<table>
<tr><td rowspan="2">Patent Right</td><td>Date</td><td>March 7, 2023</td><td rowspan="2">Court</td><td rowspan="2">Intellectual Property High Court, Fourth Division</td></tr>
<tr><td>Case number</td><td>2022 (Gyo-Ke) 10001</td></tr>
<tr><td colspan="5">- A case in which, the emergence conditions of the GSR phenomenon on which the "GSR magnetic sensor" of the Invention is based are: [i] use of a magnetic wire having a surface magnetic domain with a circumferential-direction spin array on the surface; [ii] a frequency of a pulse current conducting this magnetic wire is 0.5 GHz to 4.0 GHz; and [iii] the pulse current is equal to or larger than a current intensity required to generate a circumferential-direction magnetic field at 1.5 times or more an anisotropic magnetic field on a wire surface; [iv] the "GSR sensor" of the Invention takes out only a magnetization change in an axial direction of the wire caused by the GSR phenomenon emerging in [i] to [iii] as a coil output voltage and detects an external magnetic field by using equation (1), but the violation of the description requirement asserted by the Plaintiff is based on the assertion that the discrimination from MI phenomenon on which the MI sensor is based cannot be made without understanding these four matters (the Matters) as one technical idea, or is only impugnment by raising defects in the description of the Description and the like not on the grounds of normal understanding of a person ordinarily skilled in the art, and they are both groundless.</td></tr>
</table>

Case type: Rescission of Trial Decision

Result: Dismissed

References: Article 36, paragraph (4), item (i), paragraph (6), item (i), item (ii) of the Patent Act

Related rights, etc.: Invalidation Trial No. 2020-800007, Patent No. 5839527

Summary of the Judgment

No. 1 Outline of the case

1 Outline of procedures at the JPO and the like

(1) The Defendant filed a patent application (Patent Application No. 2015-27092, hereinafter, referred to as "the Application") of the invention titled "micro magnetic sensor with super high sensitivity" on February 16, 2015, and received registration of establishment of the patent right (Patent No. 5839527) on November 20 of the same year, but upon the Plaintiff's request for a trial for invalidation of the patent (Invalidation Trial No. 2018-800119, lack of inventive step as the grounds for invalidation), the Defendant made a request for correction (primary correction) with claims 1 to 8 in the scope of claims of the Patent as a group of claims.

The Japan Patent Office approved the primary correction on September 24, 2019, and then rendered the JPO decision that "the request for the trial regarding claims 1, 3 to 8 is not established. The request for the trial regarding claim 2 shall be dismissed" and the decision was made final and binding on November 5 of the same year.

(2) The Plaintiff made a request for patent invalidation trial (Invalidation Trial No. 2020-800007 case) regarding the Patent on January 31, 2020, on the grounds of violation of the clarity requirement, violation of the support requirement, and violation of the enablement requirement.

The Defendant made a request for correction to correct (the Correction) claims 1, 3 to 8 in the scope of claims of the Patent to a group of claims as of April 16, 2020 and submitted the written correction to the effect that claim 8 shall be corrected separately from the other group of claims in the Correction on May 28, 2021.

The Japan Patent Office approved the correction to delete claim 8 in the Correction but did not approve the correction other than that, and rendered the decision ("the Decision") on the Patent No. 5839527 that "The request for a trial for the invention according to claims 1, 3 to 7 is not established. The request for a trial for the invention according to claim 8 shall be dismissed." on November 25, 2021.

(3) The Plaintiff filed the lawsuit for rescission of the Decision with erroneous determination on the violation of the support requirement, erroneous determination on the violation of the enablement requirement, and erroneous determination on the violation of the clarity requirement as grounds for rescission.

No. 2 Gist of determination

1(1) The Plaintiff asserted that the Invention violates each of the description requirements on the premise that "the super high-speed spin rotation phenomenon" (GSR phenomenon) on which the GSR sensor of the Invention is based cannot be discriminated from the MI phenomenon on which the MI sensor is based.

However, the emergence conditions of the GSR phenomenon on which the "GSR magnetic sensor" of the Invention is based are: [i] use of a magnetic wire having a surface magnetic domain with a circumferential-direction spin array on the surface; [ii] a frequency of a pulse current conducting this magnetic wire is 0.5 GHz to 4.0 GHz; and [iii] the pulse current is equal to or larger than a current intensity required to generate a circumferential-direction magnetic field at 1.5 times or more an anisotropic magnetic field on a wire surface, and the "GSR sensor" of the Invention takes out only the magnetization change in the wire axial direction caused by the GSR phenomenon emerging by [i] to [iii] as a coil output voltage and detects the external magnetic field by using equation (1) (that is, the four matters (the Matters) approved by the Decision.) and in view of the disclosed matters in the Description as above, the Invention is found to be the invention described in the detailed description of the invention of the Description.

(2) The Plaintiff asserted that, in the matters considered to be the emergence

conditions of the "GSR emergence phenomenon", [i] and [iii] are matters in common also in the MI phenomenon on which the MI sensor is based, but since the Invention is the invention for which the Matters in [i] to [iv] are one of the technical premises, assertion that only a part of them is in common should be considered unreasonable. Note that there is insufficient evidence to find that the MI sensor has all these four matters.

Moreover, the Plaintiff asserted that, by citing close resemblance between Fig. 3 (Fig. 3-a) illustrating the relationship of the sinusoidal function in the Description and Fig. 4 in Exhibit Ko 12 document, it shows that an output by which the relationship of the sinusoidal function can be clearly recognized was acquired also in the MI sensor, which is a prior art, but there is no description or suggestion on the relationship between the coil output and the external magnetic field indicating the sinusoidal function relationship in Exhibit Ko 12 document pointed out by the Plaintiff, or, to the contrary, regarding the MI sensor, the proportional relationship between the coil output and the external magnetic field has been clarified theoretically and experimentally, and the Plaintiff's assertion above lacks reasoning and has no grounds.

(3) As the result of the progress of research, from the viewpoint of natural science, even if it will be found out that the GSR phenomenon is an "extension" of the MI phenomenon based on the MI sensor, it has no relation with patentability in a point of whether it is the effect that can be discriminated from the prior art in a sense of the natural science, but rather, if the improvement of the prior art is the technical idea that a person ordinarily skilled in the art could not have easily conceived of, a patent would be granted thereto, and in terms of the description requirement, the problems are: [i] the invention is described in the detailed description of the invention, and whether the problem is solved by the description in the detailed description of the invention (support requirement); [ii] whether a person ordinarily skilled in the art could work it without excessive trials and errors on the basis of the matters described in the detailed description of the invention (enablement requirement); [iii] whether the description in the scope of claims can be considered to be sufficiently unclear to bring an unexpected disadvantage to a third party even on the basis of the description and the like and common general technical knowledge (clarity requirement), and whether the matters described in the invention can be discriminated from the prior art from the viewpoints of effects and the natural science does not matter.

2 The Plaintiff asserted various defects in the description requirements, but they are based on the assertion that the Invention cannot be discriminated from the MI phenomenon on which the MI sensor is based without understanding the four matters

(the Matters) approved by the Decision as one technical idea, or are an impugnment by raising the defects in the description in the Description and the like not on the grounds of the normal understanding of a person ordinarily skilled in the art, and they are both groundless.

Judgment rendered on March 7, 2023
2022 (Gyo-Ke) 10001 A Case of seeking rescission of the JPO decision
Date of conclusion of oral argument: December 21, 2022

Judgment

Plaintiff: Aichi Steel Corporation

Defendant: MagneDesign Corporation

Main text

1. The Plaintiff's claim shall be dismissed.
2. The Plaintiff shall bear the court costs.

Fact and reason

No. 1 Claim

The court shall rescind the part related to claims 1, and 3 to 7 of Japanese Patent No. 5839527 in the decision issued by the Japan Patent Office (JPO) on November 25, 2021 with regard to the case of Invalidation Trial No. 2020-800007.

No. 2 Background

1. Outline of procedures, etc. at the JPO (undisputed by the parties)

(1) The Defendant filed a patent application (Japanese Patent Application No. 2015-27092, hereinafter, referred to as the "Present Application") of the invention titled "MICRO MAGNETIC SENSOR WITH SUPER HIGH SENSITIVITY" on February 16, 2015 and was granted registration of establishment of the patent right on November 20 of the same year (Patent No. 5839527, number of claims: 8, hereinafter, this patent shall be referred to as the "Present Patent").

(2) A. The Plaintiff made a request for a trial for invalidation of the patent (the case of Invalidation Trial No. 2018-800119) on September 27, 2018, regarding the Present Patent, on the grounds of lack of inventive step over the invention (hereinafter, referred to as the "Exhibit Ko 1 Invention") described in the Japanese Unexamined Patent Application Publication No. 2006-300906 (Exhibit Otsu 18), which is a publication distributed before the date of filing of this case or the invention (hereinafter, referred to as the "Exhibit Ko 4 Invention") described in International Publication No. WO2010/097932 (Exhibit Ko 15) as the primary cited references.

B. The Defendant made a request for correction for correcting claims 1 to 8 in the Scope of Claims of the Present Patent as a group of claims on December 25, 2018 (hereinafter, referred to as the "Primary Correction").

After that, the Japan Patent Office approved the primary correction on September 24, 2019, and then rendered the JPO decision that "the request for the trial regarding claims 1, and 3 to 8 is not established. The request for the trial regarding claim 2 shall be dismissed." (Hereinafter, referred to as the "Primary Decision") and the decision was made final and binding on November 5 of the same year.

C. The gist of the Primary Decision related to the invention described in claim 1 after the primary correction (hereinafter, referred to as "Corrected Invention 1".) is as follows (though the determination part with the Exhibit Ko 1 Invention as the primary cited reference will be described, but the determination with the same gist was made also for the determination with the Exhibit Ko 4 Invention as the primary cited reference.

(A) In Corrected Invention 1, the magnetic wire "is constituted by having a 2-phase magnetic domain structure of a surface magnetic domain having a circumferential-direction spin alignment and a center-part core magnetic domain having a spin alignment in an axial direction", a pulse current passed through the magnetic wire has "the frequency from 0.5 GHz to 4.0 GHz and a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field or more on the wire surface", and "means for converting the coil voltage to an external magnetic field H" is provided, in which by "causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output and is converted to a magnetic field H by using relational expression (1)", while in the Exhibit Ko 1 Invention, it is not clear whether or not the magnetic wire "is constituted by having a 2-phase magnetic domain structure", it is not specified that the frequency of the pulse current passed through the magnetic wire is "50 MHz or more" and "0.5 GHz to 4.0 GHz", it is not specified that the pulse current has "a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field or more on the wire surface", it is not specified that, by "causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, specified that only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output", or it is not clear whether or not the "means for converting the coil voltage to an external magnetic field H" is provided, either, which are differences (Difference 1).

(B) In Corrected Invention 1, the matter that the magnetic wire "is constituted by having a 2-phase magnetic domain structure of a surface magnetic domain having a circumferential-direction spin alignment and a center-part core magnetic domain having a spin alignment in an axial direction", the matter that a pulse current passed through the magnetic wire has "the frequency from 0.5 GHz to 4.0 GHz", the matter that the pulse current has "a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface", and the matter that, by "causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output and is converted to a magnetic field H by using relational expression (1)" are understood that, the new "super high-speed spin rotation phenomenon" emerges only after all of them are combined, which can be caused to function as a magnetic sensor by detecting that. Thus, in comparison between Corrected Invention 1 based on such "super high-speed spin rotation phenomenon" and the Exhibit Ko 1 Invention, which is a conventional "MI sensor", the aforementioned four matters are considered to be integrated. However, the emergence of the new "super high-speed spin rotation phenomenon" by combining the aforementioned four matters, which is caused to function as the magnetic sensor by detecting that, is not described or suggested in each of the cited documents submitted by the Plaintiff, and it cannot be considered to be a matter of common general technical knowledge before the Present Application.

Particularly, each of the aforementioned cited documents fails to set the frequency specifically to a range from "0.5 GHz to 4.0 GHz" or fails to describe or suggest that the magnetic wire "is constituted by having a 2-phase magnetic domain structure of a surface magnetic domain having a circumferential-direction spin alignment and a center-part core magnetic domain having a spin alignment in an axial direction", that the pulse current has "a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field or more on the wire surface", and that, by "causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output and is converted to a magnetic field H by using relational expression (1)" and moreover, in the aforementioned four matters, some of the cited documents are found to disclose the matter that the magnetic wire "is constituted by having a 2-phase magnetic domain structure of a surface magnetic domain having a circumferential-direction spin alignment and a center-part core magnetic domain having a spin alignment in an axial direction", but the other matters are not disclosed. Moreover, although one of the cited documents discloses the matter that "the higher the passed current value, the higher the sensitivity" in relation with the matter that the pulse current has "a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface", the other matters are not disclosed.

It is to be noted that, as asserted by the Claimant (Plaintiff), the possibility that "the 'new phenomenon GSR effect' referred to by the Claimee is a phenomenon positioned on an extension of the conventional MI effect" cannot be denied, but even if the aforementioned four matters are not integrated but can be discussed individually, at least the matter on "converted to a magnetic field H by using relational expression (1)" in the four matters is not disclosed in any of the cited documents.

(C) In the coil-detection type MI sensor as the Exhibit Ko 1 Invention, it is widely known that a detected voltage by the coil is proportional to an external magnetic field, but in this type of the sensor, to create a "calibration curve" of a sine function or to enlarge "the measurement range to a region out of linear approximation" is not suggested from the Exhibit Ko 1 Invention or any of the cited documents. Moreover, although Fig. 4 in the Japanese Unexamined Patent Application Publication No. 2010-256109 gazette (Exhibit Ko 12) shows a shape close to the sine function, there is no description that this is the sine function, and it cannot be considered that "presence of a sine function relation between an applied magnetic field and a sensor output voltage is suggested". In the first place, not only that the "relational expression (1)" in Corrected Invention 1 simply includes a sine function but more specifically, it is specified as a mathematical formula in which a "pulse frequency f" is multiplied by a sine function including the "external magnetic field H" and the "external magnetic-field intensity Hm when the coil output voltage takes a maximum value" as arguments, and such "relational expression (1)" is not suggested from any of the cited documents.

(D) Therefore, the configuration of Corrected Invention 1 related to Difference 1 could not have been easily conceived of by a person ordinarily skilled in the art on the basis of the technical matters described in the Exhibit Ko 1 Invention and the Cited Document.

(3) The Plaintiff made a request for a patent invalidation trial (Invalidation Trial No. 2020-800007 case) for the Present Patent on January 31, 2020 on the grounds of violation of the clarity requirement, violation of the support requirement, and violation of the enablement requirement.

The Defendant made a request for correction to correct claims 1, and 3 to 8 in the Scope of Claims of the Present Patent as a group of claims (hereinafter, referred to as the "Present Correction") on April 16, 2020, and submitted the written correction to the effect that claim 8 shall be corrected separately from another group of claims in the Present Correction on May 28, 2021.

After that, the Japan Patent Office approved the correction to delete claim 8 in the Present Correction but did not approve the correction other than that, and rendered the decision on the Patent No. 5839527 that "The request for a trial for the invention according to claims 1, and 3 to 7 is not established. The request for a trial for the invention according to claim 8 shall be dismissed." (hereinafter, referred to as the "JPO Decision") on November 25, 2021, and a copy of the decision was served to the Plaintiff on December 6 of the same year.

(4) The Plaintiff filed the lawsuit for rescission of the part related to claims 1, and 3 to 7 in the Present Decision on January 4, 2022.

2. Description in the Scope of Claims

In the Present Correction, the correction to delete claim 8 was approved, but the other corrections were not approved and thus, the description in the Scope of Claims of the Present Patent is constituted by claims 1 to 7 corrected by the primary correction (however, claim 2 is deleted) and claim 8 after the Present Correction (however, deleted), and the description in claims 1, and 3 to 7 is as follows (hereinafter, in accordance with the numbers of claims, the invention according to claim 1 is referred to as "Present Invention 1" and the like, and Present Inventions 1, and 3 to 7 are collectively referred to as the "Present Invention").

[Claim 1]

A micro magnetic sensor with super high sensitivity comprising a magnetic-field detection element in which a magnetic wire for detecting a magnetic field having conductivity, a circumferential coil wound around it, two electrodes for wire conduction, and two electrodes for coil voltage detection installed on a board, means for causing a pulse current to pass through the magnetic wire, a circuit for detecting a coil voltage generated when the pulse current is caused to pass, and means for converting a coil voltage to an external magnetic field H, wherein

the magnetic wire has an anisotropic magnetic field of 10 G or less and has a 2-phase magnetic domain structure of a surface magnetic domain having a circumferential-direction spin alignment and a center-part core magnetic domain having a spin alignment in an axial direction;

the pulse current passed through the magnetic wire has the frequency of 0.5 GHz to 4.0 GHz and a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface,

the coil has a coil pitch of 10 μm or less and a coil inner diameter of 25 μm or less, and by causing the pulse current to pass through the magnetic wire, the circumferential-direction spins inclined in an axial direction by a magnetic field in a wire axial direction in the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by a super high-speed spin rotation phenomenon generated at that time is taken out as a coil output and is converted to the magnetic field H by using relational expression (1):

$Vs=Vo \cdot L \cdot \pi D \cdot p \cdot Nc \cdot f \cdot \sin(\pi H/2Hm)$ ... (1)

where Vs is a coil output voltage, Vo is a proportional constant, and as control factor constants, L is a length of the wire, D is a diameter of the wire, p is a skin depth of the pulse current, Nc is a coil winding number, f is a pulse frequency, and Hm is an external magnetic-field intensity at which the coil output voltage takes a maximum value.

[Claim 3]

The micro magnetic sensor with super high sensitivity according to claim 1, wherein

a pair of or a plurality of pairs consisting of a detection element of a right-handed coil and a detection element of a left-handed coil are installed on a board, two electrodes for wire conduction and a wire terminal are connected so that the pulse current flows in opposite directions through the left-handed coil and the right-handed coil, and two electrodes for coil voltage detection and a coil terminal are connected so that, when the pulse current is passed through the wire, the output voltages of the right-handed coil and the left-handed coil proportional to the external magnetic field have the same sign, and the output voltage generated by the circumferential-direction magnetic field created by the pulse conduction when the external magnetic field is zero has a different sign.

[Claim 4]

The micro magnetic sensor with super high sensitivity according to claim 1, wherein

a pair consisting of a first coil, which is a left-handed coil, and a second coil, which is a right-handed coil, are mounted on one piece of the magnetic wire on the board by being directed to a direction in which the pulse current flows;

a first coil terminal and a second coil terminal are provided directed to a direction from which the pulse current flows in each of the first coil and the second coil;

the first coil terminal of the first coil and the first coil terminal of the second coil are connected;

a coil output electrode and the second coil terminal of the first coil are connected and a coil ground electrode and the second coil terminal of the second coil are connected;

the first coil terminals of the first coil and the second coil and the second coil terminals of the first coil and the second coil are disposed on respective sides of the magnetic wire; and

a wiring from the coil output electrode to the second coil terminal of the first coil crosses a wiring from the coil ground electrode to the second coil terminal of the second coil.

[Claim 5]

The micro magnetic sensor with super high sensitivity according to claim 1, wherein

two pieces of the magnetic wires on the board are connected in parallel and disposed such that the pulse currents flow in directions opposite to each other;

a pair consisting of the first coil, which is the left-handed coil, and the second coil, which is the right-handed coil, are mounted on one piece of the magnetic wire, directed toward the direction from which the pulse current flows;

a pair consisting of a third coil, which is the left-handed coil, and a fourth coil, which is the right-handed coil, are mounted on the other of the magnetic wire, directed toward the direction from which the pulse current flows;

on each of the first coil, the second coil, the third coil, and the fourth coil, toward the direction from which the pulse current flows, the first coil terminal and the second coil terminal are provided, connection between the coil terminals of the coil is disposed between two pieces of the magnetic wires, the first coil terminal of the first coil and the second coil terminal of the fourth coil are connected, the first coil terminal of the fourth coil and the first coil terminal of the second coil are connected, and the second coil terminal of the first coil and the second coil terminal of the third coil are connected; and

electrodes connected to the coil terminals of the coils are disposed on both sides of the two pieces of the magnetic wires, and the wiring from the coil output electrode to the first coil terminal of the third coil crosses the wiring from the coil ground electrode to the second coil terminal of the second coil between the two pieces of the magnetic wires.

[Claim 6]

The micro magnetic sensor with super high sensitivity according to any one of claims 1, and 3 to 5, wherein

by using a programing arithmetic-operation electronic circuit or means for software program arithmetic-operation, a coil induced voltage at a magnetic field zero is subtracted from a measurement value of a coil voltage in the magnetic field H.

[Claim 7]

The micro magnetic sensor with super high sensitivity according to any one of claims 1, and 3 to 6, further comprising:

means for correcting an influence of a temperature to Vs using an incorporated temperature sensor and a temperature-dependence correction program.

3. Gist of the JPO Decision (However, limited to the matters related to the grounds for rescission in note 4)

(1) Present Invention

A. The Present Invention has a main point that it was experimentally found that, when a pulse current with a pulse rise of a gigahertz order at a predetermined intensity is caused to pass through a magnetic wire having a predetermined anisotropic magnetic field and a 2-phase magnetic domain structure (surface magnetic domain in a circumferential direction and a core magnetic domain in an axial direction), a detected voltage changes as a sine function with a change in an external magnetic field, and a magnetic sensor is constituted by using the experimental expression (formula (1)) for measurement of the external magnetic field.

The super high-speed spin rotation phenomenon (GSR phenomenon) and an electromagnetic phenomenon (MI phenomenon) in which magnetic impedance of the wire is drastically changed have different operation principles; that is, the MI phenomenon emerges at the frequency of 1 MHz to 30 MHz and is caused by vibration of a 90-degree magnetic domain wall existing at a boundary between the surface magnetic domain and the core magnetic domain, while the GSR phenomenon is generated at 0.5 GHz to 4 GHz and is caused by the spin rotation in the surface magnetic domain.

In the Present Invention, the statement that the sinusoidal relation of relational expression (1) is derived from the "super high-speed spin rotation phenomenon" and is different in principle from the conventional MI phenomenon in principle is a hypothesis (hereinafter, referred to as the "GSR hypothesis") in a strict meaning, and such a possibility cannot be excluded that the validity of the GSR hypothesis would depend on future studies in the field. But in addition to international evaluation such as publication on peer-reviewed papers and invited lectures in international conferences, by considering that the Claimant (Plaintiff) does not explicitly dispute existence itself of the phenomenon called the "super high-speed spin rotation phenomenon (GSR phenomenon)", it is reasonable that the contents theoretically explaining the Present Invention on the basis of the GSR hypothesis in the Description and the drawings of the Present Patent should be treated to be correct at present.

B. The constitutions that make the sensor using the GSR phenomenon (GSR sensor) of the Present Invention substantive as compared with the prior art of the MI sensor are the four matters of the following [i] to [iv] (hereinafter, referred to as the "Present Matters"), and theoretical sides related to these matters should be considered to be correctly explained at present, and presence/absence of the invalidation reason should be examined on the basis of that.

[i] The matter that the magnetic wire is "constituted by having a 2-phase magnetic domain structure of a surface magnetic domain having a circumferential-direction spin alignment and a center-part core magnetic domain having a spin alignment in an axial direction"

[ii] The matter that the pulse current "with the frequency of 0.5 GHz to 4.0 GHz" is caused to pass through the magnetic wire

[iii] The matter that the pulse current has "a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface"

[iv] The matter that "by causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output and is converted to a magnetic field H by using relational expression (1)"

(2) Invalidation Reason 1 (violation of support requirement)

A. Criteria

In order to satisfy the support requirement, it is only necessary that a person ordinarily skilled in the art who contacted the Description can rationally recognize that the invention for which a patent was claimed is described in the Description, and moreover, regarding solution of the problem, the description only needs to have such a degree that rational expectation can be obtained that a person ordinarily skilled in the art could solve the problem also on the basis of a common general technical knowledge, and it is interpreted that a description to such a degree that reaches strictly scientific verification is not needed. That is because, since the support requirement is derived from the essence of the patent system which grants a patent right at the cost of publication of an invention, if replication studies or analyses by a person ordinarily skilled in the art who contacted the Description can contribute to further development of the art, a purpose of imposition of the support requirement can be achieved to some degree. Moreover, by considering that the Description is prepared under time pressure of the first-to-file principle, it is not reasonable to require the described contents to be demonstrated with strictness required in scientific theses.

B. Invalidation Reason 1-1

(A) Assertion by Claimant (Plaintiff)

The description "the magnetic wire" in the description that "the magnetic wire has an anisotropic magnetic field of 10 G or less" in claim 1 is interpreted to refer to a magnetic wire installed on a board from the description that a "magnetic-field detection element in which a magnetic wire for detecting a magnetic field having conductivity and ... installed on a board" before that. However, the Detailed Description of the Invention does not disclose the constitution that the magnetic wire installed on the board has an anisotropic magnetic field of 10 G or less.

(B) Determination

It is a common matter of general technical knowledge that the anisotropic magnetic field of the magnetic wire has a characteristic value which drastically changes depending on a length of a wire, and when the length is shortened, a demagnetizing factor becomes larger and thus, the anisotropic magnetic field increases (hereinafter, referred to as "common general technical knowledge A").

On the basis of the descriptions in [0034], [0036], [0059], and the like in the Description attached to the application at filing of this case (hereinafter, referred to as the "Present Description" including the drawings), the "anisotropic magnetic field" in the description that "a current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface" in the description in claim 1 means the "anisotropic magnetic field of a wire in a state installed on the board". However, the "anisotropic magnetic field" in the description that "the magnetic wire has an anisotropic magnetic field of 10 G or less" in the description in claim 1 is a characteristic of the material, and it obviously means "the "anisotropic magnetic field" of a wire in a sufficiently long state".

Therefore, it is found that the constitution of the magnetic wire having (an anisotropic magnetic field as a physical property value in a sufficiently long state) with 10 G or less is described in the Detailed Description of the Invention in the Description of the Present Patent.

C. Invalidation Reason 1-2

(A) Assertion by Claimant (Plaintiff)

It is interpreted that Claim 1 does not mean that the phenomenon slightly including a phenomenon other than the magnetization change in the axial direction by the super high-speed spin rotation phenomenon is taken out; that is, only the magnetization change in the axial direction is substantially taken out but means that the phenomenon not including the phenomenon other than the magnetization change in the axial direction by the super high-speed spin rotation phenomenon at all is taken out; that is, means as the wording itself that "only the magnetization change in the axial direction of the wire by the super high-speed rotation phenomenon generated at that time is genuinely taken out as a coil output".

However, Detailed Description of the Invention of the Present Patent does not specifically describe means or a method of "genuinely taking out only the magnetization change in the axial direction of the wire by the super high-speed rotation phenomenon generated at that time as a coil output", or it cannot be considered such means or method was a matter of common general technical knowledge. Thus, Present Invention 1 does not describe that the problem of the invention can be solved in the Detailed Description of the Invention so that a person ordinarily skilled in the art can recognize it and the description exceeds a range described in the Detailed Description of the Invention.

The coil voltage which genuinely detected only the "magnetization change" is understood to include only the voltage caused by the "magnetization change" and cannot be understood in a meaning other than that. Since the voltage caused by the "magnetization change" and the voltage caused by a thermal noise are different, the coil voltage including only the voltage caused by the "magnetization change" is understood not to include the voltage caused by the thermal noise, or cannot be understood in meaning other than that, it can be only understood that an expression that only the magnetization change as a signal is detected contradicts the inclusion of the thermal noise as a noise in the output voltage.

(B) Determination

The "thermal noise" is a noise generated by irregular thermal vibration of electrons in a substance, but it cannot be completely excluded unless it is cooled in a limit state of an absolute zero-point (T->0). Thus, the assertion by the Claimant (Plaintiff) that, in the "magnetic sensor" of the Present Invention used in an environment not falling under the limit state as above, the coil voltage does not include a voltage caused by the thermal noise and cannot be understood in meanings other than that ignores thermodynamics and statistical mechanics.

Regarding the description in claim 1 that "only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon is taken out as a coil output", the interpretation by the Claimant (Plaintiff) that it means that only the magnetization change in the axial direction is genuinely taken out as a coil output is a wrong interpretation. When the aforementioned description, including the entire description of claim 1, is to be understood on the basis of the law of the physics including thermodynamics and statistical mechanics, it is obvious for a person ordinarily skilled in the art having scientific and common knowledge that the expression "only" was used in the aforementioned description in a meaning that <u>exclusively</u> "the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon" "is taken out as a coil output" by using a region where the "magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon" is dominant as a whole as compared with the phenomenon of "magnetization rotation by movement of the 90-degree magnetic domain wall".

D. Invalidation Reason 1-3-2

(A) Assertion by the Claimant (Plaintiff)

Regarding relational expression (1) in claim 1, there is no sufficient data for supporting establishment of the sinusoidal relation in the entire range of claim 1 and thus, it cannot be considered that relational expression (1) is established at all times for the magnetic sensor including the invention specifying matters described in claim 1 is described to such a degree that a person ordinarily skilled in the art can recognize it in the Detailed Description of the Invention in the Description.

(B) Determination

a. In claim 1, it is described that "the circumferential-direction spins inclined in the axial direction by the magnetic field in the wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, and only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output and is converted to a magnetic field H by using relational expression (1)" and thus, it is obvious that the "coil output" is limited to those in proportion to "sin(πH/2Hm)" associated with the "super high-speed spin rotation phenomenon".

Moreover, it is obvious that the "coil output" is in proportion to a wire length L, a wire diameter D, a skin depth p of the pulse current, a coil winding number Nc, and a pulse frequency f, and these parameters are factors with no relationship with the aforementioned sinusoidal functional relation.

Then, it should be considered that the support requirement related to the Present Invention is satisfied only if existence of at least one experimental fact that the "coil output" satisfies the sinusoidal relation is confirmed, and even if there is only one piece of the experimental data, the experimental data is not insufficient so long as the establishment of the sinusoidal relation is confirmed.

b. By examining the frequency of the pulse current, in addition to Fig. 3 in which the sinusoidal functional relation can be clearly recognized, the graph in Fig. 4 illustrating a relationship between the pulse frequency and the coil output voltage discloses that reasonable intensity is acquired in a range at least from 0.5 GHz to 4.0 GHz, and rational and qualitative explanation for explaining a shape of the graph in Fig. 4 is disclosed in [0056] to [0057] in the Description. Thus, there is considered to be description to such a degree that a person ordinarily skilled in the art can obtain rational expectation that the sinusoidal functional relation is established even in the range from 0.5 GHz to 4.0 GHz. Moreover, the Claimant (Plaintiff) also asserts "The Detailed Description of the Invention in the Present Patent does not clearly describe even conditions for obtaining data plotted in the graph in Fig. 3 to such a degree that a person ordinarily skilled in the art can understand it.", but such circumstances that require excessive trials and errors for a person ordinarily skilled in the art are not found as experiments for illustrating the sinusoidal functional relation.

Subsequently, in consideration of the descriptions in [0040], [0041], [0056], [0057], and the like in the Description, by making the pulse frequency f sufficiently high so as to make the skin depth smaller than the thickness of the surface magnetic domain (the skin depth is in proportion to an inverse number of a square root of the frequency), the simultaneous rotation of the surface spins can be brought about, but if the pulse frequency f is made too large, the eddy current is increased with the speed increase and begins to suppress the spin rotation, and if the pulse frequency is further raised close to 5 GHz, spin precession and a spin resonance phenomenon begin to occur, each spin overcomes the exchange action force and starts rotation, whereby the coil output voltage is lowered. Therefore, it can be understood that an optimal frequency region exists, and it is from 0.5 GHz to 4 GHz. Moreover, as described in [0043] in the Description that "In order to detect a very weak and high-speed signal with a coil, a fine coil is needed. A coil pitch per unit length is set to 30 μm to 10 μm or less, a coil inner diameter to 15 μm or less, and an interval between the magnetic wire and the coil to 10 μm to 3 μm or less of the coil-type MI sensor so that electromagnetic coupling between the wire and the coil was reinforced, and the output voltage in proportion to the coil number N could be successfully acquired.", specification of the coil pitch and specification of the coil inner diameter are for increasing the signal intensity, and it is obvious that they are not essential parameters for the GSR phenomenon which generates the sinusoidal functional relation.

Therefore, since it is obvious that the GSR phenomenon is basically caused to emerge only by the pulse frequency, the assertion by the Claimant (Plaintiff) that "it is difficult to understand for a person ordinarily skilled in the art how to change a condition other than the pulse frequency in order to increase the pulse frequency to the gigahertz order, whereby the GSR phenomenon emerges, in what case the GSR phenomenon occurs, and in what case the GSR phenomenon does not occur" ignores that the essential emergence condition of the GSR phenomenon is the pulse frequency, which is unreasonable and groundless.

As described above, unlike the determination in the aforementioned a, even from a viewpoint that claim 1 is not limited to those indicating the GSR phenomenon, the description in the Scope of Claims of the Present Patent satisfies the support requirement.

Therefore, Invalidation Reason 1-3-2 is not grounded, either.

E. Invalidation Reason 1-4

(A) Assertion by the Claimant (Plaintiff)

Claim 1 includes numerical value limitation such that [i] regarding the magnetic wire, the anisotropic magnetic field is 10 G or less; [ii] the frequency of the pulse current is 0.5 G to 4 GHz; [iii] the intensity of the pulse current is such intensity that generates the circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field; and [iv] the coil pitch is 10 μm or less and the coil inner diameter is 25 μm or less, but the relationship between these constitutions and the effects are not described in the Detailed Description of the Invention such that a person ordinarily skilled in the art can understand it, the invention according to claim 1 is not considered to be capable of solving the problems of the Detailed Description of the

Invention, and moreover, critical significance of each numerical value range is not known.

(B) Determination

a. Regarding the magnetic wire, on the point that the anisotropic magnetic field is 10 G or less, from the description in [0007] of the Description that "when the anisotropic magnetic field is made larger, the magnetic permeability μ becomes extremely small to approximately 1000, and the sensitivity is drastically lowered." and from the description in [0055] and the like, it is obvious to recognize that, to set the anisotropic magnetic field to 10 G or less has technical significance as a condition of improving the sensitivity by making the weak signal as large as possible.

b. Point that the frequency of the pulse current is 0.5 to 4 GHz

From the descriptions in each of [0056] and [0057] in the Description as well as Fig. 4 illustrating a relationship between the frequency of the pulse current and the coil output voltage (sensor output), it can be read that the coil output voltage becomes the largest substantially at 2 to 3 GHz and the output lowers as it is separated from that and thus, it is obvious that the value of "0.5 to 4 GHz" in claim 1 causes the super high-speed spin rotation phenomenon (GSR phenomenon) to emerge, and it can be recognized that it has technical significance as a condition to make the intensity of the sensor output larger.

The Claimant (Plaintiff) also asserts that the Description of the Present Patent defines the pulse frequency by "f=1/2 dt" but does not have description specifically disclosing the relationship between the pulse frequency by the definition and the skin depth of the current, and it is not described such that a person ordinarily skilled in the art can understand the technical significance that the skin depth of the current becomes 1 μm or less when the pulse frequency is set to 0.5 GHz or more. However, there is no dispute between the two parties that it is a matter of common general technical knowledge that the skin depth can be acquired by the following formula "skin depth $\delta=(2\rho/\omega\mu)^{1/2}$" (here, ρ is specific resistance, μ is magnetic permeability, and ω is an angular frequency of a sinusoidal current). It is obvious that, when the pulse frequency f=1/2 dt becomes larger, a high-frequency component of ω becomes larger as a Fourier component and thus, it is obvious that, when f=1/2 dt becomes larger, the skin depth of the current becomes smaller, and it cannot be approved that a person ordinarily skilled in the art cannot understand the technical significance of the limitation on the numerical value range of the frequency.

c. Point that the intensity of the pulse current is intensity at which the circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field is generated

The "anisotropic magnetic field" means that, in a magnetic field at the value concerned or more, the spins are aligned in the direction of the magnetic field and thus, it is obvious for a person ordinarily skilled in the art that "1.5 times or more of the anisotropic magnetic field" means that a magnetic field sufficiently larger than the anisotropic magnetic field can be applied so that the spins can be sufficiently aligned in the same direction. This matches the statement in [0082] in the Description that "The intensity of the pulse current was set to 50 mA or more, and a sufficiently large circumferential magnetic field Hθ, which is 1.5 times or more of Hm, was generated on the wire surface so that simultaneous rotation of the surface spins was realized.".

d. Point that the coil pitch is 10 μm or less and the coil inner diameter is 25 μm or less

The coil inner diameter being 25 μm or less contributes at least to size reduction and thus, even if there is no special explanation on the significance of this limitation in the Description, it does not mean that the Invention is not described.

It is to be noted that, as is obvious from the description in [0060], when the coil pitch becomes smaller, the coil winding number per unit length increases and thus, it is obvious that the output voltage becomes larger.

e. Critical significance

Even if there is no critical significance on the boundary of the numerical value range, the invention can be recognized when the technical significance of the numerical value limitation can be recognized and thus, in the determination on whether or not the invention with the numerical value limitation satisfies the support requirement, even though capability of understanding the technical significance on the numerical value limitation is required, it is obvious that presence of the further critical significance of the boundary of the numerical value is not required. Therefore, the assertion by the Claimant (Plaintiff) that the critical significance is required is unreasonable and cannot be employed.

The Claimant (Plaintiff) seems to be confused with that, when there is a prior art exerting an effect of the same quality for the numerical-value limitation invention, such determination of lack of the inventive step is made in some cases, when there is no critical significance on the boundary of the numerical values.

(3) Invalidation Reason 2 (violation of clarity requirement) (Invalidation Reason 2-5)

A. Assertion by the Claimant (Plaintiff)

Regarding the "anisotropic magnetic field" in claim 1, it is defined in the Description as the "magnetic field intensity when the spin rotation is started in the surface magnetic domain of the magnetic wire, after the movement of the magnetic domain wall in the core magnetic domain of the magnetic wire has finished", but if this is applied, the "anisotropic magnetic field" is defined as magnetic field intensity applied at impossible timing as a phenomenon emerging in the magnetic wire of the "micro magnetic sensor with super high sensitivity", which cannot be understood by a person ordinarily skilled in the art and thus, the definition of the "anisotropic magnetic field" is not clear.

B. Determination

The "anisotropic magnetic field Hk", which is a technical term, refers to an equivalent virtual magnetic field when supposing such a magnetic field that tries to align magnetization in an easily-magnetizable axial direction exists in a substance having magnetic anisotropy and a virtual magnetic field acquired from a condition that energy inside the substance determined by a direction of magnetization under this virtual magnetic field becomes equivalent to the magnetic anisotropic energy and is an established technical term.

However, [0021] in the Description has description that "In the magnetization curve, a steep rising region is a magnetization process by movement of the magnetic domain wall, while a gentle increasing region is a magnetization process by the magnetization rotation. A magnetic-field intensity when the magnetization rotation is started is defined as an anisotropic magnetic field Hk.". And thus, it should be examined whether the meaning of the "anisotropic magnetic field" in the Present Patent is different from the aforementioned established technical term, but it is approved, from "Magnetism Handbook" compiled by the Magnetics Society of Japan (Maruzen, issued on January 30, 2016, p. 495 to 496, p. 499 to 500) and the like, that acquisition of the anisotropic magnetic field from an intersection between an extrapolation line of a linear part of a magnetization curve and a straight line of the "magnetization=saturated magnetization"; that is, "anisotropic magnetic field $Hk=Ms/\chi o$, where Ms is saturated magnetization, χo is inclination of the linear part of the magnetization curve", is a matter of common general technical knowledge (hereinafter, referred to as "common general technical knowledge B").

(4) Invalidation Reason 3 (violation of enablement requirement)

A. Assertion by the Claimant (Plaintiff)

The Description cannot be regarded to clearly describe materials, devices, processes, and the like which should embody technical means for "taking out only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon as a coil output" and moreover, the matter for "genuinely taking out only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time as a coil output" is not considered to be common general technical knowledge at the filing of the Present Patent. Therefore, it cannot be considered at all that a person ordinarily skilled in the art can understand the materials, devices, processes, and the like which should embody technical means for "taking out only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon as a coil output" on the basis of the common general technical knowledge at the filing and thus, it cannot be considered that Invention 1 including the technical means described in an abstract or functional manner falls under those described clearly and sufficiently enough to such a degree that a person ordinarily skilled in the art can work, and the same applies to Inventions 3 to 7.

B. Determination

Invalidation Reason 3 asserted by the Claimant (Plaintiff) is based on the interpretation that the description that "only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output" as "only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out <u>genuinely</u> as a coil output", but such interpretation is wrong as described in the aforementioned (2)C(B) and thus, the assertion by the Claimant (Plaintiff) is unreasonable and groundless.

Therefore, the Patent for the Present Inventions 1, and 3 to 7 cannot be invalidated by Invalidation Reason 3.

4. Grounds for Rescission

(1) Errors in determination on violation of support requirement (Ground for Rescission 1)

(2) Errors in determination on violation of enablement requirement (Ground for Rescission 2)

(3) Errors in determination on violation of clarity requirement (Ground for Rescission 3)

(omitted)

No. 4 Judgment of this court

1. Described matters of the Description

(1) The Detailed Description of the Invention of this Description (Exhibit Ko 69) has the description as in Attachment 1, and according to the described matters, it is found that the following matters are disclosed in the Present Invention.

A. The Present Invention relates to a micro magnetic sensor (GSR sensor) with super high sensitivity based on a super high-speed spin rotation effect (GHz Spin Rotation effect, referred to as the GSR effect.) ([0001]).

Conventionally, micro magnetic sensors with high sensitivity include a lateral FG sensor, a vertical FG sensor, an MI sensor, and the like, and the MI sensor among them is based on the MI phenomenon (magneto-impedance phenomenon) discovered in 1993. This is such a type of an electromagnetic phenomenon that a high frequency of 1 MHz to 30 MHz or a pulse current is passed through a magnetic wire (diameter: 30 μm) having two structures; that is, a surface magnetic domain magnetized in a circumferential direction of a surface (thickness is approximately 0.2 μm) and a core magnetic domain magnetized in an axial direction of a center part and the like so as to vibrate a 90-degree magnetic domain wall between the two magnetic domains, the circumferential-direction magnetic permeability increases in proportion to an increase in magnetization, while a skin depth is remarkably reduced, and a magnetic impedance of the wire is drastically changed, and an external magnetic field H is acquired from a change amount of the impedance (AC resistance). In the MI sensor, a large reduction of a length of the magnetic wire from 50 mm to 5 mm was realized, but it has demerits that an output characteristic was strongly affected by hysteresis of the wire, and moreover, it is antisymmetric and non-linear, and although these demerits were solved by using a negative feedback circuit, there was a problem in power consumption. Moreover, the coil-detection type MI sensor is of an improved type in which the MI phenomenon is detected by a coil, and a linear output was realized, but the negative feedback circuit is used for hysteresis reduction, which caused a problem of the increase in power consumption. ([0002], [0004], [0005]).

Subsequently, by using an MI element manufactured by a MEMS process, the downsized coil-detection type MI sensor with the magnetic wire with the diameter of 12 μm and the length reduced to 0.6 mm, and the coil inner diameter of 30 μm was applied and merchandized to an electronic compass (product name: AMI306) and the like. In order to supplement the lowered sensitivity, the frequency is increased from 30 MHz to 200 MHz, and in order to generate a circumferential magnetic field which overcomes the large anisotropic magnetic field, the pulse current is increased from 10 mA to 200 mA, and the negative feedback circuit is successfully omitted ([0006],

[0007]). "The inventor" studied the MI sensor with higher sensitivity by raising the frequency from 0.2 GHz to 0.5 GHz on the basis of the AMI306, but due to technical problems of a high-frequency pulse oscillation circuit and an increase in the electromagnetic induced voltage involved in the higher frequency, commercialization was not realized ([0010]).

B. The problem of the "Present Invention" is to find a magnetic sensor principle for realizing performance improvement of approximately 100 times that of the MI sensor and embodying conditions therefor, and "the inventor" discovered presence of the experimental expression in formula (1) between a voltage generated by the coil and the external magnetic field when a trapezoidal-shaped pulse with a frequency of 0.5 GHz or more was given to a fine coil using the magnetic wire with the 2-phase structure of the surface magnetic domain and the core magnetic domain and the anisotropic magnetic field at 5 G ([0014], [0016], [0017]).

$Vs=Vo\cdot L\cdot \pi D\cdot p\cdot Nc\cdot f\cdot \sin(\pi H/2Hm)$ ... (1)

Here, Vs is a coil output voltage, Vo is wire magnetic permeability, and as control factor constants, L is a length of the wire, D is a diameter of the wire, p is a skin depth of the pulse current, Nc is a coil winding number, f is a pulse frequency, H is an external magnetic field, and Hm is an external magnetic-field intensity at which the coil output voltage takes a maximum value.

C. When the pulse current with the frequency of 0.5 GHz or more is applied in a state where the spin which has been forced in the circumferential direction by an internal magnetic field in the circumferential direction existing in the surface magnetic domain of the magnetic wire is inclined by the external magnetic field H only by θ, the spin is rotated simultaneously by θ in the circumferential direction, and when this magnetic change is detected by a coil voltage, it is $V=Vo\sin 2\theta$ ((2)). Therefore, it can be considered that experimental expression (1) detects the simultaneous high-speed rotation of the spin. That is, the MI sensor detects the magnetization rotation by the movement of the 90-degree magnetic domain wall even with the same skin effect, but the sensor of the "Present Invention" is a totally new principle for genuinely detecting only the rotation of the spin in the surface magnetic domain, and "the inventor" considers it as a new-type GSR sensor based on the super high-speed spin rotation phenomenon ([0018]).

The inclination angle θ of the spin is directed to a synthesized direction of the anisotropic magnetic field in the circumferential direction and the internal magnetic field Hin, and when it is rotated in the circumferential direction from that angle, a coil voltage given by the relational formula (1) can be obtained and thus, it can be considered that the inclination angle is a source of the coil output. But since the angle is determined by a ratio between the internal magnetic field Hin applied to the spin in the surface magnetic domain and the anisotropic magnetic field in the circumferential direction, under the 2-phase structure of the surface magnetic domain and the core magnetic domain, it is important to make the anisotropic magnetic field as small as possible so that the spin can be greatly inclined in the small internal magnetic field ([0035]).

A condition under which the super high-speed spin rotation phenomenon, which is a new electromagnetic phenomenon, emerges is, by using the magnetic wire in which the surface magnetic domain having the circumferential-direction spin alignment on the surface exists, an excitation pulse having a sufficiently large current with a frequency of GHz is applied so that the skin depth p is smaller than the thickness d of the surface magnetic domain, the simultaneous rotation of the circumferential-direction spin is brought about, and the change is detected by a fine coil ([0038]).

D. As compared with an FG sensor, an MI sensor, a coil-detection type improved MI sensor, and the like, the super high-sensitivity micro-magnetic sensor based on the super high-speed spin rotation effect has realized improvement of the sensor output voltage, the sensor sensitivity, and the sensor detection capability, noise reduction, enlargement of the measurement range, lowered current consumption, improvement of temperature stability, improvement of the hysteresis characteristics and linearity, and micro-level downsizing and is extremely useful, contributing to industrial spread ([0077]).

(2) According to the disclosed matters in the aforementioned (1), the Present Invention has its technical significance as a magnetic sensor (GSR magnetic sensor) that, in a magnetic wire having a 2-layered magnetic domain structure of a surface magnetic domain having a spin alignment in the circumferential direction and a center-part core magnetic domain having the spin alignment in the axial direction, by applying an excitation pulse of a current with a large frequency so as to make the skin depth p smaller than the thickness d of the surface magnetic domain, the spin existing in the surface magnetic domain in the magnetic wire in a state inclined only by θ by the external magnetic field H is caused to perform super high-speed spin rotation so that the coil output is detected, and the size of the external magnetic field is measured by using relational formula (1).

2. Ground for Rescission 1 (errors in determination on violation of support requirement)

(1) Article 36, paragraph (6), item (i) of the Patent Act prescribes that, in description of the Scope of Claims, description should not be made exceeding a range

of the invention described in the Detailed Description of the Invention, and the purpose thereof is interpreted that, if the invention not described in the Detailed Description of the Invention is described in the Scope of Claims, a monopolistic and exclusive right for the invention which has not been published is claimed, which is not reasonable, and this shall be prevented.

Then, it is reasonable to interpret that, whether or not the description in the Scope of Claims conforms to the requirement prescribed in the clause (support requirement) should be determined by examining through comparison between description in the Scope of Claims and the description in the Detailed Description of the Invention, whether or not the invention described in the Scope of Claims is the invention described in the Detailed Description of the Invention and within a range that a person ordinarily skilled in the art can recognize that the problem of the invention can be solved by the description in the Detailed Description of the Invention and whether it is within a range that a person ordinarily skilled in the art can recognize that the problem of the invention can be solved in view of the common general technical knowledge at the filing without the description or suggestion.

(2) The Plaintiff asserts that the Present Invention violates each of the description requirements on the premise that, the "super high-speed spin rotation phenomenon" (GSR phenomenon) on which the GSR sensor of the Present Invention is based cannot be distinguished from the MI phenomenon on which the MI sensor is based as described in the aforementioned No. 3, 1(1)A and thus, this point will be examined first.

A. The Description has the description that, as an emergence condition of the "GSR phenomenon", "by using the magnetic wire in which the surface magnetic domain having the circumferential-direction spin alignment on the surface exists, an excitation pulse having a sufficiently large current with a frequency of GHz is applied so that the skin depth p is smaller than the thickness d of the surface magnetic domain, the simultaneous rotation of the circumferential-direction spin is brought about, and the change is detected by a fine coil." ([0038]), that is, it is disclosed that [i] the magnetic wire in which the surface magnetic domain having the circumferential-direction spin alignment on the surface exists is used; [ii] an excitation pulse having a sufficiently large current with a frequency of GHz is applied; and [iii] the skin depth p is smaller than the thickness d of the surface magnetic domain so that [iv] simultaneous rotation of the spins in the circumferential direction of the surface magnetic domain is brought about, and the change is detected by a fine wire. Since [i] is a physical property of the magnetic wire to be the premise under the GSR emergence condition, and [iv] is detection of generation of the super high-speed spin rotation, when considering the Description, it has the following description on [ii] and [iii].

[a] "The pulse current was assumed to have ... a pulse frequency of 0.5 GHz to 4 GHz. As a result, the skin depth of the current was controlled to 0.2 μm to 1 μm so as to be equal to or smaller than the thickness of the circumferential surface magnetic-domain." ([0023]), "The higher the frequency, the larger the output voltage. Moreover, the skin depth also becomes smaller, whereby the thickness d of the surface magnetic domain can be made smaller. ... However, as a spin resonance frequency is approached, fluctuations occur in the simultaneous rotation, and the coil voltage lowers and thus, there is an optimal frequency range, which is from 0. 5 GHz to 4 GHz. ... However, the increase in the pulse frequency increases an induced voltage induced by the circumferential pulse magnetic field in the coil and thus, this measure is more important in the GSR sensor." ([0057])

[b] "The magnetic wire which was used is ... having a diameter of 10 μm, an amorphous structure, ... with magnetic anisotropy of 1 G or 5 G, ... a 2-phase magnetic domain structure of the circumferential surface magnetic-domain having the circumferential-direction spin alignment and the center-part core magnetic domain having the axial-direction spin alignment was formed. The skin depth p of the pulse current was controlled such that the thickness d of the surface magnetic domain was approximately 1 μm, by considering the skin depth p of 0.5 μm. Moreover, a magnetic field exceeding 1.5 times of the anisotropic magnetic field Hk was generated by a sufficiently large pulse current, pulse magnetic-field annealing processing was performed at every measurement, magnetization was saturated in the circumferential direction, and a magnetization history was erased." ([0042]), "The magnetic wire was made of a Co-based alloy having 0 magnetostriction or weak negative magnetostriction and had an anisotropic magnetic field Hk of 8 G or less, relative magnetic permeability of 1000 or more, a diameter of 20 μm or less, and a stress in the axial direction was 2p or more with the thickness d of the surface magnetic domain of 1 μm or less. The thickness was adjusted to be 2p or more by applying pulse magnetic-field annealing or tension annealing by taking into consideration the applied pulse frequency. It is to be noted that, regarding residual magnetization of the core part, disappearance/reduction of an influence history of the external magnetic field before that was promoted during pulse-conduction duration time occurs, so as to suppress hysteresis." ([0058]), "Regarding the current intensity of the pulse current, the intensity of the circumferential-direction magnetic field on the surface was set to 30 G or more or a circumferential-direction magnetic-field intensity of 1.5×Hk or more was ensured as a target by considering a

diameter of the wire, and the pulse frequency was set to 0.5 GHZ to 4 GHz so as to realize the simultaneous spin rotation at a super high speed only of the spins in the surface magnetic domain. Moreover, the core magnetic domain was reduced by a large circumferential-direction magnetic field during the duration of the pulse conduction so as to increase the thickness of the surface magnetic domain." ([0059])

These descriptions are considered to disclose that, as the emergence condition of the GSR phenomenon, in order to "make the skin depth p smaller than the thickness d of the surface magnetic domain", [a] the pulse current with a high frequency on a gigahertz order (frequency at 0.5 GHz to 4.0 GHz) is caused to pass so as to make the skin depth p as small (shallow) as possible; [b] in order to make the thickness d of the surface magnetic domain larger (thicker), a magnetic field exceeding 1.5 times the anisotropic magnetic field Hk is generated by the sufficiently large pulse current.

On the basis of the above, the Description describes that, regarding the detection of generation of the super high-speed spin rotation, the experimental expression as formula (1) exists between the voltage generated by the coil and the external magnetic field ([0016]), the coil output voltage when only the rotation of the spin in the surface magnetic domain is genuinely detected is in proportion to sin2θ to the spin inclination angle θ by the external magnetic field ([0018]), and the spin inclination angle θ is directed to a synthesized direction of the anisotropic magnetic field in the circumferential direction and the internal magnetic field Hin, and when it is rotated in the circumferential direction from that angle, a coil output voltage given by relational formula (1) can be obtained ([0035]) and thus, it can be considered that experimental expression (1) detects the simultaneous high-speed rotation of the spin ([0018]).

From these descriptions, the emergence conditions of the GSR phenomenon based on the "GSR magnetic sensor" of the Present Invention are [i] by using the magnetic wire in which the surface magnetic domain having the circumferential-direction spin alignment on the surface exists; [ii] the frequency of the pulse current caused to pass through this magnetic wire is 0.5 GHz to 4.0 GHz; and [iii] the pulse current has equal to or larger than current intensity required to generate the circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface, and the "GSR sensor" of the Present Invention takes out only the magnetization change in the axial direction of the wire by the GSR phenomenon emerging under [i] to [iii] as a coil output voltage, and the external magnetic field is detected by using formula (1) (that is, the four matters approved by the JPO decision (Present Matters)), and from the disclosed matters of the Description as above, the Present Invention can be considered to be the invention described in the Detailed Description of the Invention in the Description.

B(A) The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)A(A), among the matters as the emergence conditions of the "GSR emergence phenomenon", [i] and [iii] are the matters in common with the MI phenomenon on which the MI sensor is based, but the Present Invention is the invention with the matters in [i] to [iv] as one technical premise and thus, the assertion that only a part thereof is in common is nothing but unreasonable. There is no evidence sufficient to find that the MI sensor includes all these four matters (this point was also approved in the primary JPO decision.)

(B) The Plaintiff points out, as in the aforementioned No. 3, 1(1)A(B)a, the document in which the current with the pulse frequency on the gigahertz order is applied also in the MI sensor, but as described in the aforementioned A, the technical significance of applying the current with the frequency in the gigahertz order in the GSR phenomenon is to make the skin depth p smaller than the thickness d of the surface magnetic domain by increasing the thickness of the surface magnetic domain, but the document pointed out by the Plaintiff does not illustrate the application of the current with the frequency in the gigahertz order from the technical point of view as above.

Moreover, regarding the assertion in the b above, as indicated above, it is obvious that the Present Invention does not discriminate between the MI phenomenon and the GSR phenomenon only by the frequency of the pulse current on the gigahertz order and thus, the premise is nothing but wrong.

(C) The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)A(C), it is illustrated that the output which can clearly recognize the sinusoidal functional relation can be obtained also in the MI sensor, which is a conventional art, by citing that Fig. 3 (Fig. 3-a) indicating the sinusoidal functional relation in the Description closely resembles Fig. 4 in the Exhibit Ko 12 document.

However, the Exhibit Ko 12 document pointed out by the Plaintiff does not describe or suggest that the relation between the coil output and the external magnetic field indicates a sinusoidal functional relation.

Or rather, regarding the MI sensor and the relationship between the coil output and the external magnetic field, from the description in each of the documents in Attachment 2, it is made obvious theoretically and experimentally that the relationship between the coil output and the external magnetic field has a proportional relationship in the MI sensor, and the aforementioned assertion by the Plaintiff lacks argument and is groundless.

C. As the result of progress of studies, even if it is proved that the GSR phenomenon is on the "extension" of the MI phenomenon based on the MI sensor from the viewpoint of natural science, whether or not it is such an effect that can be distinguished from the conventional art in the meaning of the natural science does not have any relation with patent requirements or rather, if improvement of the conventional art is a technical idea that could not have been easily conceived of by a person ordinarily skilled in the art, it is granted a patent, and in line with the description requirements, what matter are [i] whether the invention is described in the Detailed Description of the Invention, and the problem is solved from the description in the Detailed Description of the Invention (support requirement); [ii] whether a person ordinarily skilled in the art can work it on the basis of the matters described in the Detailed Description of the Invention without excessive trials and errors (enablement requirement); and [iii] whether the description in the Scope of Claims is so unclear that would give an unexpected disadvantage to a third party even on the basis of the Description and the common general technical knowledge (clarity requirement), and whether the matters described in the invention can be distinguished from the effect of the prior art from the viewpoint of natural science does not matter.

In addition to the points as above, according to those taught in the aforementioned A and B, the GSR phenomenon can be considered to be a technical idea different from the MI phenomenon on which the conventional MI sensor is based and thus, the determination on each of the invalidation reasons by the JPO decision by stating that the GSR phenomenon "should be considered to be explained correctly at present" has no errors.

(3) In the following, on the basis of the above, the points that the Plaintiff asserts as violation of the support requirement will be determined.

A(A) The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)C(A), it cannot be concluded that the GSR phenomenon based on a totally new principle as compared with the MI phenomenon is indicated by the frequency of the pulse current on the gigahertz order and the change of the output voltage as the sine function with the change in the external magnetic field in Fig. 3, but as described above in (2)A, the GSR phenomenon and the Invention which detects the phenomenon is a technical idea different from the MI phenomenon on which the MI sensor, which is the conventional art, is based, and it is found to be established with the four matters (Present Matters) found in the JPO decision forming one technical premise and thus, the Plaintiff's assertion cannot be employed.

Moreover, the Plaintiff asserts that the Description discloses only one piece of experiment data indicating the sinusoidal functional relation related to the pulse current with the pulse frequency of 2 GHz (Fig. 3), and it does not indicate that, when a change is made within a range of the frequency of 0.5 GHz to 4.0 GHz of the pulse current, the sinusoidal functional relation is established with all the frequencies within the range. However, the Description discloses theoretical derivation process ([0017] to [0019]) indicating the sinusoidal functional relation (relational expression (1)) between the external magnetic field and the coil output relations, and it is explained that the coil output voltage and the external magnetic field are associated by relational expression (1) ([0019] to [0037]) and from these disclosed matters, when the frequency of the pulse current is set to 0.5 GHz to 4.0 GHz other than 2.0 GHz, there is no reason to consider that the external magnetic field and the coil output relations do not indicate the sinusoidal functional relation.

(B) The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)C(B), [i] there is no description in the claim that "skin depth p < thickness d of the surface magnetic domain", which is the emergence condition of the GSR phenomenon, is ensured; and [ii] the Description describes that it is preferable to have "skin depth p < thickness d of the surface magnetic domain" ([0083]) and does not specify that to ensure the "skin depth p < thickness d of the surface magnetic domain" is not an essential requisite for the GSR emergence.

However, as in the aforementioned (2)A, the Description discloses that, in order to ensure "skin depth p < thickness d of the surface magnetic domain", which is the emergence condition of the GSR phenomenon, that the frequency of the pulse current to be passed through the magnetic wire is set to 0.5 GHz to 4.0 GHz, and the pulse current has equal to or larger than the current intensity required to generate the circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface. And claim 1 has the description of the invention specifying matters that "the pulse current to be passed through the magnetic wire has a frequency of 0.5 GHz to 4.0 GHz and current intensity required to generate a circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface" and thus, it can be considered that the matters for ensuring "skin depth p < thickness d of the surface magnetic domain", which is the condition for causing the GSR phenomenon to emerge, is described in claim 1. Moreover, [0083] pointed out by the Plaintiff has the description that "it is preferable that the pulse frequency is 0.5 GHz or more, the skin depth p of the current is 1 μm or less, and the thickness d of the circumferential surface magnetic-domain is d or less.", but this description only states that it is "preferable" that the pulse frequency is 0.5 GHz or more, the skin depth p of the current is 1 μm or less in order to have the thickness d or less of the circumferential surface magnetic-domain, and in view of the description in the Description pointed out in the aforementioned (2)A, the assertion by the Plaintiff cannot be employed at all.

(C) The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)C(B), even if the conditions in [i] to [iii] in the four matters found in the JPO decision are all satisfied, the condition that "skin depth p < thickness d of the surface magnetic domain" is not satisfied, and since the means for solving the problem of the invention described in the Detailed Description of the Invention is not reflected in claims of the Present Patent, it fails to fulfill the support requirement. However, as described above, the Present Invention is to take out only the magnetization change in the wire axial direction as a coil output by including the configuration of the four matters (Present Matters) indicated in the JPO decision, and the Description has the disclosure on the conditions of the emergence of the GSR phenomenon as taught in the aforementioned (2)A. And even in the case where the condition of the "skin depth p < thickness d of the surface magnetic domain" is not satisfied even if the matters in [i] to [iii] are satisfied, the circumferential-direction spins inclined in the axial direction by the magnetic field in the wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, and only the magnetization change in the wire axial direction by the super high-speed spin rotation phenomenon generated at that time cannot be taken out as a coil output or cannot be converted to the magnetic field H by using relational expression (1), and as a result, it can be concluded that the configuration in [iv] found in the JPO decision is not included and thus, it is only a magnetic sensor different from the Present Invention including the four matters. Since the Plaintiff's assertion cannot be the basis for the violation of the support requirement in any way, it is nothing but unreasonable.

B. The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)D, Present Invention 1 is a special parameter patent in which numerical values are limited such that "the frequency is 0.5 GHz to 4.0 GHz", the Description describes only an example of the frequency at 2 GHz, and it is not possible to understand whether the GSR phenomenon can emerge in the range of the numerical values of the aforementioned frequencies distinctively from the MI phenomenon, which is the conventional art.

However, as described in the aforementioned (2)A, the technical significance that the frequency of the pulse current to be applied to the magnetic wire is set to "0.5 GHz to 4.0 GHz" is an invention specifying matter for satisfying the condition of the "skin depth p < thickness d of the surface magnetic domain" ([0023]m, [0057], Fig. 4), the technical significance thereof was made clear, and as described in the aforementioned (2)A, the "skin depth p < thickness d of the surface magnetic domain", which is the emergence condition of the GSR phenomenon, is not generated only by the numerical value limitation of the frequency applied to the magnetic wire as above and thus, it cannot be approved that the Present Invention is a special parameter patent. Moreover, Fig. 3 in the Description is an example of the frequency 2 GHz, but there is no reason to interpret that formula (1) indicating the sinusoidal functional relation between the external magnetic field and the coil output relations does not indicate the sinusoidal functional relations at those other than the frequency of 2 GHz as described in the aforementioned A(A). Therefore, the Plaintiff's assertion cannot be employed in any way.

C. The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)E, claim 1 has the invention specifying matter that "magnetic sensor comprising a magnetic-field detection element in which <u>a magnetic wire for detecting a magnetic field having conductivity on a board</u>[i], a circumferential coil wound around it, two electrodes for wire conduction, and two electrodes for coil voltage detection are installed, means for causing a pulse current to pass through <u>the magnetic wire</u>, a circuit for detecting a coil voltage generated when the pulse current is caused to pass, and means for converting the coil voltage to an external magnetic field H, wherein <u>the magnetic wire has an anisotropic magnetic field of 10 G or less</u>[2], ... ", and since the "the magnetic wire" in [2] refers to the "magnetic wire" in [i] by "the", it is the "magnetic wire" having the conductivity "on the board" and asserts that the configuration of the magnetic wire "on the board" is not supported in the Description.

Whether "the magnetic wire" "having the anisotropic magnetic field of 10 G or less" in [ii] refers to "a magnetic wire for detecting a magnetic field having conductivity" or to the "'magnetic wire for detecting a magnetic field having the conductivity' installed 'on a board'" cannot be necessarily understood unambiguously from the invention specifying matter in claim 1 and thus, by examining the description in the Description, [0034] in the Description describes that "the magnetic material used this time had the anisotropic magnetic field Hk at 5 G, μr=32000, the anisotropic magnetic field when incorporated in the element at 40 G, μeff=600, and Nμeff=0.8", and the anisotropic magnetic field as a characteristic of the magnetic material and the anisotropic magnetic field when incorporated in the element are described distinctively. If it is interpreted that "the magnetic wire" in "the magnetic wire has an anisotropic magnetic field of 10 G or less ..." in [ii] is the "magnetic wire for detecting a magnetic field having conductivity", it can be interpreted to match the subsequent invention specifying matter that "has an anisotropic magnetic field of 10 G or less", but if the magnetic wire having the anisotropic magnetic wire of 10 G or less refers to the "'magnetic wire for detecting a magnetic field having the conductivity' installed 'on a board'", it does not match that the anisotropic magnetic field when incorporated in the element used the magnetic material of 40 G.

Therefore, it is rational to understand that "the magnetic wire" in [ii] refers to the "magnetic wire for detecting a magnetic field having conductivity", and the Plaintiff's assertion is groundless.

D. The Plaintiff asserts that, as in the aforementioned No. 3, 1(1)F, the Description does not describe means or a method of taking out only the voltage caused by the "spin rotation in the surface magnetic domain" from the coil output voltage or means or a method of enabling removal of a voltage caused by the "magnetization rotation by movement of a 90-degree magnetic domain wall" and they cannot be considered to have been matters of common general technical knowledge, and the JPO decision made determination on the basis of misunderstanding that the Plaintiff's assertion was only the assertion related to the "thermal noise", but they are careless mistakes.

The "GSR sensor" in the Present Invention "takes out only the magnetization change in the wire axial direction by the super high-speed spin rotation phenomenon generated at that time"([iv]) "by simultaneously rotating the circumferential-direction spins inclined in the axial direction by the magnetic field in the wire axial direction in the surface magnetic domain" (emergence of the GSR phenomenon) in the matters [i] to [iii] found in the JPO decision and thus, it can be considered that only the voltage caused by the spin rotation in the surface magnetic domain is taken out as the coil output voltage.

On the other hand, the Plaintiff's assertion is understood such that, in short, it is a matter of common general technical knowledge that the pulse current actually flows deeper than the skin depth of the magnetic wire, and the influence of the voltage caused by the magnetization rotation by the movement of the 90-degree magnetic domain wall by that cannot be ignored and thus, an importance is placed on that the matter in [iv] is impossible; that is, it is impossible to "take out only the magnetization change in the wire axial direction by the super high-speed spin rotation phenomenon as a coil output".

However, the web site of Welding Technology Information Center in the Japan Welding Engineering Society (Exhibit Ko 126) pointed out by the Plaintiff has the description that "a phenomenon in which an electromagnetic field is attenuated exponentially in accordance with penetration into a conductive body is called a skin effect. Since an eddy current is proportional to a magnetic flux, as shown in Fig. 1, the eddy current is also attenuated exponentially, caused by the skin effect with respect to a depth from a surface of a specimen. The skin effect is generated as an effect that the eddy current generated by a temporal change of the magnetic flux cancels and downsizes the magnetic flux. The larger the values of conductivity σ (S/m), magnetic permeability μ (H/m), and an AC frequency f (Hz), the more remarkable the skin effect. As a guide on how deep the eddy current penetrates from the surface of the specimen, a depth δ(m) from the surface, which is 1/e to the value on the surface of the eddy current is used as a penetration depth.", and Fig. 1 is as follows:

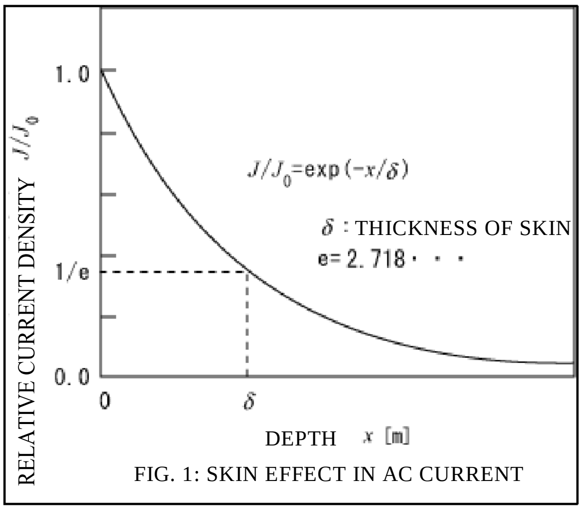


FIG. 1: SKIN EFFECT IN AC CURRENT

That is, as described in the aforementioned document, regarding the skin effect indicated by using the skin depth, since there is a possibility that the current flows even at the depth deeper than δ, the relative current density is not zero even at a spot deeper than the depth δ, but the skin depth is only a guide on how deep from the surface of the specimen the eddy current penetrates, or rather, it indicates that the farther it is from the surface, the more the current density decreases exponentially. And since the influence on the core magnetic domain or the 90-degree magnetic domain is also considered to decrease exponentially, it is considered that the magnetization rotation by the movement of the 90-degree magnetic domain wall by the pulse current also decreases exponentially. In other words, the skin effect is a phenomenon that the deeper into the conductor the electromagnetic field penetrates, the larger it attenuates exponentially, which means that the farther being separated from the surface, the more the influence of the current density on the core magnetic domain and the 90-degree magnetic domain decreases exponentially and thus, when the pulse current with a high frequency is applied to the magnetic wire so as to have the "skin depth p < thickness d of the surface magnetic domain", it is found that the influence of the magnetization rotation by the movement of the 90-degree magnetic domain wall generated by the flow deeper than the skin depth of the magnetic wire reaches an ignorable level, and a person ordinarily skilled in the art would also understand as such.

Then, the Plaintiff's assertion on the premise that the influence of the voltage caused by the aforementioned magnetization rotation cannot be ignored should be considered to be unreasonable in the first place, and even if the influence of the voltage cannot be completely removed, in view of the technical significance of the Present Invention, the necessity to completely remove the influence does not exist in the first place, and it should be considered to be obvious even for a person ordinarily skilled in the art to understand on the basis of the understanding as above that the invention specifying matter of "by causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output ..." in [iv] means that "the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon" "is taken out as a coil output" (in the meaning as above, the content determined by the JPO decision by citing the thermal noise also falls under the influence of the voltage caused by the other causes and thus, it cannot be considered that the determination in the JPO decision has a careless mistake). Therefore, none of the Plaintiff's assertions have grounds.

(4) According to the above, the Present Invention can be considered to be the invention described in the Detailed Description of the Invention and within a range that can be recognized to be capable of solving the problem by the description in the Detailed Description of the Invention and thus, the support requirement is satisfied.

The determination in the JPO decision to the same effect has no errors, and Invalidation Reason 1 asserted by the Plaintiff is groundless.

3. Ground for Rescission 2 (errors in determination on violation of enablement requirement)

(1) The Plaintiff asserts that, as in the aforementioned No. 3, 2(1)A, [i] the Description does not describe the matters required to understand the technical significance of the Present Invention so that a person ordinarily skilled in the art can clearly recognize the difference of the MI sensor and thus, even in light of the technical level at the filing, the Present Invention which is stated to be a "new physical

phenomenon different in principle" from the MI phenomenon, which is a conventional art, cannot be worked; [ii] specific technical means or the like for "taking out only the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon as a coil output" in Present Invention 1 is not described in the Description, and a person ordinarily skilled in the art cannot understand it even in the light of the common general technical knowledge at the filing of this case and thus, the Present Patent does not conform to the enablement requirement.

However, as described in the aforementioned 1(2)A, the Present Invention is an invention on the one technical premise integrating the four matters found in the JPO decision, while the MI sensor, which is the conventional art, does not include all these four matters (Present Matters), and from the matters disclosed in the Description, the Present Invention can be considered to be described so that it can be clearly recognized distinctively from the MI sensor and thus, [i] is groundless.

Moreover, regarding [ii], as described in the aforementioned 1(3)D, in addition to the description in the Description, since the skin effect is the phenomenon of the exponential attenuation as the electromagnetic field penetrates into the conductor, a person ordinarily skilled in the art would understand that, when the pulse current with a high frequency is applied to the magnetic wire so as to have the "skin depth p < thickness d of the surface magnetic domain", the influence of the magnetization rotation by the movement of the 90-degree magnetic domain wall generated when flowing at a spot deeper than the skin depth of the magnetic wire reaches an ignorable level. Therefore, it can be considered that a person ordinarily skilled in the art would understand the invention specifying matter that "by causing the pulse current to be passed through the magnetic wire, the circumferential-direction spins inclined in an axial direction by the magnetic field in a wire axial direction within the surface magnetic domain are simultaneously rotated at a super high speed, only a magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon generated at that time is taken out as a coil output ..." as the meaning that "the magnetization change in the axial direction of the wire by the super high-speed spin rotation phenomenon" "is taken out as a coil output" and thus, it cannot be considered not to conform to the enablement requirement.

(2) The Plaintiff asserts that, as in the aforementioned No. 3, 2(1)B, [i] the meaning contents of the "pulse magnetic-field annealing" is unclear, and it is not explained that the "pulse magnetic-field annealing" is means for ensuring the "skin depth p < thickness d of the surface magnetic domain", either; [ii] a method of acquiring the "thickness d of the surface magnetic domain" has not been established, and a person

ordinarily skilled in the art cannot confirm in what case the condition of the "skin depth p < thickness d of the surface magnetic domain" is satisfied; and [iii] according to the Exhibit Ko 126, the description in [0041] in the Description that, in the case of the "skin depth p < thickness d of the surface magnetic domain", the depth of the spin rotation matches the skin depth p clearly lacks technical evidence and does not satisfy the enablement requirement.

However, the Description has the descriptions that "Moreover, a magnetic field exceeding 1.5 times of the anisotropic magnetic field Hk was generated by a sufficiently large pulse current, a pulse magnetic-field annealing processing was performed at every measurement, magnetization was saturated in the circumferential direction, and a magnetization history was erased." ([0042]), "The intensity of the pulse current was ..., and a sufficiently large circumferential magnetic field Hθ, which is 1.5 times or more of Hm, was generated on the wire surface so that simultaneous rotation of the surface spins was realized. Moreover, magnetization was saturated in the circumferential direction, and the magnetization history was erased. This pulse magnetic-field annealing processing was executed for each measurement ..." ([0082]) and thus, it can be understood that the "pulse magnetic-field annealing" in the Description means that "Moreover, magnetization was saturated in the circumferential direction, and the magnetization history was erased" by the pulse current of 1.5 times or more of the anisotropic magnetic field. Therefore, as described in the aforementioned 2(2)A, such suggestion that the thickness of the surface magnetic domain is increased so as to make the skin depth p smaller than the thickness d of the surface magnetic domain can be read and thus, although the processing of the "pulse magnetic-field annealing" is disclosed to such a degree that a person ordinarily skilled in the art can work, [i] is groundless.

Moreover, whether or not it is the "skin depth p < thickness d of the surface magnetic domain", which is the GSR emergence condition, is only the description on the phenomenon side for the GSR emergence, and it is not the invention specifying matter, and even if a method of acquiring the thickness d of the surface magnetic domain is not established, a person ordinarily skilled in the art can work the invention and thus, [ii] is also groundless.

It is to be noted that, regarding [iii], as described in the aforementioned 2(3)D, the skin depth is a target concerning to what degree of depth from the surface of the specimen the eddy current penetrates and it is a matter of common general technical knowledge that the pulse current actually flows deeper than the skin depth (this point is not disputed by the Plaintiff, either (see written preparatory proceeding)). Thus, a person ordinarily skilled in the art who contacted the description in the Description that, in the case of "skin depth p < thickness d of the surface magnetic domain", the depth of the spin rotation matches the skin depth p ([0041]), would understand it as a qualitative explanation on the relationship between the skin depth and the surface magnetic domain, and it cannot be considered that the Present Invention does not conform to the enablement requirement due to the presence of the description as above.

(3) According to the above, a person ordinarily skilled in the art can work the Present Invention on the basis of the matters described in the Detailed Description of the Invention in the Description without excessive trials and errors, the determination in the JPO decision with the same gist has no errors, and Ground for Rescission 2 asserted by the Plaintiff is groundless.

4. Ground for Rescission 3 (violation of clarity requirement)

(1) The Plaintiff asserts that, as described in the aforementioned No. 3, 3(1), [0021] in the Description has the description that "In the magnetization curve, a steep rising region is a magnetization process by movement of the magnetic domain wall, while a gentle increasing region is a magnetization process by the magnetization rotation. A magnetic-field intensity when the magnetization rotation is started is defined as an anisotropic magnetic field Hk.", and according to the definition as above, the anisotropic magnetic field cannot be acquired unambiguously and thus, the "anisotropic magnetic field" in claim 1 according to Present Invention 1 is unclear.

However, as described in the aforementioned 2(3)C, regarding the significance of "the magnetic wire has an anisotropic magnetic field of 10 G or less" in claim 1, it has a meaning that the "magnetic wire" is "the magnetic wire for detecting a magnetic field having conductivity" and thus, the phrase "has an anisotropic magnetic field of 10 G or less" with "the magnetic wire" as the subject thereof is the "anisotropic magnetic field of 10 G or less" as a physical property of the "magnetic wire", and the "anisotropic magnetic field" having "the current intensity required for generating the circumferential-direction magnetic field of 1.5 times or more of the anisotropic magnetic field on the wire surface" is interpreted to have the meaning of the "anisotropic magnetic field of the magnetic wire installed on the board", while the "anisotropic magnetic field" asserted by the Plaintiff is a "magnetic field where the magnetic field reaches saturation in a magnetization curve in a hard axial direction", "intensity of such a magnetic field that the spin is to be aligned in a certain direction", the "one expressing energy to align the spins in a specific direction in a crystal as a magnetic field", and "a general definition of the anisotropic magnetic field is a magnetic field required to direct the direction of a magnetic moment to a magnetization hard direction" (see pp. 12 to 13 in the first preparatory proceeding by the Plaintiff) and thus, it should be considered that the "anisotropic magnetic field" in claim 1 is not different from the understanding of the "anisotropic magnetic field" as recognized by the Plaintiff as above. Then, even without considering the description in the Description, the "anisotropic magnetic field" in claim 1 according to the Present Invention 1 is not so unclear that would cause a third party to suffer from an unexpected disadvantage.

It is to be noted that [0021] in the Description has the description on the definition that "the magnetization intensity when the magnetization rotation starts as the anisotropic magnetic field Hk", and this can be considered to be the description related to a method of acquiring a specific value of the anisotropic magnetic field Hk, but there is no description related to the method of acquiring the specific value of the anisotropic magnetic field. Then, the "Magnetism Handbook" compiled by the Magnetics Society of Japan (issued on January 30, 2016) has a description that "Hk is estimated from an intersection between a straight line (dotted line) along an inclination of the magnetization curve from the origin and extrapolation of the saturated magnetization" (Exhibit Ko 48, p. 499, right column, lines 16 to 18), and in light of the nature of this document, it can be found that the method as above has been generally employed, while the Description has no description or suggestion which should be interpreted that the method for calculating a value of the anisotropic magnetic field of the Present Invention is different from that in the aforementioned document.

Therefore, the description on the "anisotropic magnetic field" in claim 1 according to the Present Invention 1 is not considered to be so unclear that would cause a third party to suffer from an unexpected disadvantage, and the Ground for Rescission 3 asserted by the Plaintiff are groundless.

(2) Other than the above, the Plaintiff asserts defectiveness of various description requirements, but it is only based on the assertion that the Present Invention cannot be discriminated from the MI phenomenon on which the MI sensor is based without grasping that the four matters (Present Matters) found in the JPO decision as one technical idea by referring to imperfection in the description of the Description and the like not on the basis of normal understanding of a person ordinarily skilled in the art, which has no grounds, either.

5. Conclusion

According to the above, none of the grounds for rescission asserted by the Plaintiff have grounds, and no illegality which should lead to rescission is found in the JPO decision and thus, the claim by the Plaintiff shall be dismissed.

Therefore, the judgment shall be rendered as in the Main Text.

Intellectual Property High Court, Fourth Division

Presiding Judge: KANNO Masayuki

Judge: NAKAMURA Kyo

Judge: OKAYAMA Tadahiro

(Attachment 1)

[Detailed Description of the Invention]

[Technical Field]

[0001]

The present invention relates to a micro magnetic sensor with super high sensitivity (hereinafter, referred to as a GSR sensor) based on a super high-speed spin rotation effect (GHz Spin Rotation effect in English notation, abbreviated as a GSR effect).

[Background Art]

[0002]

Micro magnetic sensors with high sensitivity include a lateral FG sensor, a vertical FG sensor, a Hall sensor, a GMR sensor, a TMR sensor, an MI sensor, a high-frequency carrier sensor, and the like. An electronic compass using these principles is currently employed for smartphones, automobiles, and the like and are widely used. Hereafter, they are expected to be employed as a motion input device for a wearable computer, and development thereof is accelerated.

[0004]

The MI sensor (Patent Document 3) is based on an MI phenomenon (magneto-impedance phenomenon) discovered in 1993. In this phenomenon, a high frequency of 1 MHz to 30 MHz or a pulse current is passed through a magnetic wire (diameter: 30 μm) or a magnetic thin film having two structures; that is, a surface magnetic domain magnetized in a circumferential direction of a surface (thickness is approximately 0.2 μm) and a core magnetic domain magnetized in an axial direction of a center part so as to vibrate a 90-degree magnetic domain wall. This results in an electromagnetic phenomenon in which an average depth of the vibration of the magnetic domain wall is 1 μm to 4 μm, a circumferential-direction magnetic permeability increases in proportion to an increase in the magnetization, a skin depth is remarkably reduced, and a magnetic impedance of the wire is drastically changed. It is a type in which an external magnetic field H is acquired from a change amount of the impedance (AC resistance).

Penetration of the 90-degree magnetic domain wall into the core magnetic domain causes the spin in the core magnetic domain to rotate in the circumferential direction; that is, the rotation of the magnetization changes the magnetization and thus, an influence of a demagnetizing field is smaller than that of the FG sensor. As a result, a large reduction of a length of the magnetic wire from 50 mm to 5 mm was realized.

Moreover, an output characteristic was strongly affected by hysteresis of the wire and moreover, it had defects of antisymmetric nature and nonlinearity. These problems were solved by using a negative feedback circuit, but there was a problem in power consumption. The MI sensor art is introduced in detail in "Magnetic Sensor Science and Engineering" by Professor Mori (CORONA PUBLISHING CO., LTD., by Kaneo Mori, 1998).

[0005]

The MI sensor of a coil detection type (Patent Document 4; 1999) is of an improved type in which the MI phenomenon is detected by a coil, and a linear output was realized. The structure thereof is the same as that of the vertical FG sensor. At energization of the pulse current, the 90-degree magnetic domain wall penetrates into the core part by the circumferential-direction magnetic field, the axial magnetization rotates in the circumferential direction, and a change in the magnetization in the axial direction occurs. This change is detected by the coil. The penetration of the 90-degree magnetic domain wall is determined by intensity of the passed current, a frequency, magnetic permeability of the wire, and the like, and is approximately 1.3 μm to 4 μm. Since the FG sensor uses the rotation of magnetization of the entire material, it is proportional to a volume of the wire, which is a magneto-sensitive body, but since a high frequency of 10 MHz is used in the case of the MI sensor, the skin depth is very shallow, and the output is proportional to the diameter. For a higher sensitivity, the FG sensor needs an increase of a wire length, but since the MI sensor utilizes a high frequency to realize the higher sensitivity, the magnetic wire with the diameter of 30 μm can be drastically downsized with a length of the FG sensor from 50 mm to 3 mm. The coil inner diameter was 3 mm.

Regarding the coil-type MI sensor, since its structure is the same as that of the FG sensor, there is an opinion that it is an improved type of the FG sensor, but by considering that the applicable frequency is high, and the electromagnetic phenomenon as the vibration of the 90-degree magnetic domain wall is detected, it should be considered to be an improved type of the MI sensor. However, the negative feedback circuit is used for the hysteresis reduction and thus, the power consumption became larger, which was a problem.

[0006]

Subsequently, by using an MI element manufactured by a MEMS process, there was developed the downsized coil-detection type MI sensor (Patent Document 5) with the magnetic wire with the diameter of 12 μm and the length reduced to 0.6 mm and moreover, the coil inner diameter of 30 μm. By means of this, reduction of current consumption was aimed at by changing a pulse waveform from a triangular wave to a trapezoidal wave simultaneously with the downsizing, by removing an influence of the hysteresis by executing pulse magnetic-field annealing processing, and by omitting the negative feedback circuit. Moreover, an anisotropic magnetic field of the magnetic wire was made extremely large to 20 G so as to enlarge a measurement range to ±10 G. It is applied and merchandized to an electronic compass (product name: AMI306) and the like as an improved type sensor of the MI sensor.

[0007]

However, when the anisotropic magnetic field is made larger, the magnetic permeability μ becomes extremely small to approximately 1000, whereby the sensitivity is drastically lowered. In order to supplement the lowered sensitivity, the frequency is increased from 30 MHz to 200 MHz. At the same time, in order to generate a circumferential magnetic field which overcomes the large anisotropic magnetic field, the pulse current is increased from 10 mA to 200 mA.

In the case of a high frequency of 200 MHz, it is difficult to move the 90-degree magnetic domain wall, which is present on an interface between the surface magnetic domain and the core magnetic domain. Thus, by paying attention to a fall of the trapezoidal-wave pulse, the 90-degree magnetic domain wall is present at a deep position inside the core immediately before the fall, and when the current is shut off, the circumferential-direction magnetic field is no longer present inside the skin depth, and the 90-degree magnetic domain wall can start moving. However, the magnetization rotation proceeds slowly in a relaxation phenomenon manner due to an electromagnetic brake generated by the movement itself of the magnetic domain wall. On the other hand, the spin directed to the circumferential direction in the surface magnetic domain produces magnetization rotation by power of the external magnetic field against the anisotropic magnetic field in the circumferential direction. These two electromagnetic phenomena are mixed and taken out as a voltage by a coil.

The thickness of the surface magnetic domain is made as thin as possible, a rectangular-wave shaped pulse is passed therein, the thickness of the surface magnetic domain is made larger by the power of the circumferential-direction magnetic field and then, the current is shut off, and at that time, the 90-degree magnetic domain wall moves to the vicinity of the original surface, and the rotation of the magnetization generated at that time and the magnetization change in the axial direction are detected by the coil. By means of the deep penetration of the 90-degree magnetic domain wall into the wire center part, the hysteresis disappears. As a result, the negative feedback circuit is successfully omitted.

[0009]

Currently, the micro magnetic sensor with high sensitivity is expected to develop as a motion input device of a wearable computer from the electronic compass such as a smartphone. For that, higher sensitivity from 2 mG to 0.2 mG, enlargement of the measurement range from ±10 G to ±40 G, downsizing from 0.6 mm to 0.2 mm, and further lower current consumption are strongly demanded. In terms of performance indexes, K=0.2 mG, W=40 G, L=0.2 mm, D=0.01 mm, which makes S=100,000, and an exponential improvement of approximately 100 times that of the coil-type MI sensor using the MEMS-type element is demanded.

[0010]

In order to solve the problem, the inventor studied the MI sensor (Patent Document 6; 2009) with higher sensitivity by raising the frequency on the basis of the aforementioned product AMI306. When the pulse frequency was increased from 0.2 GHz to 0.5 GHz, the output was improved by a factor of approximately two fold, but with the high frequency higher than that, the output hits the upper limit and decreases. However, technical problems involved in the higher frequency occurred and commercialization was not realized. That was because problems such as a technical problem of a high-frequency pulse oscillation circuit, a problem of an increase in an electromagnetic induced voltage involved in the higher frequency, and the like occurred, and comprehensive merits could not be found.

Thus, the MI sensor was reviewed from all the viewpoints, including the magnetic wire, a detection coil, an excitation pulse, a detection circuit, and a measurement principle, and the development of the micro magnetic sensor with super high sensitivity was started.

[Citation List]

[Patent Documents]

[0012]

[Patent Document 1] U.S. Patent No. 2,856,581 Description

[Patent Document 2] Japanese Patent No. 2617498

[Patent Document 3] Japanese Patent No. 3197414

[Patent Document 4] Japanese Patent No. 3645116

[Patent Document 5] Japanese Patent No. 3801194

[Patent Document 6] Japanese Patent No. 4655247

[Patent Document 7] International Publication No. WO2014/115765

[Non-Patent Documents]

[0013]

[Non-Patent Document 1] "Magnetic Sensor Science and Engineering": CORONA PUBLISHING CO., LTD., by Kaneo Mori, 1998

[Non-Patent Document 2] "New Magnetic Sensor and Its Applications": Triceps Co., Ltd., Kaneo Mori, 2012

[Summary of Invention]

[Problems to be Solved by the Invention]

[0014]

A problem of the present invention is to find a principle and an embodying condition of a magnetic sensor which realizes performance improvement of approximately 100 times that of an MI sensor. For that purpose, in a micro magnetic sensor with a super high sensitivity with a basic configuration of a magnetic-field detection element in which a magnetic wire for detecting a magnetic field having conductivity, a circumferential coil wound around it, two electrodes for wire conduction, and two electrodes for coil voltage detection installed on a board, means for causing a pulse current to pass through the magnetic wire, a circuit for detecting a coil voltage generated when the pulse current is caused to pass, and means for converting a coil voltage to an external magnetic field H, the inventor conducted comprehensive study on magnetic characteristics of the wire, downsizing of the magnetic-field detection element or particularly refinement of a detection coil, a frequency and a shape of the pulse, an electromagnetic phenomenon occurring inside the wire, electromagnetic coupling with the coil, a processing method of the coil voltage, relationship between the coil voltage and the magnetic field, and the like.

[0015]

Regarding the wires, instead of a conventional tension-heat processed wire, a wire with glass was employed. The magnetic-field detection element has a coil pitch of 30 μm to 10 μm or less, the coil inner diameter is reduced from the conventional 30 μm to 15 μm or less; that is, refinement of the wire diameter of 1.5 times or less, the pulse has a trapezoidal shape and a frequency of the rise at 0.5 GHz to 4 GHz, the pulse current intensity at 50 mA to 300 mA, and the inventor carried out, as full-scale examinations, studies on the relationship between the electromagnetic phenomenon induced by the pulse current and the coil voltage and the relationship between the coil voltage and the magnetic field, and moreover, a problem of a voltage drop by the coil voltage and the coil induction current, a problem of an indued voltage by the high-frequency pulse, review of a signal detection method, examination of a temperature correction method, investigation of a mathematical relationship between the coil voltage and the magnetic field and the like.

[Means for Solving the Problem]

[0016]

The inventor has made a detailed search on the magnetic characteristics of the wire, the size of the magnetic wire, the coil winding number, and the pulse current characteristic affecting the relationship between the coil output voltage and the external magnetic field H and as a result, found that an experimental formula as a formula (1) exists between the voltage generated by the coil and the external magnetic field when a trapezoidal pulse with a frequency of 0.5 GHz or more is given to a fine coil using a magnetic wire having a two-phase structure of the surface magnetic domain and the core magnetic domain and the anisotropic magnetic field at 5 G in the sensor of the present invention:

$$Vs=Vo\cdot L\cdot \pi D\cdot p\cdot Nc\cdot f\cdot \sin(\pi H/2Hm) \ldots (1)$$

[0017]

Here, Vs is a coil output voltage, Vo is a proportional constant determined by magnetic characteristics of wire magnetic permeability, a saturated magnetic-flux density of a wire material, a pulse current intensity, and the like, and as control factor constants, L is a length of the wire, D is a diameter of the wire, p is a skin depth of the pulse current, Nc is a coil winding number, f is a pulse frequency, H is an external magnetic field, and Hm is an external magnetic-field intensity at which the coil output voltage takes a maximum value.

[0018]

Assume that the spin which has been forced in the circumferential direction by an internal magnetic field in the circumferential direction existing in the surface magnetic domain of the magnetic wire is inclined by the external magnetic field H only by θ. When the pulse current with the frequency of 0.5 GHz or more is applied in this state, the spin is rotated simultaneously by θ in the circumferential direction. When this magnetic change is detected as a coil voltage, it is:

$$V=Vo\sin 2\theta \ldots (2)$$

Therefore, it can be considered that the experimental formula (1) detects the simultaneous high-speed rotation of the spin. That is, the MI sensor detects the magnetization rotation by the movement of the 90-degree magnetic domain wall even with the same skin effect, but the inventor considers that the sensor of the present invention is a totally new principle for genuinely detecting only the rotation of the spin in the surface magnetic domain; that is, a new-type GSR sensor based on the super high-speed spin rotation phenomenon.

On the basis of this principle, as will be introduced in detail in the following Embodiment 1, as compared with the MI sensor, the coil output is drastically improved such that a trial calculation with a performance index gave K=0.2 mG, W=40 G, L=0.2

mm, D=0.01 mm, and S=100,000, and it was found that a tremendous improvement of approximately 120 times that of the coil-type MI sensor can be realized.

[0019]

(1) First, a relationship among a spin angle θa and a coil output, which are bases of the new principle, and the external magnetic field will be explained.

The coil voltage when the super high-speed spin rotation is to be detected by a coil is proportional to a temporal change of a magnetic flux Φ. That is, $V=-d\Phi/dt$.

The magnetic flux $\Phi_{x0}(\theta)$ at a rotation start timing (time t=0) with a spin inclination angle θ is $ms \cdot L \cdot \pi D \cdot d \cdot \sin\theta$. Since an angular speed is constant at $d\theta/dt=2\pi f$ (here, f is a pulse frequency), a change speed of φx in an X-axis direction at a moment of rotation start is $d\Phi x(\theta)/dt=d\varphi x(\theta)/d\theta \cdot d\theta/dt=\cos\theta \cdot 2\pi f$.

Since the magnetic flux $\Phi_{x0}(\theta)$ has a change speed of $\cos\theta \cdot 2\pi f$, $V=-d\Phi/dt=\varphi 0(\theta) \cdot d\varphi x(\theta)/dt$. By substituting the values of $\varphi 0(\theta)$ and $d\varphi x(\theta)/dt$ for this, $V=-d\Phi/dt=-ms \cdot L \cdot \pi D \cdot d \cdot \sin\theta \cdot \cos\theta \cdot 2\pi/T=-\varphi 0 \cdot \sin 2\theta$ and thus, the coil output voltage is proportional to $\sin 2\theta$.

The coil output and the external magnetic field H are present in a sine functional relation, and under the condition performed by the inventor, it is considered to detect only the simultaneous rotation of the spin.

[0020]

Here, since it was experimentally found that the coil output and the external magnetic field are $\sin(\pi H/2Hm)$ as shown in formula (1), it is expected to become formula (3).

$\theta a=\pi H/4Hm$ ... (3)

On the other hand, however, the conventional spin angle θb can be defined as in formula (4) by an actual internal magnetic field Hin acquired by excluding an influence of the demagnetizing field from the magnetic field H related to the magnetic wire and the angle determined by the anisotropic magnetic field $K\theta$ in the circumferential direction.

$\tan\theta b=Hin/K\theta$ ... (4)

If experimental formula (1) detects the spin angle, θa and θb need to match. Hereinafter, the fact that the two match each other will be proven.

[0021]

(2) Before the explanation, as the characteristics of the used magnetic material, the axial-direction magnetization characteristic 10 of the magnetic wire is shown in Fig. 1a), and the coil output-voltage characteristic as the circumferential-direction magnetization characteristic 11 in Fig. 1b).

In the magnetization curve, a steep rising region is associated with a magnetization process by movement of the magnetic domain wall, while a gentle increasing region is associated with a magnetization process by the magnetization rotation. A magnetic-field intensity when the magnetization rotation is started is defined as an anisotropic magnetic field Hk. In the magnetization $M=\chi H$, an approximation of χ is expressed in a formula (5). When the magnetic permeability μ of the magnetic wire changes from 200 to approximately 40,000, β in the approximation correspondingly changes from 0.07 to approximately 0.7.

$\chi=\chi^{\circ}\{1-\beta\times(H/Hk)^2\}$ ... (5)

In the magnetic characteristic of the magnetic wire, the demagnetizing field is zero (in the case of an endless length wire), and the external magnetic field H matches the internal magnetic field Hin, but with a limited length wire, the demagnetizing field becomes stronger to Hin=H-NMs (here, $Ms=\chi H$) and thus, by correcting H to Hin by using formula (2), formula (6) is acquired:

$Hin=H\{1-N\chi^{\circ}+\beta N\chi^{\circ}(H/Hk)^2\}$ ... (6)

[0022]

The coil output monotonously increases in accordance with formula (1) as the external magnetic field H increases, and the external magnetic field H takes a maximum output at Hm and after that, shows a gradually decreasing tendency. Hm substantially matches the axial-direction magnetization characteristic Hk. Strictly speaking, there is a relation of $Hm=\alpha Hk$, $\alpha=0.96$. This is because, when the external magnetic field H=Hk, the core magnetic domain is saturated, and the spin of the surface magnetic domain takes a maximum inclination of 45 degrees. Since the surface magnetic domain has a smaller demagnetizing field, the spin on the outermost surface reaches 45 degrees before the core part is saturated. Therefore, Hm has a value slightly smaller than Hk. When the external magnetic field H is loaded more than Hk, the 90-degree magnetic domain wall existing on the interface with the core magnetic domain moves, and the magnetization created by the entire surface magnetic domain is decreasing. The spin maintains the inclination of 45 degrees but disappears in the end.

[0023]

The pulse current was assumed to have a current intensity sufficient to realize the magnetization saturation in the circumferential direction and a pulse frequency of 0.5 GHz to 4 GHz as the frequency (the pulse frequency was defined by f=1/2 dt, here, a transition time at rise and fall moments was set to dt.). As a result, the skin depth of the current was controlled to 0.2 μm to 1 μm so as to be equal to or smaller than the thickness of the circumferential surface magnetic-domain. The pulse time interval was set to a length of 5 n seconds, which is sufficient to be able to avoid coil signal interference.

[0024]

When the external magnetic field H in the wire axis direction is applied to an amorphous wire having the aforementioned two-phase magnetic domain structure, the circumferential-direction spin in the circumferential surface magnetic-domain is inclined in the axial direction approximately by angle θ, and the magnetization Ms (=Ns·ms·sinθ) is generated in the axial direction. Ns is a spin number per unit volume in the surface magnetic domain, and ms is the magnetization of the spin. In the core magnetic domain at the center part, the magnetic domain wall moves, and the magnetization Mc is generated.

[0025]

When the aforementioned pulse current is passed through the wire in this state, the spin is rotated at a super high speed (referring to that within a pulse transition time dt) simultaneously in the circumferential direction by a large circumferential magnetic field of approximately 60 G created by the pulse. The magnetization change of the wire generated at that time is detected as the coil output voltage Vs. The coil output voltage is proportional to the frequency, while the skin depth becomes smaller by $f^{-1/2}$, and the coil output increases in proportion to $f/p=f^{1/2}$ by combining the two effects. When the two are combined in proportion to the coil winding number Nc, an extraordinary output is obtained.

This super high-speed spin rotation effect is expected to be a new principle of a future super high-sensitive micro magnetic sensor. It is to be noted that the magnetization Mc of the core magnetic domain part is not influenced by the skin effect, and no movement of the magnetic domain wall is generated.

[0026]

(3) Subsequently, a relationship between the spin rotation angle, the magnetic field, and the coil output voltage when the super high-speed spin rotation phenomenon is detected by the coil will be explained.

The coil output voltage is proportional to the temporal change of the magnetic flux Φ and the coil winding number Nc of the magnetic flux Φ. Assume that the spin having been forced by the external magnetic field H in the circumferential direction is inclined only by θ. The magnetic flux Φ at the time t=0 is proportional to ms·L·πD·d·sinθ. At the moment of the rotation start, a temporal change of the angle dθ/dt is proportional to cosθdθ, which is differentiation of sinθ. It is considered that the rotation is made only by the angle θ at a rotation speed dθ/dt acquired at the beginning of the rotation and thus, a change amount of the magnetic flux Φ at that time is proportional to $\cos\theta$. As a result, a maximum amount of the coil voltage is proportional to $ms \cdot L \cdot \pi D \cdot d \cdot \sin\theta \cdot \cos\theta$. That is, it is proportional to $\sin 2\theta$ as in formula (7).

$V=VoNc \cdot \sin 2\theta$ ... (7)

Since it was experimentally found out that the coil output and the magnetic field are $\sin(\pi H/2Hm)$ as shown in formula (1), it becomes $\theta=\pi H/4Hm$, and the inclination angle θ of the spin can be acquired. By assuming that θ acquired from the data of the coil output voltage is θa, formula (8) is acquired:

$$\theta a=\pi H/4Hm \text{ ... (8)}$$

[0027]

Intrinsically, the inclination angle θ of the spin is an angle determined by the actual internal magnetic field Hin excluding the influence of the demagnetizing field from the magnetic field H applied to the magnetic wire and the anisotropic magnetic field $K\theta$ in the circumferential direction. When a theoretical angle θ is assumed to be θb, it can be defined as in formula (9):

$\tan\theta b=Hin/K\theta$ ... (9)

A peak value at which Vs takes a maximum value is when θ is 45 degrees and thus, it is when $Hin=K\theta$. At this time, it is $Hin=\{1-(1-\beta)N\chi°\}Hk$ and as a result, the following can be acquired:

$K\theta=\{1-(1-\beta)N\chi°\}Hk$ ... (10)

When Hin in formula (6) and $K\theta$ in formula (10) are substituted in $\tan\theta b=Hin/K\theta$, formula (11) is acquired.

$\tan\theta b=H/Hk\{(1-N\chi°)+\beta N\chi°(H/Hk)^2\}/\{1-(1-\beta)N\chi°\}$ ... (11)

[0028]

As the result of the aforementioned examination, both the angle $\theta a=\pi H/4Hm$ acquired from the experiment result of the coil output and the spin inclination angle $\theta b(\tan\theta=Hin/K\theta)$ given by theoretical expectation from basic data specific to the material exist. Thus, it will be explained that θa defined in formula (3) and θb defined in formula (6) match each other.

[0029]

Since θa is defined by Hm, and θb is defined by Hk, first, a relationship between Hk and Hm will be explained in detail. As experimental facts, $Hm=\alpha Hk$ is established, and α is approximately 0.96, here.

[0030]

The anisotropic magnetic field Hk is a value indicating a change point in a process from end of the movement of the magnetic domain wall and start of the magnetization rotation finally to saturation. In the case of the magnetic wire, when the external magnetic field H increases to Hk, the core magnetic domain reaches saturation. The spin in the surface magnetic domain is inclined in the axial direction and reaches 45 degrees. When the external magnetic field H increases to Hk or more, the increase in the magnetization in the axial direction progresses in a form such that the 90-degree magnetic domain wall penetrates into the surface magnetic domain. During this time, the spin is held at 45 degrees. Since the magnetic field when the spin is held at 45 degrees is Hm, it should be Hk=Hm. However, at this time, the magnetic field is different between the core magnetic domain and the surface magnetic domain, and the internal magnetic field, which is an effective magnetic field where the spin is inclined, is different. Regarding the demagnetizing field in the surface magnetic domain, since the demagnetizing field is formed by a leakage magnetic field of the saturated core part, it is slightly smaller than the core magnetic domain. Hm reaches the required internal magnetic field with a value smaller than Hk. In the magnetic field Hm at this time, the anisotropic magnetic field Kθ in the circumferential direction and the internal magnetic field are balanced with each other, and the spin takes an inclination angle of 45 degrees. As a result, it is Hm=0.96×Hk.

[0031]

The spin on the outermost surface in the surface magnetic domain becomes 45 degrees when a value of the magnetic field H is slightly smaller than Hk, but at a spot closer to the magnetic domain wall at a boundary with the core magnetic domain, it has not reached 45 degrees yet. On the contrary, when the external magnetic field H becomes slightly larger than Hk, the spin on the outermost surface holds 45 degrees, the magnetic domain wall moves in a surface direction, the saturated core magnetic domain part becomes thicker, while the surface magnetic domain becomes thinner, and the magnetization in the axial direction becomes bigger. The external magnetic field Hm in which the spin on the outermost surface becomes 45 degrees becomes slightly smaller than the magnetic field Hk at which the spin on the entire surface magnetic domain is balanced with the anisotropic magnetic field and becomes 45 degrees.

[0032]

(4) As the relationship between the Hk and Hm can be grasped and subsequently, the fact that θa defined in formula (8) and θb defined in formula (9) are matched with each other will be explained.

By taking tan in θa=πH/4Hm, tanθ can be approximated by the following formulas:

$\tan\theta=\theta(1+1/3\times\theta 2)$ ... (12)

$\tan\theta a=(H/Hm)\{\pi/4+1/3\times(\pi/4)^3(H/Hm)^2\}$ ... (13)

On the other hand, by substituting $Hm=\alpha Hk$ in formula (11), formula (14) is acquired:

$\tan\theta b=(H/Hm)\{\alpha(1-N\chi^o)+\beta N\chi^{o\alpha 3}(H/Hm)^2\}/\{1-(1-\beta)N\chi^o\}$ ... (14)

[0033]

Formula (13) and formula (14) have the same function form. When H is small, a quadratic term can be ignored, and linear terms of the two are equal. When calculated with $\alpha=0.96$, $N\chi^o$ is acquired as in formula (15):

$N\chi^o=1/(1+4.49\beta)$ ... (15)

Subsequently, when H is large, by comparing the quadratic terms of the two with each other, it can be confirmed that the two are equal, when a conditional expression (15) is established. That is, when $\alpha = 0.96$ and the conditional expression (15) are established, $\tan\theta a=\tan\theta b$ is acquired, and $\theta a=\theta b$.

[0034]

Here, $N\chi^o$ takes a value from 0.25 to 0.77 or the like, and its physical meaning will be examined. A relation between effective magnetic permeability μeff and a demagnetizing coefficient N is known to have the relation expressed by the following formula (13):

$N\mu eff=1-(\mu eff/\mu r)$ ... (16)

Here, μr is magnetic permeability specific to the material.

For an ideal magnetic material, $\mu r=\infty$, and $N\mu eff=1$. For the actual magnetic material, it lowers to $N\mu eff=0.2$ to 0.8. Regarding magnetic materials used this time, the anisotropic magnetic field Hk is 5 G, $\mu r=32000$, and the anisotropic magnetic field when incorporated in an element is 40 G, $\mu eff=600$, and $N\mu eff=0.8$.

Moreover, μr of the amorphous wire used is 4,000, and regarding μeff, when the length of the wire is changed so as to change the effective magnetic permeability from 3000 to approximately 920, it changes from $N\mu eff=0.25$ to approximately 0.77. Moreover, since it is $\mu=\chi+1$ (μ and χ are sufficiently larger than 1), when it is approximated to $\chi^o\approx\mu eff$, $N\chi^o=N\mu eff$ is acquired.

[0035]

As the result of the aforementioned examinations, when the inclination angle θ of the spin is directed to a synthesized direction of the anisotropic magnetic field in the circumferential direction and the internal magnetic field Hin and is rotated in the circumferential direction from that angle, a coil output voltage given by formula (1) can be obtained. That is, it was made clear that the inclination angle of the spin is a source of the coil output.

The angle is determined by a ratio of the internal magnetic field Hin applied to the spin in the surface magnetic domain and the anisotropic magnetic field in the circumferential direction, but how to control is important. The larger the anisotropic magnetic field, the more difficult for the spin to be inclined, which requires a large external magnetic field. Moreover, even if the external magnetic field is made larger, it is difficult to make the internal magnetic field in the surface magnetic domain larger. That is because, under the 2-phase structure of the surface magnetic domain and the core magnetic domain, the core part performs magnetic-domain wall movement in a small external magnetic field, is easily magnetized, and generates a large demagnetizing field. That is because the spin in the surface magnetic domain is strongly subjected to an influence also from the core magnetic domain with the leakage magnetic field as the demagnetizing field. Therefore, it is important to make the anisotropic magnetic field as small as possible so that the spin can be greatly inclined in the small internal magnetic field.

[0036]

(5) How to control the inclination angle of the spin in the surface magnetic domain of the magnetic wire will be explained first from the relationship between the inclination angle of the spin and the external magnetic field.

Fig. 2 illustrates a spin structure of the magnetic wire by being divided into a wire axial-direction section 12 and a section 13. The spin in the surface magnetic domain 14 is directed to the circumferential direction, and the spin in the core magnetic domain 15 is directed to the axial direction and is divided into four parts of the rightward spin 16 and the leftward spin 17. A change in the spin structure when the external magnetic field H is applied is illustrated.

a) In the case where the external magnetic field H=0, the magnetic domain structure 15 of the core part is symmetrically divided into four magnetic domains with the spins directed to positive and negative in the axial direction, and the magnetization M is zero. All the spins in the surface magnetic domain 14 are aligned in a pulse-magnetized direction in the circumferential direction.

b) When the external magnetic field of approximately H=Hk/2 is applied, the magnetization having the spin 17 directed to an application magnetic field of the core magnetic domain 15 becomes thicker, while that of the spin 16 in the opposite direction becomes thinner, whereby the magnetization $M=\chi H$ is generated, and a large demagnetizing field is created. All the spins 18 in the surface magnetic domain are inclined to the direction of the application magnetic field H, and can be acquired from

θ in experiment formula (1), and the inclination angle θ is $\theta=\pi H/4\ Hm$. A target region of the GSR sensor is from zero to Hm, and the sensor output is determined by the demagnetizing field determining θ, the anisotropic magnetic field $K\theta$ in the circumferential direction. Moreover, it is known that a spin total amount determined by a rotation speed of θ depending on the pulse frequency and a thickness and a surface area of the surface magnetic domain is important.

c) When the external magnetic field H=Hk is applied, the spins in the core magnetic domain are all aligned in the direction of the application magnetic field. All the spins in the surface magnetic domain are inclined by an inclination angle of 45 degrees to the direction of the application magnetic field H. At Hm=0.96 Hk, which is a value slightly smaller than Hk, the spin on the outermost surface part is inclined by 45 degrees, and the coil output takes a maximum value. On the contrary, when H becomes Hk or more, while the inclination angle of the spin stays at 45 degrees, a boundary magnetic-domain wall between the core magnetic domain and the surface magnetic domain starts moving to the outer side, the thickness of the surface magnetic domain is getting smaller, and the coil output begins to lower. The measurement range is defined by Hm.

d) When the external magnetic field H which is sufficiently larger than Hk is applied, all the spins in the core part are aligned in the direction of the application magnetic field and moreover, the magnetic domain wall between the core part and the surface magnetic domain moves to the outer side, and finally, the surface magnetic domain disappears or becomes extremely thin. It takes a magnetized state outside the measurement range of the GSR sensor. Since Hk and Hm take substantially the same value, when the external magnetic field H further increases from Hk, the spin on the outermost surface is fixed stronger than that staying at 45 degrees, indicating resistance against the pulse circumferential magnetic field, and the coil output lowers. At the same time, it is expected that the thickness of the surface magnetic domain starts decreasing, and the coil output starts reducing.

[0037]

When the external magnetic field H is small; that is, when the spin angle θ is equal to or smaller than 0.2 radian (12 degrees), the coil output is proportional to the external magnetic field H. In other words, it is the case of 0.2 Hk or less. On the contrary, when the external magnetic field H becomes larger than the anisotropic magnetic field Hk, the core-part magnetic domain becomes thicker, while the surface magnetic domain becomes thinner, and the coil output lowers. While H is from 0.2 Hk to Hk, H can be acquired from the coil output voltage by using formula (1).

[0038]

(6) Subsequently, a condition under which the super high-speed spin rotation phenomenon, which is a new electromagnetic phenomenon, emerges will be explained. It will be explained that the emergence condition is, by using the magnetic wire in which the surface magnetic domain having the circumferential-direction spin alignment on the surface exists, an excitation pulse having a sufficiently large current with a frequency of GHz which is applied so that the skin depth p is smaller than the thickness d of the surface magnetic domain, the simultaneous rotation of the circumferential-direction spin is brought about, and the change is detected by a fine coil.

[0039]

As causes of the coil output voltage, the magnetization rotation by movement of the 90-degree magnetic domain wall and the spin rotation of the surface magnetic domain are considered. The 90-degree magnetic domain wall can move in the small magnetic field, but it becomes extremely slow due to an electromagnetic brake by an eddy current, when the frequency becomes high. On the other hand, in the spin rotation in the surface magnetic domain, the spins rotate simultaneously in a group, and the movement completes instantaneously. The number of spins participating in the rotation is limited, and an output signal is very weak.

[0040]

In the MI phenomenon, the 90-degree magnetic domain wall, which is a boundary between the surface magnetic domain and the core magnetic domain, is present on the outermost surface and vibrates with a width of the skin depth p (In this case, 1 μm to 4 μm) in a frequency range from 1 MHz to 30 MHz. The thickness of the surface magnetic domain is considered to be 0.2 μm to 0.8 μm. When the frequency increases to 0.5 GHz or more, the movement of the 90-degree magnetic-domain wall becomes extremely slow due to the electromagnetic brake by the eddy current. Moreover, the skin depth p becomes 0.2 μm to 0.8 μm, which is approximately the thickness of the surface magnetic domain, and the vibration of the magnetic domain wall stops.

On the other hand, the GSR phenomenon brings about the simultaneous rotation of the surface spins with the thickness of the surface magnetic domain at 1 μm, the frequency at 0.5 GHz or more, the magnetic permeability of the magnetic wire at 3000 or more, and the skin depth at approximately 0.2 μm.

[0041]

As is known from formula (1), when the thickness d of the surface magnetic domain is approximately 1 μm and the skin depth p is from 0.1 μ to 1 μ or less, the coil output voltage is proportional to the square root of the frequency. The reason is that the skin depth p, which is the depth of the spin rotation, is proportional to an inverse number of the square root of the frequency. On the other hand, when the thickness d is 0.2 μm, which is smaller than the skin depth p, the depth of the spin rotation does not penetrate to p but is fixed at a position d of the 90-degree magnetic-domain wall and thus, they become constant as p = d, and the coil output voltage is linearly proportional to the frequency. In an experiment using a wire with glass, it is considered that a sufficient depth is provided, since the coil output voltage is proportional to the square root of the frequency, and the thickness of the surface magnetic domain is approximately 1 μm.

[0042]

The magnetic wire which was used is a magnetic wire with high magnetic permeability formed of a magnetic Co alloy and having a diameter of 10 μm, an amorphous structure, and weak negative magnetostrictive characteristics, with magnetic anisotropy of 1 G or 5 G, and relative permeability of 20,000 and 3000. A tensile stress was loaded to the wire, and the magnetic anisotropy Ku and the magnetic anisotropy Kθ were caused to be generated in the axial direction and the circumferential direction, respectively to thereby form a 2-phase magnetic domain structure of the circumferential surface magnetic-domain having the circumferential-direction spin alignment and the center-part core magnetic domain having the axial-direction spin alignment. The skin depth p of the pulse current was controlled such that the thickness d of the surface magnetic domain was approximately 1 μm, by considering the surface depth p of 0.5 μm.

Moreover, a magnetic field exceeding 1.5 times of the anisotropic magnetic field Hk was generated by a sufficiently large pulse current, a pulse magnetic-field annealing processing was performed at every measurement, magnetization was saturated in the circumferential direction, and a magnetization history was erased.

[0043]

Under the aforementioned condition, only the simultaneous rotation phenomenon of the spin can be genuinely brought about. In order to detect a very weak and high-speed signal with a coil, a fine coil is needed. A coil pitch per unit length is set to 30 μm to 10 μm or less, a coil inner diameter to 15 μm or less, and an interval between the magnetic wire and the coil to 10 μm to 3 μm or less of the coil-type MI sensor so that electromagnetic coupling between the wire and the coil was reinforced, and the output voltage in proportion to the coil number N could be successfully acquired.

[0044]

(7) A super high-speed spin-rotation effect type GSR sensor and a coil detection type MI sensor will be compared so as to make characteristics of the new principle clear.

The MI sensor uses such a phenomenon that, when a high-frequency current or a pulse current with a frequency of 1 MHz to 30 MHz is passed through a magnetic wire or a magnetic thin film in the external magnetic field H, impedance is greatly changed due to a skin effect. When the 90-degree magnetic domain wall existing at the boundary between the surface magnetic domain and the core magnetic domain vibrates, the magnetic permeability largely depends on the external magnetic field H and changes, makes the skin depth smaller, and brings about a large impedance change. From the change amount, the external magnetic field H is detected. An excellent sensitivity of 1 mG is realized with a sensor having a sensor length of 5 mm.

[0045]

The output has a non-linear characteristic that it is positive/negative symmetric to the external magnetic field and moreover, shows a monotonic increase to the size of the external magnetic field but gradually decreases at a certain critical magnetic field or more. Moreover, since the output is strongly subjected to an influence of hysteresis of the magnetic wire, it has a premise that, by using a negative feedback circuit, an output which is linear and small in hysteresis is acquired from the current strength of the feedback.

The FG sensor, which is a prior art, takes a coil output voltage in proportion to the external magnetic field H by using a magnetic material of permalloy or the like having a general magnetic-domain structure and using an AC current with the frequency of 30 KHz. The MI sensor was an epoch-making invention which realized high performance of approximately 1000 times by utilizing a high frequency of 30 MHz. An epoch-making invention that a 90-degree magnetic-domain wall existing at a boundary between the surface magnetic domain and the core magnetic domain vibrates was the basis thereof.

[0046]

The improved-type MI sensor with a coil developed by the inventors is a type which succeeded in reduction of current consumption by omitting a negative feedback circuit through execution of the pulse magnetic-field annealing by giving a trapezoidal-shaped pulse current. Moreover, by manufacturing the MI element by the MEMS process, the length was made smaller, from 3 mm to 0.6 mm. By raising the pulse frequency to 200 MHz, improvement of the coil output was promoted. At the same time, the anisotropic magnetic field of the magnetic wire was made remarkably large to

20 G so as to enlarge the measurement range. By promoting the size reduction and the enlargement of the measurement range as above, the sensitivity in a trade-off relationship is greatly lowered to 2 mG. Improvement of the sensitivity and further size reduction/enlargement of a measurement range are future challenges.

[0047]

The frequency of 200 MGz exceeds a frequency range where the MI phenomenon emerges. Thus, by using a fall of a pulse of the trapezoidal-shaped pulse current, the movement of the 90-degree magnetic-domain wall was made possible. The 90-degree magnetic-domain wall having penetrated into the core slowly moves to a surface direction by a power of the external magnetic field with disappearance of the circumferential-direction magnetic field when the pulse is shut down.

On the other hand, at the fall of the pulse, with the disappearance of the circumferential-direction magnetic field, the spin in the surface magnetic domain starts to be inclined, but the inclination is small by the strong anisotropic magnetic field, and the rotation speed is also slow, whereby an increase in the coil output is suppressed. The coil output is mainly caused by the movement of the 90-degree magnetic domain wall, which is the MI phenomenon, but an influence of the spin rotation, which is the GSR phenomenon is also partially detected.

[0048]

The maximum value of the coil output voltage based on the MI effect is proportional to the external magnetic field H. Since the MI phenomenon and the GSR phenomenon are mixed in this method, the linear range is made small to approximately 1/3 of the measurement region. On the other hand, the output of the GSR sensor can be used in all the ranges in the measurement region by arithmetic processing, since a clear mathematic equation is established.

[0049]

An electronic circuit of the MI sensor accumulates a coil current in a capacitor of an integration circuit, receives a coil signal, acquires an integrated voltage thereof, acquires a maximum value thereof in a peak-hold circuit, and outputs it. Since it was made as a MEMS coil, resistance of the coil increases, and a voltage drop (IR drop) occurs in a process of obtaining the integrated voltage, which is a problem. Moreover, since the coil is formed in a plating process so as to make a film thickness larger and to lower resistance, cost was drastically increased.

[0050]

Moreover, the inventor examined how to increase the pulse frequency from 0.2 GHz to 1 GHz in the aforementioned MEMS coil-type MI sensor (Patent Document 6).

When it is raised to 0.5 GHz, the output can be improved approximately twice, but, on the contrary, at 1 GHz or more the output lowers. When the frequency is raised on the basis of the MI phenomenon, the magnetization rotation by the movement of the 90-degree magnetic domain wall in the core magnetic domain and the simultaneous rotation of the inclined spins in the surface magnetic domain are both detected as a coil voltage. Even with the raised frequency, the movement of the magnetic domain wall stays slow, and the influence of the spin rotation in the surface magnetic domain becomes larger. However, although the spin rotation is capable of a high-speed rotation, a magnetic signal is weak, and in a case of a coil with an inner diameter of 30 μm, a distance between a wire and a coil is as long as 10 μm, electromagnetic coupling is weak, and sufficient detection could not be realized. In order to detect the spin rotation phenomenon, the distance between the coil and the wire needs to be made smaller from 10 μm to 3 μm or less, and by increasing a coil pitch per unit length, the electromagnetic coupling between the spin rotation on the wire surface and the coil needs to be reinforced.

[0051]

Moreover, with presence of a contradiction problem between the sensitivity and the measurement range, since the measurement range of the MI sensor is limited to a range capable of linear approximation, it was difficult to enlarge. Improvement of approximately two-fold was realized by raising the frequency. However, technical problems involved in the higher frequency occurred and it could not be commercialized as a product.

Regarding the technical problems of the high-frequency pulse oscillation circuit, an increase in parasitic capacitance associated with a coil and a wiring circuit caused smoothing of a pulse rise and attenuation of an output by an IR drop, whereby a large output circuit was required, which was not practical. An increase in an electromagnetically induced voltage involved in the higher frequency became larger than the coil voltage caused by the magnetization change on the surface, and removal of it has become a problem. The large electromagnetically induced voltage caused large errors such as limitation on a degree of amplification of a signal, lowered linearity and accuracy of a detection signal, deterioration of temperature characteristics, and the like, and a practical sensitivity has rather lowered. The inventor determined that the idea of raising a frequency on the basis of the MI sensor would be tangled in the trade-off, and an improvement measure for performance upgrade could not be discovered.

[0052]

(8) Basic differences between the principle of the GSR sensor and the principle

of the MI sensor will be summarized.

The MI phenomenon emerges at the frequency from 1 MHz to 30 MHz and is caused by the vibration of the 90-degree magnetic domain wall present at the boundary between the surface magnetic domain and the core magnetic domain, while the GSR phenomenon is generated at 0.5 GHz to 4 GHz and is caused by the spin rotation in the surface magnetic domain. Regarding the coil output of the MI sensor, the output voltage is accumulated in the capacitor of the integrated circuit, and a magnetic field is acquired from a proportional relationship between the voltage and the magnetic field. With the GSR sensor, an instantaneous voltage of the coil is directly detected by a buffer circuit, and since the voltage and the magnetic field are in a mathematical relationship in formula (1), the magnetic field is acquired. When the coil of the MI sensor is made finer, resistance increases, and an IR drop occurs. Thus, the effect by the refinement of the coil and the increase in the coil winding number Nc becomes limited. In the GSR sensor, the coil resistance is extremely large, and only an extremely small amount of current flows through the coil. Since the coil output voltage needs to be directly detected as the voltage, it is detected through the buffer circuit. A detection capability by the coil can be increased with little influence of the increased resistance caused by the coil winding number and the coil refinement.

[0053]

On the other hand, in the GSR sensor based on the GSR phenomenon, a drive pulse frequency is raised from <u>0.5 GHz</u> to 3 GHz, and by simultaneously rotating the spins in the surface magnetic domain at a high speed and by detecting a generated high-speed signal with the fine coil, a large output proportional to the frequency and the coil winding number can be realized. Specifically, it was found that the coil output increases in proportion to the square root of the frequency by making the depth d of the surface magnetic domain larger than the skin depth p of the pulse, and an astounding output could be successfully extracted <u>by means of</u> integration with a fine-coil manufacturing art.

[0054]

Moreover, between the coil output voltage and the external magnetic field H, a clear mathematical relationship as shown in formula (1) exists within a range of the measurement region ±Hm, and hysteresis hardly occurs and thus, an excellent output characteristic and a low current-consumption characteristic with a wide measurement range as shown in Fig. 3 can be obtained. Fig. 3-a) illustrates a relationship between the external magnetic field and the coil output voltage Vs. Fig. 3-b) illustrates a relationship between a converted value obtained by applying arcsin conversion of the coil output voltage Vs and the external magnetic field H. It is clearly known that a linear relation is present between the converted voltage value and the external magnetic field within the measurement range (range from a maximum value to a minimum value).

[0055]

The establishment of this mathematical relationship is realized by paying attention to a difference in magnetization behaviors of the two-phase magnetic domains; that is, the surface magnetic domain having a circumferential-direction spin on the surface with respect to the external magnetic field H and the axial-direction spin magnetic domain of the center core part, by adjusting the anisotropic magnetic field to 8 G or less and the surface magnetic-domain depth to the skin depth or more, by setting the frequency of the pulse current to 0.5 GH or more and the skin effect depth to 1 μm or less, and by setting the condition that can genuinely detect only the circumferential-direction spin rotation at a super high speed.

[0056]

The physical basis of the electromagnetic phenomenon of the super high-speed simultaneous spin rotation is an exchange interaction between spin-spin. The spin groups aligned in the circumferential direction are strongly coupled to each other by this exchange interaction so that the simultaneous rotation of the spins can be performed at the super high speed of 2 GHz. Moreover, when the frequency is raised in a case where the thickness of the surface magnetic domain is sufficiently ensured, the skin depth becomes smaller, and the coil output increases in proportion to $f/p = f^{1/2}$.

However, the eddy current increases with the speed increase, whereby the spin rotation is suppressed and thus, a maximum value is taken at a certain frequency. Furthermore, when the pulse frequency is raised to the vicinity of 5 GHz, spin precession and spin resonance phenomenon begin to occur, and each spin overcomes the exchange action force and starts rotation, whereby the coil output voltage is lowered. By means of heat generation of a spin system by lattice heat generation by the eddy current and the precession, the decrease of the coil output is amplified.

[0057]

The higher the frequency, the larger the output voltage. Moreover, the skin depth also becomes smaller, whereby the thickness d of the surface magnetic domain can be made smaller. This means that, by making a stress in the circumferential direction smaller, the magnetic permeability of the magnetic wire can be increased; that is, a value of the coefficient Vo can be increased, and the output can be improved.

However, as a spin resonance frequency is approached, fluctuations occur in the simultaneous rotation, and the coil voltage lowers and thus, there is an optimal frequency range, which is from 0.5 GHz to 4 GHz. Fig. 4 illustrates the result of examination of an influence of the frequency on the coil output by using Embodiment 1. (A) is a product of the present invention of a type, in which the measurement range is ±40 G and the sensor length is 0.2 mm. (B) and (C) are embodiments of two MI sensors having sensor length of 0.6 mm and measurement ranges of 2 G and ±30 G in Patent Document 6. The GSR sensor of the present invention is superior to the MI sensor in both sensitivity and the measurement range. The voltage increases to a higher frequency range as the frequency increases. It shows the highest value at 2 GHz and then gradually decreases. This is considered to be caused by increases in the spin precession and the eddy current braking. Therefore, a desirable range of frequencies is from 0.5 GHz to 4 GHz.

However, the increase in the pulse frequency increases an induced voltage induced by the circumferential pulse magnetic field in the coil and thus, this measure is more important in the GSR sensor.

[0058]

(9) Specific sensor specifications which realize the following GSR effect will be made clear.

The inventor elucidated the following sensor specifications and invented a measure for embodying it on the basis of the electromagnetic phenomenon of the aforementioned GSR effect.

The magnetic wire was made of a Co-based alloy having 0 magnetostriction or weak negative magnetostriction and had an anisotropic magnetic field Hk of 8 G or less, relative magnetic permeability of 1000 or more, a diameter of 20 μm or less, and a stress in the axial direction was 2p or more with the thickness d of the surface magnetic domain of 1 μm or less. The thickness was adjusted to be 2p or more by applying pulse magnetic-field annealing or tension annealing by taking into consideration the applied pulse frequency. It is to be noted that, regarding residual magnetization of the core part, disappearance/reduction of an influence history of the external magnetic field before that were promoted during pulse-conduction duration time so as to suppress hysteresis.

[0059]

Regarding the current intensity of the pulse current, the intensity of the circumferential-direction magnetic field on the surface was set to 30 G or more or a circumferential-direction magnetic-field intensity of 1.5×Hk or more was ensured as a target by considering a diameter of the wire, and the pulse frequency was set to 0.5 GHZ to 4 GHz so as to realize the simultaneous spin rotation at a super high speed only of the spins in the surface magnetic domain. Moreover, the core magnetic domain was reduced by a large circumferential-direction magnetic field during the duration of the pulse conduction so as to increase the thickness of the surface magnetic domain.

Regarding a rising speed of the pulse, steep rising was ensured by reduction of the parasitic capacitance of the coil, a change from the wiring wire bonding to soldering joining, ASIC incorporation of the capacitor, and the like.

A length of a pulse time interval was set to 10 n seconds or more in order to avoid coil signal interference, and natural cooling of the wire was performed at the same time.

[0060]

Regarding a size of the element, the coil output is proportional to a diameter D of the wire, but if the diameter is too large, the circumferential-direction spin magnetic domain on the surface cannot be formed and thus, the size should be 30 μm or less. However, by considering minimization of the coil pitch and size reduction of a sensor size, it is realistic to set the diameter to 20 μm or less. Although the length L increases the coil output, the measurement range of the magnetic field becomes smaller, and there is a trade-off relationship between the coil output and the measurement range. As a measure against this, it is desirable to increase the coil output by making the coil pitch smaller and by increasing the coil winding number so as to increase the coil output and by making the wire length L as small as possible. In a case where the measurement range may be small, it is desirable to secure a sufficient length so as to increase the coil output and the sensor sensitivity.

[0061]

Regarding the detection coil, in order to reinforce the GSR phenomenon on the wire surface and the electromagnetic coupling with the coil, the inner diameter of the coil should be 25 μm or less, and the distance between the wire and the coil should preferably be 3 μm or less. Regarding the coil winding number, it is important to make the coil pitch smaller to 10 μm or less in order to reduce the size of the GSR element on the outermost surface.

The structure of the fine coil is obtained by a three-layered structure of a recessed coil lower part, a protruding coil upper part, and a joint part for connecting them via a level difference between both or in a case of a special case where the level difference is zero, by a two-layered irregular structure in which only the lower part of the magnetic wire is embedded in a board groove with a coil lower-part wiring provided, it is fixed with a resin having an adhesive function, the upper part of the wire is thinly covered with a surface tension of the resin, or in a case of an insulating-coated magnetic wire, the coil upper-part wiring and the wiring of the joint part of the coil lower-part and the upper-part are performed in a partially exposed state.

[0062]

Moreover, in the manufacture of the coil, the insulation between the coil and the wire is ensured by using an insulating material directly coated on the wire, and regarding connection between the wire and the electrode, a connecting part with high strength can be realized by connecting with a conductive metal material including the wire upper-surface part in a contact portion from which the wire insulating-coating material is removed. It is to be noted that the manufacture may be performed by using the resin insulating coating inserted into a space between the coil and the wire.

[0063]

(10) When the frequency of the pulse current is increased, the induced voltage Vc generated in the coil increases due to the relationship between the circumferential-direction magnetic field generated by the pulse current and the coil wiring structure. An art for removing it from the coil voltage Vm was devised and invented.

There are three types of the induced voltage Vc: (1) a voltage that electrostatically senses a wire potential difference during pulse conduction; (2) a voltage generated when a coil directly senses a change in a circumferential-direction magnetic field; and (3) a voltage sensed by a wiring loop on a board surface. A magnitude of the induced voltage is affected the most by the electrostatic potential difference followed by the voltage the coil directly senses. For the wiring loop, cancellation is easy and can usually be made smaller, but undesirable wiring generates a large voltage.

[0064]

A pair of or a plurality of pairs consisting of a detection element of a right-handed coil and a detection element of a left-handed coil are installed on a board, two electrodes for wire conduction and a wire terminal are connected so that the pulse current flows in opposite directions through the left-handed coil and the right-handed coil, and two electrodes for coil voltage detection and a coil terminal are connected such that, when the pulse current is passed through the wire, the output voltages of the right-handed coil and the left-handed coil proportional to the external magnetic field have the same sign, and the output voltage generated by the circumferential-direction magnetic field created by the pulse conduction, when the external magnetic field is zero, has a different sign, whereby the aforementioned induced voltage Vc can be eliminated. Moreover, the voltage generated by the wiring loop formed by the coil and the electronic circuit on the board can be removed by cross structure of the wiring.

A plan view of the GSR element used in Embodiment 4 (hereinafter, referring to a front view of a wiring structure) is shown in Fig. 9.

By generally expressing this wiring structure, a pair consisting of a first coil, which is a left-handed coil, and a second coil, which is a right-handed coil, is mounted on one piece of the magnetic wire on the board by being directed to a direction in which the pulse current flows. Moreover, a first coil terminal and a second coil terminal are provided by being directed to the direction from which the pulse current flows on each of the first coil and the second coil.

The first coil terminal of the first coil and the first coil terminal of the second coil are connected, a coil output electrode and the second coil terminal of the first coil are connected, and a coil ground electrode and the second coil terminal of the second coil are connected. Regarding disposition of the coil terminals, the first coil terminals of the first coil and the second coil and the second coil terminals of the first coil and the second coil are disposed on respective sides of the magnetic wire. Connection between the coil electrode and the coil terminal is done such that wiring from the coil output electrode to the second coil terminal of the first coil and wiring from the coil ground electrode to the second coil terminal of the second coil cross each other.

By means of this wiring structure, when the left-handed coil and the right-handed coil are attached to one wire, and a current is caused to pass in the same direction, the magnetic field has a negative sequence voltage, while a coil voltage by an electrostatic potential difference becomes the common-mode voltage. When the coil terminals are reversely joined, the output voltage by the magnetic field is added, and the voltage by the electrostatic potential difference is cancelled. Moreover, when the output wirings are crossed each other, an upward magnetic field and a downward magnetic field in the loop are cancelled, and the voltage generated by the wiring loop substantially disappears.

In this case, regarding the voltages generated in the right and left coils, the voltages of the right-handed coil and the left-handed coil are reverse voltages, since the currents are directed to the same direction, but the voltages remain in the same direction, since the coils are reversely connected, which is a problem. However, although the induced voltage does not disappear completely, but it can be made sufficiently small to 1/4 or less, when compared with the induced voltage of a simple coil, and although it is not preferable, it is a usable wiring structure when there is restriction on a size or the like.

[0072]

(12) Regarding the temperature dependency of the coil voltage, after the induced

voltage is reduced, temperature stability of the circuit was improved by setting a detection timing to a peak point of the voltage Vs so that, even if it is slightly shifted by an influence of the temperature, the coil output is not drifted. By using an output of a temperature sensor incorporated in the sensor and a temperature correction program, a temperature at the origin was executed. As a result, 0.02 mG/°C or less was realized for the temperature drift at the origin.

[0073]

By acquiring the external magnetic field H from the coil voltage Vs by using an electronic circuit or program operating means capable of processing functional relations in formula (1), the measurement range can be enlarged to the magnetic field Hm indicating the maximum value of the coil voltage. The measurement range so far of the coil-type MI sensor using the MEMS element was approximately 0.3×Hm.

[0074]

Regarding the temperature stability or temperature dependency of an element output, as is known from formula (1), there is temperature dependency of an average magnetization amount of the circumferential-direction spin group and the anisotropic magnetic field Hk. As for the average magnetization amount, Co has a high Curie point of 1422 K and is not affected by a temperature change around 300 K. As for the anisotropic magnetic field, the output sensitivity is affected, but a temperature change is hardly found.

[Advantageous Effect of the Invention]

[0077]

As compared with an FG sensor, an MI sensor, a coil-detection type improved MI sensor, and the like, the super high-sensitivity micro-magnetic sensor based on the super high-speed spin rotation effect has realized improvement of the sensor output voltage, the sensor sensitivity, and the sensor detection capability, noise reduction, enlargement of the measurement range, lowered current consumption, improvement of the temperature stability, improvement of the hysteresis characteristics and linearity, and micro-level downsizing and is extremely useful, contributing to industrial spread.

[Brief Description of the Drawings]

[0078]

[Fig. 1] Figs. 1 are magnetization characteristic diagrams of an amorphous magnetic wire. Fig. 1a) is an axial MH magnetization characteristic diagram. Fig. 1b) is a relationship diagram of an output and a magnetic field of a GSR sensor.

[Fig. 2] Figs. 2 are diagrams of changes in a magnetization state of the amorphous magnetic wire when an external magnetic field H is changed. Fig. 2a) shows H=0,

Fig. 2b) H=Hk/2, Fig. 2c) H=Hk, and Fig. 2 d) H>Hm.

[Fig. 3] Figs. 3 are graphs illustrating relationships between a coil output voltage and a magnetic field of Embodiment 1. Fig. 3a) shows a relationship between an external magnetic field and a coil output. Fig. 3b) shows a relationship between the external magnetic field and a converted coil output.

[Fig. 4] Fig. 4 is a graph illustrating an influence of a frequency on the coil output of Embodiment 1.

[Fig. 5] Fig. 5 is a plan view of a GSR element according to Embodiment 1.

[Fig. 6] Figs. 6 are structural diagrams (sectional views) of the GSR element of Embodiment 1. Fig. 6a) is a top view of a unit magnetic-field detecting element for explaining a cross sectional view, Fig. 6b) is a cross sectional view of a coil part, and Fig. 6c) is a cross sectional view of a wire electrode part.

[Fig. 7] Fig. 7 is a plan view of a GSR element of Embodiment 2.

[Fig. 8] Fig. 8 is a plan view of a GSR element according to Embodiment 3.

[Fig. 9] Fig. 9 is a plan view of a GSR element according to Embodiment 4.

[Fig. 10] Fig. 10 is a circuit diagram used in Embodiment.

[Best Mode for Carrying Out the Invention]

[0079]

The present invention will be explained in more detail with reference to Embodiments of the invention.

A GSR sensor based on the principle of the super high-speed spin rotation effect according to Embodiment 1 has a minute magnetic field with small geomagnetism of approximately 0.5 mG as a measurement target.

That is constituted by a GSR element (hereinafter, referred to as a GSR sensor element) constituted by a magnetic wire and a loop coil, means for passing a pulse current through the magnetic wire, a circuit for detecting a coil voltage generated when the pulse current is passed, and means for converting a coil voltage into an external magnetic field H. The external magnetic field H and the coil output voltage are expressed by a mathematical relationship as in the aforementioned formula (1).

[0080]

The magnetic wire is a wire made of a CoFeSiB amorphous alloy having a diameter of 3 μm to 10 μm and covered with insulating coating with a thickness of 1 μm or less. Its crystal structure is preferably an amorphous structure, but a nanocrystalline structure is also possible. It is a high magnetic-permeability magnetic wire having relative magnetic permeability of approximately 1000 to 100,000 and having a small magnetic anisotropy of 8 G or less and zero or weak negative magnetostriction characteristic. A wire without insulating coating can also be used, but it is necessary to ensure insulation between the coil and the wire by interposing a resin therebetween.

When a wire with smaller magnetic anisotropy and higher magnetic permeability is used, Hm becomes smaller, and sensitivity of the coil output becomes higher in proportion thereto, but the measurement range becomes narrower. With respect to this problem of the trade-off relationship, it is possible to increase the number of coils per unit length by refining the coil pitch and to use a wire having excellent magnetic permeability characteristic and then, the measurement range is enlarged by shortening the wire length and strengthening the demagnetizing field, and subsequently, by solving the problem of lowered sensitivity by increasing the number of coil windings, all three of demands; that is, high sensitivity, a wide measurement range, and size reduction of the element to micro size, can be satisfied.

[0081]

By applying a tensile stress to the wire so as to generate magnetic anisotropy Ku and magnetic anisotropy Kθ in the axial direction and the circumferential direction, respectively, a 2-phase magnetic domain structure of a circumferential surface magnetic-domain having a circumferential-direction spin alignment and a center-core part magnetic domain having an axial-direction spin alignment were formed.

The thickness d of the surface magnetic domain becomes larger as Kθ is made larger, but since the sensitivity lowers, it does not have to be twice or more of the skin depth p formed by the pulse current. After the measurement magnetic-field range ±Hm is determined, the depth d is adjusted to approximately d = 2p by considering pulse frequencies to be used. Practically, the thickness is preferably 1 μm or less.

[0082]

The intensity of the pulse current was set to 50 mA or more, and a sufficiently large circumferential magnetic field Hθ, which is 1.5 times or more Hm, was generated on the wire surface so that simultaneous rotation of the surface spins was realized. Moreover, magnetization was saturated in the circumferential direction, and the magnetization history was erased. This pulse magnetic-field annealing processing was executed for each measurement so as to remove hysteresis characteristics from the output.

When the strength of the anisotropic magnetic field is large, Hθ needs to be correspondingly increased, but excessive current heats the wire and increases current consumption of the sensor, which is not preferable. It is preferable to be approximately 70 mA to 150 mA, and Hθ is preferably approximately 40 G to 80 G.

[0083]

It is preferable that the pulse frequency is 0.5 GHz or more, the skin depth p of the current is 1 μm or less, and the thickness d of the circumferential surface magnetic-domain is d or less.

When the frequencies are increased under these conditions, the skin depth becomes smaller, the number of rotating spins decreases, and the coil output increases to $f/p=f^{1/2}$ from linear proportion of f by a proportion of $f^{1/2}$.

However, since the eddy current increases with an increase in speed and suppresses the spin rotation, the increasing tendency by f is further suppressed, and a maximum value is taken at a certain frequency. Moreover, when the pulse frequency is increased to the vicinity of the 5 GHz, the precession of the spins and the spin resonance phenomenon begin to be brought about, each spin overcomes the exchange action force and starts to rotate, and the coil output voltage lowers. Lattice heat generation by the eddy current and heat generation of the spin system by the precession amplify lowering of the coil output. Therefore, 4 GHz or less is preferable.

The optimal frequency range is from 1 GHz to 3 GHz. When the magnetic permeability is high, the anisotropic magnetic field is small, and the thickness d of the circumferential surface magnetic-domain is small at 1 μm or less, it is necessary to increase the pulse frequency correspondingly. It is preferable to control the skin depth p to d or less. If d is small, it is preferable to increase the pulse frequency accordingly so that all of the spins in the surface magnetic domain rotate. However, under the condition that p is larger than d, since the number of rotating spins in the surface magnetic domain does not change even if the frequency is increased so as to make p smaller, the output increases in proportion to the frequency f. This means that the combination of the anisotropic magnetic field of the wire and the frequency is not optimized under this condition. It is to be noted that, since the magnetization Ms in the center part is shielded by the magnetic domain wall between the surface magnetic domain and the core magnetic domain, which does not move at a high frequency, it is not affected by the skin effect.

The pulse time interval should be 10 n seconds or more, preferably 50 n seconds, in order to avoid coil signal interference.

[0084]

When the aforementioned pulse current is passed through the wire in this state, the spin is simultaneously rotated in the circumferential direction at a very high speed (within a transition time dt of the pulse) by a large circumferential magnetic field at approximately 60 G generated by the pulse. A change in magnetization of the wire occurring at that time is detected as the coil output voltage Vs.

The coil output increases in proportion to the diameter D of the wire, but if the diameter is too large, the circumferential-direction spin magnetic domain on the surface cannot be formed and thus, the wire diameter should be 20 μm or less. Moreover, the larger the diameter, the larger the required pulse current. Furthermore, since it is difficult to manufacture a fine coil having a small pitch, preferably, the pitch should be 5 μm to 12 μm.

[0085]

The length L is a control factor which increases the coil output but makes the measurement range ±Hm smaller, and the coil output and the measurement range are in a trade-off relationship. In general, it is preferable to increase the coil output by reducing the coil pitch and increasing the coil winding number and to enlarge the measurement range by making the wire length L as small as possible to 0.1 mm to 0.5 mm.

[0086]

Regarding the coil winding number, the higher sensitivity and the size reduction of the sensor can be realized at the same time and thus, it is extremely important to increase the unit coil winding number by making the coil pitch smaller. A lower half or a part of a magnetic wire is embedded in a groove formed in a board, a lower coil is disposed on a bottom surface of the groove, an upper coil is disposed on the upper part of the wire, and the upper and lower coils are joined on the surface of the board to form a coil, whereby the coil pitch can be made 10 μm or less. Considering the level of the current refinement processing art, the coil pitch is preferably 1 μm to 6 μm.

[0101]

The five Embodiments have been described above, and the present sensor has an advantage that a degree of freedom in sensor design is high in accordance with a measurement target.

Under the condition that the depth d of the surface magnetic domain of the magnetic wire is ensured at the skin depth p or more of the pulse by controlling the anisotropic magnetic field Hk (substantially equal to Hm) of the magnetic wire, the relationship in formula (1) exists between the coil output voltage and the external magnetic field by the super high-speed spin rotation effect. That is because performances of the output characteristics can be optimized in accordance with applications such as sensitivity and a measurement range by combining the length and the diameter of the magnetic wire, the coil pitch, the pulse frequency, the current intensity, and a circuit configuration.

[Embodiments]
[0102]
[Embodiment 1]

Fig. 5 shows a plan view of the GSR element according to Embodiment 1. Moreover, a top view and a cross-sectional structural view of a unit magnetic-field detection element for explaining a structural view (cross-sectional view) of the GSR element are shown in Figs 6.

Embodiment 1 of the GSR sensor based on the principle of the super high-speed spin rotation effect is constituted by a GSR element constituted by a magnetic amorphous body and a circumferential coil, means for causing a pulse current to pass through the magnetic wire, a circuit which detects a coil voltage generated when the pulse current is caused to pass, and means for converting the coil voltage to the external magnetic field H. The external magnetic field H and the coil output voltage are expressed in a mathematical relationship as in formula (1).

[0103]

The magnetic wire is a glass-coated wire made of a CoFeSiB amorphous alloy with a diameter of 10 μm and a thickness of 1 μm or less. The magnetic wire has an amorphous crystal structure and has weak negative magnetostriction of 10^{-6} and high magnetic permeability with relative magnetic permeability of 10,000. By applying a tensile stress to the wire so as to generate the magnetic anisotropy $K\theta$ at 5 G in the axial direction and the circumferential direction, 2-phase magnetic domain structures; that is, the circumferential surface magnetic-domain having a circumferential-direction spin alignment and the center core-part magnetic domain having the axial-direction spin alignment, were formed. The thickness d of the surface magnetic domain was set to 1 μm or less.

[0104]

The intensity of the pulse current was set to be equal to or greater than 100 mA so as to generate a sufficiently large circumferential magnetic field $H\theta$ at 60 G on the wire surface, and the spins of the surface magnetic domains inclined by θ were simultaneously rotated in the circumferential direction by power of the magnetic field. At the same time, a pulse duration of 2 n seconds was ensured to cause a 90-degree magnetic domain wall existing at the boundary between the core-part magnetic domain and the surface magnetic domain to penetrate into the core center part, whereby the core-part magnetic domain was reduced and was brought into a magnetizing saturation state or a magnetized state close thereto in the circumferential direction and then, the magnetization history was erased. This pulse magnetic-field annealing processing was executed at each measurement so as to remove hysteresis characteristics from the output.

[0105]

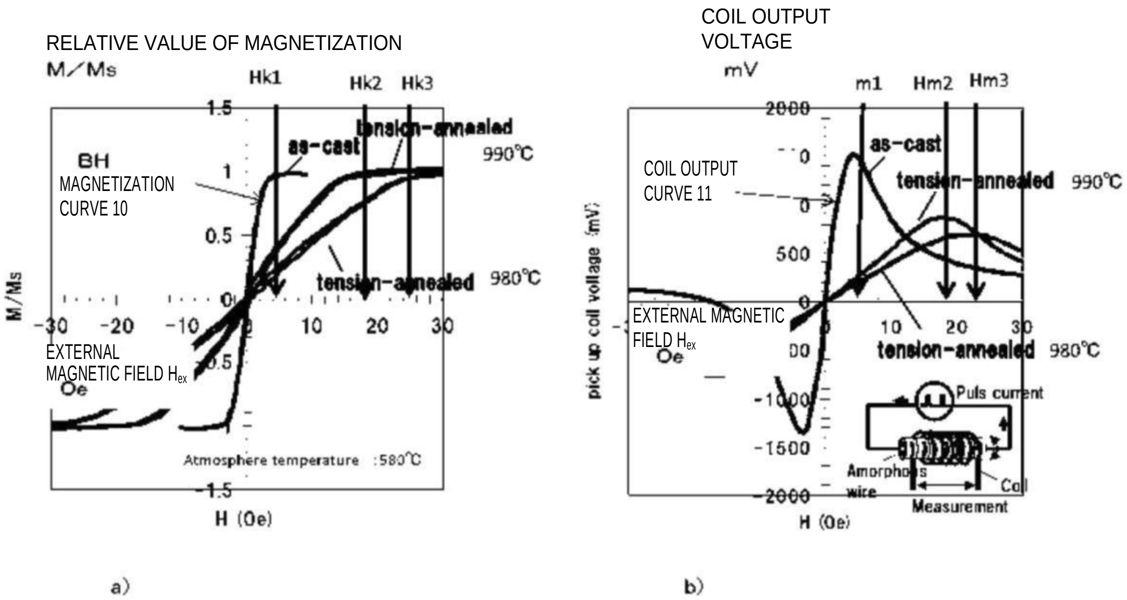
The pulse frequency was set to 2 GHz, the skin depth p of the current to 0.12 μm, and the thickness of the circumferential surface magnetic-domain to 1 μm or less. The measurement range ±Hm was adjusted to 40 G by setting the diameter of the amorphous wire having the aforementioned characteristics to 10 μm and the length L to 0.2 mm.

[Industrial Applicability]

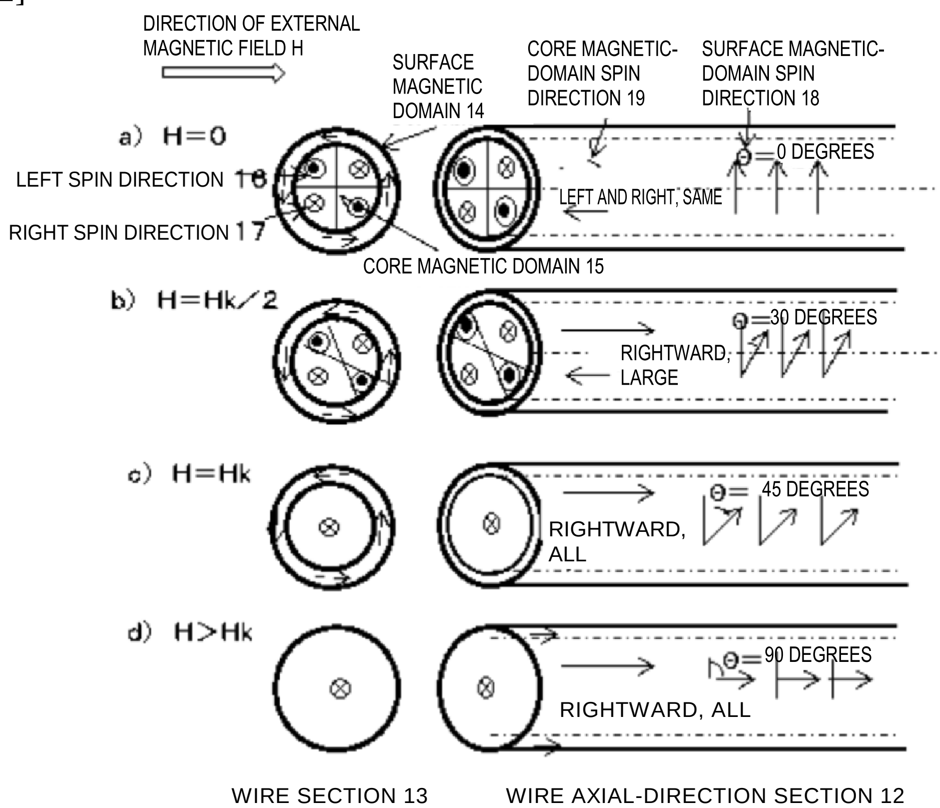
[0123]

The super high-sensitive micro-magnetic sensor based on the super high-speed spin rotation phenomenon of the present invention provides micro-magnetic field detection capability, high-speed measurement, high sensitivity, low current consumption, and a high-quality magnetic signal, and in use for measuring micro-geomagnetism of an electronic compass, a magnetic gyro, and the like, it is expected to be used in a wide range of applications such as application to a three-dimensional compass and a real-time three-dimensional compass, a medical sensor for measuring biomagnetism, application to an inside of a living body by size reduction to a micro size, magnetic mapping application utilizing the high-speed measurement capability, and an industrial magnetic sensor with an enlarged measurement range.

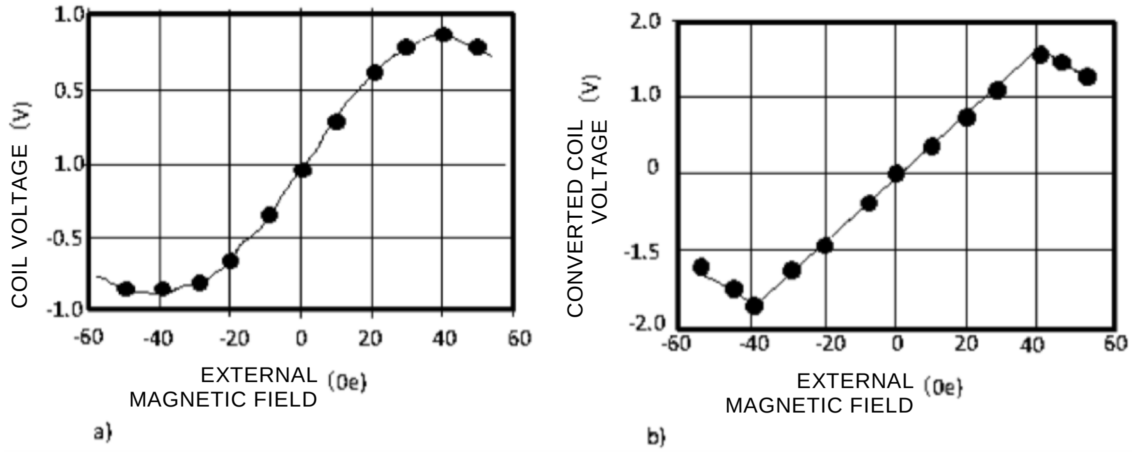
[Fig. 1]


RELATIVE VALUE OF MAGNETIZATION
M/Ms
Hk1
Hk2
Hk3
BH
MAGNETIZATION
CURVE 10
as-cast
tension-annealed
990℃
tension-annealed
980℃
EXTERNAL
MAGNETIC FIELD H_{ex}
Oe
Atmosphere temperature :580℃
H (Oe)
a)
COIL OUTPUT
VOLTAGE
mV
m1
Hm2
Hm3
COIL OUTPUT
CURVE 11
as-cast
tension-annealed
990℃
tension-annealed
980℃
EXTERNAL MAGNETIC
FIELD H_{ex}
Oe
pick up coil voltage (mV)
Puls current
Amorphous
wire
Coil
Measurement
H (Oe)
b)

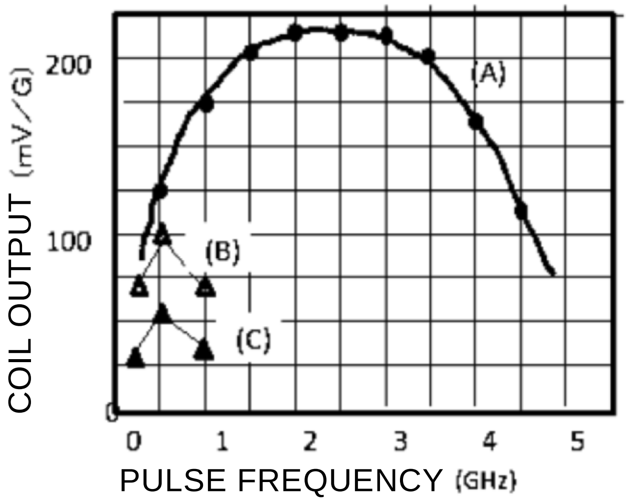
[Fig. 2]


DIRECTION OF EXTERNAL
MAGNETIC FIELD H
SURFACE
MAGNETIC
DOMAIN 14
CORE MAGNETIC-
DOMAIN SPIN
DIRECTION 19
SURFACE MAGNETIC-
DOMAIN SPIN
DIRECTION 18
a) H=0
LEFT SPIN DIRECTION 16
RIGHT SPIN DIRECTION 17
Θ=0 DEGREES
LEFT AND RIGHT, SAME
CORE MAGNETIC DOMAIN 15
b) H=Hk/2
Θ=30 DEGREES
RIGHTWARD,
LARGE
c) H=Hk
Θ= 45 DEGREES
RIGHTWARD,
ALL
d) H>Hk
Θ=90 DEGREES
RIGHTWARD, ALL
WIRE SECTION 13
WIRE AXIAL-DIRECTION SECTION 12

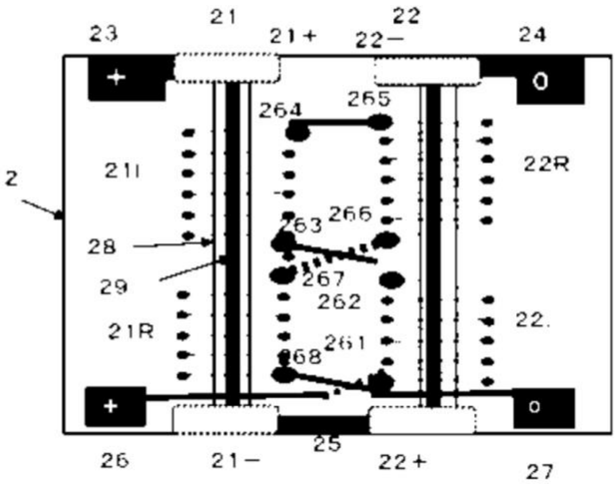
[Fig. 3]



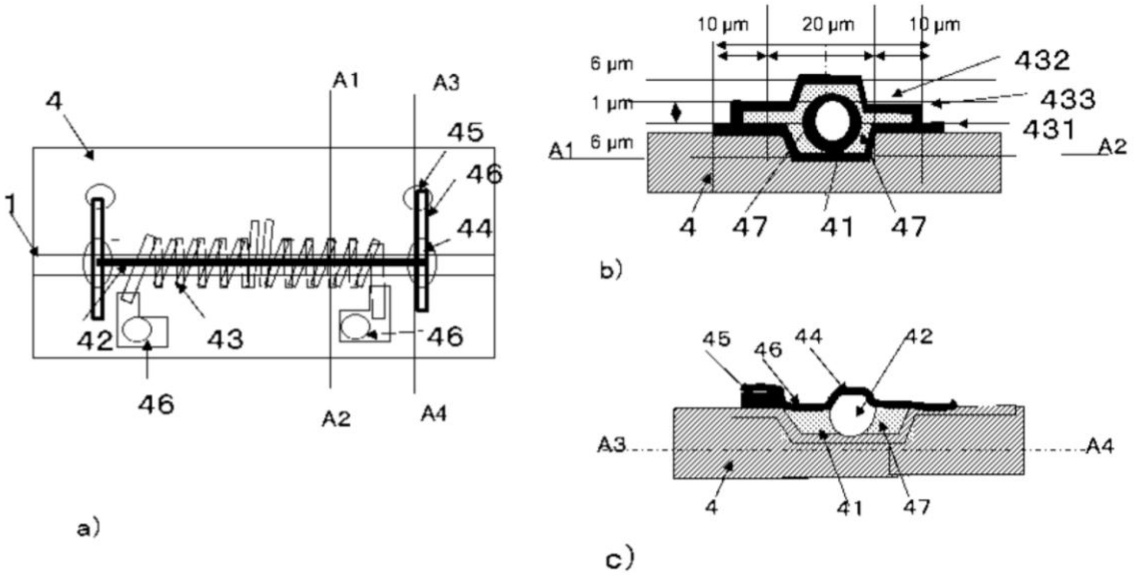
[Fig. 4]



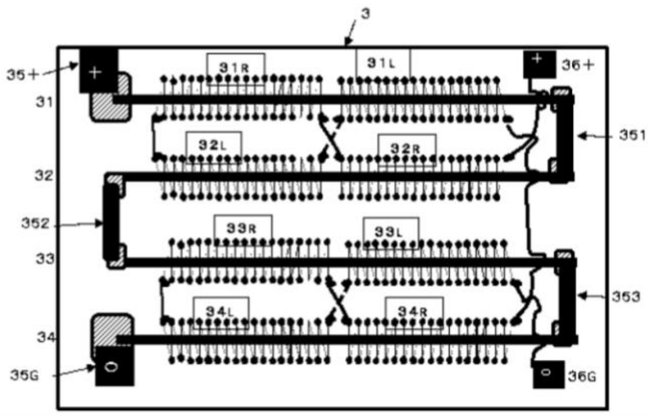
[Fig. 5]



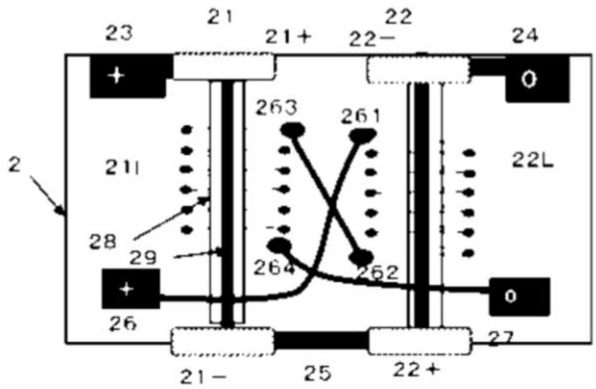
[FIG. 6]



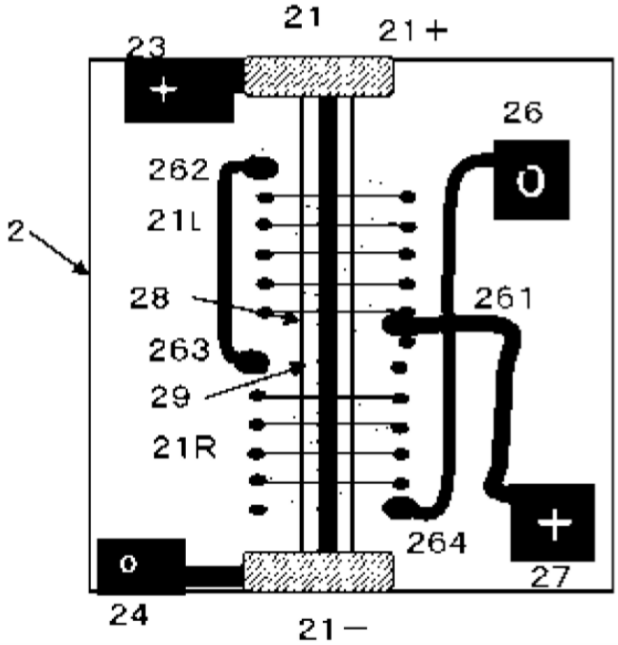
[Fig. 7]



[Fig. 8]

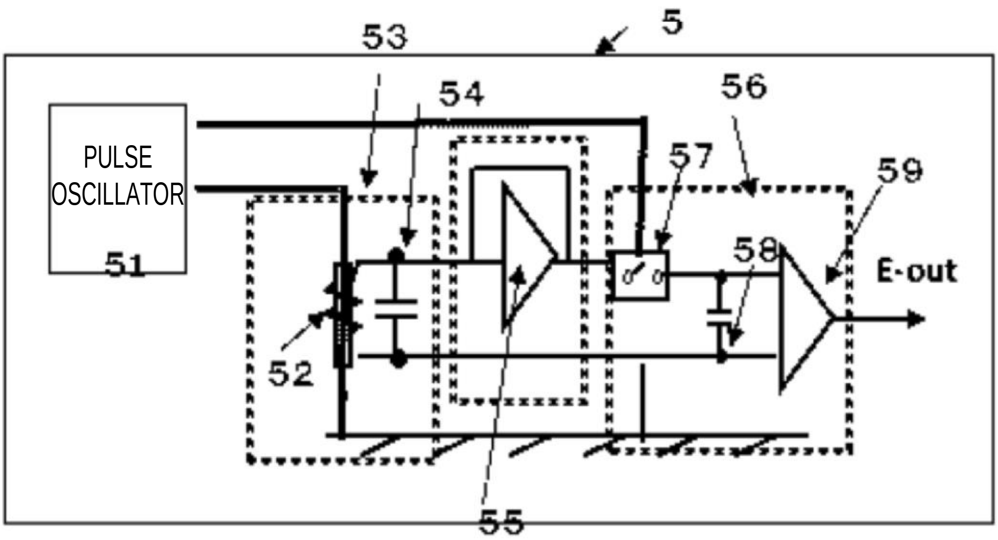


[FIG. 9]



21
21+
23
+
26
O
262
21L
2
28
261
263
29
21R
264
+
o
27
24
21−

[Fig. 10]



5
53
54
56
PULSE
OSCILLATOR
57
59
51
58
E-out
52
55

(Attachment 2)

1 "Magnetic Sensor Science and Engineering (expanded edition)" by Kaneo Mori (Expanded, January 18, 2016) (Exhibit Ko 118)

(1) "An induced voltage e_p ... of a coil wound around an amorphous wire N times in a circumferential direction is in direct proportion to a detection magnetic field H_{ex} as indicated by $e_p=GH_{ex}$." (p. 158, ll. 4 to 8)

(2) "Fig. 7.5 shows DC magnetic-field detection characteristics of an amorphous wire MI sensor incorporated in an electronic compass chip in 2005." (p. 158, ll. 12 to 13)

2 Larissa Panina et al. "off-Diagonal Impedance in Amorphous Wires and Its Application to Linear Magnetic Sensors" (November 2004) (Exhibit Otsu 5)

"... shown in Fig. 12(b) has an almost linear portion in the field range H_{ex}≈±20e." (p. 3510, ll. 3 to 4)

Note: The document above is a thesis on theoretical analyses of coil-type MI sensors and comparison of measurement results of coil voltages, but Fig. 12 discloses that a linear output is indicated.

3 "Large Barkhausen Effect of Amorphous Magnetic Alloy Wire and Magnetic Impedance Effect / MI Sensor" by Kaneo Mori (issued on September 11, 2013) (Exhibit Otsu 15)

(1) "As shown in Fig. (a), by installing a detection coil in an amorphous wire and by detecting a coil voltage, H_{ex} should be able to be linearly detected in principle similarly to the FG sensor from Fig. 14, ... Fig. (c) shows linear magnetic sensor characteristics by a pulse voltage Ep obtained by synchronous rectification of the coil voltage." (p. 33, ll. 15 to 10 from the bottom)

(2) "... in direct proportion to H_{ex}. This is an important principle constituting the linear magnetic sensor having high linearity and without hysteresis. The height Ep of the pulse voltage of the detection coil is $Ep=(\pi\delta(2a-\delta)NMs^2/2Kutr)H_{ex}(1.11)$, ... the magnetic sensor circuit in Fig. 14(a) is a linear magnetic sensor circuit with high linearity and high sensitivity but without hysteresis." (p. 35, ll. 5 to 12)

(3) "Fig. 16 shows DC magnetic-field detection characteristics by the MI sensor in Fig. 14." (p. 35, ll. 10 to 9 from the bottom)

4 T. Uchiyama et al. "Recent Advances of Pico-Tesla Resolution Magneto-Impedance Sensor Based on Amorphous Wire CMOS IC MI Sensor" (Issued on October 18, 2012) (Exhibit Ko 102)

In Fig. 4, it is described that linearities of the magnetic field and the output are good ("good linearity are obtained") (p. 3835, left column, ll. 8 to 4 from the bottom).