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Application of Giant Magnetoresistive Sensor for Nondestructive Evaluation

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***Abstract*—This paper describes the applications of spin-valve type giant magnetoresistance sensor (GMR) for nondestructive evaluation. One is the eddy-current testing (ECT) probe which enables us to inspect micro defect and to detect micro conductors. The proposed ECT probe was applied to the inspection of bare printed circuit board and the recognition of micro solder bead for IC surface mounting package. Another is the measurement of the density of magnetic fluid injected in living body for the hyperthermia treatment. For this purpose, the needle type GMR probe was developed. The experimental results verify the possibility of the proposed system.**

I. Introduction

Magnetic sensing techniques use a broad range of ideas and phenomena from the field of physics and material science. Spin-valve type giant magnetoresistance (SV-GMR) is a magnetic sensor that has the maximum resistance change with approximately 15-20 % for external magnetic fields. The operating range of magnetic field density is from nano tesla to milli tesla. Moreover, SV-GMR sensor has a high sensitivity over the frequency range up to 100 MHz and a high spatial resolution because of micro structure up to submicron size. To improve the spatial resolution and measuring speed, it is possible to fabricate the structure of array sensor [1], [2].

Nondestructive evaluation (NDE) is an examination, inspection, or evaluation of tested object without change in order to determine the discontinuities that may have an effect on the usefulness of the object. NDE may also be carried out to measure characteristics of the test objects, such as size, dimension, configuration, and structure. There are many kinds of magnetic sensor developed for NDE application such as solenoid coil, planar mesh coil, superconducting quantum interference device (SQUID), fluxgate, hall, and GMR. There are three major criteria in choosing the suitable magnetic sensor; low field operating range, wide operating frequency, and small dimension in order to obtain high spatial resolution. Therefore, SV-GMR sensor is suitable for NDE application because of aforementioned performance [3]-[5].

We reported a new application of SV-GMR sensor for NDE application. For the ECT application, the SV-GMR for eddy-current testing (ECT) probe was fabricated. Due to the SV-GMR advantages, the inspection of micro defect on PCB conductor and the detection of micro conductors can be performed by the proposed probe. The measurement of magnetic fluid density was also described in this paper. Magnetic fluid density was measured based on magnetic field differential between inside and outside magnetic fluid.

II. SV-GMR Sensor Characteristics

In this research, SV-GMR sensor has to operate at low

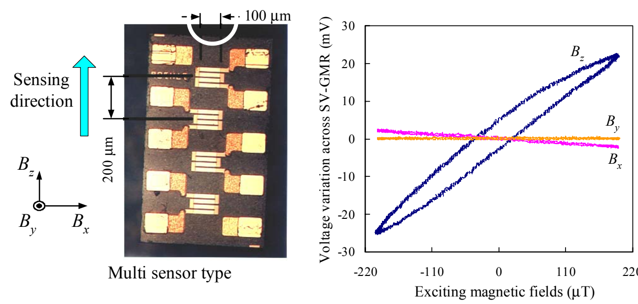


Fig. 1 Proposed SV-GMR and characteristics.

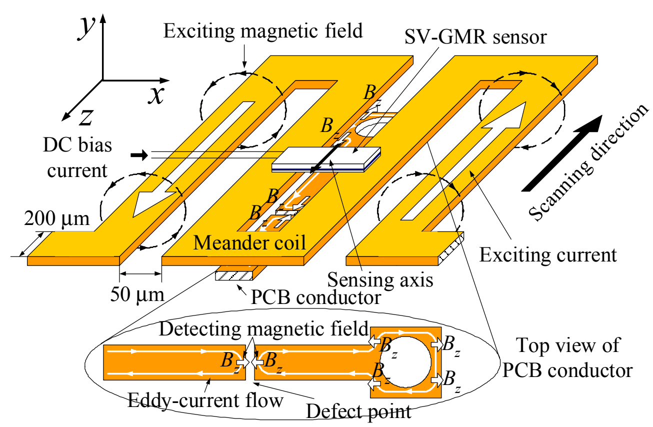
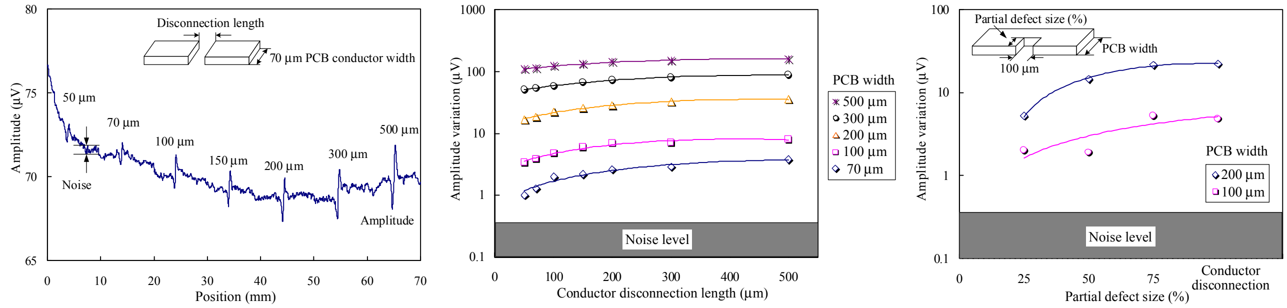


Fig. 2 Proposed SV-GMR based ECT probe.



(a) ECT signal obtained from scanning over 70 µm PCB conductor.

(b) ECT signal variations against conductor disconnection length.

(c) ECT signal variations against partial defects on PCB conductor track widths

Fig. 3 ECT signal variation on different knids of defect.

AC magnetic field. Therefore, a small signal characteristics of the SV-GMR sensor were studied. Figure 1 shows the photograph and characteristics of the SV-GMR multi-sensor. Each of SV-GMR sensor consists of 4 strips and each strip dimension was 100 µm in length and 18 µm in width. The normal resistance of the SV-GMR sensor and the maximum MR ratio were approximately 400 Ω and 12 % respectively.

The small signal characteristics of the SV-GMR sensor were tested at the frequency of 100 kHz. Sinusoidal magnetic field ranging from -200 to 200 µT is applied to SV-GMR sensor. The sensitivity in the sensing axis (z-axis) is approximately 150 µV/µT with the bias current of 5 mA whereas it is lower than 15 µV/µT in the x- and y-axis.

III. Application Based on ECT Technique

A. ECT Probe Construction

As shown in Fig. 2, the high-frequency ECT probe was fabricated by the purpose of the inspection of micro crack on flat surface. The probe is consisted of a long meander coil and SV-GMR serving as an exciting coil and a magnetic sensor respectively. High-frequency excitation current was fed to long meander coil to generate eddy-currents flowing in PCB conductor. The magnetic field B_z occurs only at the defect point or PCB conductor boundary that perpendicular to scanning direction. When the SV-GMR sensor was mounted on the long meander coil, its sensing axis was set to detect only the magnetic field B_z. The use of the long meander coil provides the advantage which is to induce eddy currents on printed circuit and to fabricate multi-sensor [3].

B. Detection of Microdefect on PCB Conductor

The performances of the proposed ECT probe were tested to PCB inspection. The simple PCB model made from Cu with a thickness of 9 µm was used in the experiment. Conductor disconnections ranging from 50 to 500 µm were allocated on the PCB conductor.

The variation of ECT signal occurs at the defect points as shown in Fig. 3 (a). The proposed ECT probe was capable of inspecting 50-µm disconnection on the 70-µm PCB conductor. Furthermore, the imperfection on PCB conductor track can be also inspected by the ECT probe. The variation of amplitude depends on PCB conductor width, defect length and defect type as shown in Figs. 3 (b) and (c). The signal-to-noise ratio increases gradually in exponential when the PCB conductor becomes wider.

Figure 4 presents the PCB pictures and the ECT image after the simple image processing was applied. The defects were allocated on the PCB model. The smallest conductor disconnection was only 20 µm. Furthermore, different kinds of partial defects were located on this model. The scanning results present that the proposed ECT probe is able to inspect the defects on the PCB conductor. It is not difficult to identify the defects on PCB conductor although the images are not clear. PCB conductor gap is one of parameters that effect the signal variations.

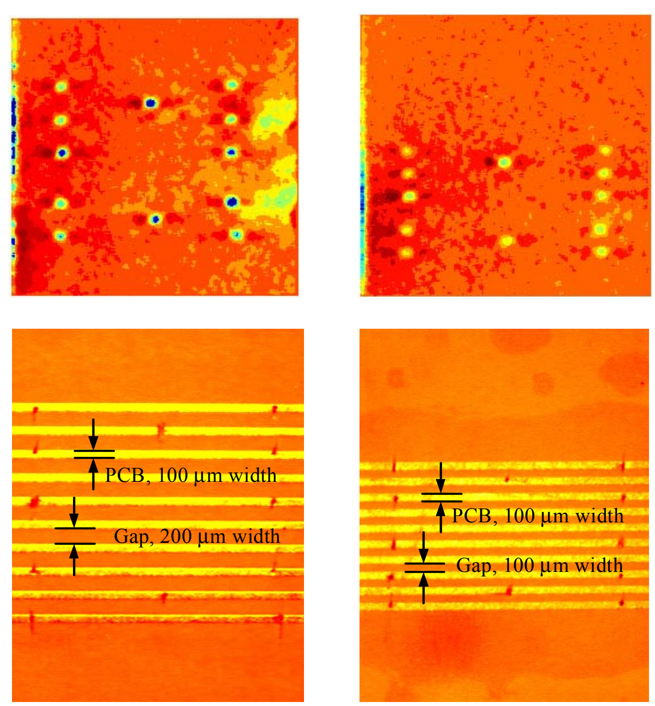


Fig. 4 PCB model (lower) and scanning result (upper).

C. *Microbead Detection*

The ECT signal waveforms in Fig. 5 obtained from the detection of a conductive microbead with 125 µm radius at the frequency of 5 and 10 MHz agree with the ECT signal waveforms obtained from analytical solution. The determinations of the microbead diameter and its position are done by considering the peak of ECT signal and peak of signal gradient respectively. Figure 6 shows the maximum variation of the ECT signal versus the radius of the conductive microbead, ranged from 125 to 300 µm.

The application of numerical gradient technique to ECT signal enables us to easily determine the conductive microbead position as shown in Fig. 7 (a). In addition, the pitches of the conductive microbead are also measured by considering the peak of the signal gradient. The conductive microbead array model with 125 µm radius and 410 – 460 µm microbeads pitches and its detection results are shown in Figs. 7 (b) and (c) respectively. The conductive microbeads are clearly recognized and the pitches of the conductive microbead are also accurately specified with error within 50 µm.

IV. MEASUREMENT OF MAGNETIC FLUID DENSITY

Hyperthermia in cancer treatment with magnetic fluid has developed as minimally invasive treatment [6]. The density of magnetic fluid injected into live body has to be confirmed before treatment. The proposed measurement technique for measuring the density is shown in Fig. 8. Magnetic field, B_0, is generated by Helmholtz coil and applied to magnetic fluid. The magnetic field, B_1, at the center of magnetic fluid can be expressed as

$$B_1 = \mu^* B_0 / \{1 + N(\mu^* - 1)\} \cong \{1 + (1 - N)(\mu^* - 1)\} B_0 \qquad (1)$$

μ^* is magnetic fluid relative permeability which is slightly greater than one and N is the demagnetizing factor [7]. Assuming that the magnetic nanoparticles are uniformly distributed in the fluid and its shape is cylindrical as shown in Fig. 9. When magnetic fluid is regarded as a bulk, the magnetic permeance of a unit volume can be calculated [8].

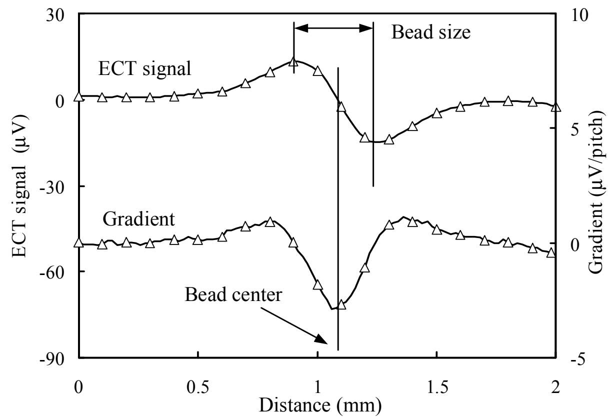


Fig.5 ECT signal obtained from the detection of a conductive microbead (PbSn) with 125 µm radius and its signal gradient.

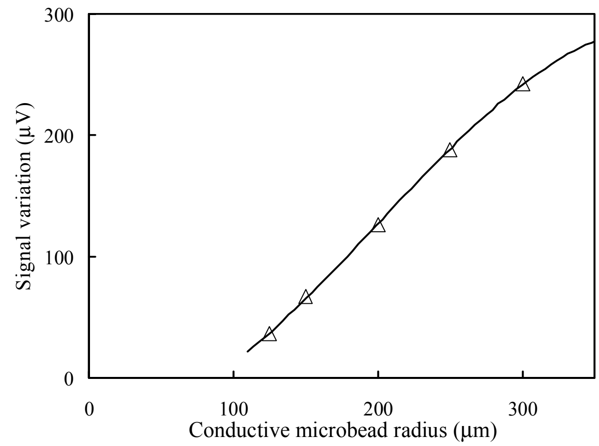
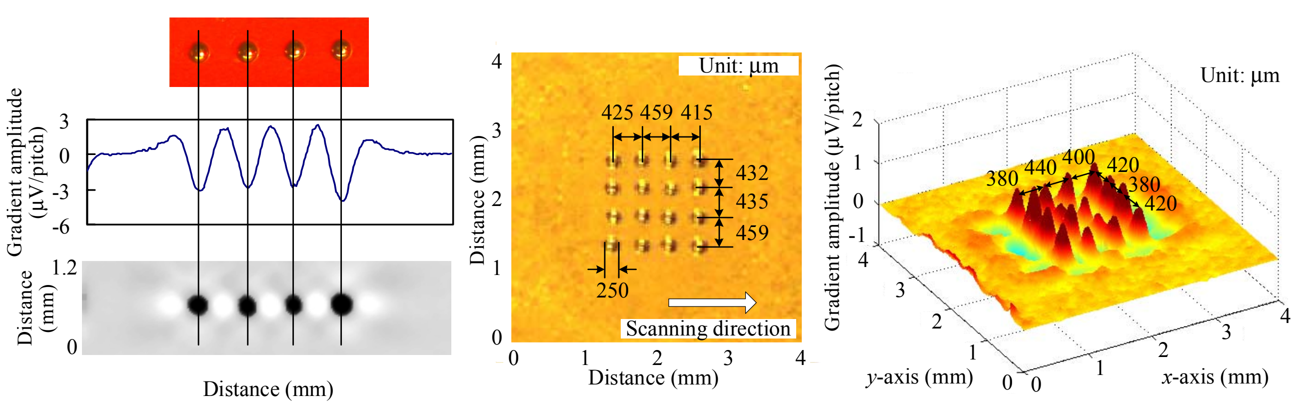


Fig. 6 Signal variation vs. microbead (PbSn) radius.

Then, magnetic fluid relative permeability can be derived as

$$\mu^* = 1 + 4D_v. \qquad (2)$$

where D_v is the volume density of magnetic fluid. It notes that the relative permeability is independent on the shape



(a) Detection of bead position (b) Conductive microbead array model (c) Detection result

Fig. 7 Identification of the conductive microbead (PbSn) position, conductive microbead array model and its detection results.

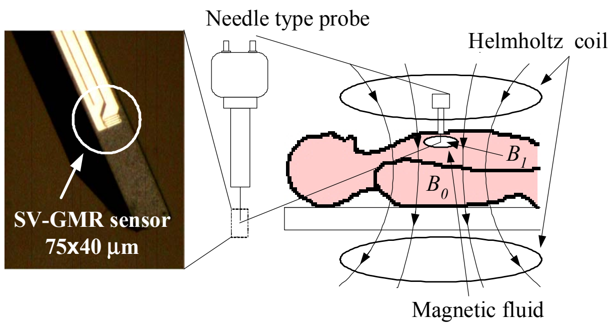


Fig. 8 Application of needle type SV-GMR to estimate volume density of magnetic fluid.

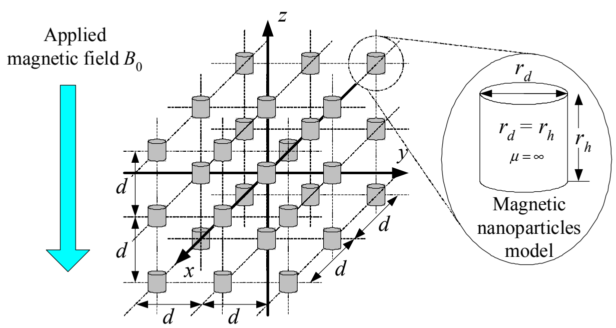


Fig. 9 Model of magnetic nanoparticals uniformly distributed inside magnetic liquid.

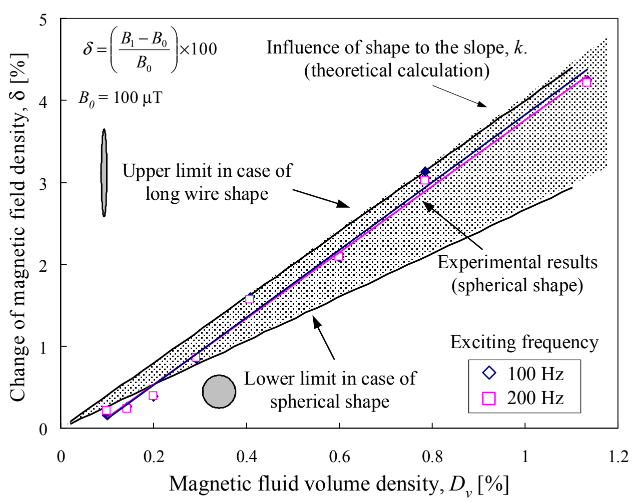


Fig. 10 Measurement results.

and size of magnetic particles. By substituting Eq.(2) into Eq.(1), the difference of magnetic field between inside and outside the magnetic fluid imbedded cavity is also directly proportional to magnetic fluid volume density as follows;

$$(B_1 - B_0)/B_0 = k_v D_v \tag{3}$$

where $k_v = 4(1-N)$. The slope, k_v, depends on shape of the cavity imbedded magnetic fluid. If we assume it as long wire shape (N = 0) or sphere (N = 1/3), its value varies within $2.67 \le k \le 4$ approximately. The proposed SV-GMR sensor was fabricated on the tip of the needle and was used to measure the differential magnetic field between B_1 and B_0 to indicate magnetic fluid volume density.

The AC exciting magnetic flux density with the frequency of 100 and 200 Hz and the external field of 100 μT is applied to the magnetic fluid. Lock-in amplifier is used to measure voltage across the SV-GMR sensor. The experimental result of the estimation is shown in Fig. 10. This figure denotes the relationship between the volume density of magnetic fluid and the change ratio of magnetic flux density. When the cavity is long, the relationship shows the upper limit of the shaded area. For the spherical shape, we obtain the lower limit. On the other hand, the experimental results show the solid line. We can conclude that the density of magnetic fluid inside body can be estimated with an accuracy of about one digit.

V. Conclusion

The structure and characteristics of giant magneto-resistive sensor is attractive for nondestructive evaluation because of micro size, high frequency operation, and high sensitivity. We discussed the inspection of printed circuit board and the detection of conductive microbead at electronic engineering, which are the novel applications of eddy-current testing technology. Moreover, we proposed the measurement of the density of magnetic fluid in living body in bio-engineering. The interesting characteristics of GMR sensor enable us to invent the drastic methodology of nondestructive evaluation by magnetic measurement.

References

[1] J. Lenz and A. S. Edelstein, “Magnetic Sensors and Their Applications,” IEEE Sensors J., vol. 6, no. 3, 2006, pp. 631- 649.

[2] C. H Smith and R. W. Schneider, “Low-Field Magnetic Sensing with GMR Sensors Part 1: The Theory of Solid-State Sensing,” Sensors, vol. 16, no. 9, 1999, pp. 76-83.

[3] T. Dogaru and S. T. Smith, “Giant Magnetoresistance-Based Eddy-Current Sensor,” IEEE Trans. on Magnetics., vol. 37, no. 5, 2001, pp. 3836-3838.

[4] D. L. Graham, H. A. Ferreira, and P. P. Freitas, “Magnetoresistive-Based Biosensors and Biochips,” Trends in BioTechnology, vol. 22, no. 9, 2004, pp. 455-462.

[5] H. Wakiwaka, “Characteristics of Giant Magnetoresistance Sensor and Their Application,” J. of Magnetic Society in Japan., vol. 28, no. 7, 2004, pp. 825-833.

[6] M. Jonathan, etal., “Clinical hyperthermia of prostate cansor using magnetic nanoparticles:presentation of a new interstitial technique,” Int. J. Hyperthermia, vol.21, no.7, 2005, pp.637-647.

[7] R. M. Bozorth, Ferromagnetism, 3rd ed., Vol. 2. Oxford: Clarendon, 1989, pp. 845-873.

[8] S.Yamada, etal., “Detection of Volume Density of Magnetic Fluid with SV-GMR Sensor,” Digest of the 30th annual conference of Magnetics in Japan, 14aB04, 2006, p319.