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Utilization of SV-GMR Sensor for Detection Conductive Microbead with Helmholtz Coil Exciter Based on Eddy Current Testing

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This paper presents the utilization of spin-valve giant magnetoresistance (SV-GMR) as a sensor and Helmholtz coil as an exciter for detection of both single and array conductive microbead based on eddy current testing (ECT) technique. The magnetic field distribution of the proposed ECT probe was calculated by finite element method (FEM). The experiment was performed to detect a single and array conductive microbead. The results enabled us to determine the position and achieve good level of signals.

Key Words: Conductive microbead, Spin-valve giant magnetoresistance, Eddy-current testing.

1. Introduction

Eddy current Testing (ECT) technique has been widely utilized to detect cracks and flaws of specimens within several fields such as airplane, automobile, nuclear power plant and electronic assembly [1], [2]. In ECT applications many popular sensor technologies have been used such as hall, fluxgate, superconducting quantum interference device (SQUID) and spin valve giant magnetoresistance (SV-GMR) [3]. SV-GMR has many advantages, such as high-sensitivity to low magnetic field, high-spatial resolution, low cost etc. [4]. Hence, it has been successfully applied to detect micro defect on printed circuit board and conductive microbead by using the meander coil as an exciter [5], [6]. In this paper, we describe the detection of both single and array conductive microbead with SV-GMR as a sensor and Helmhotz coil as an exciter based on ECT technique.

2. Detection of Conductive Microbead by ECT Technique

2.1 Proposed ECT probe structure

The proposed ECT probe consisted of a Helmholtz coil pair and SV-GMR sensor. The coils were of copper and had a circular shape with 8 mm radius. The upper coil and lower coil were connected in series as shown in Fig. 1. An AC exciting current

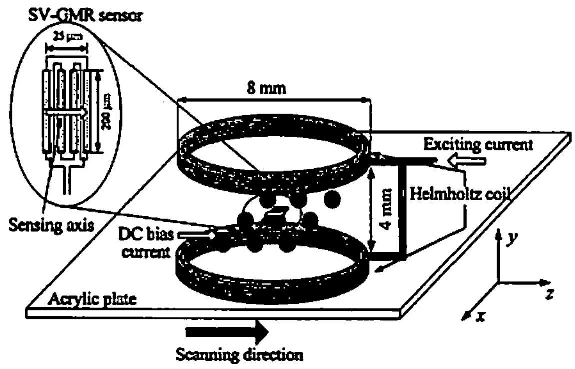

Fig. 1. Proposed ECT probe structure

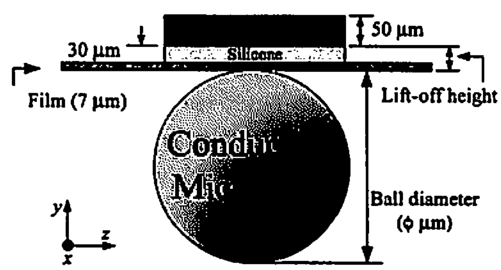

Fig. 2. Lay out of proposed ECT probe structure

was fed to the coils to generate the magnetic field. Two exciting frequencies were used: 5 MHz and 10 MHz. The y direction of the coordinate system was defined as the direction of the magnetic field, with the upward direction arbitrarily chose as the positive sense.

The SV-GMR sensor had an effective area of 25 µm x 200 µm. The sensor had a lift-off height of

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approximately 37 μm. as shown in Fig. 2. The lower face of the sensor, meaning the lower face of the protective film of the sensor, was placed slightly above the plane of the highest point on the specimen. The sensitive axis of the sensor which is at a right angle to the magnetic field was defined to be the *z*-direction.

The Helmholtz coil and SV-GMR sensor were mounted on an acrylic frame that moved as one rigid body. This assembly was scanned over the surface of the specimen area using a two-axis stage controller. The position resolution of the scanner was 20 μm. The scan plane was the *x*-*z* plane using the coordinates defined above.

Several specimen arrangements were studied. In all experiments the microbead material was Pb-Sn solder. Firstly, a single microbead was used. In the single-microbead experiments six radiuses were tested (125 μm, 150 μm, 200 μm, 250 μm, 300 μm and 380 μm). Secondly, a grid of four by four 125 μm beads were used and the beads were laid out on a square grid with average pitch 480 μm. The advantages of the proposed ECT probe are the lift-off height was considerably decrease and also generated uniform magnetic field over the specimen.

2.2 SV-GMR characteristics

The SV-GMR sensor was designed to have a most-sensitive direction. However some response was also expected for magnetic fields at right angles to this direction. To evaluate this, the sensor was placed between the Helmholtz coils but in three different orientations: with the sensitive direction aligned with the global *x*-, *y*- and *z*-directions. The magnetic field for these tests was driven at 10 kHz and with strength approximately 400 μT peak-to-peak.

The SV-GMR sensor was biased with a constant current of 2.5 mA. A lock-in amplifier was used to measure the voltage across the SV-GMR sensor. Fig. 3 shows the response of the sensor. It can be seen that the sensitive direction responded at a sensitivity of approximately 72 μV/μT and that this response was greater than for the other two directions (15 μV/μT).

The normal resistance of the GMR sensor, in the absence of an applied magnetic field, is about 1.9 kΩ. The conductivity of the copper Helmholtz coil wire was 5.76×10^7 S/m and the conductivity of the solder microbead material was 6.8×10^6 S/m [7].

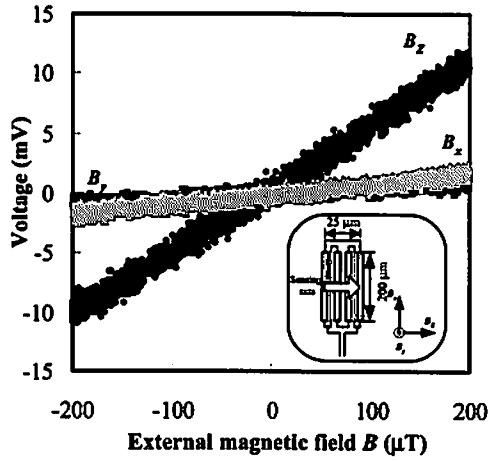

Fig. 3. SV-GMR characteristic

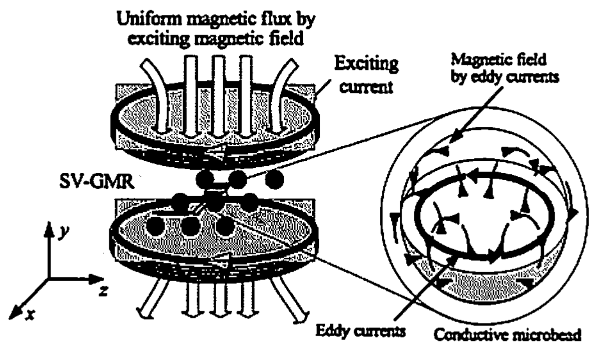

Fig. 4. Detection Principle

2.3 Detection Principle

Fig. 4 shows the principle of microbead detection. The exciting current was fed to the Helmholtz coil with frequency of 5 MHz. The circular coil form was chosen because it produces a reasonably homogenous and straight magnetic field, which is normal to the planes of the coils [8].

Fig. 4 is drawn to show the current flowing clockwise around the loops. The coils generated a magnetic field that induces an eddy current in the conductive microbead. Note that the direction of the eddy current in the bead opposes that in the exciting coil. The eddy current in the microbead generates a small magnetic field as shown.

The detection approach was to measure the *z*-axis component of the magnetic field generated by the microbead eddy currents.

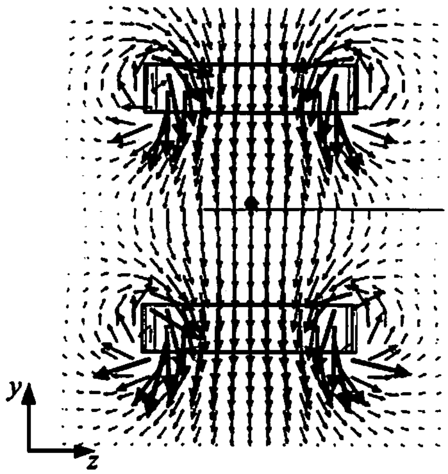

Fig. 5. Magnetic field distribution as calculated by FEM

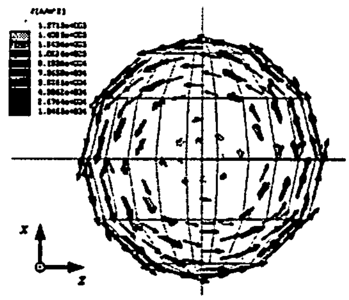

Fig. 6. Eddy-current on surface of bead at 125 µm radius

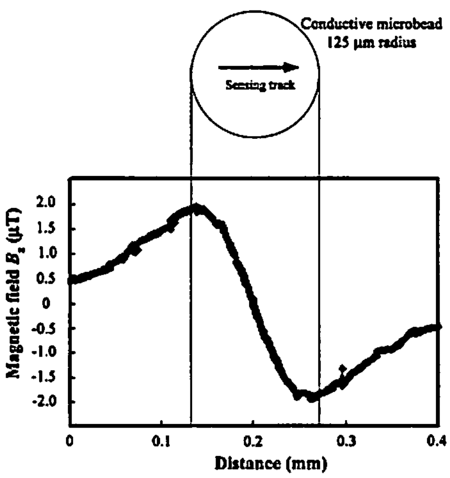

Fig. 7. Magnetic field, B_z, over the sensing track obtained from FEM

2.4 FEM calculation

The experimental apparatus described above was designed to produce a uniform magnetic field close to the specimen and SV-GMR sensor. The FEM model was used for verification.

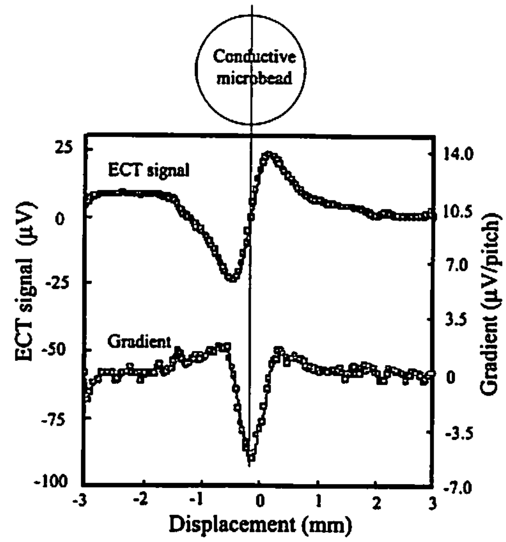

Fig. 8. ECT signal and gradient obtained from the detection of bead with 250 µm radius at the exciting frequency 5 MHz.

The model parameters included exciting current 200 mA at 5 MHz, and the simulated specimen resembling a single microbead with 125 µm radius. The physical arrangement of the model elements simulated the real equipment as described above. Maxwell® 3D software version 10 from Ansoft Corporation was used [9].

Fig. 5 shows a plot of the magnetic field vector as calculated by Maxwell FEM software. According to the software the field is quite uniform near the centre of the coils.

Fig. 6 shows a plot of the eddy-current vectors inside the conductive microbead, projected on the x-z plane.

FEM can be used to calculate the magnetic field of the bead and the signals indicated the bead position as shown in Fig. 7.

3. Investigation of Conductive Microbead

3.1 Single conductive microbead detection

The position of conductive microbead can be classified by the ECT signal and its gradient. The reference line was drawn through the center of bead as shown in the Fig. 8.

Fig. 9 expresses the signal variation vs. conductive microbead radius that was obtained by experiment method. The two exciting frequencies used were, 5 and 10 MHz. It was found that the 5 MHz exciting frequency reached a higher signal than the 10 MHz exciting frequency when the bead radius was higher than 200 µm radius.

3.2 Ball grid array detection

The ball grid array (BGA) was made by conductive microbead, of 125 μm radius and approximately 450 μm pitch, as shown in Fig. 10. The gradient of magnetic flux density expressed the position of each ball in the array. In addition, this technique can be used to investigate the position resolution. Fig. 11 shows such a plot with an error position around 60 μm.

4. Conclusion

An experimental method for the detection of conductive microbeads using a Helmholtz coil and SV-GMR sensor has been presented. A FEM model was used to express the magnetic field distribution.

This method could be applied to detect single and array conductive microbead. The signal variation of conductive microbead conveys information of the bead size. The positions of 125 μm radius conductive microbeads in an array arrangement of pitch of approximately 450 μm can be detected using the method described. The typical positional error in the measurement was approximately 60 μm. This technique enables us to detect smaller conductive bead when the GMR sensor was kept as close as possible to the specimen. In addition, it is possible to use this technique in physical measurement and biosensor applications.

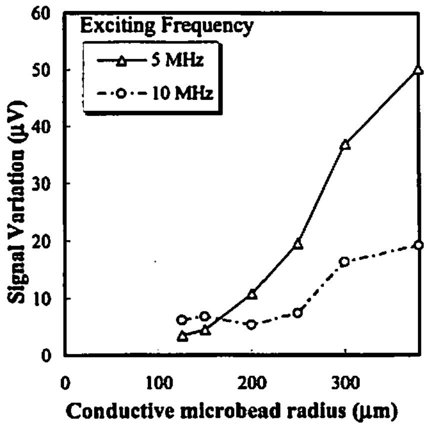

Fig. 9. Signal variation vs. conductive microbead radius

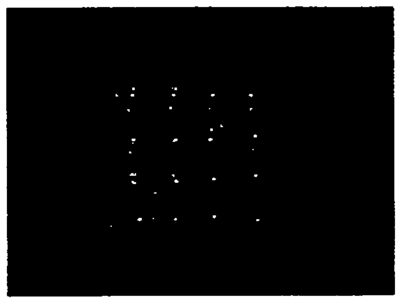

Fig. 10. Ball grid array model

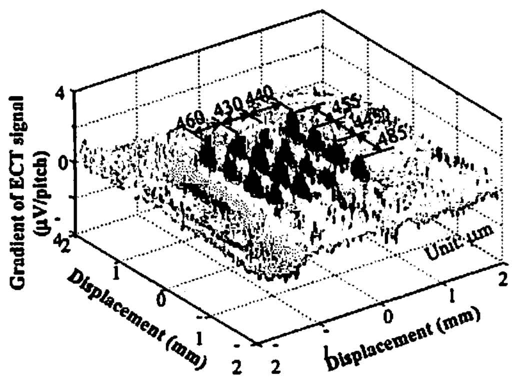

Fig. 11. 3-D plot of measured signals

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