KISH GRAPHITE AS A MAGNETIC FIELD SENSOR

Yutaka Kaburagi, Yuichiro Asano, Yoshihiro Hishiyama *Fucalty of Engineering, Musashi Institute of Technology, 1-28-1, Tamazutsumi, Setagaya-ku, Tokyo 158-8557, Japan*

ykabura@sc.musashi-tech.ac.jp

Introduction

Magnetoresistance effect (MRE) and Hall effect have been applied to magnetic field sensors. As materials for the field sensor due to MRE, semiconductor compounds and ferromagnetic metals have been used, but graphite materials have not, though graphite exhibits positive magnetoresistance. A purified high quality Kish graphite (KG) exhibits a large transverse magnetoresistance $\Delta\rho/\rho$ even at room temperature. KG is a graphite flake precipitated from molten iron at high temperatures [1]. When the flakes are made at a very high temperature above boiling point of iron and purified carefully, they have higher crystallinity than that of HOPG and exhibit a nature very similar to single crystal graphite. In the present study, therefore, a sensitive magnetic field sensor was tried to prepare using such KG flakes. On the MRE sensors, a magnetic field is measured as a voltage change ΔV induced by the magnetic field under a constant electric current: $\Delta\rho/\rho = \Delta V/V$. ΔV increases with the increase of the sample voltage V under zero magnetic field, if the defect concentration in the sample does not increase with increasing V. V increases with the increase of current, sample length and sample thickness. However, the power W increases with increasing current I as $W = I^2R$, where R is the sample resistance, i.e. Joule heat generates and temperature of the sample should rise under a large current flow. In the case of KG, sample sizes are limited because of flakes. Therefore, reducing the sample thickness is important factor to increase V and ΔV in the present study, but a careful treatment for reducing the thickness is needed to increase $\Delta\rho/\rho$, i.e. not to increase the defect concentration.

Experimental

Purified high quality KG flakes were supplied by Toshiba ceramics Co. Ltd. The approximate sizes of the flakes were 15 mm × 8 mm × 0.5 mm. Each of the flakes glued artificial graphite plates and was sandwiched between them. The sandwiched flake was cut into a rectangular shape with 6 mm × 2 mm and a rectangular KG plate was separated from the artificial graphite plates by dipping the sandwiched flake into the solvent of glue. Thin plate samples with flat surface and various thickness were prepared by peeling off carefully the both surfaces of the rectangular KG plates using adhesive tapes. The samples with the thickness of 0.256, 0.146, 0.080, 0.050 and 0.040 mm were obtained and denoted hereafter as KG followed by the thickness, such as KG0.256. For each sample, V was measured under zero magnetic field and then ΔV was measured when the magnetic field B was applied perpendicular to each sample surface. The measurement was also made in the reverse direction of the field to eliminate Hall voltage, though the voltage appeared is very small. For these measurements, four-terminal-method was performed and a constant current of 50 mA was flowed. The field dependence of $\Delta V/V$ i.e., $\Delta\rho/\rho$, was obtained in fields up to 1.0T at room temperature (about 20°C). In addition, to obtain larger $\Delta\rho/\rho$ in a low field region, the sensor using the thin KG plate was equipped with a bias magnet because $\Delta\rho/\rho$ is proportional to B^2 in a low field region [2]. A commercially available neodymium magnet with 4 mmϕ × 2 mm in size was attached to the sensor as a bias magnet. The magnetic field applied to each sensor by the magnet is 130 mT.

Results and Discussion

In Fig.1, the field dependence of $\Delta\rho/\rho$ in fields up to 1T at room temperature (a) and the low field behavior (b) are shown for the KG samples with various thicknesses. KG0.256 is a relatively thick sample obtained by just removing irregular surfaces on both side of it and exhibits a positive $\Delta\rho/\rho$ larger than 100% in a field of 1T, indicating highly crystallized nature. $\Delta\rho/\rho$ changes randomly with sample thickness as shown in Fig.1, but may depend systematically on crystallinity. Fortunately, we can obtained thin samples of KG0.050 and KG0.040 with good crystal condition. For all samples, the fluctuation of $\Delta\rho/\rho$ was slight on the temperature change of several degrees around 20°C, and the reproducibility of $\Delta\rho/\rho$ measured on different days was good, less than 2 % in a constant magnetic field.

Figure 2 shows the field dependence of ΔV in fields up to 1T at room temperature (a) and the low field behavior (b) for the KG samples with various thicknesses. At a constant magnetic field, ΔV increases with decreasing sample thickness, and is 18 mV in a field of 0.1T for KG0.040. Figure 3 shows the field dependence of ΔV in fields up to 0.2T at room temperature for the KG samples equipped with the bias magnet. In each magnetic field,

ΔV is increased remarkably by the bias magnet for the samples, and each curve is much closer to a straight line than that without bias magnet. In fig. 4 the ΔV versus magnetic field plots are shown. Most sensitive field sensor obtained, KG0.040 equipped with bias magnet of 130 mT, exhibits the performance of about 0.8 μV/mT around 0.1 T, which enable us to measure magnetic field precisely down to mT order.

Conclusion

It was demonstrated that the thin flake of KG can be applied to a sensitive magnetic field sensor. The 0.04 mm thick-sensor equipped with bias magnet gives a voltage sensitivity of about 0.8 μV/mT induced by magnetic field under constant current of 50 mA at room temperature.

References

[1] Inagaki M. New Carbons –Control of structure and functions–. Amsterdam: Elsevier, 2000;31-35.

[2] Kaburagi Y. Magnetoresistance of highly oriented graphite at 77K and 4.2K. J. Phys. C: Solid State Phys. 1982; 15: 5425-5440.

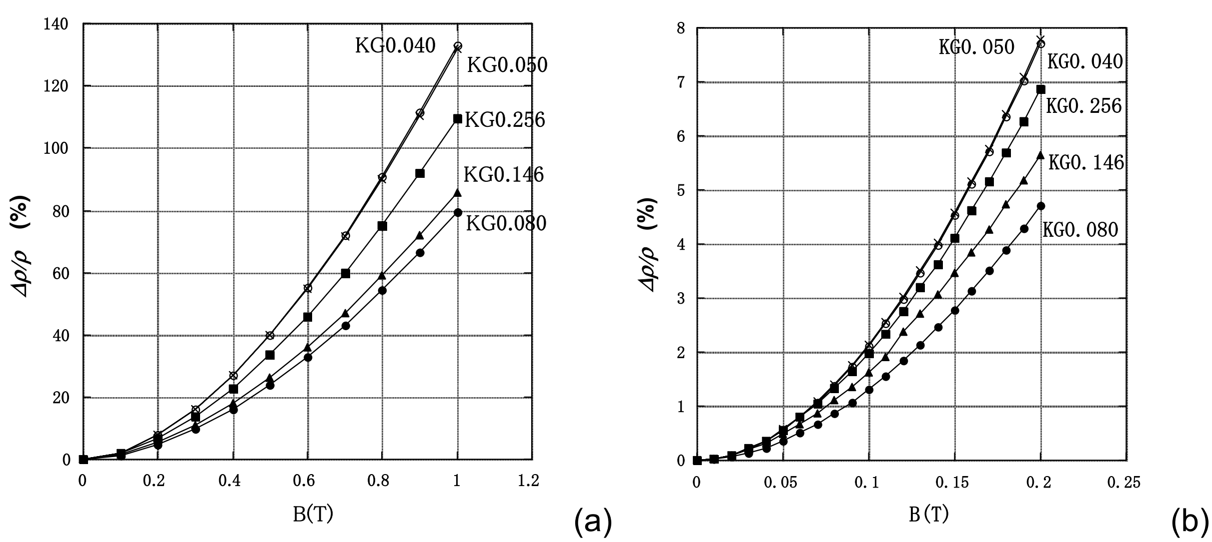

Fig. 1. Field dependence of maximum transverse magnetoresistance at room temperature in fields up to 1.0 T (a) and 0.2 T (b) for samples with various thicknesses.

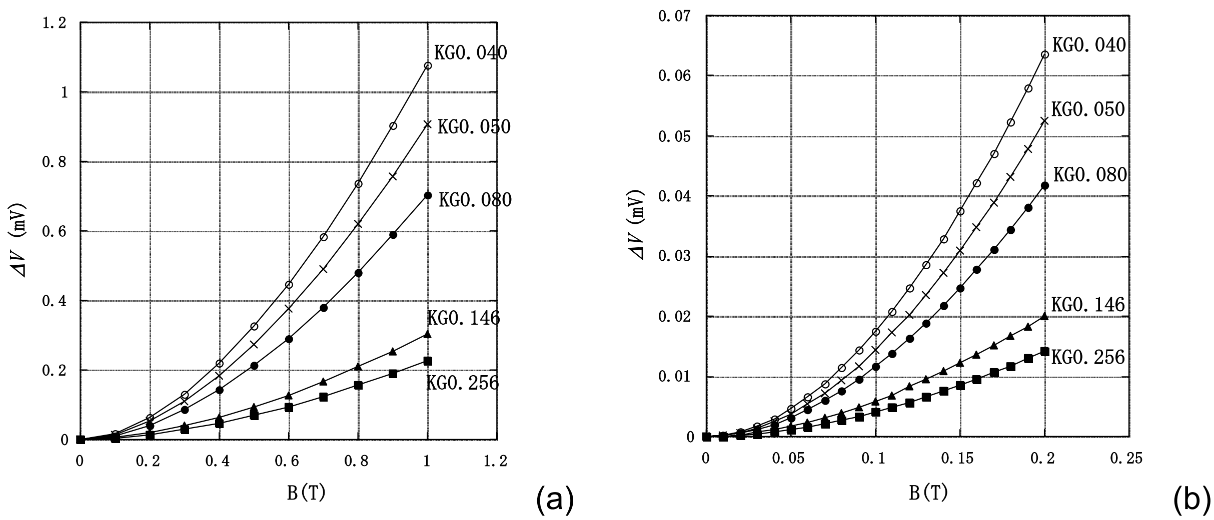

Fig. 2. Field dependence of ΔV in fields up to 1T (a) and 0.2 T (b) at room temperature for KG samples with various thicknesses.

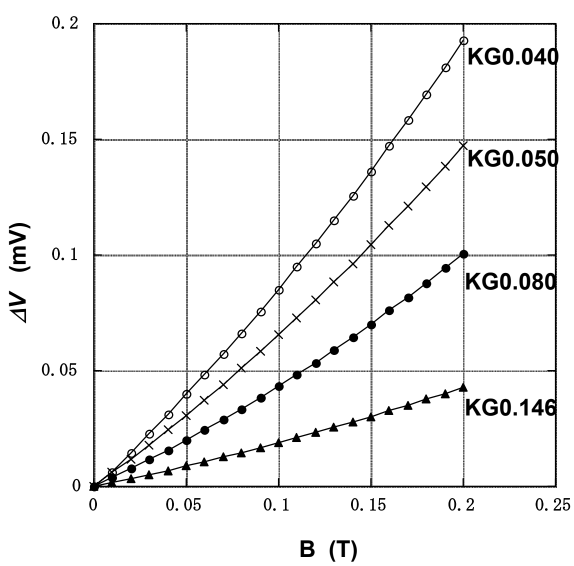

Fig. 3. Field dependence of ΔV in fields up to 0.2T at room temperature for KG samples equipped with bias magnet.

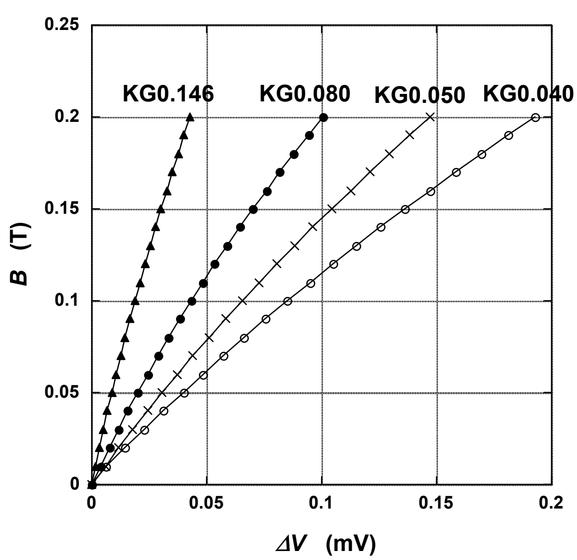

Fig. 4. ΔV versus magnetic field plots at room temperature for KG samples equipped with bias magnet.