

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

WESTERN DIGITAL TECHNOLOGIES, INC.,
Petitioner,

v.

GODO KAISHA IP BRIDGE 1,
Patent Owner.

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

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. 11,968,909 (“the ’909 Patent”) (EX1017).

2. In the course of preparing this Declaration, I reviewed the ’909 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 ’909 Patent, or the owner of the ’909 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)

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 '909 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 '909 Patent priority date were around the March 12, 2004 date of the first Japanese priority application to the '909 Patent, the October 28, 2004 date of the second Japanese priority application to the '909 Patent, or the March 10, 2005 PCT filing date of the '403 Patent from which the '909 Patent claims priority.

VI. LEVEL OF ORDINARY SKILL IN THE ART

25. Based on my review of the '909 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 '909 Patent generally relates to “a magnetic tunnel junction device and a method of manufacturing the same.” EX1017 ('909 Patent) at col. 1:37-38.

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 '909 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.

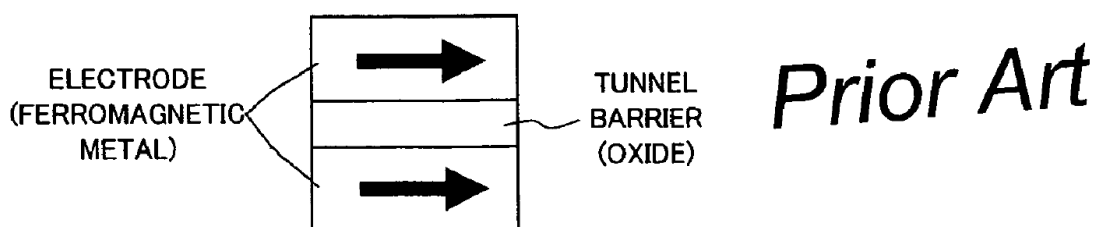
B. Magnetic Tunnel Junctions (MTJs) And Spintronics

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 (Klaua) 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 ’909 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).

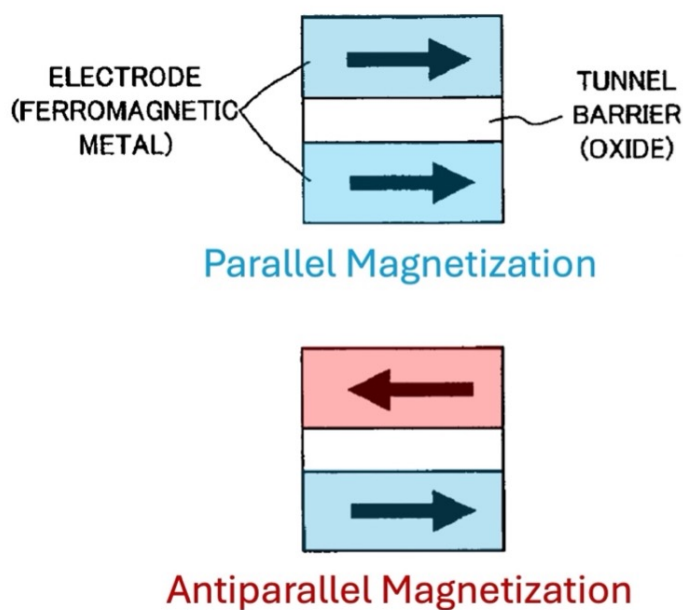


EX1017 (’909 Patent) at Fig. 8(A); *see also id.* at Fig. 8(B), cols. 1:51-2:9; EX1057 (Dieny textbook) at page 9.

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; EX1017 ('909 Patent) at cols. 1:60-2:4. 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; EX1017 ('909 Patent) at cols. 1:60-2:9.



EX1017 ('909 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:

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

EX1035 (Moodera 1995) at page 3273; EX1027 (Nagahama) ¶2; EX1017 ('909 Patent) at col. 5:8-16 (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

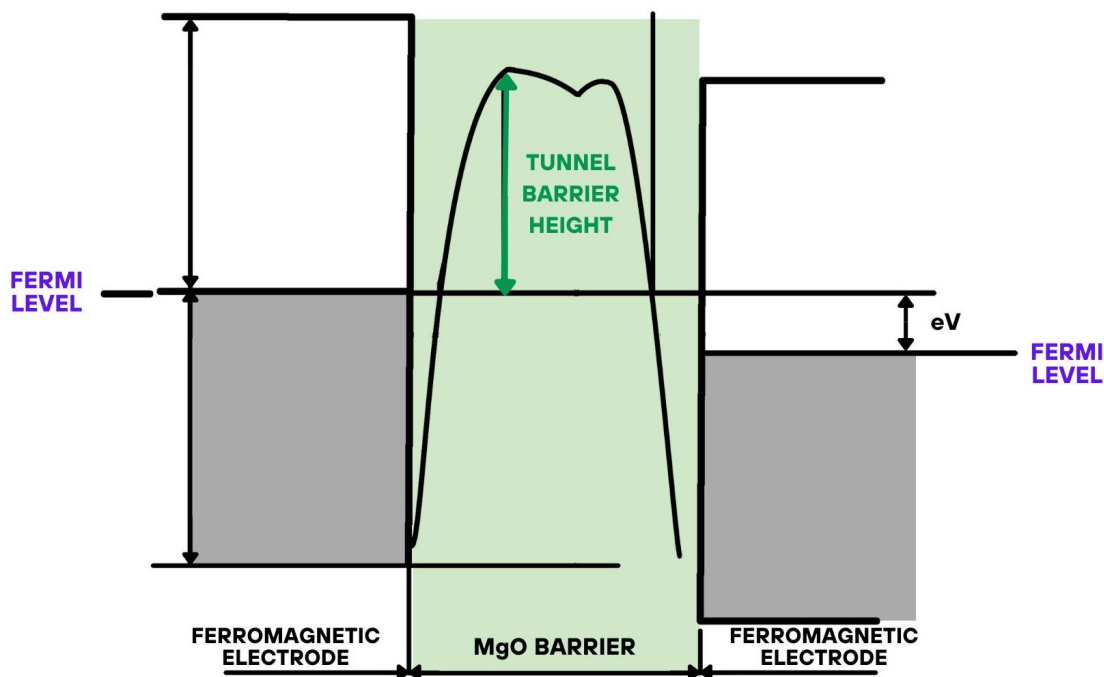
over 100% MR ratio in the future.... The key issues of MRAM technology as a future memory candidate are resistance control and low current operation for small enough device size.”); EX1057 (Dieny textbook) at page 9 (“[L]arger TMR ratios... enabled new types of MRAM that could be scaled down in size 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.” EX1017 (’909 Patent) at col. 4:2-6.

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:

$$J = [3(2m\varphi)^{\frac{1}{2}}/2s](e/h)^2 V \times \exp[-(4\pi s/h)(2m\varphi_0)^{\frac{1}{2}}].$$

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.

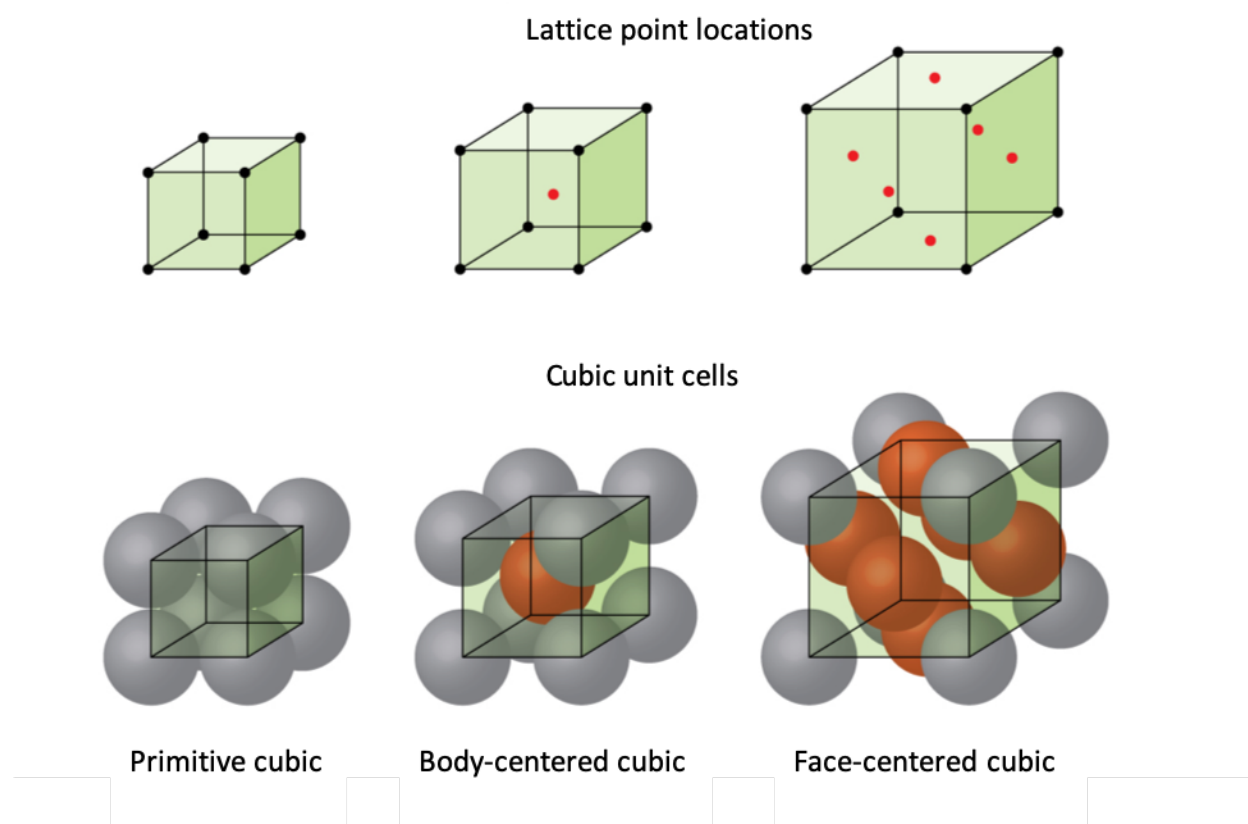
E. MTJ Materials

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.

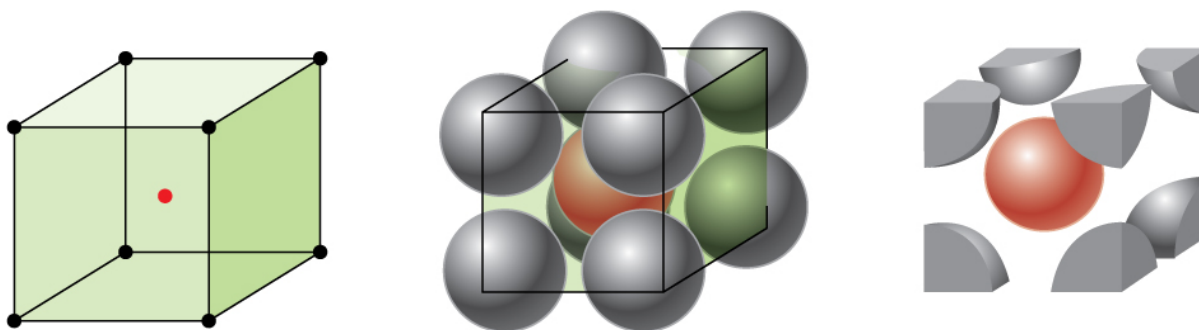
1. Crystalline Structures

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

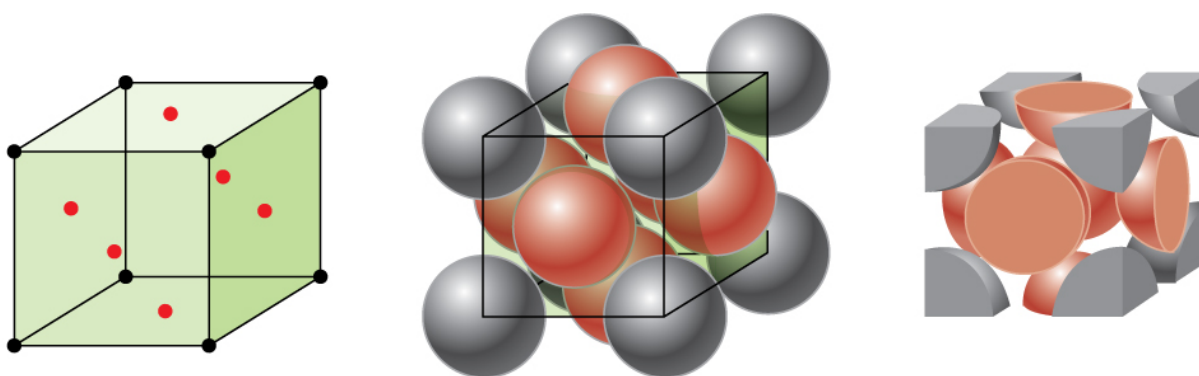


UW Madison Chemistry 103/104 Resource Book (“UW Chemistry Book”), Topic 61, Fig. 1, *available at* <https://wisc.pb.unizin.org/minimisgenchem/chapter/types-of-unit-cells-body-centered-cubic-and-face-centered-cubic-m11q5/>.

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:



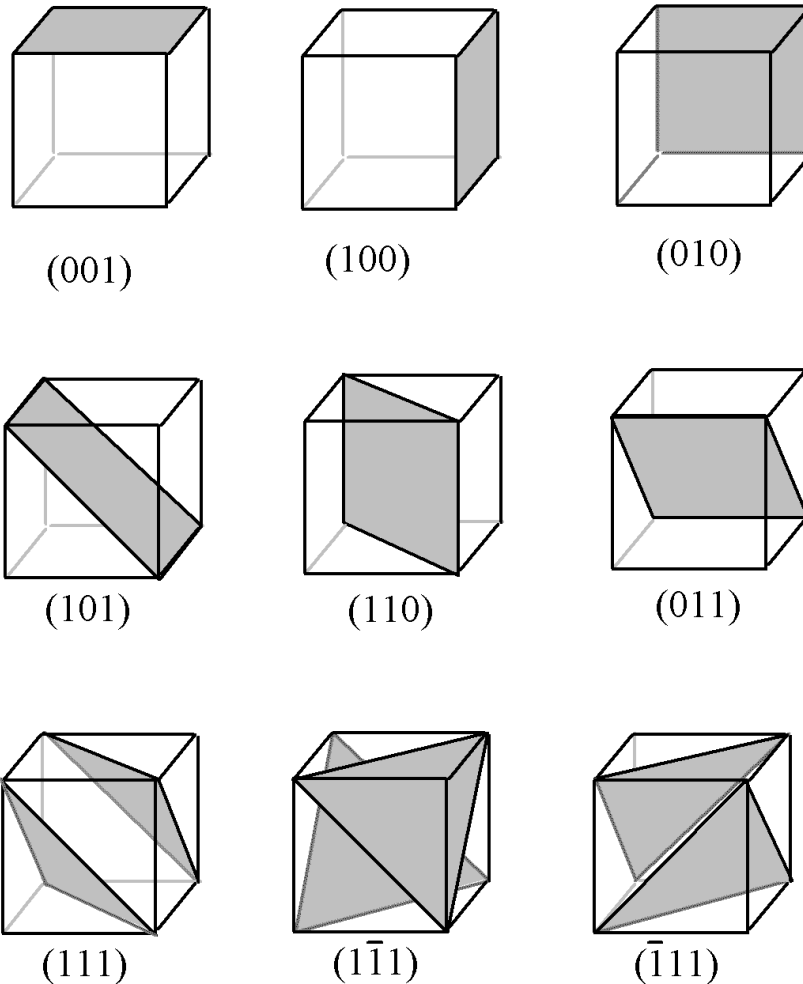
Body-centered cubic structure



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 '909 Patent agrees. EX1017 ('909 Patent) at col. 4:52-54 (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:

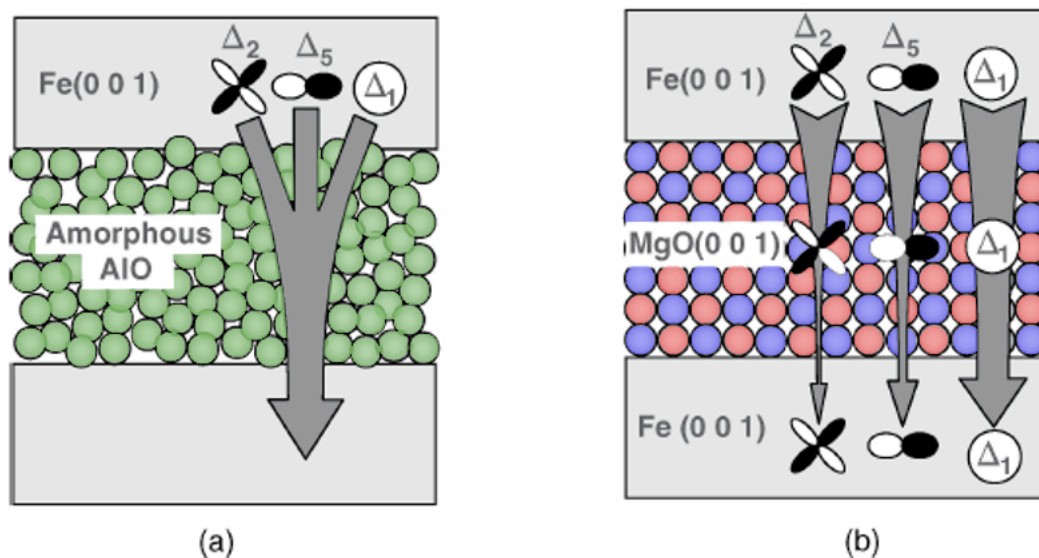


Figure 2.19 Schematic of electron tunneling through (a) an amorphous AlO barrier and (b) a crystalline $\text{MgO}(0 0 1)$ barrier.

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”); EX1017 (’909 Patent) at col. 4:52-53 (“ 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.

EX1017 ('909 Patent) at col. 4:52-54. 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 (Klaua) 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.

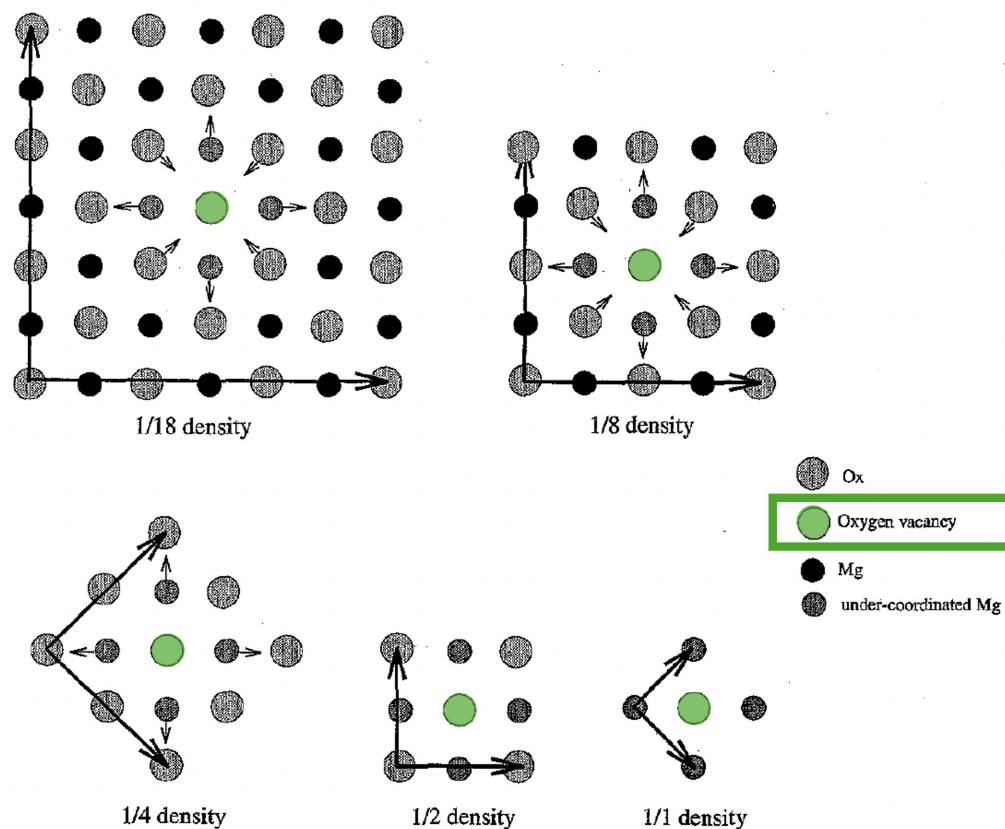
F. Oxygen Vacancy Defects In MgO Thin Films

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 '909 Patent. EX1017 ('909 Patent) at cols. 7:18-19 (“[T]here is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).”), 7:34-36. The '909 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.

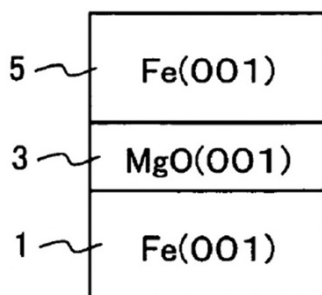
82. Similarly, Bowen observed a lower barrier height for an MgO thin film and hypothesized that it may have resulted from “the presence of stoichiometric and/or thickness inhomogeneities in the insulating film.” EX1026 (Bowen) at

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 ’909 PATENT

83. The ’909 Patent is titled “Method of Manufacturing a Magnetoresistive Random Access Memory (MRAM).” EX1017 (’909 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.” EX1017 (’909 Patent) at col. 1:51-58; *see also id.* at cols. 1:58-2:9. As shown in Figure 1(B) below, the ’909 Patent discloses two Fe electrodes surrounding a single-crystalline or polycrystalline MgO barrier layer:

FIG. 1 (B)



EX1017 (’909 Patent) at Fig. 1(B) (modified), col. 5:51-57.

84. The '909 Patent's claims are directed to an MTJ device with a magnesium oxide tunnel barrier layer containing oxygen vacancy defects: " MgO_x " where " x " is " $(0 < x < 1)$," " $(0.9 < x < 1)$," " $(0.98 < x < 1)$," or " $(0.99 < x < 1)$." EX1017 ('909 Patent) at cols. 9:65-10:13 (Claims 1-4). Claims 5-6, 9, 12, and 15 require, *inter alia*, that the tunnel barrier layer has a "barrier height" that is "in a range of 0.1 eV to 0.85 eV" or "in a range of 0.2 to 0.5 eV." EX1017 ('909 Patent) at cols. 10:14-20, 10:27-35, 10:42-43, 10:51-57.

85. Claims 8, 11, 13, and 17-18 require, *inter alia*, that the first and/or second ferromagnetic material layer be "partially or entirely crystallized" or "exhibits a body-centered cubic (BBC) structure." EX1017 ('909 Patent) at cols. 10:24-26, 10:39-41, 10:44-47, 10:61-67. Claim 7 requires that the first and/or second ferromagnetic material layer "comprises Boron," *id.* at col. 10:21-23, while Claims 14 and 19 require that the ferromagnetic material layers "comprise[] Cobalt and Iron," *id.* at cols. 10:48-50, 11:1-3.

86. Claims 10 and 16 require the tunnel barrier layer "comprises partially or fully crystalline magnesium oxide," EX1017 ('909 Patent) at cols. 10:36-38, 10:58-60, and Claim 20 requires the tunnel barrier layer "has a thickness less than 10 nm" *id.* at col. 11:4-5.

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 '909 Patent's specification. Where relevant, I have identified teachings in the '909 Patent that inform the plain and ordinary meaning of the claim limitations.

X. PRIOR ART TO THE '909 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 '909 Patent except for the textbook, *Introduction to Magnetic Random-Access Memory* by Bernard Diény *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 Diény'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.

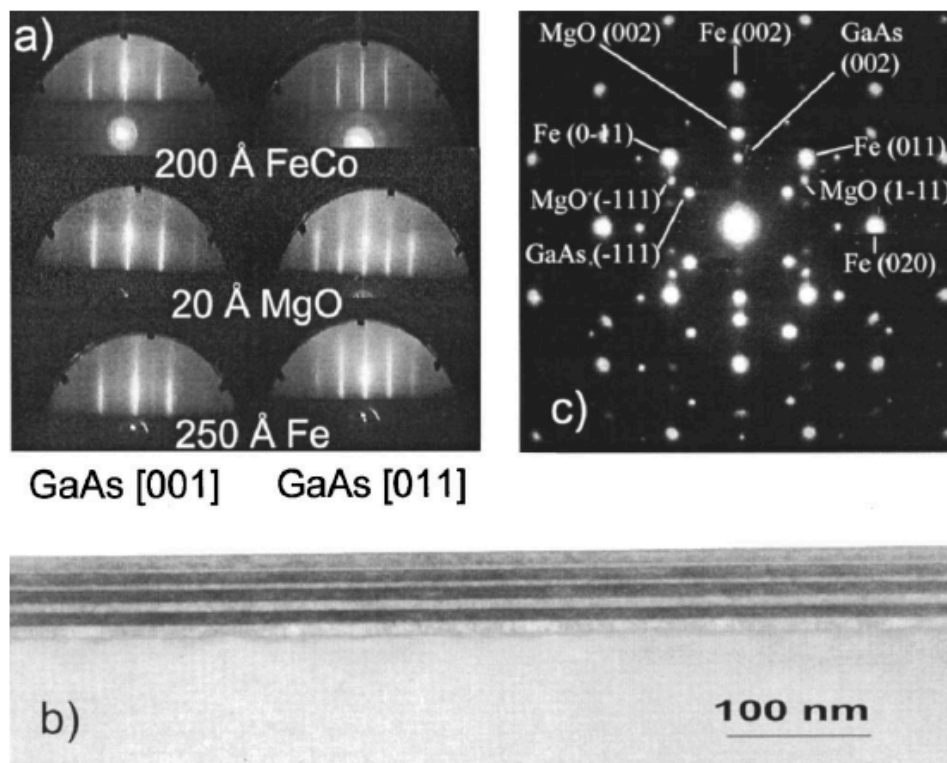


FIG. 1. (a) RHEED patterns along the GaAs [100] and [110] substrate azimuths of a typical FeCo/MgO/Fe epitaxial structure; (b) cross section TEM image of a Fe/MgO(001) multilayer with gradually decreasing MgO layer thickness; (c) TEM electron diffraction pattern.

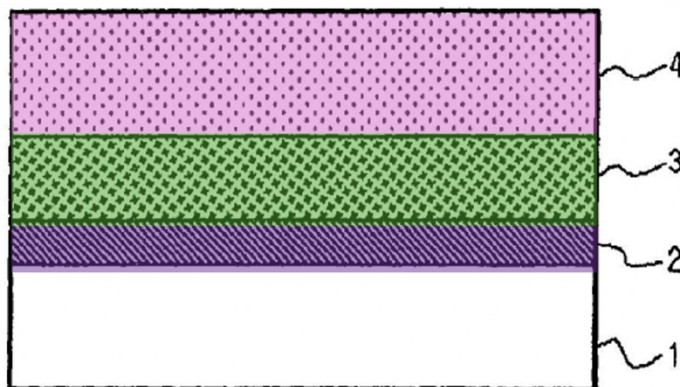
EX1026 (Bowen) at Fig. 1.

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 '909 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

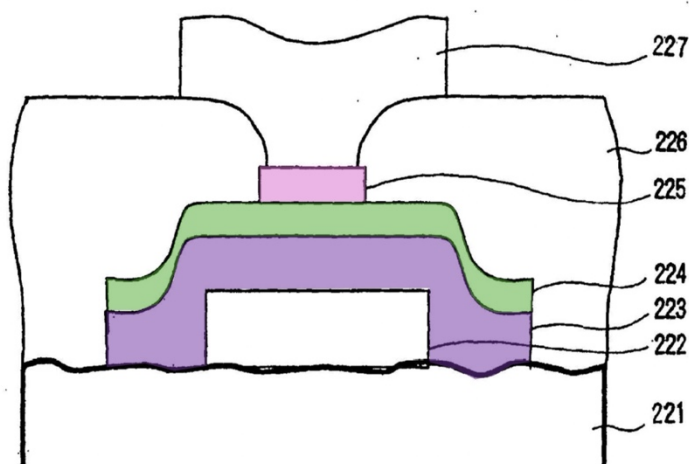


EX1027 (Nagahama) at Fig. 3 (excerpted, annotated).

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”)

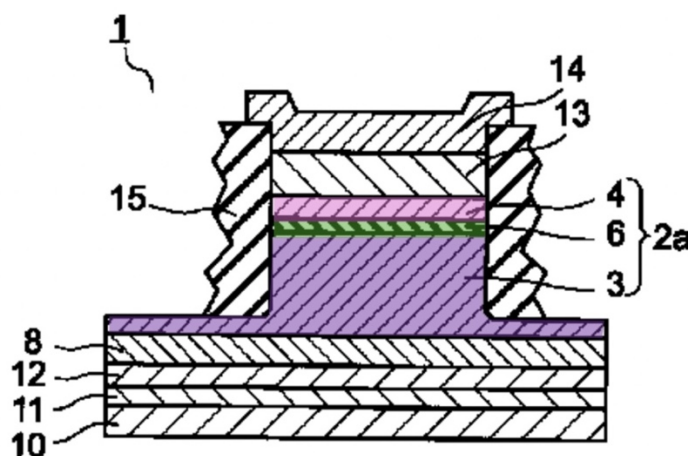
99. Published in 2002, Sunai is a Japanese patent application titled “Magnetoresistance effect element, magnetic memory, magnetic head, and magnetic reproducing device.” EX1030 (Sunai) at page 1.

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.

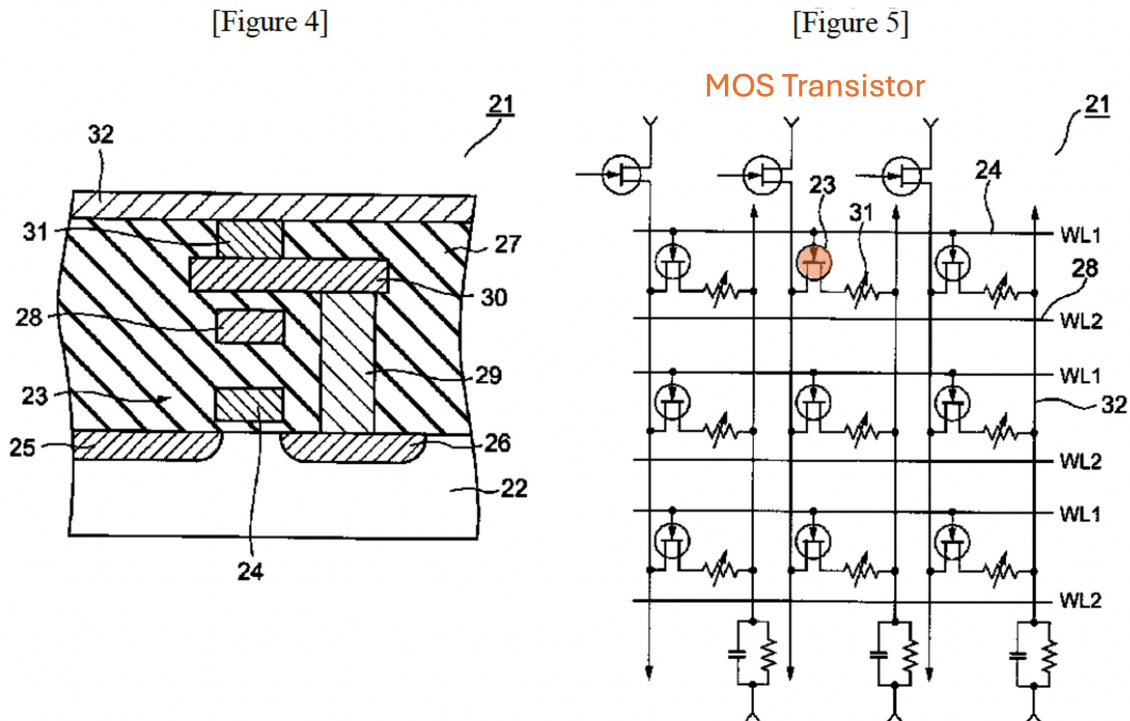
[Figure 1]



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:



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 (Co₇₃Fe₂₇)₇₄B₂₆." 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.

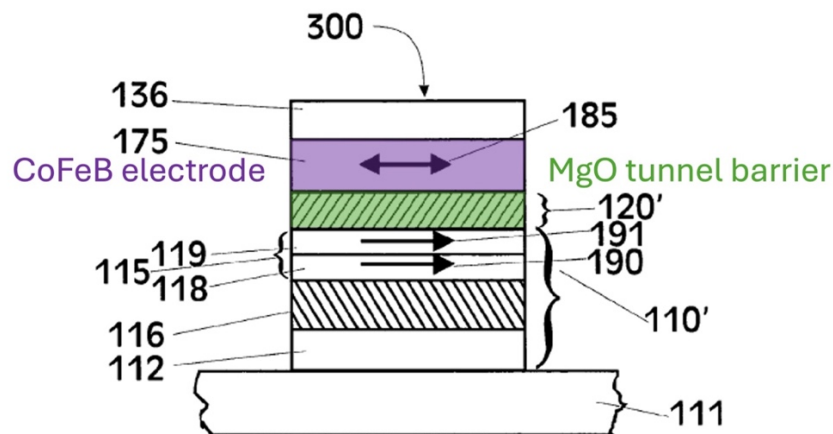


FIG. 3A

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 using conventional alumina tunnel barriers,” *id.* at cols. 18:63-19:10.

XI. SUMMARY OF OPINIONS OFFERED

107. In my opinion, Claims 1-20 are obvious over the two grounds presented in this Declaration.

XII. GROUND 1: CLAIMS 1-20 ARE OBVIOUS OVER BOWEN (AND SUNAI OR PARKIN AND/OR SOUKUP)

108. In my opinion, Claims 1-20 are obvious over the prior art. Specifically:

- a. Claims 1 and 8 are obvious over Bowen alone or in view of Soukup;
- b. Claims 2-6 and 9-20 are obvious over Bowen in view of Soukup; and

c. Claim 7 is obvious over Bowen in view of Sunai or Parkin and optionally Soukup.

A. Claim 1: Obviousness Over Bowen Alone Or In View Of Soukup

1. Claim 1[preamble]: “A magnetoresistive device comprising a magnetic tunnel junction structure comprising a multi-layer material stack including:”

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 '909 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.

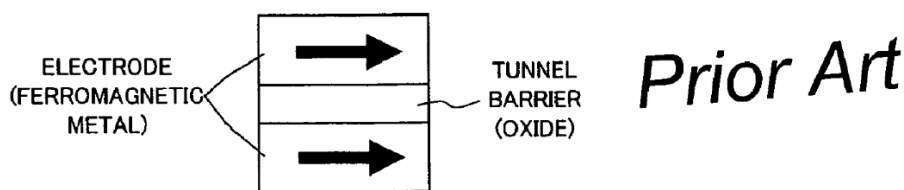
110. Bowen disclosed or suggested a magnetoresistive device having a tunnel barrier structure, as recited in this claim. Bowen taught an MTJ with a tunnel barrier layer and two ferromagnetic layers, as I explain for Claims 1[a]-1[c]. *See* Sections XII.A.2-XII.A.4 of this Declaration.

111. Bowen explained that: “The magnetoresistance of magnetic tunnel junctions (MTJs) is of uncontested interest for important applications with, in particular, promising perspectives for the fabrication on nonvolatile memories (Magnetic RAM).” EX1026 (Bowen) at page 1655; *id.* at Abstract, page 1655 (discussing FeCo/MgO/Fe epitaxial structure), Fig. 1.

112. In addition, magnetic tunnel junctions (MTJs), including those with a three-layer MTJ structure, were well known in the art.

113. This is evident from the '909 Patent itself. EX1017 ('909 Patent) at Figs. 8(A)-8(B), cols. 1:51-2:9. For example, Figure 8(A) of the '909 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 material.” EX1017 ('909 Patent) at col. 1:54-58. The patent correctly identifies and labels this conventional MTJ design as “Prior Art”:

FIG. 8 (A)



EX1017 ('909 Patent) at Fig. 8(A) (“Prior Art” legend in original).

114. Similarly, Tehrani described a “[t]ypical MTJ material stack” like that shown in the prior art. EX1039 (Tehrani) at page 2816, Fig. 5. Tehrani’s Figure 5 showed an “MTJ Material Structure” with layers of materials including the seed and contact layers, and ferromagnetic electrodes sandwiching an aluminum oxide barrier layer. EX1039 (Tehrani) at page 2816, Fig. 5.

115. IP Bridge itself also described MTJ material layers by stating: “[t]he MTJ... comprises a stack that includes multiple materials and multiple layers, which is a multi-layer material stack.” EX1071 ('909 claim chart) at page 3 (Claim chart

in IP Bridge's amended complaint: asserting that the WD Accused Products comprise an MTJ, including a layered stack).

2. Claim 1[a]: “first and second ferromagnetic material layer; and”

116. Bowen taught or suggested Claim 1[a].

117. Claim 1[a]'s “ferromagnetic material layer” refers to an electrode made of a “ferromagnetic metal.” EX1017 ('909 Patent) at col. 1:54-58, Fig. 8(a). As specified in Claim 1[b], “first” indicates the “lower” ferromagnetic material layer beneath the tunnel barrier layer, and “second” indicates the “upper” ferromagnetic material layer above the tunnel barrier layer.

118. Bowen's lower Fe electrode satisfied this claim limitation. Bowen taught growing “FeCo/MgO/*Fe* epitaxial structures” on a substrate. EX1026 (Bowen) at page 1655 (emphasis added); *see also* EX1026 (Bowen) at Abstract, Fig. 1. Bowen described his lower electrode “Fe(200 Å)” of its “Fe(200 Å)/MgO(20 Å)/FeCo(250 Å) trilayer” as the “first” ferromagnetic material layer. EX1026 (Bowen) at pages 1655-56. Bowen taught that its “Fe bottom electrode” is formed on a first side of its MgO barrier layer. EX1026 (Bowen) at page 1655, Abstract, Fig. 1.

119. Bowen also disclosed a second, “top” FeCo ferromagnetic layer that met this claim limitation. Bowen acknowledges that MTJs use “ferromagnetic

electrodes.” EX1026 (Bowen) at page 1655. He says: “FeCo/MgO/Fe epitaxial structures were grown on GaAs(001) in a combined sputtering/laser ablation system” and explains that the FeCo layer is the “top electrode” and is thus formed above the MgO barrier layer. EX1026 (Bowen) at page 1655; *id.* at Abstract, Fig. 1.

120. Bowen shows these three layers in Figure 1 below:

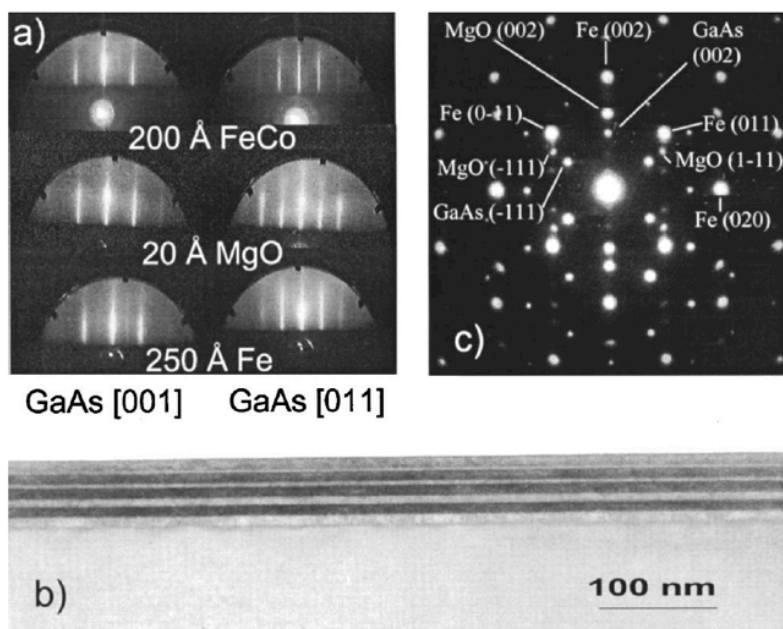


FIG. 1. (a) RHEED patterns along the GaAs [100] and [110] substrate azimuths of a typical FeCo/MgO/Fe epitaxial structure; (b) cross section TEM image of a Fe/MgO(001) multilayer with gradually decreasing MgO layer thickness; (c) TEM electron diffraction pattern.

EX1026 (Bowen) at Fig. 1(annotated).

121. Iron (Fe) is a ferromagnetic material. EX1030 (Sunai) ¶33 (“[F]erromagnetic materials” include “Fe, Co, Ni, and alloys containing them.”); EX1057 (Dieny textbook) at page 3 (“The ferromagnetic transition metals, such as Fe, Co, Ni, and their alloys... are the key compounds in today’s spintronic

devices....”); *id.* at page 2 (Fe and Co are “magnetic materials.”). The ’909 Patent agrees. EX1017 (’909 Patent) at col. 6:26-27 (“Fe(001) refers to a ferromagnetic material....”).

122. Iron cobalt (FeCo) was also a well-known ferromagnetic material. EX1030 (Sunai) ¶33 (“[F]erromagnetic materials” include “Fe, Co, Ni, and alloys containing them.”); EX1057 (Dieny textbook) at page 3 (“The ferromagnetic transition metals, such as Fe, Co, Ni, and their alloys... are the key compounds in today’s spintronic devices....”); *id.* at page 2 (Fe and Co are “magnetic materials.”).

123. MTJs containing two ferromagnetic layers were conventional by 2004, as the ’909 Patent acknowledges. EX1017 (’909 Patent) at col. 1:54-58 (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”).

3. **Claim 1[b]: “a tunnel barrier layer between the first and second ferromagnetic material layers such that the tunnel barrier layer is above the first ferromagnetic material layer and below the second ferromagnetic material layer,”**

124. This claim limitation is disclosed or suggested by Bowen.

125. Claim 1[b]’s “tunnel barrier layer” refers to “an oxide [that] is sandwiched between a first and a second electrode made of a ferromagnetic metal.” EX1017 (’909 Patent) at col. 1:54-58.

126. Bowen taught that its tunnel barrier layer was MgO. Bowen explained: “We present tunneling experiments on Fe(001)/MgO (20 Å)/FeCo(001) single-crystal epitaxial junctions of high quality grown by sputtering and laser ablation.” EX1026 (Bowen) at Abstract; *id.* at page 1655 (“Fe(001)/MgO(001)/FeCo(001) epitaxial tunnel junctions”). Bowen’s “MgO barrier is grown at 400 °C in order to obtain good crystallinity.” EX1026 (Bowen) at page 1655, Fig. 1.

127. Bowen taught that its “Fe bottom electrode” is formed on a first side of its MgO barrier layer. EX1026 (Bowen) at page 1655, Abstract, Fig. 1. It also explained that the FeCo layer is the “top electrode” and thus formed on a second side of the MgO barrier layer. EX1026 (Bowen) at page 1655; *id.* at Abstract, Fig. 1. Thus, Bowen’s tunnel barrier layer was located in between the first and second ferromagnetic material layers. EX1026 (Bowen) at Abstract (describing its MTJ as an “Fe(001)/MgO (20 Å)/FeCo(001) single-crystal epitaxial junction[.]”); *id.* at page 1656 (describing an “Fe(200 Å)/MgO(20 Å)/FeCo(250 Å) trilayer”). Because Bowen’s tunnel barrier was located “between” the first and the second ferromagnetic electrode, this means one of skill would have understood that Bowen’s tunnel barrier

layer was located above the first ferromagnetic electrode and below the second ferromagnetic electrode, as shown for example in Bowen's Figure 1.

128. MTJs containing barrier layers, including barrier layers located between two ferromagnetic layers, were conventional by 2004, as the '909 Patent acknowledges. EX1017 ('909 Patent) at col. 1:54-58 (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]: "wherein said tunnel barrier layer comprises crystalline MgO_x (001) with oxygen vacancy defects and ($0 < x < 1$)."

129. This claim limitation is taught or suggested by either (1) Bowen alone or (2) Bowen in view of Soukup.

a) Crystalline $\text{MgO}(001)$

130. As I explained for Claim 1[b] in Section XII.A.3 of this Declaration, Bowen disclosed an $\text{MgO}(001)$ tunnel barrier layer. EX1026 (Bowen) at Abstract, page 1655. Bowen deposited a single-crystal $\text{MgO}(001)$ tunnel barrier layer epitaxially:

A test of these models can be performed on *single-crystal* epitaxially grown structures.... In this letter, we present experimental results showing large TMR values in Fe(001)/**MgO(001)**/FeCo(001) epitaxial tunnel junctions.

EX1026 (Bowen) at page 1655 (emphases added); EX1026 (Bowen) at Abstract (“We present tunneling experiments on Fe(001)/**MgO**(20 Å)/FeCo(001) *single-crystal* epitaxial junctions of high quality....” (emphases added)). Bowen’s explanation that he epitaxially grew a “single-crystal” MTJ confirms that the MgO barrier layer was also single-crystalline MgO. EX1026 (Bowen) at Abstract, page 1655. His reference to MgO(001) refers to the (001) crystalline plane. EX1026 (Bowen) at Abstract, page 1655.

b) Oxygen vacancy defects

131. Obviousness over Bowen. Bowen also taught 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”).

132. The '909 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.” EX1017 ('909 Patent) at col. 6:39-46. It explains that when fabricating the MTJ, “there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).” EX1017 ('909 Patent) at col. 7:18-19. The '909 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.

133. 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.

134. 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.

135. Obviousness over Bowen and Soukup. This limitation was also taught or suggested by Bowen in view of Soukup. As discussed in the preceding Paragraph 134, 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” of 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.

136. For the reasons I provided for Claim 5 in Section XII.E.1 of this Declaration, a skilled artisan would have been motivated to apply Soukup's teachings about 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 tunneling and 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 tunneling and TMR. EX1028 (Soukup) at page 3232.

B. Claim 2: Obviousness Over Bowen In View Of Soukup

1. Claim 2: "The magnetoresistive device of claim 1, wherein $0.9 < x < 1$."

137. As I explained in Section XII.A of this Declaration, Claim 1 is obvious over Bowen alone or in view of Soukup. Claim 2 depends from Claim 1, and thus incorporates all of Claim 1's requirements. Claim 2 is obvious over Bowen in view of Soukup.

138. The claimed MgO_x oxygen vacancy defect range of $0.9 < x < 1$ was also inherent to Bowen's and Soukup's MgO barrier layers for the same reasons that I explained for Claim 1[c] in Section XII.A.4 of this Declaration. Indeed, as I explained above in Paragraphs 74-75 and 133 of this Declaration, oxygen vacancy defects were understood to be inherent to MgO_x layers where $0 < x < 1$. One of skill

would understand that the claimed range of $0.9 < x < 1$ is a subrange of the oxygen vacancy defects inherent to Bowen's and Soukup's MgO barrier layers. Because $0.9 < x < 1$ is a subrange of $0 < x < 1$, it necessarily overlaps with $0 < x < 1$.

139. Claim 2 is also obvious because the general conditions for fabricating an MTJ with the claimed MgO barrier layer oxygen vacancy range of $0.9 < x < 1$ were already disclosed in the prior art. For example, Castanier studied oxygen vacancies for “non-stoichiometric MgO{100} surfaces, with several densities of neutral oxygen vacancies” studied. EX1037 (Castanier) at Abstract. They modeled oxygen vacancies down to a 1/18 density as shown in the image below, which would correspond to MgO_x with x approximately equal to 0.944, within the claimed range. EX1037 (Castanier) at page 3, Fig. 1. Others in the field at the time of the 2004 priority date would have been both motivated and able to obtain MgO barrier layer oxygen vacancy defects in this range through routine optimization.

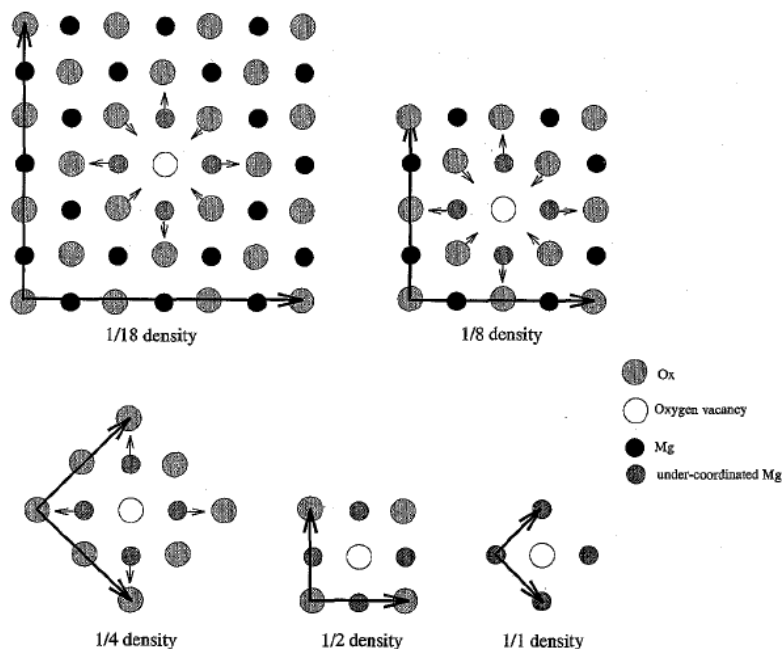


Fig. 1. Surface cells for sub-stoichiometric MgO{100} surfaces with various densities of oxygen vacancies. The magnesiums located close to a vacancy are specified and an arrow indicates their displacement in the surface plane.

EX1037 (Castanier) at Fig. 1.

140. The claimed invention of the '909 Patent is directed to an MTJ device that produced a high TMR. EX1017 ('909 Patent) at cols. 1:37-40, 3:2-4, 5:10-16 (disclosing the equation for determining the “magnetoresistance (MR) ratio of a MTJ device”). Others in the field at the time of the 2004 priority date of the '909 Patent were also interested in increasing the TMR. Increasing the TMR was an obvious improvement to MgO MTJs. As I explain in Sections VII.C and XII.E of this Declaration, increasing TMR was a prerequisite to improving MRAM performance to obtain smaller, denser devices. As Bowen explained, researchers long sought to optimize TMRs to improve MRAM:

magnetoresistance of magnetic tunnel junctions (MTJs) is of uncontested interest for important applications with, in particular, promising perspectives for the fabrication of nonvolatile memories (Magnetic RAM).

EX1026 (Bowen) at page 1655.

141. In 2001, both Butler and another group led by Mathon each calculated very high TMRs for MgO MTJs due to symmetry matching between the MgO and Fe layers. EX1044 (Butler) at Fig. 16; EX1046 (Mathon) at Abstract, page 1 (optimistic TMR “in excess of 1000%” for an MgO barrier). The close match of the crystalline symmetry between MgO and Fe facilitated tunneling of parallel electrons compared to antiparallel electrons, opening the door to these very high TMRs. EX1044 (Butler) at page 1; EX1046 (Mathon) at page 1.

142. After Butler and Mathon announced their findings of four-figure TMRs for MgO MTJs, many researchers sought to experimentally validate their results. The '909 Patent itself acknowledged that existing MTJ devices with aluminum oxide barriers had already achieved an “MR ratio of approximately 70%.” EX1017 ('909 Patent) at col. 5:32-38; *see also* EX1017 ('909 Patent) at col. 2:61-63. Indeed, before the '909 Patent in 2004, other researchers had observed TMRs exceeding 70% in MTJs with MgO barriers. EX1027 (Nagahama) ¶74 (disclosing “a larger tunnel

magnetoresistive effect of more than 90%"); EX1052 (Faure-Vincent) at Abstract (reporting TMR of 100% in an Fe/MgO/Fe/Co tunnel junction).

143. Bowen cited research by Butler calculating a high TMR for MgO MTJs like Bowen's. Bowen stated: "TMR values calculated by Butler *et al.* are much higher (2000% for 20 Å MgO) than our experimental value of 60%...." EX1026 (Bowen) at page 1657. Bowen reported a TMR of 60% for an MgO MTJ and expressed his intent to "aim to confirm the predicted relative increase of the TMR" in "future experiments." EX1026 (Bowen) at page 1657. Thus, Bowen itself expressly provided a motivation for one of skill in the art to increase the TMR of his MTJ. EX1026 (Bowen) at page 1657. As I also explain for Claim 5 in Section XII.E of this Declaration, one of skill in the art would have found it obvious to do exactly that.

144. Others in the field before 2004 were already aware of the general MTJ conditions for fabricating MgO barrier layers that could result in the claimed MgO_x wherein 0.9<x<1. For example, Bowen hypothesized that his observed decrease in MgO barrier height was due to oxygen vacancy defects. EX1026 (Bowen) at page 1656. Soukup examined the "effect of nonstoichiometry on the device characteristics," EX1028 (Soukup) at page 3232, and experimented with devices fabricated with different levels of nonstoichiometry, EX1028 (Soukup) at Abstract, pages 3232-33, Table I. Bowen's and Soukup's MgO barrier layer fabrication

methodologies were consistent with the fabrication methods disclosed for the '909 Patent's two MTJ device embodiments.

145. The '909 Patent's first embodiment is identified as the "Fe(001)/MgO(001)/Fe(001) MTJ device." EX1017 ('909 Patent) at col. 6:19-26. The disclosure explains that the fabrication schematics are illustrated in Figures 2(A) through 2(D). EX1017 ('909 Patent) at col. 6:22-26. The first step of the fabrication method includes growing an "MgO(001) seed layer 15" onto the "single-crystal MgO(001) substrate 11" using "molecular beam epitaxy (MBE)." EX1017 ('909 Patent) at col. 6:27-31, Fig. 2(A). Then the "epitaxial Fe(001) lower electrode (first electrode) 17" is grown on top of the "MgO(001) seed layer 15." EX1017 ('909 Patent) at col. 6:31-34, Fig. 2(B). The "MgO(001) barrier layer 21" was then "epitaxially grown on the Fe(001) lower electrode (first electrode) at room temperature" using "the MgO electron-beam evaporation method." EX1017 ('909 Patent) at col. 6:50-54, Fig. 2(C). Finally, the "Fe(001) upper electrode (a second electrode) 23" was then "formed on the MgO(001) barrier layer 21" followed by deposition of the "Co layer 25" on top of the "Fe(001) upper electrode (second electrode) 23." EX1017 ('909 Patent) at col. 6:57-62.

146. Focusing specifically on the fabrication of the MgO barrier layer of this first embodiment, the '909 Patent discloses the following:

The source material of the electron-beam evaporation was MgO of the stoichiometric composition (the ratio of Mg to O being 1:1), the distance between the source and the substrate was 40 cm, the base vacuum pressure was 1×10^{-8} Pa, and the O₂ partial pressure was 1×10^{-6} Pa. Alternatively, a source with oxygen vacancy defects may be used instead of the MgO of the stoichiometric composition (the ratio of Mg to O being 1:1).

EX1017 ('909 Patent) at col. 6:39-46. One of skill would understand that “vacuum pressure” refers to pressure that is less than atmospheric pressure. It would also be understood that “O₂ partial pressure” refers to the pressure attributable to O₂ gas in the deposition chamber in relation to the total pressure attributable from all the gas in the deposition chamber. The '909 Patent goes on to disclose that “MgO evaporation using an electron beam involved the formation of a film under ultrahigh vacuum of 10^{-9} Torr.” EX1017 ('909 Patent) at col. 7:1-3. One of skill would understand that 10^{-9} Torr converts to 1.3×10^{-7} Pa (1 Torr equals 133.3 Pascals).

147. The '909 Patent discloses that this first MTJ device embodiment produced a TMR value of 88% at room temperature, as illustrated in Figure 6. EX1017 ('909 Patent) at col. 8:15-19, Fig. 6.

148. Regarding oxygen vacancy defects in the MgO barrier layer of the first MTJ device embodiment, the '909 Patent discloses the following related to data provided in its Figure 5:

These results indicate the separation of oxygen from MgO during the deposition of MgO. Since the separated oxygen is pumped out of the deposition chamber using vacuum pumps, there is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).

EX1017 ('909 Patent) at col. 7:14-19. These purported results are consistent with the understanding at the time that MgO layers inherently had oxygen vacancy defects. Specifically, despite depositing the “MgO(001) barrier layer 21” using “stoichiometric MgO,” oxygen vacancy defects were still expected to exist in this layer.

149. The '909 Patent also discloses a second MTJ device embodiment, which is also referred to as an “Fe(001)/MgO(001)/Fe(001) MTJ device.” EX1017 ('909 Patent) at col. 8:53-57. There are no disclosures of any TMR values or quantification of any oxygen vacancy defects of the MgO barrier layer for this second embodiment. *See generally* EX1017 ('909 Patent). Additionally, the '909 Patent only provides fabrication details for the MgO layer, presumably the barrier layer, disclosing that “MgO(001) is initially deposited in a poly-crystalline or amorphous state by sputtering or the like, and then an annealing process is performed such that a poly-crystal in which the (001) crystal plane is preferentially oriented or a single-crystal is obtained.” EX1017 ('909 Patent) at col. 8:57-61. The '909 Patent goes on to explain that “sputtering was conducted in an Ar atmosphere” at “room

temperature,” and the temperature was increased to “300° C” to “crystalize[]” the “amorphous” MgO. EX1017 (’909 Patent) at cols. 8:62-9:3.

150. One of skill would appreciate that “Ar atmosphere” referred to argon gas, and that this disclosure implied that deposition occurred in the absence of oxygen. According to this disclosure, one of skill would also understand that the vacuum pressure is “on the order of no more than 10^{-6} Pa” because “oxygen is not introduced.” EX1017 (’909 Patent) at col. 9:48-52. “[O]n the order of” is understood to mean an order of magnitude. For example, within an order of magnitude of 10^{-6} Pa (also written as 1×10^{-6} Pa or 0.000001 Pa), would include a pressure of 9×10^{-6} Pa (also written as 0.000009 Pa). Likewise, the ’909 Patent discloses that the vacuum pressures “where oxygen is introduced” are on the “order of 10^{-4} Pa” (also written 1×10^{-4} Pa or 0.0001 Pa), indicating that other pressure values within the ten-thousandths place or smaller, would be acceptable. EX1017 (’909 Patent) at col. 9:48-52.

151. Bowen’s and Soukup’s general fabrication methods were comparable to those disclosed in the ’909 Patent. According to the ’909 Patent’s disclosure, “while the MgO layer has been described to be deposited by electron-beam evaporation or sputtering, it should be obvious that other deposition methods are also possible.” EX1017 (’909 Patent) at col. 9:45-48. Indeed, the ’909 Patent does not

attribute or highlight anything about its disclosed fabrication methods that are inventive or unexpectedly leading to higher-than-expected performance.

152. Bowen's MgO barrier layer was fabricated using sputtering, which is the same methodology used to fabricate the '909 Patent's MTJ device of the second embodiment. Bowen describes fabricating its "FeCo/MgO/Fe epitaxial structures... in a combined sputtering/laser ablation system with a base pressure of 2×10^{-9} mbar," wherein the MgO layer is deposited at "400 °C." EX1026 (Bowen) at page 1655. One of skill would understand that 2×10^{-9} mbar converts to 2×10^{-7} Pa (1 mbar equals 100 Pa). One of skill would also understand that 2×10^{-7} is the same number as 0.2×10^{-6} . While Bowen does not disclose the gas composition used during deposition, the vacuum pressure is acceptable according to the '909 Patent's disclosure whether or not oxygen is present. EX1017 ('909 Patent) at col. 9:48-52.

153. Soukup's fabrication method is the same method the '909 Patent discloses using for its first MTJ device embodiment. Soukup discloses fabricating the MgO barrier layer using evaporation at a vacuum pressure of " 10^{-8} Torr," wherein the substrates were heated to "400°C." EX1028 (Soukup) at page 3230. 10^{-8} Torr converts to 1.33×10^{-6} Pa, which is also within the acceptable "ultrahigh" vacuum pressures the '909 Patent discloses whether or not oxygen is present. EX1017 ('909 Patent) at col. 9:48-52. Specifically, Soukup describes using an

electron beam as indicated by his explanation that the “thickness of the films were determined by precalibrating deposition rate vs electron beam power using a quartz crystal monitor.” EX1028 (Soukup) at page 3230.

154. As the disclosed general MgO barrier layer fabrication conditions were understood by others in the field by 2004, a skilled artisan would readily optimize oxygen vacancy defects through experimentation to determine the level of oxygen vacancy defects that produced the best result. And a skilled artisan would have known that the claimed $0.9 < x < 1$ range, overlapping with $0 < x < 1$, was within the zone of potential oxygen vacancy defects to be considered. As I explained previously, both Bowen and Soukup indicated that oxygen vacancy defects in their respective MgO barrier layers likely impacted their calculated barrier heights. EX1026 (Bowen) at page 1656; EX1028 (Soukup) at Abstract, page 3232. Despite not quantifying these defects, as I explained for Claim 1[c] in Section XII.A.4, one of skill would understand that Bowen’s and Soukup’s MgO barrier layers inherently had oxygen vacancy defects in their MgO_x layers wherein $0 < x < 1$. Others in the field by 2004 were also interested in reducing the height of the barrier layer to achieve higher TMR values. EX1044 (Butler) at page 1; EX1046 (Mathon) at page 1. One of skill would have been motivated to optimize MgO barrier layers during MTJ fabrication by optimizing oxygen vacancy defects through experimentation because it was understood that these defects impacted barrier height and thus also affected

TMR values. Oxygen vacancy defects in the MgO barrier layer had an understood relationship to TMR within the grasp of one of skill by the time of the '909 Patent's priority date.

155. In further support, the '909 Patent also did not disclose that the oxygen vacancy defects in the claimed range of $0.9 < x < 1$ had an unexpected or novel impact on its MTJ devices of the claimed invention. The '909 Patent explains that oxygen vacancy defects could be introduced using several methods and did not indicate any were particular or critical to the object of the invention:

Oxygen vacancy defects may be introduced by a method whereby oxygen vacancy defects is [sic] produced during growth, a method whereby oxygen vacancy defects is introduced subsequently, or a method whereby a state with oxygen vacancy defects is subjected to an oxygen plasma process or natural oxidation so as to achieve a certain oxygen deficit level.

EX1017 ('909 Patent) at col. 9:4-10.

156. Additional disclosure in the '909 Patent further supports the conclusion that the $0.9 < x < 1$ claimed range is not critical. When referring to the purported oxygen vacancy defects measured for its first MTJ device embodiment, the patent appears to speculate:

Since the separated oxygen is pumped out of the deposition chamber using vacuum pumps, there is the *possibility* that there are oxygen

vacancy defects *such as* MgO_x ($0.9 < x < 1$). When there are oxygen vacancy defects, the potential barrier height of the MgO tunnel barrier is thought to decrease (such as in the range of 0.10 to 0.85 eV; more specifically, 0.2 to 0.5 eV), which is thought to result in an increase in the tunneling current.

EX1017 ('909 Patent) at col. 7:16-23 (emphases added). One of skill would understand from this disclosure that this oxygen vacancy defect range was more of an estimate, not an accurate quantification.

157. Soukup's barrier height of 0.33 eV was within the range disclosed by the '909 Patent as indicative of "oxygen vacancy defects." EX1028 (Soukup) at Abstract; EX1017 ('909 Patent) at col. 7:19-23. One of skill would understand from the '909 Patent that Soukup's barrier height of 0.33 eV indicated that Soukup's MgO barrier layer had the preferred oxygen vacancy defect ranges disclosed by the '909 Patent, according to the '909 Patent's own teachings.

158. The '909 Patent's specification also explains that there are ways to impact barrier height other than introducing oxygen vacancy defects in the MgO barrier layer. Specifically, that "the height of the tunnel barrier may be adjusted by doping Ca or Sr, *instead* of introducing an [sic] oxygen vacancy defects to the MgO layer." EX1017 ('909 Patent) at col. 9:42-45 (emphasis added). By disclosing other approaches to manipulating the barrier height, one of skill would also understand

that introducing MgO barrier layer oxygen vacancy defects was not the only way to achieve the object of the invention.

C. Claim 3: Obviousness Over Bowen In View Of Soukup

1. Claim 3: “The magnetoresistive device of claim 2, wherein $0.98 < x < 1$.”

159. As I explained previously in Section XII.B of this Declaration, Claim 2 was disclosed or suggested by Bowen in view of Soukup. Claim 3 depends from Claim 2 and thus incorporates all of Claim 2’s requirements. Claim 3 is also obvious over Bowen in view of Soukup.

160. For the same reasons I explained previously for Claims 1 and 2 in Sections XII.A and XII.B of this Declaration, Claim 3’s MgO_x oxygen vacancy defect range of $0.98 < x < 1$ is obvious because it overlaps with the $0 < x < 1$ range inherent in Bowen and Soukup, because oxygen vacancy defects in the MgO barrier layer had an understood relationship to TMR, and because even this narrower range is inherent in Soukup based on Soukup’s 0.33 eV barrier height.

161. For the same reasons I explained previously for Claim 2 in Section XII.B of this Declaration, Claim 3’s MgO_x oxygen vacancy defect range of $0.98 < x < 1$ is also speculative. The only reference to this range in the ’909 Patent is a general reference to the fabrication method of the first MTJ device embodiment, which discloses the “possibility” of having oxygen vacancy defects within the range of “ $(0.9 < x < 1)$ ”: “Using the method according to the present embodiment of the

invention.... [t]he value of x in the MgO_x due to oxygen vacancy defects is such that **$0.98 < x < 1$** , and more preferably $0.99 < x < 1$.” EX1017 ('909 Patent) at cols. 7:16-19, 7:29-36 (emphasis added). This disclosure is not in reference to any disclosed experimental result, and is a speculative range based on an already speculative range of $0.9 < x < 1$.

D. Claim 4: Obviousness Over Bowen In View Of Soukup

1. Claim 4: “The magnetoresistive device of claim 3, wherein $0.99 < x < 1$.”

162. As I explained previously in Section XII.C of this Declaration, Claim 3 was disclosed or suggested by Bowen in view of Soukup. Claim 4 depends from Claim 3 and thus incorporates all of Claim 3’s requirements. Claim 4 is also obvious over Bowen in view of Soukup.

163. For the same reasons I explained previously for Claims 1, 2, and 3 in Sections XII.A, XII.B, and XII.C of this Declaration, Claim 4’s MgO_x oxygen vacancy defect range of $0.99 < x < 1$ was obvious because it overlaps with the $0 < x < 1$ range inherent in Bowen and Soukup, because oxygen vacancy defects in the MgO barrier layer had an understood relationship to TMR, and because even this narrower range is inherent in Soukup based on Soukup’s 0.33 eV barrier height.

164. For the same reasons I explained previously for Claim 3 in Section XII.C of this Declaration, Claim 4’s MgO_x oxygen vacancy defect range of $0.99 < x < 1$ was both inherent and speculative.

E. Claim 5: Obviousness Over Bowen In View Of Soukup

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

165. As I explained in Section XII.A of this Declaration, Claim 1 is obvious over Bowen alone or in view of Soukup. Claim 5 depends from Claim 1, and thus incorporates all of Claim 1’s requirements. Claim 5 is obvious over Bowen in view of Soukup as explained in the following paragraphs.

166. Bowen in view of Soukup taught or suggested a tunnel barrier height between 0.1 to 0.85 eV. As I explained previously in Section VII.D of this Declaration, the tunnel barrier height measures the difference between the Fermi level of the electrode and the bottom of the conduction band of the barrier layer.

167. 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 ’909 Patent’s disclosed range of 0.1 to 0.85 eV. EX1028 (Soukup) at Abstract, pages 3231-32, Fig. 5, Table I; EX1017 (’909 Patent) at col. 7:19-23 (“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.”).

168. 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.

169. A skilled artisan would have had a motivation to take Soukup’s teachings about 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 (Moodera 1995) at page 3273; EX1027 (Nagahama) ¶2; EX1017 (’909 Patent) at col. 5:8-16 (TMR equation); EX1057 (Dieny textbook) at page 13.

170. 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.

171. 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 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 '909 Patent. EX1017 ('909 Patent) at Abstract, cols. 1:37-2:39. 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.

172. A skilled artisan also would have had a reasonable expectation of success in applying Soukup's teachings to Bowen to achieve a tunnel barrier height in the range of 0.1 to 0.85 eV. 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 been motivated to use a barrier height with the same or similar height in an MgO MTJ to improve tunneling and hence TMR in Bowen.

173. The claimed tunnel barrier height range of 0.1 to 0.85 eV was obvious. As I explained above in Paragraphs 168-169 of this Declaration, a skilled artisan would have looked to Soukup's teachings to lower Bowen's calculated barrier height. The claimed upper limit of "0.85 eV" is only marginally lower than the "0.9 eV" barrier height disclosed by Bowen and others, and one of skill would have been motivated using Soukup to try to deposit an MgO barrier with a lower barrier height. EX1026 (Bowen) at page 1656 (citing EX1038); EX1038 (Moodera 1996) at pages

4725-26. One of skill applying Soukup's teachings to Bowen would have readily achieved lowering tunnel barrier height to be within the claimed range.

174. As I mentioned in Paragraph 168 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 (Klaue) 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 (Wulfhekel) at page 510 (observing "defects

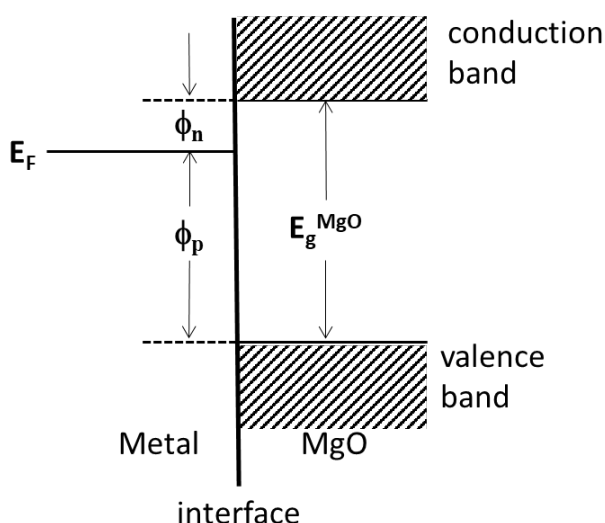
in the MgO barrier” and concluding that spikes in current are likely caused by “a lower tunneling barrier”).

175. According to the '909 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 0.1 to 0.85 eV...), which is thought to result in an increase in the tunneling current.” EX1017 ('909 Patent) at col. 7:19-23. Thus, the '909 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.

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

177. 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.

178. 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: $\phi_p + \phi_n = E_g^{MgO}$, 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.

179. 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 1.8 for Co 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.

180. In sum, Claim 5 was taught or suggested by Bowen in view of Soukup.

F. Claim 6: Obviousness Over Bowen In View Of Soukup

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

181. Claim 6’s requirement of a tunnel barrier height in “a range of 0.2 eV to 0.5 eV” overlaps with Claim 5’s tunnel barrier height in “a range of 0.1 eV to 0.85 eV.” Claim 6 is disclosed or suggested for at least the same reasons explained above for Claim 5. *Supra* §XII.E of this Declaration.

G. Claim 7: Obviousness Over Bowen In View Of Sunai or Parkin And Optionally Soukup

- 1. Claim 7: “The magnetoresistive device of claim 1, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Boron.”**

182. As I explained in Section XII.A of this Declaration, Claim 1 is obvious over Bowen alone or in view of Soukup. Claim 7 depends from Claim 1, and thus incorporates all of Claim 1’s requirements. Claim 7 is obvious over Bowen in view of Sunai or Parkin (and optionally Soukup).

183. Claim 7 does not specify the specific molecular composition or stoichiometry of the claimed “ferromagnetic material layer [that] comprises Boron.” EX1017 (’909 Patent) at col. 10:21-23. Thus, I was asked to assume that any ferromagnetic material layer that comprises Boron satisfies Claim 7. Further, a skilled artisan understood that CoFeB and FeCoB refer to the same alloy.

184. As I explained above for Claim 1[a] in Section XII.A.2 of this Declaration, Bowen taught or suggested a first Fe ferromagnetic layer and a second FeCo ferromagnetic layer.

185. Bowen in view of Sunai. It would have been obvious to replace Bowen's lower Fe electrode and/or upper FeCo electrode with a CoFeB ferromagnetic layer, as taught by Sunai, including to improve TMR. EX1030 (Sunai) ¶¶28 (teaching CoFeB electrode by adding B to Co₉Fe), 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.

186. To improve Bowen's MTJ, one of skill would have looked to Sunai's teachings. Bowen and Sunai both sought to improve the TMR of magnetoresistive devices, one of the problems the '909 Patent claimed to address. EX1026 (Bowen) at Abstract, page 1655; EX1030 (Sunai) at Abstract, ¶¶1, 10; EX1017 ('909 Patent) at Abstract, cols. 1:37-2:39. Like the '909 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; EX1017 ('909 Patent) at cols. 1:44-50, 2:45-49. Further, they both used an MgO barrier layer and ferromagnetic alloy electrodes. EX1026 (Bowen) at Abstract, page 1655; EX1030 (Sunai) ¶¶24, 35.

187. 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 (~35%) and larger H_f (~5-6 Oe) and H_c (~12-14 Oe) [compared to CoFeB-based junctions].”). CoFe was also known to increase TMR compared to Fe. EX1035 (Moodera 1995) 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.

188. Bowen aimed to increase the TMR in 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*.

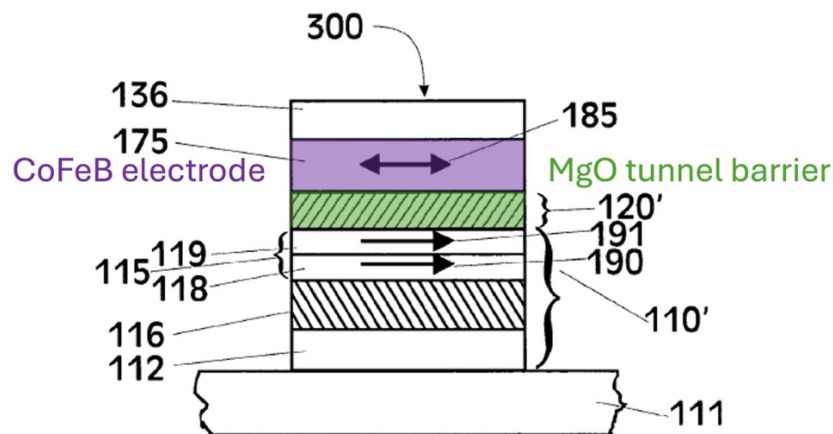
EX1026 (Bowen) at page 1657 (emphasis added). Because TMR was so important to optimizing MTJ design for commercial applications like MRAM, as I explained in detail in Section VII.C of this Declaration, Sunai's and other researchers' teachings about CoFeB would have provided a strong motivation to modify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

189. One of skill would have been motivated to replace either or both of Bowen's MTJ electrodes with a CoFeB electrode. 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 '909 Patent's priority date, a 1995 paper by Moodera taught 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.

190. Bowen in view of Parkin. Alternatively, in my opinion, Claim 7 is also taught or suggested by Bowen in view of Parkin. As shown in Figure 3A below, Parkin taught a ferromagnetic CoFeB layer. In particular, Parkin taught a “CoFeB layer 175” next to an “MgO crystalline layer 120’.” EX1062 (Parkin) at col. 19:16-17.



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

191. Parkin taught a CoFeB layer 175, EX1062 (Parkin) at col. 17:43-44, and explained that “a portion of the storage layer 175 adjacent to the MgO tunnel barrier 120’ has crystallized and is, moreover, textured in the same orientation as the crystalline MgO tunnel barrier.” EX1062 (Parkin) at col. 18:51-55; *see also id.* at col. 19:15-22. Parkin explained that the crystalline CoFeB 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. 19:19-22.

192. 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 ($R \times A \sim 500 \Omega \cdot \mu\text{m}^2$) have lower TMR ($\sim 35\%$) and larger H_f ($\sim 5\text{-}6$ Oe) and H_c ($\sim 12\text{-}14$ 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 used as an upper or lower electrode, or both.

193. To improve Bowen’s MTJ, one of skill would have looked to Parkin’s teachings. Both Bowen and Parkin sought to improve the TMR of magnetoresistive devices, a problem the ’909 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....”); EX1017 (’909 Patent) at Abstract, cols. 1:37-2:39. Like the ’909 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.”); EX1017 (’909 Patent) at col. 3:1-4. Additionally, they both used 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.”).

194. In sum, Claim 7 was taught or suggested by Bowen in view of Sunai or Parkin and optionally Soukup. Because CoFeB electrodes had already been used with MTJs, one of skill would have found it to be straightforward and predictable to replace Bowen’s lower and/or upper electrodes with CoFeB. Certainly 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 lower and/or upper electrodes with a CoFeB alloy was a straightforward and desirable improvement that would have predictably succeeded.

H. Claim 8: Obviousness Over Bowen Alone Or In View Of Soukup

- 1. Claim 8: “The magnetoresistive device of claim 1, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.”**

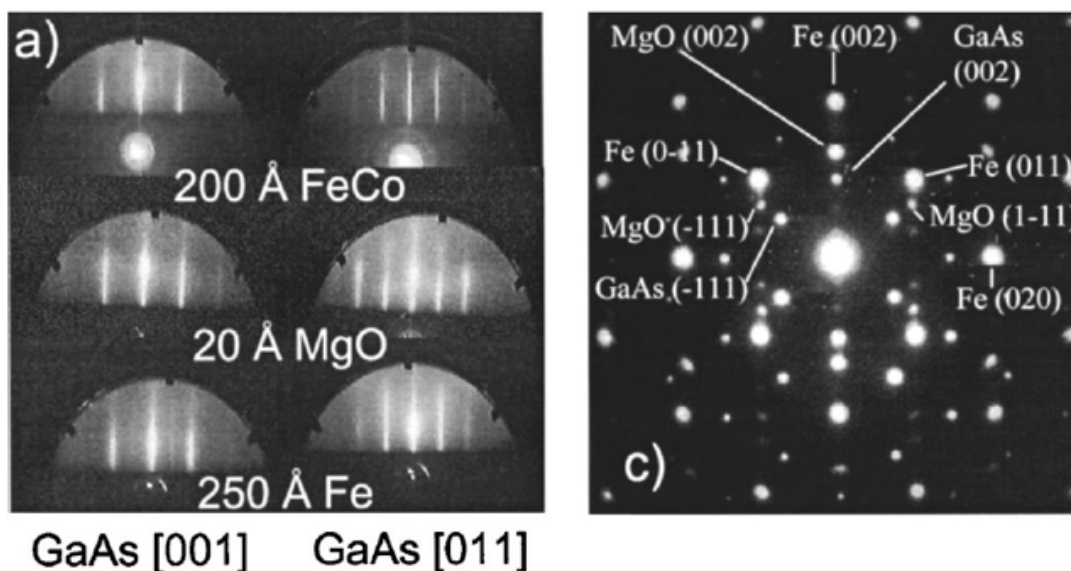
195. As I explained in Section XII.A of this Declaration, Claim 1 is obvious over Bowen alone or in view of Soukup. Claim 8 depends from Claim 1, and thus

incorporates all of Claim 1's requirements. Claim 8 is obvious over Bowen alone or in view of Soukup.

196. As I explained for Claim 1[a] in Section XII.A.2 of this Declaration, Bowen disclosed or suggested a first Fe ferromagnetic layer and a second FeCo ferromagnetic layer. EX1026 (Bowen) at Abstract, pages 1655-56.

197. Bowen's first Fe ferromagnetic layer and second FeCo ferromagnetic layer were crystallized. Bowen used TEM to analyze his MTJ and determined that the layers were "indicative of the crystallinity and high quality of the structure." EX1026 (Bowen) at page 1656; *see also* EX1026 (Bowen) at page 1655, Fig. 1.

198. Bowen's Fe and FeCo ferromagnetic layers were bcc structured, indicating a crystalline structure. As shown in Bowen's excerpted Figure 1 below, Bowen reported that his "*Fe₅₀Co₅₀ and Fe layers are bcc structured* with sharp diffraction lines for both azimuths," and the TEM electron diffraction patterns from the x-ray diffraction scans "*confirm that the whole structure is epitaxial* with lattice parameters close to bulk values":



EX1026 (Bowen) at page 1655 (emphases added), Fig. 1 (excerpted); *see also id.* at page 1656 (TEM images of Bowen’s MTJ layers were “indicative of the crystallinity and high quality of the structure.”).

199. As I explained in Section VII.E.1 of this Declaration, crystalline structures with metal atoms are broken up into three basic types of structures. BCC structured refers to a crystalline body-centered cubic lattice structure. EX1057 (Dieny textbook) at page 16 (“bcc stands for body-centered cubic, relative to the arrangement of the atoms in the crystal”). The ’909 Patent agrees. EX1017 (’909 Patent) at cols. 4:57-60 (“BCC structure” means “body-centered cubic lattice structure.”), 6:26-27 (“Fe(001) refers to a ferromagnetic material with the BCC structure.”).

200. Iron (Fe) and cobalt (Co) were known ferromagnetic materials. 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.

I. Claim 9: Obviousness Over Bowen In View Of Soukup

1. Claim 9[preamble]: “A magnetoresistive device comprising a magnetic tunnel junction structure comprising:”

201. As I explained above for Claim 1[preamble] in Section XII.A.1 of this Declaration, Bowen disclosed or suggested this limitation.

2. Claim 9[a]: “first and second ferromagnetic material layer; and”

202. As I explained above for Claim 1[a] in Section XII.A.2 of this Declaration, Bowen disclosed or suggested this limitation.

3. Claim 9[b]: “a tunnel barrier layer between the first and second ferromagnetic material layers,”

203. As I explained above for Claim 1[b] in Section XII.A.3 of this Declaration, Bowen disclosed or suggested this limitation.

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

204. As I explained above for Claims 1[c] and 5 in Sections XII.A.4 and XII.E of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

J. Claim 10: Obviousness Over Bowen In View Of Soukup

1. **Claim 10: “The magnetoresistive device of claim 9, wherein the tunnel barrier layer comprises partially or fully crystalline magnesium oxide.”**

205. As I explained above in Section XII.I of this Declaration, Claim 9 was disclosed or suggested by Bowen in view of Soukup. Claim 10 depends from Claim 9 and thus incorporates all of Claim 9’s requirements. Claim 10 is also obvious over Bowen in view of Soukup.

206. As I explained above for Claim 1[c] in Section XII.A.2 of this Declaration, Bowen disclosed fabricating a single-crystal MgO(001) tunnel barrier layer. Bowen also experimentally confirmed “the crystallinity and high quality” of his MgO (001) tunnel barrier layer. EX1026 (Bowen) at page 1656, Fig. 1. Thus, Bowen’s MgO tunnel barrier layer was partially or fully crystallized as required by Claim 10.

K. Claim 11: Obviousness Over Bowen In View Of Soukup

1. **Claim 11: “The magnetoresistive device of claim 10, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.”**

207. As I explained above for Claims 8 and 10 in Sections XII.H and XII.J of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

L. Claim 12: Obviousness Over Bowen In View Of Soukup

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

208. As I explained above for Claims 6 and 11 in Sections XII.F and XII.K of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

M. Claim 13: Obviousness Over Bowen In View Of Soukup

1. **Claim 13: “The magnetoresistive device of claim 11, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer exhibits a body-centered cubic (BCC) structure.”**

209. As I explained in Section XII.K of this Declaration, Claim 11 was disclosed or suggested by Bowen in view of Soukup. Claim 13 depends from Claim 11 and thus incorporates all of Claim 11’s requirements. Claim 13 is also obvious over Bowen in view of Soukup.

210. As I first explained for Claim 1[a] in Section XII.A.2, Bowen’s first and second ferromagnetic material layers were Fe and FeCo, respectively.

211. Bowen's first and second ferromagnetic material layers also "exhibit[] a body-centered cubic (BCC) structure" as required by Claim 13. As I previously explained for Claim 8 in Section XII.K, Bowen's x-ray diffraction studies indicated his "Fe₅₀Co₅₀ and Fe layers are *bcc structured*," EX1026 (Bowen) at page 1655 (emphasis added), Fig. 1.

212. As I also explained in Section VII.E.1 of this Declaration, BCC structured refers to a crystalline body-centered cubic lattice structure. EX1057 (Dieny textbook) at page 16 ("bcc stands for body-centered cubic, relative to the arrangement of the atoms in the crystal." The '909 Patent agrees. EX1017 ('909 Patent) at cols. 4:57-60 ("BCC structure" means "body-centered cubic lattice structure."), 6:26-27 ("Fe(001) refers to a ferromagnetic material with the BCC structure.").

N. Claim 14: Obviousness Over Bowen In View Of Soukup

1. Claim 14: "The magnetoresistive device of claim 11, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Cobalt and Iron."

213. As I explained in Section XII.K of this Declaration, Claim 11 was disclosed or suggested by Bowen in view of Soukup. Claim 14 depends from Claim 11 and thus incorporates all of Claim 11's requirements. Claim 14 is also obvious over Bowen in view of Soukup.

214. As I first explained for Claim 1[a] in Section XII.A.2, Bowen disclosed a “second ferromagnetic material layer” made of iron and cobalt, or FeCo, which Bowen referred to as his “FeCo top electrode.” EX1026 (Bowen) at Abstract, 1655.

O. Claim 15: Obviousness Over Bowen In View Of Soukup

1. Claim 15[preamble]: “A magnetoresistive device comprising:”

215. As I explained above for Claim 1[preamble] in Section XII.A.1 of this Declaration, Bowen disclosed or suggested this limitation.

2. Claim 15[a]: “a first ferromagnetic material layer;”

216. As I explained above for Claim 1[a] in Section XII.A.2 of this Declaration, Bowen disclosed or suggested this limitation.

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

217. As I explained above for Claims 1[c] and 6 in Sections XII.A.4 and XII.F of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

4. Claim 15[c]: “a second ferromagnetic material layer disposed on the tunnel barrier layer and separated from the first ferromagnetic material layer by the tunnel barrier layer.”

218. As I explained above for Claims 1[a]-1[b] in Sections XII.A.2-XII.A.3 of this Declaration, Bowen disclosed or suggested this limitation.

219. As I explained for Claim 1[b] in Section XII.A.3 of this Declaration, Claim 1[b]’s “tunnel barrier layer” refers to “an oxide [that] is sandwiched between a first and a second electrode made of a ferromagnetic metal.” EX1017 (’909 Patent) at col. 1:54-58. According to the ’909 Patent, “first ferromagnetic material layer” refers to the “lower” ferromagnetic electrode that is below the tunnel barrier layer, and the “second ferromagnetic material layer” refers to the “upper” ferromagnetic electrode located above the tunnel barrier layer. EX1017 (’909 Patent) at Abstract.

220. Bowen disclosed a second, upper or “top” FeCo ferromagnetic layer that met this claim limitation. Bowen described his MTJ was fabricated as follows: “**FeCo**/MgO/Fe epitaxial structures were grown on GaAs(001) in a combined sputtering/laser ablation system” and explains that the FeCo layer is the “top electrode” and is thus formed on the MgO barrier layer. EX1026 (Bowen) at page 1655 (emphasis added); *id.* at Abstract, Fig. 1 (showing FeCo layer above MgO barrier layer).

221. Bowen also disclosed a lower Fe electrode that satisfied this claim limitation. Bowen taught growing “FeCo/MgO/**Fe** epitaxial structures” on a substrate. EX1026 (Bowen) at page 1655 (emphasis added); *see also* EX1026 (Bowen) at Abstract, Fig. 1. Bowen taught that its “Fe bottom electrode” is formed below the MgO barrier layer such that the MgO barrier layer separates the lower Fe

electrode from the upper FeCo electrode. EX1026 (Bowen) at page 1655, Abstract, Fig. 1 (showing Fe layer below MgO barrier layer).

P. Claim 16: Obviousness Over Bowen In View Of Soukup

- 1. Claim 16: “The magnetoresistive device of claim 15, wherein the tunnel barrier layer comprises partially or fully crystalline magnesium oxide.”**

222. As I explained above for Claims 1[c] and 15 in Sections XII.A.4 and XIII.O of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

Q. Claim 17: Obviousness Over Bowen In View Of Soukup

- 1. Claim 17: “The magnetoresistive device of claim 16, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.”**

223. As I explained above for Claims 8 and 16 in Sections XII.H and XII.P of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

R. Claim 18: Obviousness Over Bowen In View Of Soukup

- 1. Claim 18: “The magnetoresistive device of claim 17, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer exhibits a body-centered cubic (BCC) structure.”**

224. As I explained above for Claims 13 and 17 in Sections XII.M and XII.Q of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

S. Claim 19: Obviousness Over Bowen In View Of Soukup

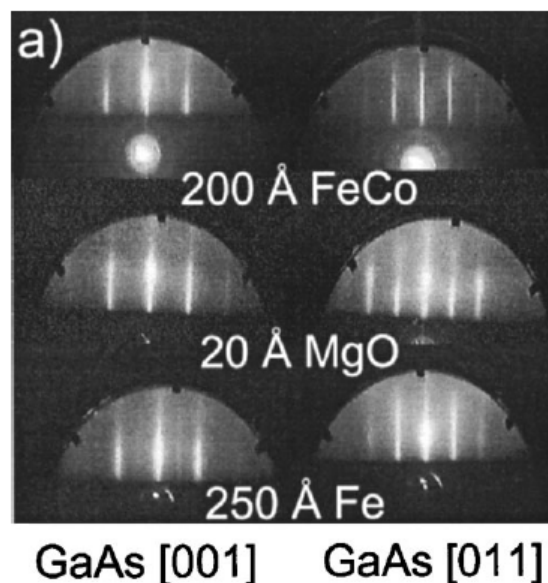
- 1. Claim 19: “The magnetoresistive device of claim 17, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Cobalt and Iron.”**

225. As I explained above for Claims 14 and 17 in Sections XII.N and XII.Q of this Declaration, Bowen in view of Soukup disclosed or suggested this limitation.

T. Claim 20: Obviousness Over Bowen In View Of Soukup

- 1. Claim 20: “The magnetoresistive device of claim 15, wherein the tunnel barrier layer has a thickness less than 10 nm.”**

226. As I explained in Section XII.O of this Declaration, Claim 15 is obvious over Bowen in view of Soukup. Claim 20 depends from Claim 15, and thus incorporates all of Claim 15’s requirements. Claim 20 is also obvious over Bowen in view of Soukup.



EX1026 (Bowen) at Fig. 1 (excerpted).

227. Bowen disclosed fabricating an MgO barrier layer with a thickness of 20 Å. EX1026 (Bowen) at Abstract, page 1656, Fig. 1. Bowen disclosed the thickness of its MgO barrier layer in Figure 1, shown above. Because one angstrom (Å) equals 0.1 nanometers (nm), Bowen's MgO barrier layer equals 2 nm, which is within Claim 20's requirement of "less than 10 nm."

XIII. GROUND 2: CLAIMS 1-20 ARE OBVIOUS OVER NAGAHAMA (AND SUNAI OR PARKIN AND/OR SOUKUP)

228. In my opinion, Claims 1-20 are obvious over the prior art. Specifically:

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

A. Claim 1: Obviousness Over Nagahama Alone Or In View Of Soukup

- 1. **Claim 1[preamble]: "A magnetoresistive device comprising a magnetic tunnel junction structure comprising a multi-layer material stack including:"**

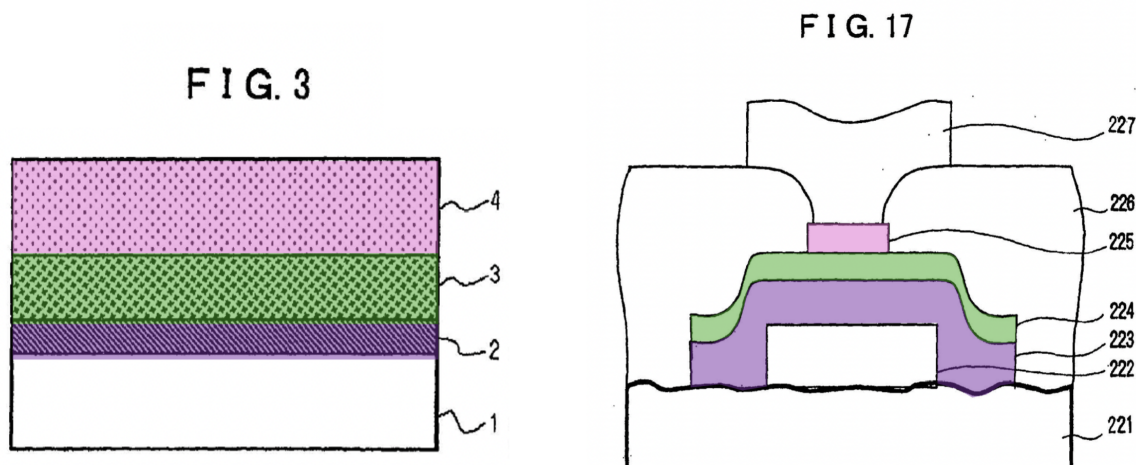
229. I am informed and understand that claim preambles may or may not limit the claim. I have been asked to assume the preambles of the '909 Patent claims are limiting for purposes of this analysis. Assuming that the preamble of Claim 1 is limiting, Nagahama taught or suggested it.

230. As I explained in Ground 1, an MTJ having a material stack was known and conventional. *Supra* §XII.A.1 of this Declaration; EX1039 (Tehrani) at page 2816, Fig. 5 (referring to an MTJ illustrated in Figure 5 as having a “[t]ypical MTJ material stack.”).

231. Nagahama disclosed that its present invention related to “tunnel magnetoresistive elements, and particularly to a ferromagnetic tunnel magnetoresistive element outputting a large signal... and a tunnel magnetoresistive element whose crystal orientation is set to the (001) direction of a body-centered cubic lattice, a face-centered cubic lattice, or a tetragonal lattice.” EX1027 (Nagahama) ¶1. Nagahama disclosed a series of embodiments, including the embodiment of paragraphs 73-74. In that example, Nagahama taught, “[s]till another 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.

232. Thus, Nagahama disclosed a magnetoresistive device having a tunnel barrier structure as recited in this claim. Nagahama taught an MTJ with a tunnel barrier layer and two ferromagnetic layers, as explained above and as I explain for Claims 1[a]-1[c]. *See* Sections XII.A.2-XII.A.4 of this Declaration.

233. Nagahama's magnetoresistive devices took the conventional form, as depicted in Figures 3 and 17 below.

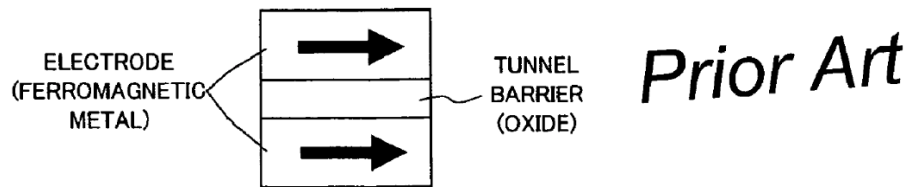


EX1027 (Nagahama) at Figs. 3, 17 (Fig. 3 excerpted, both annotated).

234. In addition, magnetic tunnel junctions (MTJs), including those with a three-layer MTJ structure, were well known in the art.

235. This is evident from the '909 Patent itself. EX1017 ('909 Patent) at Figs. 8(A)-8(B), cols. 1:51-2:9. For example, Figure 8(A) of the '909 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." EX1017 ('909 Patent) at col. 1:54-57. The patent correctly identifies and labels this conventional MTJ design as "Prior Art":

FIG. 8 (A)



EX1017 ('909 Patent) at Fig. 8(A) (“Prior Art” legend in original).

2. Claim 1[a]: “first and second ferromagnetic material layer; and”

236. This claim limitation is also taught or suggested by Nagahama.

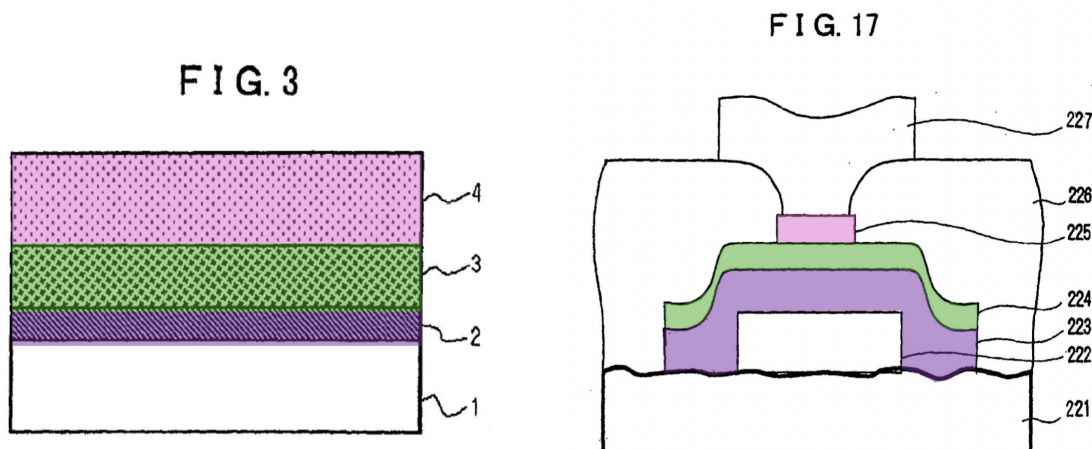
237. Claim 1[a]’s “ferromagnetic material layer” refers to an electrode made of a “ferromagnetic metal.” EX1017 ('909 Patent) at col. 1:54-58, Fig. 8(a). As specified in Claim 1[b], “first” refers to the ferromagnetic material layer that is beneath the tunnel barrier layer, and “second” refers to the “upper” ferromagnetic material layer above the tunnel barrier layer.

238. As I explain in the following paragraphs, Nagahama’s “lower ferromagnetic electrode layer” is the claimed “first” ferromagnetic material layer, and its “upper ferromagnetic electrode layer” is the claimed “second” ferromagnetic material layer.

239. 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 on the MgO double underlayer of the present invention.” EX1027 (Nagahama) ¶73 (emphases added).

240. Figures 3 and 17 of Nagahama show this conventional arrangement of an MTJ structure. EX1027 (Nagahama) ¶¶21-22, 75-76; *id.* at Figs. 3, 17. In Figures 3 and 17, 1 and 222 represent a substrate (or underlayer); 2 and 223 represent a **lower ferromagnetic electrode**; 3 and 224 represent a **barrier layer**; and 4 and 225 represent **upper ferromagnetic electrode**. EX1027 (Nagahama) ¶¶21-22, 75-76.



EX1027 (Nagahama) at Figs. 3, 17 (Fig. 3 excerpted, both annotated). Nagahama’s “**lower ferromagnetic electrode**” was a first ferromagnetic material layer and Nagahama’s “**upper ferromagnetic electrode**” was a second ferromagnetic material layer. Nagahama taught that “ferromagnetic metals such as Fe, Co, Ni, or an alloy of these metals” were used for these ferromagnetic electrodes and taught using Fe as the lower electrode and CoFe as the upper electrode. EX1027 (Nagahama) ¶¶28, 31.

241. MTJs containing ferromagnetic layers were conventional by 2004, as the '909 Patent acknowledges. EX1017 ('909 Patent) at col. 1:54-58 (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”).

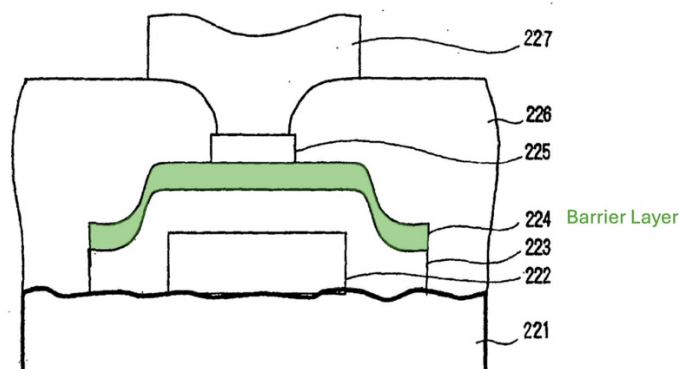
3. **Claim 1[b]: “a tunnel barrier layer between the first and second ferromagnetic material layers such that the tunnel barrier layer is above the first ferromagnetic material layer and below the second ferromagnetic material layer,”**

242. This claim limitation is taught or suggested by Nagahama.

243. Claim 1[b]’s “tunnel barrier layer” refers to “an oxide [that] is sandwiched between a first and a second electrode made of a ferromagnetic metal.” EX1017 ('909 Patent) at col. 1:54-58.

244. Nagahama taught that its “tunnel magnetoresistive element” included “a (001)-highly-oriented MgO barrier layer.” EX1027 (Nagahama) ¶73. Shown below in Figure 17 is an example of this **barrier layer**. EX1027 (Nagahama) ¶¶75-76 (“224, a barrier layer”).

FIG. 17



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

245. As I explained above for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama taught that its lower ferromagnetic electrode is located below the tunnel barrier layer, such as the “(001)-highly-oriented MgO barrier layer,” and that its upper ferromagnetic electrode is located above the tunnel barrier layer, such that the tunnel barrier layer is located between the lower and upper ferromagnetic electrodes. EX1027 (Nagahama) ¶¶73, 75-76. Nagahama’s various MTJ embodiments, including the paragraphs 73-74 embodiment, describe this same basic structure, and thus disclose or suggest this arrangement to one of skill. *Supra* §XIII.A.2 .

246. MTJs containing barrier layers, including barrier layers located between two ferromagnetic layers, were conventional by 2004, as the ’909 Patent acknowledges. EX1017 (’909 Patent) at col. 1:54-58 (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]: “wherein said tunnel barrier layer comprises crystalline MgO_x (001) with oxygen vacancy defects and ($0 < x < 1$).”

247. This claim limitation is taught or suggested by either (1) Nagahama alone or (2) Nagahama in view of Soukup.

a) Poly-crystalline MgO (001)

248. As I explained for Claim 1[b] in Section XIII.A.3, Nagahama disclosed a tunnel barrier layer. Nagahama disclosed using 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.

249. 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 '909 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.” EX1017 ('909 Patent) at col. 4:52-55.

b) Oxygen vacancy defects

250. Obviousness over Nagahama. The requirement of MgO_x where $0 < x < 1$ would be inherently satisfied by Nagahama. One of skill would have understood this 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 '909 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).” EX1017 ('909 Patent) at col. 6:44-46; *see also id.* at cols. 7:18-19 (“[T]here is the possibility that there are oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).”), 7:34-36 (“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.”).

251. 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....").

252. Obviousness over Nagahama and Soukup. This limitation 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.

253. For the reasons I provided for Claim 5 in Section XIII.E.1 of this Declaration, 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 tunneling and 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 tunneling and TMR. EX1028 (Soukup) at page 3232.

B. Claim 2: Obviousness Over Nagahama In View Of Soukup

1. Claim 2: "The magnetoresistive device of claim 1, wherein $0.9 < x < 1$."

254. As I explained in Section XIII.A of this Declaration, Claim 1 is obvious over Nagahama alone or in view of Soukup. Claim 2 depends from Claim 1, and thus incorporates all of Claim 1's requirements. Claim 2 is obvious over Nagahama in view of Soukup.

255. The claimed MgO_x oxygen vacancy defect range of $0.9 < x < 1$ was also inherent to Nagahama's and Soukup's MgO barrier layers for the same reasons that I explained in Sections XII.A.4 (Ground 1, Claim 1[c]) and XIII.A.4 (Ground 2, Claim 1[c]) of this Declaration.

256. Specifically, and as I explained above in Paragraphs 74-75 and 133 of this Declaration, oxygen vacancy defects were understood to be inherent to MgO_x layers where $0 < x < 1$. Even though Nagahama and Soukup did not provide a quantification of the oxygen vacancy defects present in their MgO barrier layers, Nagahama's and Soukup's MgO barrier layers inherently included them. *See generally* EX1027 (Nagahama); EX1028 (Soukup). One of skill also would understand that the claimed range of $0.9 < x < 1$ is a subrange of the oxygen vacancy

defects inherent to Nagahama's and Soukup's MgO barrier layers. Because $0.9 < x < 1$ is a subrange of $0 < x < 1$, it necessarily overlaps with $0 < x < 1$.

257. Claim 2 is also obvious because the general conditions for fabricating an MTJ with the claimed MgO barrier layer oxygen vacancy range of $0.9 < x < 1$ were already disclosed in the prior art. Others in the field at the time of the 2004 priority date would have been both motivated to and able to obtain MgO barrier layer oxygen vacancy defects in this range through routine optimization. Specifically, there was already an interest in reducing barrier height to achieve a higher TMR. EX1044 (Butler) at page 1; EX1046 (Mathon) at page 1. One of skill would have been motivated to optimize MgO barrier layers during MTJ fabrication by experimenting with oxygen vacancy defects because it was understood that these defects impacted barrier height and thus TMR values. Oxygen vacancy defects in the MgO barrier layer had an understood relationship to TMR within the grasp of one of skill by the time of the '909 Patent's priority date.

258. The '909 Patent disclosed that its claimed invention was directed to an MTJ device that produced a high TMR. EX1017 ('909 Patent) at cols. 1:37-40, 2:2-4, 5:10-16. As I explained previously in Ground 1 for Claims 2 and 5 in Sections XII.B and XII.E of this Declaration, by 2004, others in the field were already interested in increasing TMR values to achieve improved MRAM performance. Indeed, this was the focus for Nagahama, who disclosed that the "Industrial

Applicability” of his invention was to “a magnetic sensor of a pickup head of a hard disk drive or a ferromagnetic random access memory.” EX1027 (Nagahama) ¶82; *see also* 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”); EX1027 (Nagahama) ¶6 (“obtain[ing] a high magnetoresistive effect”); EX1027 (Nagahama) ¶¶3-8. Nagahama sought to increase TMR by modifying properties of the MgO barrier layer. EX1027 (Nagahama) ¶¶15-17.

259. As I previously explained in Ground 1 for Claim 2 in Section XII.B of this Declaration, the general MTJ conditions for fabricating MgO barrier layers that could achieve the claimed MgO_x wherein $0.9 < x < 1$ were already known in the art. To this end, the '909 Patent disclosed that “while the MgO layer has been described as being deposited by electron-beam evaporation or sputtering, it should be obvious that other deposition methods are also possible.” EX1017 ('909 Patent) at col. 9:45-48. One of skill would understand from this disclosure that MgO barrier layer methods were not considered inventive or surprisingly leading to higher-than-expected performance.

260. As I explained above in Paragraph 153 of this Declaration, Soukup’s disclosed MgO barrier layer fabrication method was similar to the method the '909

Patent disclosed using to grow the MgO barrier layer of its first MTJ device embodiment.

261. Even though Nagahama did not provide disclosure regarding oxygen vacancy defects in the MgO barrier layers of his disclosed MTJ device embodiments, oxygen vacancy defects are necessarily present because these defects occur in all MgO barriers. EX1042 (Pacchioni) at page 162. Nagahama also did not provide a disclosure of its methodology for fabricating its MTJ device referred to as “a (001)-highly-oriented lower ferromagnetic electrode layer, a (001)-highly-oriented MgO barrier layer, and a (001)-highly-oriented upper ferromagnetic electrode layer.” *See* EX1027 (Nagahama) ¶73; *id.* ¶¶75-76. Nagahama’s disclosure indicates that depositing MgO underlayers to generate an “MgO(001)-oriented highly oriented crystal layer” using the sputtering fabrication technique was within the grasp of Nagahama’s research group. EX1027 (Nagahama) ¶58. Nagahama disclosed depositing an MgO underlayer using sputtering, *id.* ¶¶57, 62 (third group of the present invention), wherein the MgO underlayer initially grew amorphous, but then formed an “MgO(001)-oriented highly oriented crystal layer.” *Id.* ¶58; *see also id.* ¶¶64-65. Nagahama also reported measuring a TMR “of more than 90%” with its “(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) ¶¶73-76.

262. Considering that the '909 Patent did not attribute the object of the invention to anything novel or extraordinary regarding its MgO barrier layer fabrication methods together with Nagahama's disclosed TMR value of more than 90%, one of skill would understand Nagahama's MTJ device 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," was capable of achieving the object of the invention. EX1027 (Nagahama) ¶¶73-74; EX1017 ('909 Patent) at col. 8:15-19, Fig. 6.

263. As I explained previously for Ground 1, Claim 2 in Section XII.B of this Declaration, the claimed range of $0.9 < x < 1$ was not novel. The '909 Patent explains that oxygen vacancy defects could be introduced using several methods and did not indicate any were particular or critical to the object of the invention. EX1017 ('909 Patent) at col. 9:4-10.

264. As I explained previously in Ground 1 for Claim 2 in Paragraph 157 of this Declaration, Soukup's barrier height of 0.33 eV was within the range disclosed by the '909 Patent as indicative of "oxygen vacancy defects." EX1028 (Soukup) at Abstract; EX1017 ('909 Patent) at col. 7:19-23. One of skill would understand from the '909 Patent that Soukup's barrier height of 0.33 eV indicated that Soukup's MgO barrier layer had the preferred oxygen vacancy defect ranges disclosed by the '909 Patent, according to the '909 Patent's own teachings.

265. As I explained previously in Ground 1 for Claim 2 in Paragraphs 156-157 of this Declaration, the lack of criticality of the $0.9 < x < 1$ claimed range is also supported by the '909 Patent's speculation that there is the "possibility" that the MTJ device of the first embodiment had "oxygen vacancy defects such as MgO_x ($0.9 < x < 1$).” EX1017 ('909 Patent) at col. 7:16-19. In further support, the '909 Patent also provides that there are other means for manipulating the barrier height than introducing oxygen vacancy defects, including “by doping Ca or Sr, instead of introducing an [sic] oxygen vacancy defects in the MgO layer.” EX1017 ('909 Patent) at col. 9:42-45.

C. Claim 3: Obviousness Over Nagahama In View Of Soukup

1. Claim 3: “The magnetoresistive device of claim 2, wherein $0.98 < x < 1$.”

266. As I explained previously in Section XIII.B of this Declaration, Claim 2 was disclosed or suggested by Nagahama in view of Soukup. Claim 3 depends from Claim 2 and thus incorporates all of Claim 2's requirements. Claim 3 is also obvious over Nagahama in view of Soukup.

267. For the same reasons I explained previously for Claims 1 and 2 in Sections XIII.A and XIII.B of this Declaration, Claim 3's MgO_x oxygen vacancy defect range of $0.98 < x < 1$ is obvious because it overlaps with the $0 < x < 1$ range inherent in Nagahama and Soukup, because oxygen vacancy defects in the MgO

barrier layer had an understood relationship to TMR, and because even this narrower range is inherent in Soukup based on Soukup's 0.33 eV barrier height.

268. For the same reasons I explained previously for Claim 2 in Section XIII.B of this Declaration, Claim 3's MgO_x oxygen vacancy defect range of $0.98 < x < 1$ is also speculative. The only reference to this range in the '909 Patent is a general reference to the fabrication method of the first MTJ device embodiment, which discloses the "possibility" of having oxygen vacancy defects within the range of " $(0.9 < x < 1)$ ": "Using the method according to the present embodiment of the invention.... [t]he value of x in the MgO_x due to oxygen vacancy defects is such that **$0.98 < x < 1$** , and more preferably $0.99 < x < 1$." EX1017 ('909 Patent) at cols. 7:16-19, 7:31-39 (emphasis added). This disclosure is not in reference to any disclosed experimental result, and is a speculative range based on an already speculative range of $0.9 < x < 1$.

D. Claim 4: Obviousness Over Nagahama In View Of Soukup

1. Claim 4: "The magnetoresistive device of claim 3, wherein $0.99 < x < 1$."

269. As I explained previously in Section XII.C of this Declaration, Claim 3 was disclosed or suggested by Nagahama in view of Soukup. Claim 4 depends from Claim 3 and thus incorporates all of Claim 3's requirements. Claim 4 is also obvious over Nagahama in view of Soukup.

270. For the same reasons I explained previously for Claims 1, 2, and 3 in Sections XIII.A, XIII.B, and XIII.C of this Declaration, Claim 4's MgO_x oxygen vacancy defect range of $0.99 < x < 1$ was obvious because it overlaps with the $0 < x < 1$ range inherent in Nagahama and Soukup, because oxygen vacancy defects in the MgO barrier layer had an understood relationship to TMR, and because even this narrower range is inherent in Soukup based on Soukup's 0.33 eV barrier height.

271. For the same reasons I explained previously for Claim 3 in Section XIII.C of this Declaration, Claim 4's MgO_x oxygen vacancy defect range of $0.99 < x < 1$ was both inherent and speculative.

E. Claim 5: Obviousness Over Nagahama In View Of Soukup

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

272. As I explained in Section XIII.A of this Declaration, Claim 1 is obvious over Nagahama alone or in view of Soukup. Claim 5 depends from Claim 1, and thus incorporates all of Claim 1's requirements. Nagahama in view of Soukup taught or suggested a tunnel barrier height between 0.1 to 0.85 eV as required by Claim 5.

273. Nagahama in view of Soukup taught or suggested an MgO tunnel barrier height for an MgO barrier layer in the claimed range of 0.1 to 0.85 eV. Nagahama disclosed using an MgO barrier for its MTJ. EX1027 (Nagahama) ¶¶73-76, Abstract, Figs. 3, 17. Soukup observed a "barrier height" of "about 0.33

eV” for its MgO thin film. EX1028 (Soukup) at Abstract; *id.* at pages 3231-32, Fig. 5, Table I.

274. Soukup studied the “effect of nonstoichiometry on the device characteristics,” EX1028 (Soukup) at page 3232, documenting 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.

275. In my opinion, one of skill would have been motivated to apply Soukup’s teachings about an MgO thin-film barrier with a “barrier height” of “about 0.33 eV” to Nagahama’s MgO barrier. Soukup fabricated an MgO thin-film barrier with a low tunnel barrier height in the range of 0.1 to 0.85 eV and taught that 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 understood and would have been motivated to fabricate Nagahama’s MTJ with an

MgO tunnel barrier with a tunnel barrier height having a value in the range of 0.1 to 0.85 eV by introducing oxygen vacancy defects as taught by Soukup.

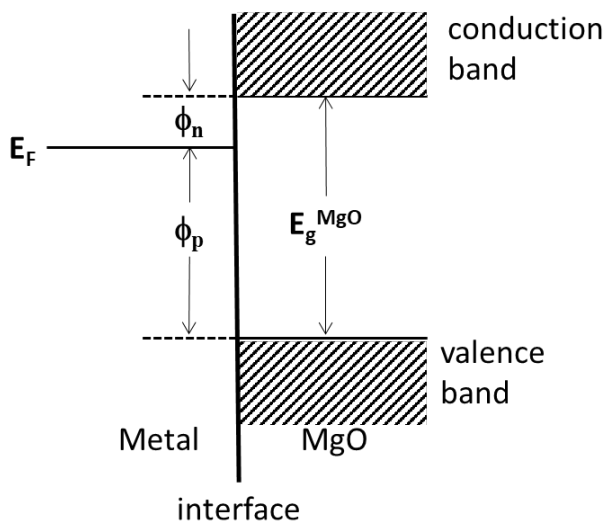
276. As I explained previously in Section XII.E of this Declaration, the TMR was and is a key parameter for improving MRAM performance, and skilled artisans have long been interested in increasing TMRs to enable better performing MRAM. Additionally, lowering the resistance (barrier height) for parallel spin electrons compared to antiparallel would improve TMRs. *Supra* §XII.E; EX1035 (Moodera 1995) at page 3273; EX1027 (Nagahama) ¶2; EX1017 ('909 Patent) at col. 5:8-16 (TMR equation); EX1057 (Dieny textbook) at page 13.

277. 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”); EX1027 (Nagahama) ¶6 (“obtain[ing] a high magnetoresistive effect”); EX1027 (Nagahama) ¶¶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 0.1 and 0.85 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.

278. 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.

279. 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.

280. 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 1.8 for Co 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.

281. 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 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 '909 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.

282. A skilled artisan also would have had a reasonable expectation of success in applying Soukup's teachings to Nagahama to achieve a tunnel barrier height in the range of 0.1 to 0.85 eV. 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 been motivated to use a barrier height with the same or similar height in an MgO MTJ to improve tunneling and hence TMR in Nagahama.

283. A tunnel barrier height in the range of 0.1 to 0.85 eV would have been obvious to one of skill. 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).

284. 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 (Wulfhekel) 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”).

285. As I explained above for Ground 1, Claim 5 in Section XII.E of this Declaration, the '909 Patent itself recognized that the tunnel barrier height is lowered when there are oxygen vacancy defects. EX1017 ('909 Patent) at col. 7:19-23.

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

F. Claim 6: Obviousness Over Nagahama In View Of Soukup

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

287. Claim 6’s requirement of a tunnel barrier height in “a range of 0.2 eV to 0.5 eV” overlaps with Claim 5’s tunnel barrier height in “a range of 0.1 eV to 0.85 eV.” Claim 6 is disclosed or suggested for at least the same reasons explained above for Claim 5. *Supra* §XIII.E of this Declaration.

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

- 1. Claim 7: “The magnetoresistive device of claim 1, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Boron.”**

288. As I explained in Section XIII.A of this Declaration, Claim 1 is obvious over Nagahama alone or in view of Soukup. Claim 7 depends from Claim 1, and

thus incorporates all of Claim 1's requirements. Claim 7 is obvious over Nagahama in view of Sunai or Parkin (and optionally Soukup).

289. Claim 7 does not specify the specific molecular composition or stoichiometry of the claimed "ferromagnetic material layer [that] comprises Boron." EX1017 ('909 Patent) at col. 10:21-23. Thus, I was asked to assume that any ferromagnetic layer that comprises Boron satisfies Claim 7.

290. As I explained above for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama taught or suggested a first, lower ferromagnetic layer and a second, upper ferromagnetic layer.

291. Nagahama in view of Sunai. It would have been obvious to replace Nagahama's lower ferromagnetic layer and/or upper 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), 24 (teaching "ferromagnetic layer 4 is represented by the general formula $(\text{CoFe})_{100-x}\text{Y}_x$ " and specifying Y is an "element selected from the group consisting of B" or other elements); *id.* ¶¶25-29; EX1061 (Cardoso) at Abstract.

292. 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 an “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.

293. As I explained above in Ground 1, one of skill would have been motivated to use Sunai’s CoFeB electrode in an MTJ. *Supra* Claim 7, §XII.G 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; 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].”). Nagahama sought to “obtain a high magnetoresistive effect” in 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 using 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).

294. To improve Nagahama's MTJ, one of skill would have looked to Sunai's teachings. Nagahama and Sunai sought to improve the TMR of magnetoresistive devices, a problem to which the '909 Patent was directed. EX1027 (Nagahama) ¶¶6, 15; EX1030 (Sunai) at Abstract, ¶¶1, 10; EX1017 ('909 Patent) at Abstract, cols. 1:37-2:39. 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 used an MgO barrier layer and similar ferromagnetic alloy electrodes. EX1027 (Nagahama) ¶¶6, 73; EX1030 (Sunai) ¶¶24, 35.

295. 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 MTJ by using CoFeB in Nagahama's lower electrode because CoFeB

was already proven successful in increasing TMR in MTJs. EX1030 (Sunai) ¶¶27-28.

296. Nagahama in view of Parkin. Alternatively, in my opinion, Claim 7 is also taught or suggested by Nagahama in view of Parkin. As I explained above for Ground 1, Claim 7 in Section XII.G of this Declaration, Parkin taught a ferromagnetic CoFeB layer. EX1062 (Parkin) at cols. 17:43-44, 18:51-55 (CoFeB layer 175 in which “a portion of the storage layer 175 adjacent to the MgO tunnel barrier 120’ has crystallized”), 19:15-22 (“CoFeB layer 175”). For the same reasons I previously provided, it would have been obvious to replace Nagahama’s first ferromagnetic layer with Parkin’s CoFeB layer, satisfying Claim 7. *Supra* §XII.G.

297. To improve Nagahama’s MTJ, one of skill would have looked to Parkin’s teachings. Nagahama and Parkin sought to improve the TMR of magnetoresistive devices, a problem the ’909 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....”); EX1017 (’909 Patent) at Abstract, cols. 1:37-2:39. Like the ’909 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.”); EX1017 (’909 Patent) at col. 3:1-4. Further, they both used 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.”).

H. Claim 8: Obviousness Over Nagahama Alone Or In View Of Soukup

- 1. Claim 8: “The magnetoresistive device of claim 1, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.”**

298. As I explained in Section XIII.A of this Declaration, Claim 1 is obvious over Nagahama alone or in view of Soukup. Claim 8 depends from Claim 1, and thus incorporates all of Claim 1’s requirements. Claim 8 is obvious over Nagahama alone or in view of Soukup.

299. As I explained for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama disclosed or suggested a first and a second ferromagnetic material layer. EX1027 (Nagahama) ¶73 (describing “*a (001)-highly-oriented lower ferromagnetic electrode layer*, a (001)-highly-oriented MgO barrier layer, and *a (001)-highly-oriented upper ferromagnetic electrode layer* on the MgO double underlayer of the present invention” (emphases added)).

300. As I also explained in Paragraph 249 above, Nagahama’s reference to “highly-oriented” referred to polycrystalline. *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”). One of skill would understand that “highly-oriented” referred to the predominant orientation of a polycrystalline layer containing many crystals.

301. Nagahama’s ferromagnetic layers were crystallized. According to Nagahama, the MTJ of its “present invention” utilized “a tunnel magnetoresistive element whose crystal orientation is set to the (001) direction of a ***body-centered cubic lattice***, a face-centered cubic lattice, or a tetragonal lattice.” EX1027 (Nagahama) ¶1 (emphasis added); *see also id.* ¶23 (“Fe atoms enter a crystal to form a body-centered cubic lattice....”). A body-centered cubic lattice structure is also referred to as bcc, as I explained in Section VII.E.1 of this Declaration, and refers to a type of crystal structure. One of skill in the art would have found Nagahama’s teachings of a bcc ferromagnetic electrode in paragraphs 1, 18, and 23 to be applicable to Nagahama’s disclosure of the MTJ in paragraphs 73-74. This is because one of skill would have understood that using a bcc structure for the ferromagnetic electrodes would have been a desirable and obvious option. Nagahama itself explained that using a bcc structure was desirable to

achieve “a large magnetoresistive effect.” EX1027 (Nagahama) ¶¶18 (item [20]), 81 (item [F]); *id.* at page 11 (claim 20).

302. Nagahama recognized that using crystallized ferromagnetic layers increases TMR. EX1027 (Nagahama) ¶¶73-74. Others found that “nearly perfect crystalline MgO(001) films on high-quality single crystals of Fe” was effective in improving TMR. EX1045 (Klaua) at page 1. Crystallizing improves tunneling and hence TMR, as researchers observed for crystallized Fe electrodes. EX1045 (Klaua) at page 6 (“[T]he entire Fe layer has crystalline structure.... This indicates 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.”). Thus, one of skill would have been motivated to use crystalline ferromagnetic electrodes.

I. Claim 9: Obviousness Over Nagahama In View Of Soukup

1. Claim 9[preamble]: “A magnetoresistive device comprising a magnetic tunnel junction structure comprising:”

303. As I explained above for Claim 1[preamble] in Section XII.A.1 of the Declaration, Nagahama disclosed or suggested this limitation.

2. Claim 9[a]: “first and second ferromagnetic material layer; and”

304. As I explained above for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama disclosed or suggested this limitation.

3. Claim 9[b]: “a tunnel barrier layer between the first and second ferromagnetic material layers,”

305. As I explained above for Claim 1[b] in Section XIII.A.3 of this Declaration, Nagahama disclosed or suggested this limitation.

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

306. As I explained above for Claims 1[c] and 5 in Sections XIII.A.4 and XIII.E of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

J. Claim 10: Obviousness Over Nagahama In View Of Soukup

1. Claim 10: “The magnetoresistive device of claim 9, wherein the tunnel barrier layer comprises partially or fully crystalline magnesium oxide.”

307. As I explained in Section XIII.I of this Declaration, Claim 9 is obvious over Nagahama in view of Soukup. Claim 10 depends from Claim 9, and thus incorporates all of Claim 9’s requirements. Claim 10 is obvious over Nagahama in view of Soukup.

308. As I also explained for Claim 1[c] in Section XIII.A.4 of this Declaration, Nagahama disclosed using a polycrystalline MgO tunnel barrier layer, which one of skill would understand to mean that the MgO layer was partially or fully crystallized as required by Claim 10. Specifically, Nagahama disclosed a “(001)-highly-oriented MgO barrier layer.” EX1027 (Nagahama) ¶73. One of skill

would understand “highly-oriented” referred to polycrystalline. *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”). One of skill would also understand that polycrystalline referred to a layer containing many crystals and that “highly-oriented” referred to the predominant orientation of those crystals.

K. Claim 11: Obviousness Over Nagahama In View Of Soukup

- 1. Claim 11: “The magnetoresistive device of claim 10, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.”**

309. As I explained above for Claims 8 and 10 in Sections XIII.H and XIII.J of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

L. Claim 12: Obviousness Over Nagahama In View Of Soukup

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

310. As I explained above for Claims 6 and 11 in Sections XIII.F, and XIII.K of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

M. Claim 13: Obviousness Over Nagahama In View Of Soukup

- 1. Claim 13: “The magnetoresistive device of claim 11, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer exhibits a body-centered cubic (BCC) structure.”**

311. As I explained in Section XIII.K of this Declaration, Claim 11 is obvious over Nagahama in view of Soukup. Claim 13 depends from Claim 11, and thus incorporates all of Claim 11’s requirements. Claim 13 is obvious over Nagahama in view of Soukup.

312. As I previously explained for Claim 8 in Section XIII.H of this Declaration, Nagahama disclosed that its MTJ utilized “a tunnel magnetoresistive element whose crystal orientation is set to the (001) direction of a *body-centered cubic lattice*, a face-centered cubic lattice, or a tetragonal lattice.” EX1027 (Nagahama) ¶1 (emphasis added); *see also id.* ¶23 (“Fe atoms enter a crystal to form a body-centered cubic lattice....”). One of skill understood that bcc was another term for body-centered-cubic lattice structure. *See* Section VII.E.1 of this Declaration. One of skill would have also found the bcc ferromagnetic electrodes taught by Nagahama in paragraphs 1, 18, and 23 applicable to the MTJ disclosed in Nagahama’s paragraphs 73-74. This is because one of skill would have understood that using a bcc structure for the ferromagnetic electrodes would have been a desirable and obvious option. Nagahama itself explained that using a bcc structure

was desirable to achieve “a large magnetoresistive effect.” EX1027 (Nagahama) ¶¶18 (item [20]), 81 (item [F]); *id.* at page 11 (claim 20).

N. Claim 14: Obviousness Over Nagahama In View Of Soukup

1. Claim 14: “The magnetoresistive device of claim 11, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Cobalt and Iron.”

313. As I explained in Section XIII.K of this Declaration, Claim 11 is obvious over Nagahama in view of Soukup. Claim 14 depends from Claim 11, and thus incorporates all of Claim 11’s requirements. Claim 14 is obvious over Nagahama in view of Soukup.

314. As I also explained for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama disclosed a cobalt and iron, or “CoFe upper electrode” as its second ferromagnetic material layer. EX1027 (Nagahama) ¶28. In my opinion, it also would have been obvious to one of skill to use a ferromagnetic electrode comprising cobalt and iron because ferromagnetic metals such as Fe and Co and their alloys were well known and commonly used, as Nagahama itself and others taught. *Supra* §§VII.E.2, XIII.A.2; EX1027 (Nagahama) ¶¶28, 31.

O. Claim 15: Obviousness Over Nagahama In View Of Soukup

1. Claim 15[preamble]: “A magnetoresistive device comprising:”

315. As I explained above for Claim 1[preamble] in Section XIII.A.1 of this Declaration, Nagahama disclosed or suggested this limitation.

2. Claim 15[a]: “a first ferromagnetic material layer;”

316. As I explained above for Claim 1[a] in Section XIII.A.2 of this Declaration, Nagahama disclosed or suggested this limitation.

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

317. As I explained above for Claims 1[c] and 6 in Sections XIII.A.4 and XIII.F of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

4. Claim 15[c]: “a second ferromagnetic material layer disposed on the tunnel barrier layer and separated from the first ferromagnetic material layer by the tunnel barrier layer.”

318. As I explained above for Claims 1[a]-1[b] in Sections XIII.A.2 and XIII.A.3 of this Declaration, Nagahama disclosed or suggested this limitation.

P. Claim 16: Obviousness Over Nagahama In View Of Soukup

1. Claim 16: “The magnetoresistive device of claim 15, wherein the tunnel barrier layer comprises partially or fully crystalline magnesium oxide.”

319. As I explained above for Claims 1[c] and 15 in Sections XIII.A.4 and XIII.O of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

Q. Claim 17: Obviousness Over Nagahama In View Of Soukup

- 1. Claim 17: “The magnetoresistive device of claim 16, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.”**

320. As I explained above for Claims 8 and 16 in Sections XIII.H and XIII.P of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

R. Claim 18: Obviousness Over Nagahama In View Of Soukup

- 1. Claim 18: “The magnetoresistive device of claim 17, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer exhibits a body-centered cubic (BCC) structure.”**

321. As I explained above for Claims 13 and 17 in Sections XII.M and XII.Q of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

S. Claim 19: Obviousness Over Nagahama In View Of Soukup

- 1. Claim 19: “The magnetoresistive device of claim 17, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Cobalt and Iron.”**

322. As I explained above for Claims 14 and 17 in Sections XIII.N and XIII.Q of this Declaration, Nagahama in view of Soukup disclosed or suggested this limitation.

T. Claim 20: Obviousness Over Nagahama In View Of Soukup

1. Claim 20: “The magnetoresistive device of claim 15, wherein the tunnel barrier layer has a thickness less than 10 nm.”

323. As I explained in Section XIII.O of this Declaration, Claim 15 is obvious over Nagahama in view of Soukup. Claim 20 depends from Claim 15, and thus incorporates all of Claim 15’s requirements. Claim 20 is obvious over Nagahama in view of Soukup.

324. Nagahama disclosed “a (001)-highly-oriented MgO barrier layer.” EX1027 (Nagahama) ¶73; *see also id.* ¶76, Fig. 17. Nagahama did not provide the specific thickness of the MgO barrier layer illustrated in Figure 17 but taught depositing MgO layers in the claimed range: “the thickness of the (001)-highly-oriented MgO layer is set in the range of 3 to 10 nm.” EX1027 (Nagahama) ¶18 (item [16]); *see also id.* ¶¶58, 66, 81 (item (B)); *id.* at page 11 (claim 16). One of skill in the art would have known of depositing thin MgO barrier layers less than 10 nm thick based on Nagahama itself. Nagahama expressly cited to the research of Bowen and Mathon, EX1027 (Nagahama) ¶14, both of which described MgO MTJs having an MgO barrier layer of less than 10 nm. As explained in Paragraph 227 of this Declaration, Bowen expressly taught a 2 nm (20 Å) thick MgO barrier. EX1026 (Bowen) at Abstract, 1656, Fig. 1. Mathon described its MgO barrier layers as ranging from 7 to 20 atomic planes. EX1046 (Mathon) at page 3. This corresponds to a barrier height thickness of approximately 1.47–4.2 nm for 7 to 20 MgO atomic

planes because one of skill knew that the height of an atomic plane is the distance between levels in the MgO crystal, and that the height of one atomic plane in bulk MgO crystal was 2.106 Å (.2106 nm). *E.g.*, EX1051 (Meyerheim) at page 3 (“The vertical MgO interlayer distances... are slightly enhanced as compared with bulk MgO (2.106 Å).”).

325. Further, fabricating MgO layers with a “thickness less than 10 nm” as required by Claim 20 was known and conventional and would have been obvious.

326. As I explained for Claim 1[c], Nagahama’s goal was to improve TMR. EX1027 (Nagahama) ¶¶6, 15 (The “first object of the present invention is to provide a tunnel magnetoresistive element capable of producing a larger magnetoresistive effect.”); *see also id.* ¶¶3-8; *supra* §XIII.A.4 of this Declaration. Nagahama manipulated properties of the MgO barrier layer in an attempt to increase the TMR of its MTJ. EX1027 (Nagahama) ¶¶15-17. Nagahama acknowledged the works of Bowen, Moodera, and Mathon, noting that Bowen obtained “a giant tunnel magnetoresistive effect of more than 60%,” *id.* ¶14, while Mathon “pointed out that a barrier layer formed of MgO (001) single crystal produces a giant tunnel magnetoresistive effect,” *id.*, and Moodera “attempted to vary the dependence of magnetoresistance on bias voltage by disposing a polycrystalline nonmagnetic interlayer between a ferromagnetic electrode and a barrier layer,” *id.* ¶10; *see also id.* ¶¶2-14.

327. One of skill would have looked to Bowen's teachings regarding the fabrication of its MgO barrier layer, including the MgO barrier layer thickness, to improve Nagahama's MTJ. Bowen disclosed a 20 Å, or 2 nm, thick MgO barrier layer. EX1026 (Bowen) at Abstract, page 1656, Fig. 1.

328. Similarly, one of skill would have looked to Moodera who used an MTJ with ferromagnetic electrodes and an MgO barrier to achieve higher TMR values consistent with Jullière's model. EX1038 (Moodera 1996) at Abstract, page 4724. Moodera disclosed an MgO barrier that was 1.2 to 2.0 nm thick, which is within the claimed "less than 10 nm" requirement. EX1038 (Moodera 1996) at page 4725.

329. One of skill also would have looked to Mitani's different fabrication methods. Mitani recognized that "MgO is one of the most attractive materials suitable for an epitaxial insulating barrier because of the small lattice mismatch for Fe (3.7%) and the large TMR." EX1053 (Mitani) at page 8041; *id.* at Abstract. Mitani disclosed MgO barrier layers that were 6.4 to 26 Å thick, or 0.64 to 2.6 nm. EX1053 (Mitani) at page 8041.

330. In looking to the teachings of Bowen, Mitani, and Moodera, one of skill would have had a reasonable expectation of success in achieving an improved TMR by modifying the MgO barrier layer thickness.

XIV. SECONDARY INDICIA OF NONOBVIOUSNESS

331. 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 '909 Patent. Should I become aware of such evidence, I may offer opinions on it at that time.

XV. CONCLUSION

332. Based on the foregoing, it is my opinion that Claims 1-20 of the '909 Patent are obvious as discussed above.

333. 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.

334. 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.

335. 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 26, 2024



Jeffrey Bokor

XVI. APPENDIX: LIST OF PATENT CLAIMS

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

1[a] first and second ferromagnetic material layer; and

1[b] a tunnel barrier layer between the first and second ferromagnetic material layers such that the tunnel barrier layer is above the first ferromagnetic material layer and below the second ferromagnetic material layer,

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

2. The magnetoresistive device of claim 1, wherein $0.9 < x < 1$.

3. The magnetoresistive device of claim 2, wherein $0.98 < x < 1$.

4. The magnetoresistive device of claim 3, wherein $0.99 < x < 1$.

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

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

7. The magnetoresistive device of claim 1, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Boron.

8. The magnetoresistive device of claim 1, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.

9[pre] A magnetoresistive device comprising a magnetic tunnel junction structure comprising:

9[a] first and second ferromagnetic material layer; and

9[b] a tunnel barrier layer between the first and second ferromagnetic material layers,

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

10. The magnetoresistive device of claim 9, wherein the tunnel barrier layer comprises partially or fully crystalline magnesium oxide.

11. The magnetoresistive device of claim 10, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.

12. The magnetoresistive device of claim 11, wherein the barrier height is in a range of 0.2 eV to 0.5 eV.

13. The magnetoresistive device of claim 11, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer exhibits a body-centered cubic (BCC) structure.

14. The magnetoresistive device of claim 11, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Cobalt and Iron.

15[pre] A magnetoresistive device comprising:

15[a] a first ferromagnetic material layer;

15[b] a tunnel barrier comprising magnesium oxide and having a barrier height in a range of 0.2 eV to 0.5 eV; and

15[c] a second ferromagnetic material layer disposed on the tunnel barrier layer and separated from the first ferromagnetic material layer by the tunnel barrier layer.

16. The magnetoresistive device of claim 15, wherein the tunnel barrier layer comprises partially or fully crystalline magnesium oxide.

17. The magnetoresistive device of claim 16, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer is partially or entirely crystallized.

18. The magnetoresistive device of claim 17, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer exhibits a body-centered cubic (BCC) structure.

19. The magnetoresistive device of claim 17, wherein the first ferromagnetic material layer and/or the second ferromagnetic material layer comprises Cobalt and Iron.

20. The magnetoresistive device of claim 15, wherein the tunnel barrier layer has a thickness less than 10 nm.