 < x < 1$).” EX1013 (’167 Patent) at col. 10:30. Claim 8 is disclosed or suggested for the same reasons explained above for Claim 7. *Supra* Section XII.D.1 of this Declaration.

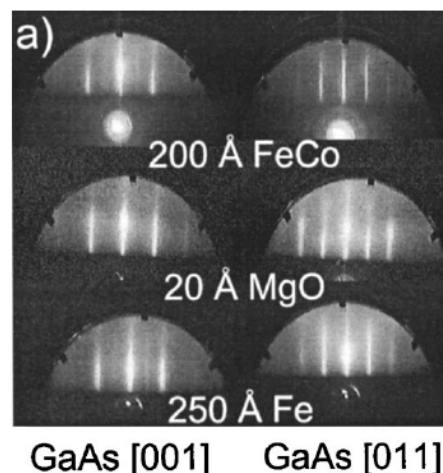
F. Claim 9: Obviousness Over Bowen In View Of Sunai Or Parkin

- 1. Claim 9: “The method of claim 1, wherein in the forming the MgO layer, the MgO layer is formed directly on the first CoFeB layer.”**

208. As I explained previously in Section XII.A of this Declaration, Claim 1 is taught or suggested by Bowen in view of Sunai or Parkin. Claim 9 depends from Claim 1 and thus incorporates all of Claim 1’s requirements. Claim 9 was taught or suggested by Bowen in view of Sunai or Parkin.

209. As I explained for Claim 1[b] in Section XII.A.3 of this Declaration, Bowen in view of Sunai or Parkin taught or suggested forming an MgO layer over the first CoFeB layer.

As shown in Figure 1 (excerpted) on the right and described by Bowen, Bowen's MgO tunnel



barrier layer is located between the lower and upper electrodes, forming a "trilayer." EX1026 (Bowen) at page 1656 ("Fe(200 Å)/MgO(20 Å)/FeCo(250 Å) trilayer").

210. In that trilayer, the MgO layer is in between the "Fe bottom electrode" and the "FeCo top electrode." EX1026 (Bowen) at page 1655. Thus, Bowen's "MgO barrier is grown" or formed directly on the lower, Fe electrode that, as I explained above for Claim 1[a], a skilled artisan would have been motivated to replace with a CoFeB layer. EX1026 (Bowen) at pages 1655-56, Fig. 1; *supra* §XII.A.2. Indeed, to form Bowen's trilayer structure, one of skill would have understood that Bowen's epitaxial methods involved first forming the lower electrode, then forming the MgO tunnel barrier layer directly on the lower electrode, followed by forming the upper electrode directly on the MgO barrier.

G. Claim 10: Obviousness Over Bowen In View Of Sunai Or Parkin

1. Claim 10[preamble]: “The method of claim 1, wherein:”

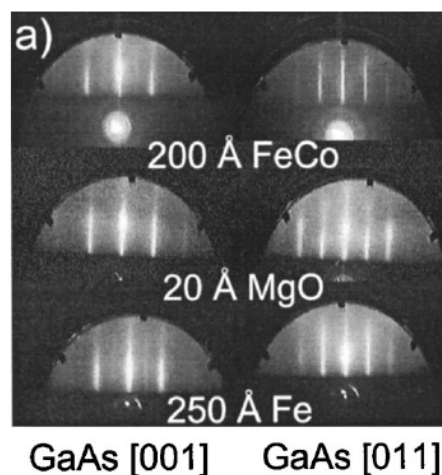
211. As I explained above in Section XII.A of this Declaration, Bowen in view of Sunai or Parkin taught or suggested a method of manufacturing a magnetic tunnel junction (MTJ) device satisfying Claim 1.

2. Claim 10[a]: “in the forming the MgO layer, the MgO layer is formed directly on the first CoFeB layer, and”

212. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 9. *Supra* Section XII.F.1 of this Declaration.

3. Claim 10[b]: “in the forming the second CoFeB layer, the second CoFeB layer is formed directly on the MgO layer.”

213. As I explained for Claim 1[c] in Section XII.A.4 of this Declaration, Bowen in view of Sunai or Parkin taught or suggested forming a second CoFeB layer over the MgO layer. As shown in Figure 1 (excerpted) on the right and described by Bowen, Bowen’s MgO tunnel barrier layer is located between the lower and upper electrodes, forming a “trilayer.” EX1026 (Bowen) at page 1656 (“Fe(200 Å)/MgO(20 Å)/FeCo(250 Å) trilayer”).



214. In that trilayer, the MgO layer is in between the “Fe bottom electrode” and the “FeCo top electrode.” EX1026 (Bowen) at page 1655. Thus, Bowen’s upper

FeCo electrode—that as I explained above for Claim 1[c], a skilled artisan would have been motivated to replace with a CoFeB layer—is formed directly on Bowen’s MgO tunnel barrier layer. EX1026 (Bowen) at pages 1655-56, Fig. 1; *supra* §XII.A.4. To form Bowen’s trilayer structure, a skilled artisan understood that Bowen’s epitaxial methods required first forming the lower electrode, then forming the MgO tunnel barrier layer directly on the lower electrode, followed by forming the upper electrode directly on the MgO barrier.

H. Claim 11: Obviousness Over Bowen In View Of Sunai Or Parkin

1. Claim 11[preamble]: “A method of manufacturing a magnetic tunnel junction (MTJ) device, comprising:”

215. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 1[preamble]. *Supra* Section XII.A.1 of this Declaration.

2. Claim 11[a]: “forming a first ferromagnetic layer including a first CoFeB layer that is amorphous;”

216. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 1[a]. *Supra* Section XII.A.2 of this Declaration. A CoFeB layer is a ferromagnetic layer. *Supra* §VII.E.2; EX1013 (’167 Patent) at col. 9:16 (“ferromagnetic alloy, such as CoFeB layers”); EX1030 (Sunai) ¶33 (“various ferromagnetic materials can be used, such as... Fe, Co, Ni, and alloys containing them”).

3. **Claim 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;”**

217. This claim limitation is disclosed or suggested for the same reasons explained above for Claims 1[b] and 1[f]. *Supra* Sections XII.A.3 and XII.A.7 of this Declaration. As explained for Claim 1[b], Bowen taught an “MgO barrier” layer. EX1026 (Bowen) at page 1655; *supra* § XII.A.3.

4. **Claim 11[c]: “forming a second ferromagnetic layer including a second CoFeB layer that is amorphous over the barrier layer; and”**

218. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 1[c]. *Supra* Section XII.A.4 of this Declaration. A CoFeB layer is a ferromagnetic layer. *Supra* §VII.E.2; EX1013 (’167 Patent) at col. 9:16 (“ferromagnetic alloy, such as CoFeB layers”); EX1030 (Sunai) ¶33 (“various ferromagnetic materials can be used, such as... Fe, Co, Ni, and alloys containing them”).

5. **Claim 11[d]: “annealing the first and second ferromagnetic layers and the barrier layer, to crystallize the first and second CoFeB layers.”**

219. This claim limitation is disclosed or suggested for the same reasons explained above for Claims 1[d] and 1[e]. *Supra* Sections XII.A.5 and XII.A.6 of this Declaration.

I. Claim 14: Obviousness Over Bowen In View Of Sunai Or Parkin And Optionally Soukup

- 1. Claim 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.”**

220. Claim 14 is disclosed or suggested for the same reasons explained above for Claim 7. *Supra* Section XII.D.1 of this Declaration.

J. Claim 15: Obviousness Over Bowen In View Of Sunai Or Parkin

- 1. Claim 15[preamble]: “The method of claim 11, wherein:”**

221. As I explained above in Section XII.H of this Declaration, Bowen in view of Sunai or Parkin taught or suggested a method of manufacturing a magnetic tunnel junction (MTJ) device satisfying Claim 11.

- 2. Claim 15[a]: “in the forming the barrier layer, the barrier layer is formed directly on the first ferromagnetic layer, and”**

222. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 9. *Supra* Section XII.F.1 of this Declaration. As explained for Claim 1[b], Bowen taught an “MgO barrier” layer. EX1026 (Bowen) at page 1655; *supra* § XII.A.3.

- 3. Claim 15[b]: “in the forming the second ferromagnetic layer, the second ferromagnetic layer is formed directly on the barrier layer.”**

223. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 10[b]. *Supra* Section XII.G.3 of this Declaration. A

CoFeB layer is a ferromagnetic layer. *Supra* §VII.E.2; EX1013 ('167 Patent) at col. 9:16 (“ferromagnetic alloy, such as CoFeB layers”); EX1030 (Sunai) ¶33 (“various ferromagnetic materials can be used, such as... Fe, Co, Ni, and alloys containing them”).

XIII. GROUND 2: CLAIMS 1, 3, 5, 7-11, AND 14-15 ARE OBVIOUS OVER NAGAHAMA IN VIEW OF SUNAI OR PARKIN (AND SOUKUP)

224. In my opinion, Claims 1, 3, 5, 7-11, and 14-15 are obvious over the prior art. Specifically:

- a. Claims 1, 3, 5, 9-11, and 15 are obvious over Nagahama in view of Sunai or Parkin, and
- b. Claims 7-8 and 14 are obvious over Nagahama in view of Sunai or Parkin and optionally Soukup.

A. Claim 1: Obviousness Over Nagahama In View Of Sunai Or Parkin

1. Claim 1[preamble]: “A method of manufacturing a magnetic tunnel junction (MTJ) device, comprising:”

225. I am informed and understand that claim preambles may or may not limit the claim. I have been asked to assume the preambles of the '167 Patent claims are limiting for purposes of this analysis. Assuming that the preamble of Claim 1 is limiting, it is taught or suggested by Nagahama.

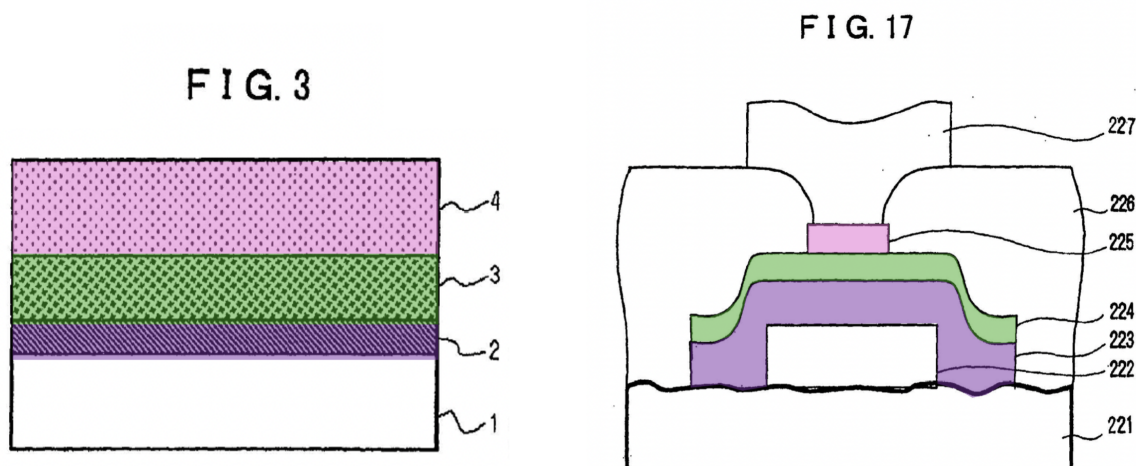
226. Claim 1[preamble] does not specify any particular method or process for manufacturing the claimed magnetic tunnel junction (MTJ) device. Thus, for

purposes of my analysis in this Declaration, I have assumed that any method of manufacturing an MTJ device satisfies Claim 1[preamble].

227. Nagahama taught or suggested a method of manufacturing a magnetic tunnel junction device. Nagahama taught that a “magnetoresistive element was prepared,” EX1027 (Nagahama) ¶73, including

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 of the present invention.

EX1027 (Nagahama) ¶73; *id.* at Abstract, ¶¶21-22, 74-76, Figs. 3, 17. Nagahama’s magnetoresistive devices took the conventional form, as depicted in Figures 3 and 17 below.



EX1027 (Nagahama) at Figs. 3, 17 (Fig. 3 excerpted, both annotated); *see also* Sections XIII.A.2-XIII.A.7 of this Declaration.

228. Nagahama taught a “method of manufacturing” its MTJ that one of skill would have understood was generally applicable to its MTJ examples. Those fabrication methods, including deposition techniques such as “sputtering,” were routine and conventional. EX1027 (Nagahama) ¶62; *see also id.* ¶78. For example, in its various disclosures, it discussed “[d]eposit[ing] MgO (10 nm) by sputtering,” “[d]eposit[ing] the MgO 212 (10 nm) by sputtering,” “[d]eposit[ing] the Fe 213 (20 nm) by sputtering,” “[a]nnealing,” and other conventional fabrication techniques. EX1027 (Nagahama) ¶¶57, 62.

229. As explained in Paragraph 112 of my Declaration for this limitation in Ground 1, various deposition methods were conventional and known manufacturing techniques for MTJs and spintronic devices.

230. Nagahama describes certain manufacturing methods. For the MTJ in Figure 12, Nagahama describes preparing a “magnetoresistive element” by deposition and sputtering. EX1027 (Nagahama) ¶57; *id.* ¶¶55-59. Nagahama describes another “method of manufacturing” by also using deposition and sputtering for his Figure 13 device. EX1027 (Nagahama) ¶62; *id.* ¶¶60-63. As explained in Paragraph 112 of my Declaration, various deposition methods were conventional manufacturing techniques for MTJs. Because Nagahama’s paragraphs 73-74 embodiment describes a similar MTJ, one of skill would have understood that Nagahama’s conventional fabrication methods were suitable for use with his

paragraphs 73-74 embodiment. Indeed, like the paragraphs 73-74 embodiment, Figures 12-13 are also part of Nagahama's "third group of the present invention." EX1027 (Nagahama) at page 7, ¶¶55, 60, 73-75. Figures 12-13 and paragraphs 73-74 describe similar MTJ structures and a skilled artisan would have understood that conventional manufacturing techniques used in Figures 12-13 would be easily used with, or adapted, the paragraphs 73-74 embodiment. *E.g.*, EX1027 (Nagahama) at Figs. 3, 12-13, 17 (depicting tunnel magnetoresistive elements). Because various deposition methods were widely used for fabricating MTJs as explained in Paragraph 112 of my Declaration, one of skill would have a reasonable expectation of success in applying the manufacturing techniques described in Nagahama's paragraphs 57 and 62 to his paragraphs 73-74 embodiment.

231. Nagahama also described "a technique for allowing highly oriented crystals to grow evenly." EX1027 (Nagahama) ¶17. Nagahama explained that where "the crystal orientation of the nonmagnetic metal film is set in the direction of $(100) \pm 10^\circ$, $(111) \pm 10^\circ$, $(110) \pm 10^\circ$, or $(112) \pm 10^\circ$ of a cubic system... evenness is increased." EX1027 (Nagahama) ¶18 (item [8]); *see also id.* ¶¶13, 27, 79.

232. In connection with its conventional Figure 3 embodiment, Nagahama also disclosed the well-known process where a "thin Fe layer is deposited" and then a thin "insulating layer and a CoFe upper electrode are deposited on the Fe layer to form a ferromagnetic tunnel junction." EX1027 (Nagahama) ¶28. Similarly,

Nagahama taught manufacturing its MTJ device by explaining that a “magnetoresistive element was prepared which 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 of the present invention.” EX1027 (Nagahama) ¶73. Nagahama further taught that “by combining heat treatment,” “a larger tunnel magnetoresistive effect of more than 90% was produced.” EX1027 (Nagahama) ¶74.

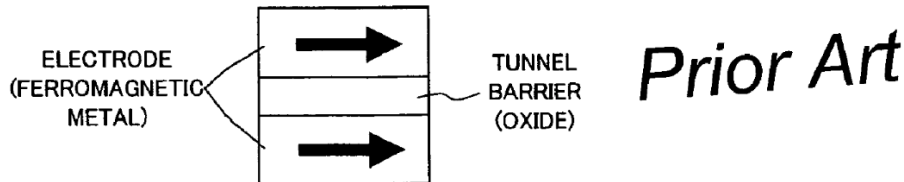
233. As with Bowen, Nagahama’s disclosed manufacturing methods are also akin or comparable to those described in the ’167 Patent. As I explained for Ground 1 in Section XII.A.1 of this Declaration, the ’167 Patent disclosed routine and conventional fabrication methods, including deposition methods such as “evaporation or sputtering,” and explained that “it should be obvious that other deposition methods are also possible.” EX1013 (’167 Patent) at cols. 9:16-18, 9:35-38; *see also id.* at col. 3:19-27. The ’167 Patent’s fabrication techniques were routine and conventional.

234. Nagahama analyzed the MTJs it formed using cross-sectional transmission electron microscopy. EX1027 (Nagahama) ¶19. For example, Figures 15-16 each show a “cross-sectional transmission electron micrograph of a high-quality tunnel magnetoresistive element.” EX1027 (Nagahama) ¶19, Figs. 15-16.

235. In addition, magnetic tunnel junctions (MTJs), including those with a three-layer MTJ structure, and methods of forming them were well known in the art.

236. This is evident from the '167 Patent itself. EX1013 ('167 Patent) at Figs. 8(A)-8(B), col. 1:39-64. For example, Figure 8(A) of the '167 Patent below shows an “MTJ device compris[ing] a tunnelling junction structure in which a tunnel barrier... made of an oxide is sandwiched between a first and a second electrode made of a ferromagnetic metal.” EX1013 ('167 Patent) at col. 1:42-46. The patent correctly identifies and labels this conventional MTJ design as “Prior Art”:

FIG. 8 (A)



EX1013 ('167 Patent) at Fig. 8(A) (“Prior Art” legend in original); *see also id.* at col. 9:35-38.

2. Claim 1[a]: “forming a first CoFeB layer that is amorphous;”

237. Nagahama in view of Sunai or Parkin taught or suggested this limitation.

238. Claim 1[a] does not specify the specific molecular composition or stoichiometry of the claimed “CoFeB.” EX1013 ('167 Patent) at col. 9:57. Thus, I

was asked to assume that any CoFeB alloy satisfies Claim 1[a]. Further, a skilled artisan understood that CoFeB and FeCoB refer to the same alloy.

239. For purposes of this Declaration, “first” will refer to the CoFeB layer that is closest to the substrate, and “second” will refer to the “upper” CoFeB layer. As I explained for Ground 1 in Section XII.A.2, one of skill would have understood that the “first” CoFeB layer is the CoFeB layer below the claimed MgO layer, and the “second” CoFeB layer is the CoFeB layer above the claimed MgO layer.

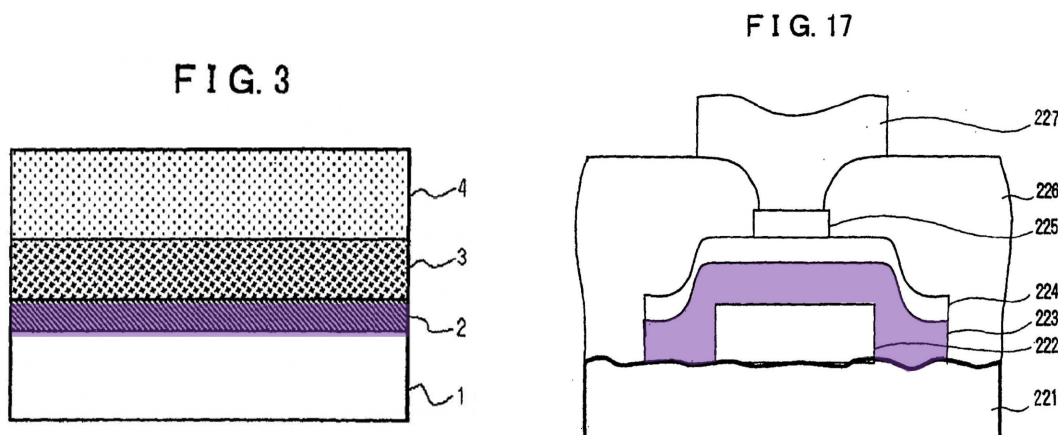
240. Nagahama taught various MTJ embodiments relating to forming a conventional structure of a ferromagnetic electrode on top of an insulating layer on top of an ultrathin ferromagnetic electrode that is above an underlayer. EX1027 (Nagahama) at page 10 (claim 1), ¶¶73-74 (describing same arrangement with MgO barrier layer); *see also id.* at Abstract, ¶¶21-22, Fig. 3. One of skill would have found it obvious to use Nagahama’s teachings on manufacturing an MTJ device to form an MTJ according to the conventional method described in Claim 1.

241. As I explained for Claim 1[preamble] in Section XIII.A.1 of this Declaration, Nagahama taught a conventional “method of manufacturing” its MTJ that one of skill would have understood generally applied to Nagahama’s various MTJ examples and embodiments.

242. As part of its “high-quality tunnel magnetoresistive element,” Nagahama taught or suggested forming a “**lower ferromagnetic electrode.**”

EX1027 (Nagahama) ¶¶73, 75-76, Fig. 17 (reference numeral 223); *see also id.* ¶22, Fig. 3. Nagahama taught that its “lower ferromagnetic electrode” could be comprised of various materials, including Fe, Co, Ni, or an alloy thereof. EX1027 (Nagahama) ¶¶28, 31, 61, 68, Fig. 17. In one example, Nagahama taught that a “thin Fe layer is deposited” for the lower ferromagnetic layer. EX1027 (Nagahama) ¶28; *id.* ¶62 (“Deposit the MgO 212 (10 nm) by sputtering.”). One of skill would have understood that Nagahama’s ferromagnetic layers, including its lower ferromagnetic layer, was formed by conventional deposition methods.

243. As shown below in Figures 3 and 17, “2” and “223” represent a **lower ferromagnetic layer**. EX1027 (Nagahama) ¶¶21-22, 75-76.



EX1027 (Nagahama) at Figs. 3, 17 (Fig. 3 excerpted, both annotated).

244. As I explained for Ground 1 in Section XII.A.2 of this Declaration, manufacturing MTJs by forming ferromagnetic layers was well known and

conventional by 2004, as the '167 Patent acknowledges. EX1013 ('167 Patent) at col. 1:42-46; *id.* at Figs. 8(A)-8(B).

245. Nagahama in view of Sunai. It would have been obvious to replace Nagahama's lower ferromagnetic layer with a CoFeB ferromagnetic layer, as taught by Sunai, including to improve TMR as well as lower H_f and H_c . EX1030 (Sunai) ¶¶28 (teaching CoFeB electrode by adding B to Co_9Fe so that "a continuous film can be formed"), 24 (teaching "ferromagnetic layer 4 is represented by the general formula $(CoFe)_{100-x}Y_x$ " and specifying Y is an "element selected from the group consisting of B" or other elements); *id.* ¶¶25-29; EX1061 (Cardoso) at Abstract.

246. Iron (Fe) and cobalt (Co) were known ferromagnetic materials, and CoFeB was a known ferromagnetic alloy based on Fe and Co. EX1030 (Sunai) ¶33 ("[F]erromagnetic materials" include "Fe, Co, Ni, and alloys containing them."); EX1057 (Dieny textbook) at pages 2-3, 18 ("ferromagnetic metals, such as cobalt (Co) and alloys based on Fe and Co"). Nagahama taught using a "Fe-Co Alloy" for the ferromagnetic layers to "increase the spin polarization." EX1027 (Nagahama) ¶6. It would have been obvious to use CoFeB as taught by Sunai in Nagahama's "(001)-highly-oriented lower ferromagnetic electrode layer" of the paragraphs 73-74 embodiment.

247. As I explained above in Ground 1, one of skill would have been motivated to use Sunai's CoFeB electrode in forming an MTJ. *Supra* Claim 1[a],

§XII.A.2 of this Declaration. One of skill would have been motivated to replace either or both of Nagahama's lower and upper electrodes with CoFeB to improve TMR, as well as lower H_f and H_c . EX1055 (Wang) at page 2270 ("[I]t is natural to replace both the free and pinned layers to CoFeB to further increase the TMR value."); EX1056 (Hosomi) ¶¶67-68; EX1035 (Moodera 1995) at page 3274 (forming different Co, Fe, CoFe alloys for "both bottom and top electrodes"); EX1061 (Cardoso) at Abstract ("CoFe-based junctions ($R \times A \sim 500 \Omega \cdot \mu m^2$) have lower TMR (~35%) and larger H_f (~5-6 Oe) and H_c (~12-14 Oe) [compared to CoFeB-based junctions]."). Nagahama sought to "obtain a high magnetoresistive effect" in forming its MgO MTJ, EX1027 (Nagahama) ¶6, and understood that the properties of the ferromagnetic electrodes impacted TMR, EX1027 (Nagahama) ¶23. It was understood by one of skill that forming a CoFeB alloy for the electrodes improved TMR in an MTJ. EX1055 (Wang) at pages 2269-70 ("The benefit of using CoFeB is multifold: a higher TMR value...."); EX1056 (Hosomi) ¶39 ("larger TMR ratio" when "CoFeB alloy" is used); EX1030 (Sunai) ¶¶27-28 (discussing improved TMR resulting from adding B to CoFe).

248. To improve Nagahama's method of manufacturing its MTJ, one of skill would have looked to Sunai's teachings. Nagahama and Sunai sought to fabricate thin film structures to improve the TMR of magnetoresistive devices, a problem to which the '167 Patent was directed. EX1027 (Nagahama) ¶¶6, 15; EX1030 (Sunai)

at Abstract, ¶¶1, 10; EX1013 ('167 Patent) at Abstract, cols. 1:27-2:26. Both Nagahama and Sunai also discussed improving MRAM memory performance. EX1027 (Nagahama) ¶¶3, 49; EX1030 (Sunai) at Figs. 4-5, ¶¶1, 4, 38-40. Further, they both formed an MgO barrier layer and similar ferromagnetic alloy electrodes. EX1027 (Nagahama) ¶¶6, 73; EX1030 (Sunai) ¶¶24, 35.

249. It would have been predictable and routine to replace Nagahama's lower electrode with a CoFeB electrode. CoFeB alloys had long been used in MTJ electrodes. EX1030 (Sunai) ¶¶24, 28; EX1055 (Wang) at pages 2269-70; EX1056 (Hosomi) ¶39. One of skill was aware that using CoFeB would increase the TMR of an MTJ as well as lower H_f and H_c . EX1030 (Sunai) ¶¶24, 28; EX1061 (Cardoso) at Abstract (describing increased TMR as well as decreased H_f and H_c when moving from CoFe to CoFeB). It would have been obvious and straightforward to improve Nagahama's method of fabricating an MTJ by using CoFeB in Nagahama's lower electrode because CoFeB was already proven successful in increasing TMR in MTJs. EX1030 (Sunai) ¶¶27-28.

250. As explained, Sunai discussed a "normal film formation method," and observed that adding boron resulted in an amorphous CoFeB layer. *Supra* §XII.A.2; EX1030 (Sunai) ¶¶24-25, 27, 30; EX1055 (Wang) at Abstract; EX1056 (Hosomi) at Abstract.

251. Nagahama in view of Parkin. Alternatively, in my opinion, Claim 1[a] is also taught or suggested by Nagahama in view of Parkin. As I explained above for Ground 1, Claim 1[a] in Section XII.A.2 of this Declaration, Parkin taught forming an “amorphous ferromagnetic layer 175” that “may be comprised of 75 Å thick $(\text{Co}_{73}\text{Fe}_{27})_{74}\text{B}_{26}$.” EX1062 (Parkin) at cols. 17:42-46, 19:16-17, Fig. 3A. It was known that adding boron resulted in an amorphous CoFeB layer. *Supra* §XII.A.2; EX1030 (Sunai) ¶¶24-25, 30; EX1055 (Wang) at Abstract; EX1056 (Hosomi) at Abstract.

252. For the same reasons I previously provided in Ground 1, it would have been obvious to replace Nagahama’s first ferromagnetic layer with Parkin’s CoFeB, which satisfies Claim 1[a]. *Supra* §XII.A.2.

253. To improve Nagahama’s MTJ, one of skill would have looked to Parkin’s teachings. Nagahama and Parkin sought to fabricate thin film structures to improve the TMR of magnetoresistive devices, a problem the ’167 Patent claimed to address. EX1027 (Nagahama) ¶¶6, 15; EX1062 (Parkin) at col. 1:18-21 (“[T]his invention relates to an improved MTJ exhibiting high tunneling magnetoresistance....”); EX1013 (’167 Patent) at Abstract, cols. 1:27-2:26. Like the ’167 Patent, Nagahama and Parkin also discussed improving MRAM memory performance. EX1027 (Nagahama) ¶¶3, 49; EX1062 (Parkin) at cols. 2:65-3:1 (“[F]or non-volatile magnetic memory storage cells, high TMR values are needed

for improving the performance of these devices.”); EX1013 (’167 Patent) at col. 2:54-57. Further, they both formed the same MgO barrier layer and similar ferromagnetic alloy electrodes. EX1027 (Nagahama) ¶¶6, 73; EX1062 (Parkin) at Abstract, col. 1:18-21 (“[T]his invention relates to an improved MTJ... with one or more electrodes formed from amorphous ferromagnetic materials.”).

254. MTJs already used CoFeB alloy electrodes, and one of skill would have found it to be straightforward and predictable to replace Nagahama’s first ferromagnetic layer with CoFeB, including to increase TMR as well as lower H_f and H_c . *Supra* §XII.A.2; EX1030 (Sunai) ¶¶27-28; EX1062 (Parkin) at cols. 18:49-51, 18:63-19:10; EX1055 (Wang) at pages 2269-70; EX1056 (Hosomi) ¶¶39, 78; EX1061 (Cardoso) at Abstract.

3. Claim 1[b]: “forming a magnesium oxide (MgO) layer over the first CoFeB layer;”

255. This claim limitation is taught or suggested by Nagahama in view of Sunai or Parkin.

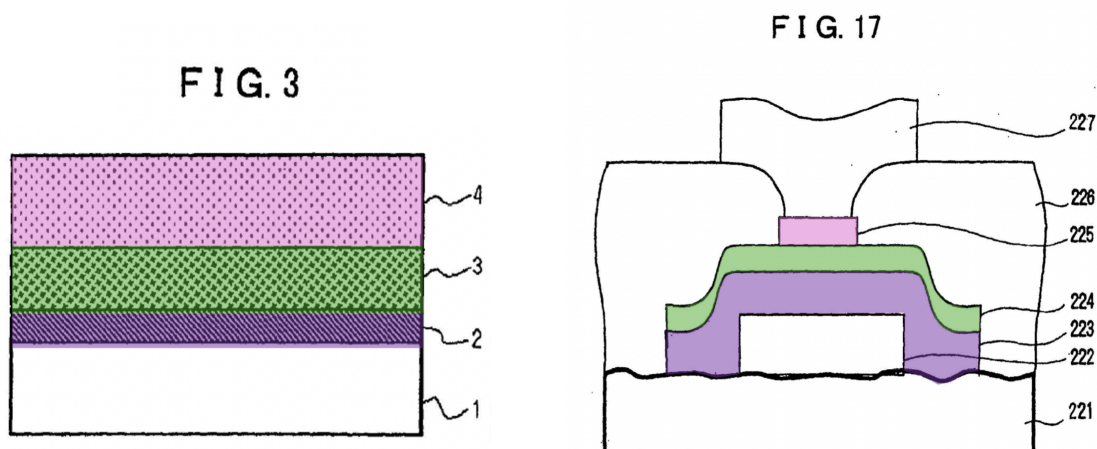
256. As I discussed for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama in view of Sunai or Parkin taught or suggested forming a first CoFeB layer. To increase TMR and lower H_f and H_c , it would have been obvious to replace Nagahama’s lower ferromagnetic layer with a CoFeB layer as taught by Sunai or Parkin. *Supra* §XIII.A.2.

257. Nagahama taught fabricating an MTJ with an MgO barrier layer, explaining that a “magnetoresistive element was prepared which includes... a (001)-highly-oriented MgO barrier layer.” EX1027 (Nagahama) ¶73. Nagahama taught forming its “(001)-highly-oriented MgO barrier layer” over the “(001)-highly-oriented *lower* ferromagnetic electrode layer” in its paragraphs 73-74 example. EX1027 (Nagahama) ¶¶73-74 (emphasis added); *see also id.* ¶¶21-22, Fig. 3, ¶¶75-76, Fig. 17. As part of Nagahama’s conventional “method of manufacturing,” Nagahama taught in one example that a “thin Fe layer is deposited” as a lower ferromagnetic layer and that an “insulating [barrier] layer” is “deposited on the Fe layer.” EX1027 (Nagahama) ¶¶28, 62. One of skill would have understood that Nagahama’s insulating barrier was formed by conventional deposition methods.

258. In one example, Nagahama taught depositing an MgO layer using sputtering. EX1027 (Nagahama) ¶¶57, 62. In that example, the MgO layer is initially grown amorphous and subsequently formed an “MgO(001)-oriented highly oriented crystal layer.” EX1027 (Nagahama) ¶58; *see also id.* ¶¶64-65. Thus, Nagahama taught using sputtering as one method for forming a “(001)-highly-oriented MgO” layer.

259. Nagahama’s MgO barrier is formed over the lower electrode that one of skill would have been motivated to replace with a CoFeB layer. *See* Section XIII.A.2 of this Declaration.

260. The conventional arrangement of Nagahama's "tunnel magnetoresistive element" is depicted in Figures 3 and 17. EX1027 (Nagahama) ¶¶21-22, 75-76. As shown below in Figures 3 and 17, "2" and "223" represent a lower ferromagnetic layer; "3" and "224" represent a barrier layer; and "4" and "225" represent an upper ferromagnetic layer. EX1027 (Nagahama) ¶¶21-22, 75-76.



EX1027 (Nagahama) at Figs. 3, 17 (Fig. 3 excerpted, both annotated).

261. As I explained for Ground 1 in Section XII.A.3 of this Declaration, forming an MgO layer over a ferromagnetic layer in an MTJ was conventional by 2004, as the '167 Patent acknowledges. EX1013 ('167 Patent) at col. 1:42-46; *id.* at Figs. 8(A)-8(B).

4. Claim 1[c]: "forming a second CoFeB layer that is amorphous over the MgO layer; and"

262. This claim limitation is taught or suggested by Nagahama in view of Sunai or Parkin.

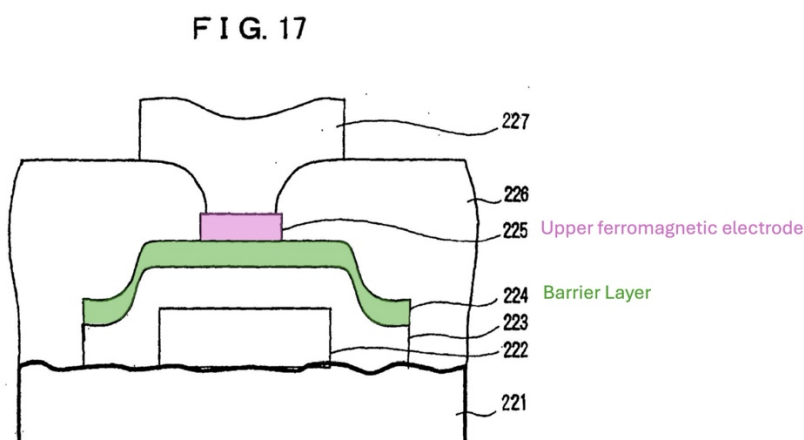
263. As I discussed for Claim 1[a] in Section XIII.A.2 of this Declaration, forming a first CoFeB layer that is amorphous was obvious over Nagahama in view of Sunai or Parkin. Claim 1[c]’s requirement of forming a second CoFeB layer that is amorphous over the MgO layer was also obvious over Nagahama in view of Sunai or Parkin. As I explained above with respect to Claim 1[a], although Claim 1 does not specify which layer is the “second,” for purposes of this Declaration, “second” will refer to the “upper” CoFeB layer.

264. As part of its “high-quality tunnel magnetoresistive element,” Nagahama taught or suggested forming an “**upper ferromagnetic electrode.**” EX1027 (Nagahama) ¶¶73, 75-76, Fig. 17 (reference numeral 225); *see also id.* ¶22, Fig. 3. Nagahama taught that its “upper ferromagnetic electrode” could be comprised of various materials, including Fe, Co, Ni, or an alloy thereof. EX1027 (Nagahama) ¶¶28, 31, 61, 68, Fig. 17.

265. Nagahama taught forming its “(001)-highly-oriented **upper** ferromagnetic electrode layer” over its “(001)-highly-oriented MgO barrier layer” in its paragraphs 73-74 example. EX1027 (Nagahama) ¶¶73-74 (emphasis added); *see also id.* ¶¶21-22, Fig. 3, ¶¶75-76, Fig. 17. In another example, Nagahama taught “deposit[ing]” an “insulating [barrier] layer” followed by a “CoFe upper electrode” over it. EX1027 (Nagahama) ¶¶28, 62. A skilled artisan would have understood

that Nagahama's upper ferromagnetic layer was formed by conventional deposition methods over its MgO barrier layer.

266. As shown below in Figures 3 and 17, "3" and "224" represent a **barrier layer** and "4" and "225" represent an **upper ferromagnetic layer formed** over the barrier layer. EX1027 (Nagahama) ¶¶21-22, 75-76.



EX1027 (Nagahama) at Fig. 17 (annotated).

267. As I explained for Ground 1 in Section XII.A.2 of this Declaration, manufacturing MTJs by forming ferromagnetic layers was well known and conventional by 2004, as the '167 Patent acknowledges. EX1013 ('167 Patent) at col. 1:42-46; *id.* at Figs. 8(A)-8(B).

268. Nagahama in view of Sunai. One of skill would have been motivated to replace Nagahama's second or upper ferromagnetic layer with a CoFeB layer, as taught by Sunai, for the same reasons a skilled artisan would have been motivated to replace Nagahama's first or lower ferromagnetic layer with Sunai's amorphous

CoFeB layer, as I explained above for Claim 1[a]. *Supra* §XIII.A.2. For the reasons I provided with respect to Nagahama's first ferromagnetic layer, replacing Nagahama's second ferromagnetic layer with a CoFeB layer would have further improved Nagahama's device, including improved tunneling and higher TMR as well as lower H_f and H_c . *Supra* §XIII.A.2.

269. Nagahama in view of Parkin. Alternatively, Claim 1[c] is also obvious over Nagahama in view of Parkin. As I explained above for Ground 1 in Section XII.A.4 of this Declaration, Parkin taught a second amorphous CoFeB layer. EX1062 (Parkin) at cols. 17:42-46, 19:16-17. A skilled artisan would have been motivated and found it obvious to replace Nagahama's upper ferromagnetic layer with Parkin's second CoFeB layer for the same reasons I explained for Nagahama's lower ferromagnetic layer in Section XIII.A.2 of this Declaration, including to improve tunneling and TMR and lower H_f and H_c .

5. Claim 1[d]: “annealing the first and second CoFeB layers and the MgO layer,”

270. Nagahama in view of Sunai or Parkin taught or suggested this claim limitation.

271. As I explained for Claims 1[a] and 1[c] in Sections XIII.A.2 and XIII.A.4 of this Declaration, it would have been obvious to replace Nagahama's

lower and upper ferromagnetic electrode layers with CoFeB layers as taught by Sunai or Parkin to increase TMR and lower H_f and H_c .

272. Claim 1[d]’s requirement of annealing both of the CoFeB electrodes as well as the MgO layer was also taught or suggested by Nagahama in view of Sunai or Parkin.

273. As explained for Ground 1 in Section XII.A.5 of this Declaration, it was well known and conventional to anneal an MTJ, including ferromagnetic CoFeB electrodes and MgO barrier layers. As explained, a skilled artisan would have been motivated to anneal the MTJ’s CoFeB and MgO barrier layers to improve TMR and obtain crystallized layers. *Supra* Claim 1[d], §XII.A.5.

274. According to Nagahama, annealing its MgO MTJ led to a higher TMR. For example, Nagahama reported that “a larger tunnel magnetoresistive effect of more than 90% was produced by combining heat treatment.” EX1027 (Nagahama) ¶¶73-74; *see also id.* ¶¶62, 68 (“Heat treatment of a sample... resulted in a magnetoresistive effect of more than 70% at room temperature.”). One of skill would have understood that Nagahama’s “heat treatment” referred to annealing. Further, other researchers also reported that annealing an MTJ improved TMR. *Supra* §XII.A.5; EX1062 (Parkin) at col. 7:53-58.

6. Claim 1[e]: “wherein the first and second CoFeB layers are crystallized by the annealing, and”

275. Nagahama in view of Sunai or Parkin taught or suggested this claim limitation.

276. As I explained for Claim 1[d] in Section XIII.A.5 of this Declaration, annealing CoFeB layers was taught or suggested by Nagahama in view of Sunai or Parkin.

277. Claim 1[e]’s requirement that the first and second CoFeB layers are crystallized by the annealing was also taught or suggested Nagahama in view of Sunai or Parkin.

278. As explained for Ground 1 in Section XII.A.6 of this Declaration, it was known and conventional to anneal CoFeB electrodes to crystallize them. EX1060 (Jimbo) at pages 309, 311; EX1061 (Cardoso) at pages 2272-73.

279. Nagahama in view of Sunai. For the same reasons I provided for Ground 1 in Section XII.A.6 of this Declaration, skilled artisans would have been motivated to anneal Nagahama’s MTJ with its CoFeB electrodes to crystallize the CoFeB layers. Nagahama itself observed high TMRs for crystallized ferromagnetic layers. EX1027 (Nagahama) ¶¶73-74. It was known that crystallizing led to improved tunneling and TMR. EX1045 (Klaue) at pages 1 (finding that “nearly perfect crystalline MgO(001) films on high-quality single crystals of Fe” improved

TMR), 6 (explaining that “the thin Fe film is basically transparent for electrons that tunnel and that diffuse transport in the Fe film does not play an important role” for an “Fe layer [that] has crystalline structure”). The same, as well as lower H_f and H_c , is true for crystallizing CoFeB electrodes. EX1061 (Cardoso) at Abstract (describing increased TMR as well as decreased H_f and H_c when moving from CoFe to CoFeB); EX1062 (Parkin) at cols. 18:49-59 (observing “very high TMR values” where “a portion of the [CoFeB] storage layer 175 adjacent to the MgO tunnel barrier 120’ has crystallized”), 18:63-19:17.

280. Nagahama in view of Parkin. Alternatively, Claim 1[e] is obvious over Nagahama in view of Parkin. As I explained for Ground 1, Parkin disclosed that annealing its MTJ results in its CoFeB layer containing an interface of crystalline CoFeB. *Supra* Claim 1[e], §XII.A.6; EX1062 (Parkin) at cols. 18:51-55, 19:16-22 (“The highly (100) textured MgO layer is likely to form an excellent template layer for the formation of a thin crystalline layer of CoFeB... during thermal anneal treatments....”). A skilled artisan would have been motivated to anneal Nagahama’s MTJ to crystallize the CoFeB electrodes because doing so was known to improve TMR as taught by Parkin. *Supra* §XII.A.6; EX1062 (Parkin) at cols. 18:49-51, 18:63-19:10.

7. **Claim 1[f]: “wherein the MgO layer is poly-crystalline in which a (001) crystal plane is preferentially oriented.”**

281. This claim limitation was taught or suggested by Nagahama.

282. As I explained for Claim 1[b] in Section XIII.A.3 of this Declaration, Nagahama taught or suggested forming an MgO layer. Nagahama disclosed forming a polycrystalline MgO tunnel barrier layer that is preferentially oriented in the (001) plane in its MTJ: “a (001)-highly-oriented MgO barrier layer.” EX1027 (Nagahama) ¶73.

283. Given its reference to “highly-oriented,” one of skill would have understood Nagahama’s “(001)-highly-oriented MgO barrier layer” to refer to a polycrystalline MgO barrier. *See, e.g.*, EX1027 (Nagahama) ¶¶40, 43 (referring to “single-crystal *or* highly-oriented-polycrystalline” (emphasis added)); *id.* ¶54 (referring to “single crystal *or* a highly oriented polycrystal” (emphasis added)); *see also* EX1040 (Yoon) at page 2842 (MgO “polycrystalline structures” have “preferred orientation”); EX1057 (Dieny) at page 46 (“highly oriented polycrystalline”). Indeed, because single-crystal layers have equivalent orientations throughout the crystalline lattice, the term “highly-oriented” is used to describe the predominant orientation of a polycrystalline layer containing many crystals. Although Nagahama disclosed the claimed (001) orientation, the ’167 Patent also explained that “because MgO has a cubic crystal structure (NaCl structure), the (001) plane, the (100) plane, and the (010) plane are all equivalent.” EX1013 (’167 Patent) at col. 4:39-41.

B. Claim 3: Obviousness Over Nagahama In View Of Sunai Or Parkin

- 1. Claim 3: “The method of claim 1, wherein after the annealing, each of the first and second CoFeB layers is polycrystalline in which a (001) crystal plane is preferentially oriented.”**

284. As I explained previously in Section XIII.A of this Declaration, Claim 1 is taught or suggested by Nagahama in view of Sunai or Parkin. Claim 3 depends from Claim 1 and thus incorporates all of Claim 1’s requirements. Claim 3 was taught or suggested by Nagahama in view of Sunai or Parkin.

285. One of skill understood that annealing an MgO(001) MTJ with CoFeB layers would result in CoFeB layers having a (001) crystal plane that is preferentially oriented. *See* Section XII.B.1 of this Declaration. Nagahama taught that its tunnel barrier layer was a “(001)-highly-oriented MgO barrier layer.” EX1027 (Nagahama) ¶73; *supra* Claim 1[f], §XIII.A.7.

286. Thus, in annealing Nagahama’s MTJ with a “(001)-highly-oriented MgO barrier layer” and CoFeB layers, it was known that the “MgO layer... provides a template for the formation of a thin crystalline ferromagnetic layer which... is oriented in the *same (100) direction* as the MgO layer.” EX1062 (Parkin) at col. 18:55-59 (emphasis added). Because MgO has a symmetrical cubic structure, MgO(100) is the same as MgO(001). *See* Section VII.E.3 of this Declaration.

287. For the same reasons I provided for Ground 1 in Section XII.B.1 of this Declaration, one of skill also would have known that annealing Nagahama's MTJ with CoFeB layers would predictably produce polycrystalline CoFeB layers. EX1061 (Cardoso) at page 2273; EX1062 (Parkin) at cols. 14:46-50, 15:47-49.

C. Claim 5: Obviousness Over Nagahama In View Of Sunai Or Parkin

- 1. Claim 5: "The method of claim 1, wherein after the annealing, each of the first and second CoFeB layers is polycrystalline 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."**

288. As I explained previously in Section XIII.A of this Declaration, Claim 1 is taught or suggested by Nagahama in view of Sunai or Parkin. Claim 5 depends from Claim 1 and thus incorporates all of Claim 1's requirements. Claim 5 was taught or suggested by Nagahama in view of Sunai or Parkin.

289. As I explained for Claim 3 in Section XIII.B.1 of this Declaration, Nagahama in view of Sunai or Parkin taught or suggested that after the annealing, each of the first and second CoFeB layers is polycrystalline in which a (001) crystal plane is preferentially oriented.

290. In annealing Nagahama's MTJ with a "(001)-highly-oriented MgO barrier layer" and CoFeB layers, it was understood that the "MgO layer... provides a template for the formation of a thin crystalline ferromagnetic layer which has the *bcc structure* of CoFe...." EX1062 (Parkin) at col. 18:55-59 (emphasis added);

EX1027 (Nagahama) ¶73. As I explained in Section VII.E.1 of this Declaration, the term “bcc” refers to “body-centered cubic.” Thus, Nagahama in view of Sunai or Parkin taught or suggested that after the annealing, each of the first and second CoFeB layers includes a BCC (body-centered cubic) structure.

291. Further, Nagahama itself disclosed that its MTJ had “ferromagnetic electrode layer[s]... oriented in the (001) direction of a body-centered cubic lattice....” EX1027 (Nagahama) ¶18 (item [20]); *id.* ¶1 (explaining that “[t]he present invention relates to... a tunnel magnetoresistive element whose crystal orientation is set to the (001) direction of a body-centered cubic lattice....”). One of skill would have found it obvious to form Nagahama’s ferromagnetic layers to be bcc structured. Nagahama taught that a bcc structure would help obtain “a large magnetoresistive effect” and thus was advantageous. EX1027 (Nagahama) ¶¶18 (item [20]), 81 (item [F]); *id.* at page 11 (claim 20).

D. Claim 7: Obviousness Over Nagahama In View Of Sunai Or Parkin And Optionally Soukup

1. Claim 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.”

292. As I explained previously in Section XIII.A of this Declaration, Claim 1 is taught or suggested by Nagahama in view of Sunai or Parkin. Claim 7 depends from Claim 1 and thus incorporates all of Claim 1’s requirements. Claim 7 was taught or suggested by Nagahama in view of Sunai or Parkin and optionally Soukup.

As I explained for Claim 1[b] in Section XIII.A.3 of this Declaration, Nagahama taught or suggested forming an MgO layer.

a) Oxygen vacancy defects

293. Obviousness over Nagahama. Nagahama also taught or suggested forming an MgO layer as MgO_x where $0 < x < 1$, which one of skill would have understood to be inherently satisfied by Nagahama. One of skill would have understood “ MgO_x where $0 < x < 1$ ” to be a mathematical notation to indicate oxygen vacancy defects in the MgO layer. EX1041 (Wollschläger) at page 132 (“understoichiometric MgO_x ($x < 1$)”); *supra* §VII.F. This is evident from the ’167 Patent itself, which discusses using “a source with oxygen vacancy defects” instead of “the MgO of the stoichiometric composition (the ratio of Mg to O is 1:1).” EX1013 (’167 Patent) at col. 6:31-33; *see also id.* at cols. 7:5-6 (“[T]here is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).”), 7:22-24 (“The value of x in MgO_x due to oxygen vacancy defects is such that $0.98 < x < 1$, and more preferably $0.99 < x < 1$.”), EX1002 (’403 Patent File History) at page 168 (Applicant: “ MgO_x ($0 < x < 1$)” means the MgO “crystals have oxygen vacancy defects.”).

294. One of skill would have understood that oxygen vacancy defects would be present in Nagahama’s MgO tunnel barrier because oxygen vacancies are naturally present in every oxide, including MgO, and would necessarily be present

in a thin-film MgO barrier like Nagahama's. EX1042 (Pacchioni) at page 162 ("Oxygen vacancies are naturally present in every oxide... and their concentration can be increased or reduced in several ways.... Oxygen vacancies in MgO are known as color centers or F centers....").

295. Obviousness over Nagahama and Soukup. Forming an MgO layer with oxygen vacancy defects was also taught or suggested by Nagahama in view of Soukup. Soukup taught an MgO barrier layer with oxygen vacancy defects. Soukup studied the "effect of nonstoichiometry on the device characteristics." EX1028 (Soukup) at page 3232. Soukup reported on experiments with devices fabricated with different levels of nonstoichiometry. EX1028 (Soukup) at Abstract, pages 3232-34, Table I. One of skill would have understood Soukup's nonstoichiometric MgO meant it had oxygen vacancy defects.

296. Soukup adjusted the level of oxygen vacancy defects in the MgO film by varying the amount of oxygen present during deposition of MgO. EX1028 (Soukup) at Abstract, pages 3229 ("oxygen gas was admitted to various pressures during deposition of the MgO film"), 3232 (discussing "devices fabricated with more oxygen present during MgO deposition, which could mean more stoichiometric oxide films" and explaining that "admitting oxygen gas during deposition of the MgO film increases the stoichiometry of the film"), 3236 (same).

297. A skilled artisan would have been motivated to apply Soukup's teachings about oxygen vacancy defects in the MgO barrier to Nagahama's MgO barrier. Nagahama sought to improve the TMR of its MTJ, EX1027 (Nagahama) ¶¶6, 15, and sought to do so by modifying the properties of the MgO barrier, *id.* ¶¶2-17. One of skill in the art looking to improve the TMR of Nagahama's MTJ would have been motivated to optimize levels of oxygen vacancy defects to study their impact on the MgO barrier properties and therefore improve TMR. EX1028 (Soukup) at page 3232.

b) Barrier height

298. Nagahama in view of Soukup taught or suggested a tunnel barrier height between 0.2 to 0.5 eV.

299. Soukup documented that higher oxygen vacancy defects in the MgO barrier resulted in lowering the barrier height. According to Soukup, "the barrier height was a function of the amount of oxygen present... during deposition of the MgO film with a higher barrier for larger amounts of oxygen present" and "[r]aising the oxygen pressure during deposition of the MgO film probably leads to a more stoichiometric film." EX1028 (Soukup) at page 3236. One of skill would have understood Soukup as teaching a lower barrier height with less stoichiometric oxide films, or equivalently, a higher level of oxygen vacancy defects, by using a relatively

low oxygen pressure during deposition of the MgO film. EX1028 (Soukup) at pages 3232, 3236.

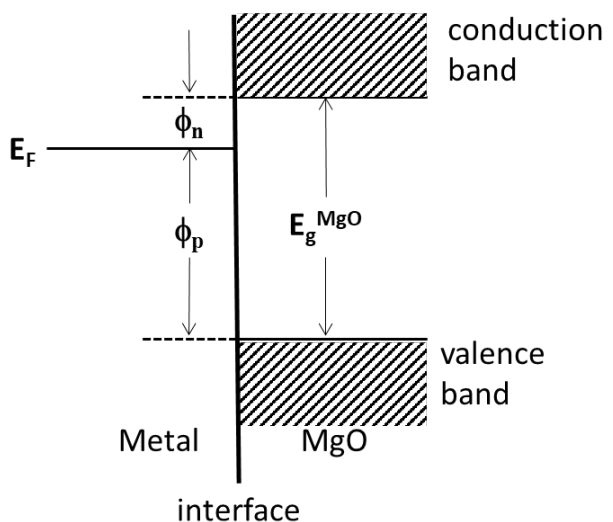
300. As I explained previously in Section XII.D.1 of this Declaration, the TMR was and is a key parameter for improving MRAM performance, and skilled artisans have long been interested in increasing TMRs to enable better performing MRAM. Additionally, lowering the resistance (barrier height) for parallel spin electrons compared to antiparallel would improve TMRs. *Supra* §XII.D.1; EX1035 (Mooder 1995) at page 3273; EX1027 (Nagahama) ¶2; EX1013 ('167 Patent) at cols. 4:62-5:3 (TMR equation); EX1057 (Dieny textbook) at page 13.

301. Nagahama aimed to improve the TMR in its MTJ. EX1027 (Nagahama) ¶¶15 (stating that “a first object of the present invention is to provide a tunnel magnetoresistive element capable of producing a larger magnetoresistive effect”), 6 (“obtain[ing] a high magnetoresistive effect”); *id.* ¶¶3-8. Nagahama sought to increase TMR by modifying properties of the MgO barrier layer. EX1027 (Nagahama) ¶¶15-17. It was understood to one of skill that lowering the barrier height to increase tunneling would have increased the TMR. Soukup documented how to fabricate an MgO thin-film barrier with a low tunnel barrier height between 0.2 and 0.5 eV, explaining how higher levels of oxygen vacancy defects in the MgO barrier resulted in lowering the barrier height. EX1028 (Soukup) at Abstract, pages 3232, 3236. One of skill would have been motivated to modify Nagahama’s MgO

barrier layer to increase TMR by increasing oxygen vacancy defects and thus lowering the barrier height as taught by Soukup.

302. Soukup's report of a barrier height as low as 0.33 eV pertained to Au-MgO barriers. However, one of skill would have expected a barrier height for ferromagnetic layers such as Fe or Co adjacent to an MgO barrier layer to be about the same or even lower.

303. Goniakowski studied barrier heights for a large number of metal/MgO interfaces. In Figure 1, Goniakowski showed experimental data exhibiting a strong trend for p-type Schottky barrier heights, ϕ_p , for many metals on MgO in which the barrier height decreases linearly with the increase of the Pauling electronegativity of the metal. EX1054 (Goniakowski) at Fig. 1; *see also id.* at page 96, Table 2. One of skill would have understood the tunnel barrier height for electrons, ϕ_n , is related to ϕ_p by the relation: $\phi_p + \phi_n = E_g^{\text{MgO}}$, where E_g^{MgO} is the band gap of MgO. This is depicted schematically in the figure on the right, where E_F represents the Fermi-level of the metal.



Thus, Goniakowski showed a strong trend for tunnel barrier heights in which the barrier height increases linearly with the increase of the Pauling electronegativity of

the metal, or correspondingly decreases with the decrease of the Pauling electronegativity of the metal.

304. Trasatti reported experimental data for the Pauling electronegativity for many metals. EX1032 (Trasatti) at Table 1; *see also id.* at pages 229-31. In Table 1, Trasatti showed two values for the Pauling electronegativity for Au. 2.37 is given as the value by “a number of authors,” but 2.10 is the value given as the “operative” value “corresponding to the state of the metal as used in electrochemistry or catalysis.” EX1032 (Trasatti) at page 231, Table 1. Trasatti’s Table 1 also showed a value for the Pauling electronegativity of Co as 1.8 and 1.77 for Fe. EX1032 (Trasatti) at Table 1. For either value of Pauling electronegativity cited for Au, the values of the Pauling electronegativity of Co and Fe are each lower. EX1032 (Trasatti) at Table 1. Thus, one of skill reading Goniakowski in light of Trasatti would have concluded that a tunnel barrier height for Fe or Co on MgO would be lower than the value found by Soukup for Au on MgO. At a minimum, one of skill would have been aware of the trend for tunnel barrier heights disclosed in Goniakowski and would have understood that there would be a reasonable expectation of success in achieving a low barrier height using Fe or Co, or an alloy of Fe or Co.

305. In my opinion, one of skill looking to improve tunneling and TMR in Nagahama’s MgO barrier would have been motivated to read the literature on MgO

thin films, including Soukup's study of forming an MgO barrier. EX1028 (Soukup) at Abstract, page 3229. Nagahama acknowledged and discussed prior research on increasing TMR in MgO barriers by Mathon, Bowen, and others. EX1027 (Nagahama) ¶¶2-14. Nagahama and Soukup both studied tunneling and other properties of MgO barriers and were focused on improving tunneling devices, the problem to which the '167 Patent was directed. EX1027 (Nagahama) ¶¶2-4, 13-15; EX1028 (Soukup) at pages 3229-30. One of skill would have been aware of Soukup's teachings about the low barrier height of Au on MgO thin films, would have been aware of Goniakowski's and Trasatti's teachings about the low barrier height of Fe or Co on MgO films and would have been motivated to apply Soukup's teachings to Nagahama to increase oxygen vacancy defects to increase TMR.

306. Others in the field also found a lower tunneling barrier for defects in the MgO film. For example, Heinrich observed that "sharp increases in tunneling current were caused by localized defects in the MgO layer" and "the tunneling barrier is significantly decreased." EX1043 (Heinrich) at page 1. Klaua and others also observed a similar relationship. *See, e.g.*, EX1045 (Klaua) at Abstract ("Tunneling I-V curves at the defects showed a lower tunneling barrier than that in the majority of the MgO film."); *id.* at page 4 ("But if defect states exist within the band gap of MgO, as in Fig. 6(c), then the tunneling probability via these defect states is largely enhanced."); *id.* at page 7 ("[S]mall variations in the electronic

structure of the MgO lead to strong variations in the local tunneling current.”); EX1047 (Wulfskel) at page 510 (observing “defects in the MgO barrier” and concluding that spikes in current are likely caused by “a lower tunneling barrier”); EX1053 (Mitani) at page 8042 (observing “the resistance decreases dramatically” for “tunneling transport through the MgO barrier,” attributing it to “defects in the MgO barrier”).

307. A skilled artisan also would have had a reasonable expectation of success in applying Soukup’s teachings to Nagahama to achieve oxygen vacancy defects. Soukup had already fabricated an MgO barrier with oxygen vacancy defects resulting in a tunnel barrier height of 0.33 eV, EX1028 (Soukup) at Abstract, and one of skill in the art would have understood that Soukup’s barrier height was obtained by adjusting the level of oxygen vacancy defects in the MgO barrier and thus would have been motivated to predictably do the same.

308. One of skill would have known that the presence of oxygen vacancy defects affected barrier height. Soukup documented the relationship between barrier height and the stoichiometry of the MgO film. EX1028 (Soukup) at pages 3232 (observing “higher barrier” for “more stoichiometric oxide films”), 3236 (noting that “barrier height was a function of the amount of oxygen present... with a higher barrier for larger amounts of oxygen present” or “more stoichiometric” MgO film).

309. As I explained above for Ground 1, Claim 7 in Section XII.D.1 of this Declaration, the '167 Patent itself recognized that the tunnel barrier height is lowered when there are oxygen vacancy defects. EX1013 ('167 Patent) at col. 7:6-10.

310. One of skill would have been motivated to adjust oxygen vacancy defects to improve TMR by lowering the barrier height.

E. Claim 8: Obviousness Over Nagahama In View Of Sunai Or Parkin And Optionally Soukup

1. **Claim 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.”**

311. Claim 8 specifies “the value of x in MgO_x for the MgO layer is greater than 0 and less than 1.” EX1013 ('167 Patent) at col. 10:31-34. That is equivalent to the mathematical notation used in Claim 7 of “ MgO_x ($0 < x < 1$).” EX1013 ('167 Patent) at col. 10:30. Thus, Claim 8 is disclosed or suggested for the same reasons explained above for Claim 7. *Supra* Section XIII.D.1 of this Declaration.

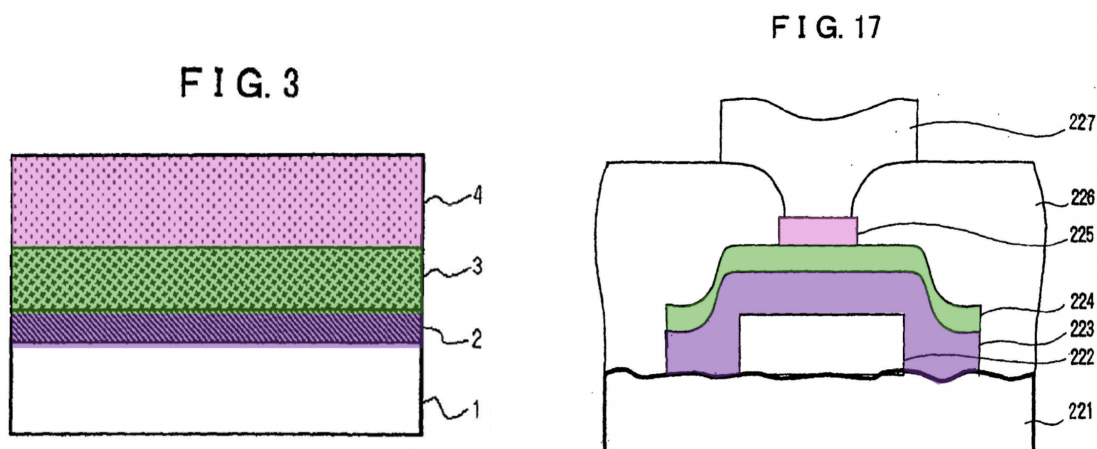
F. Claim 9: Obviousness Over Nagahama In View Of Sunai Or Parkin

1. **Claim 9: “The method of claim 1, wherein in the forming the MgO layer, the MgO layer is formed directly on the first CoFeB layer.”**

312. As I explained previously in Section XIII.A of this Declaration, Claim 1 is taught or suggested by Nagahama in view of Sunai or Parkin. Claim 9 depends

from Claim 1 and thus incorporates all of Claim 1's requirements. Claim 9 was taught or suggested by Nagahama in view of Sunai or Parkin.

313. As I explained for Claim 1[b] in Section XIII.A.3 of this Declaration, Nagahama in view of Sunai or Parkin taught or suggested forming an MgO layer over the first CoFeB layer, as shown in Figures 3 and 17 below.



EX1027 (Nagahama) at Figs. 3, 17 (Fig. 3 excerpted, both annotated). As illustrated, Nagahama taught forming the **barrier layer** (3, 224) directly on the **lower ferromagnetic layer** (2, 223) that one of skill would have been motivated to replace with a CoFeB layer. EX1027 (Nagahama) ¶¶21-22, 73-74 (“(001)-highly-oriented MgO barrier layer”), 75-76, Figs. 3, 17; *supra* Claim 1[a], §XIII.A.2.

G. Claim 10: Obviousness Over Nagahama In View Of Sunai Or Parkin

1. Claim 10[preamble]: “The method of claim 1, wherein:”

314. As I explained above in Section XIII.A of this Declaration, Nagahama in view of Sunai or Parkin taught or suggested a method of manufacturing a magnetic tunnel junction (MTJ) device satisfying Claim 1.

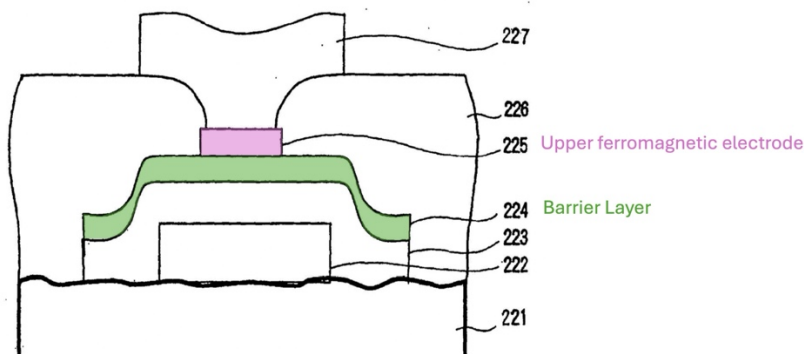
2. Claim 10[a]: “in the forming the MgO layer, the MgO layer is formed directly on the first CoFeB layer, and”

315. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 9. *Supra* Section XIII.F.1 of this Declaration.

3. Claim 10[b]: “in the forming the second CoFeB layer, the second CoFeB layer is formed directly on the MgO layer.”

316. As I explained for Claim 1[c] in Section XIII.A.4 of this Declaration, Nagahama in view of Sunai or Parkin taught or suggested forming a second CoFeB layer over the MgO layer, as shown for example in Figure 17 below.

FIG. 17



EX1027 (Nagahama) at Fig. 17 (annotated). As illustrated, Nagahama taught forming the **upper ferromagnetic layer** (225)—that one of skill would have been motivated to replace with a CoFeB layer—directly on the **barrier layer** (224). EX1027 (Nagahama) ¶¶21-22, 73-74 (“(001)-highly-oriented MgO barrier layer”), 75-76, Figs. 3, 17; *supra* §XIII.A.4.

H. Claim 11: Obviousness Over Nagahama In View Of Sunai Or Parkin

1. Claim 11[preamble]: “A method of manufacturing a magnetic tunnel junction (MTJ) device, comprising:”

317. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 1[preamble]. *Supra* Section XIII.A.1 of this Declaration.

2. Claim 11[a]: “forming a first ferromagnetic layer including a first CoFeB layer that is amorphous;”

318. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 1[a]. *Supra* Section XIII.A.2 of this Declaration. A CoFeB layer is a ferromagnetic layer. *Supra* §VII.E.2; EX1013 (’167 Patent) at col. 9:16 (“ferromagnetic alloy, such as CoFeB layers”); EX1030 (Sunai) ¶33 (“various ferromagnetic materials can be used, such as... Fe, Co, Ni, and alloys containing them”).

3. **Claim 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;”**

319. This claim limitation is disclosed or suggested for the same reasons explained above for Claims 1[b] and 1[f]. *Supra* Sections XIII.A.3 and XIII.A.7 of this Declaration. As explained for Claim 1[b], Nagahama taught a polycrystalline MgO(001) barrier layer. EX1027 (Nagahama) ¶¶73-74; *supra* § XIII.A.3.

4. **Claim 11[c]: “forming a second ferromagnetic layer including a second CoFeB layer that is amorphous over the barrier layer; and”**

320. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 1[c]. *Supra* Section XIII.A.4 of this Declaration. A CoFeB layer is a ferromagnetic layer. *Supra* §VII.E.2; EX1013 ('167 Patent) at col. 9:16 (“ferromagnetic alloy, such as CoFeB layers”); EX1030 (Sunai) ¶33 (“various ferromagnetic materials can be used, such as... Fe, Co, Ni, and alloys containing them”).

5. **Claim 11[d]: “annealing the first and second ferromagnetic layers and the barrier layer, to crystallize the first and second CoFeB layers.”**

321. This claim limitation is disclosed or suggested for the same reasons explained above for Claims 1[d] and 1[e]. *Supra* Sections XIII.A.5 and XIII.A.6 of this Declaration.

I. Claim 14: Obviousness Over Nagahama In View Of Sunai Or Parkin And Optionally Soukup

- 1. Claim 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.”**

322. Claim 14 is disclosed or suggested for the same reasons explained above for Claim 7. *Supra* Section XIII.D.1 of this Declaration.

J. Claim 15: Obviousness Over Nagahama In View Of Sunai Or Parkin

- 1. Claim 15[preamble]: “The method of claim 11, wherein:”**

323. As I explained above in Section XIII.H of this Declaration, Nagahama in view of Sunai or Parkin taught or suggested a method of manufacturing a magnetic tunnel junction (MTJ) device satisfying Claim 11.

- 2. Claim 15[a]: “in the forming the barrier layer, the barrier layer is formed directly on the first ferromagnetic layer, and”**

324. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 9. *Supra* Section XIII.F.1 of this Declaration. As explained for Claim 1[b], Nagahama taught a polycrystalline MgO(001) barrier layer. EX1027 (Nagahama) ¶¶73-74; *supra* § XIII.A.3.

- 3. Claim 15[b]: “in the forming the second ferromagnetic layer, the second ferromagnetic layer is formed directly on the barrier layer.”**

325. This claim limitation is disclosed or suggested for the same reasons explained above for Claim 10[b]. *Supra* Section XIII.G.3 of this Declaration. A

CoFeB layer is a ferromagnetic layer. *Supra* §VII.E.2; EX1013 ('167 Patent) at col. 9:16 (“ferromagnetic alloy, such as CoFeB layers”); EX1030 (Sunai) ¶33 (“various ferromagnetic materials can be used, such as... Fe, Co, Ni, and alloys containing them”).

XIV. SECONDARY INDICIA OF NONOBVIOUSNESS

326. Pertinent to both Grounds 1 and 2 above, I am not aware of any evidence of secondary considerations of nonobviousness for which there is any nexus to any claim of the '167 Patent. Should I become aware of such evidence, I may offer opinions on it at that time.

XV. CONCLUSION

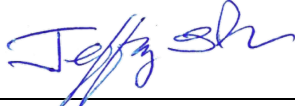
327. Based on the foregoing, it is my opinion that Claims 1, 3, 5, 7-11, and 14-15 of the '167 Patent are obvious as discussed above.

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

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

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

Dated: September 27, 2024



Jeffrey Bokor

XVI. APPENDIX: LIST OF PATENT CLAIMS

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,

1[e] wherein the first and second CoFeB layers are crystallized by the annealing, and

1[f] wherein the MgO layer is poly-crystalline in which a (001) crystal plane is preferentially oriented.

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.

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.

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;

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.

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.