XX IMEKO World Congress
Metrology for Green Growth
September 9–14, 2012, Busan, Republic of Korea

Giant Magnetoresistive Effect in Non-magnetic Silicon

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Abstract: We report that a simple device, based on a lightly doped silicon substrate contacted with two indium contacts, shows a positive magnetoresistance over 1,000 per cent for magnetic fields between 0 and 1 T at low temperature of 3 K. Current-voltage characteristics exhibit a nonlinear behavior, which is highly sensitive to temperature and magnetic field. Since our device is based on a conventional silicon platform and is highly sensitive to low magnetic field, it could be used to develop new devices of silicon-based magnetoelectronics.

Keywords: Magnetoresistance, Silicon.

1. INTRODUCTION

Recently magnetoresistive effects in non-magnetic semiconductors, particularly silicon, have gained considerable attention owing to the large magnitude of the effect [1-3], which is comparable, or even larger than, that of the performance of commercial giant magnetoresistance devices. Extremely large (over 10,000 %) positive magnetoresistance has been observed in boron-doped *p*-type Si [1] and an intrinsic or *n*-type Si [2], respectively. The underlying mechanism responsible for the giant magnetoresistance in silicon, however, is still controversial. The authors in ref. [1] claim that the electrical transport in the Si device is attributed to the impact ionization process, the onset of which is postponed to higher electric field by the magnetic field to result in such high magnetoresistance at low temperature. Contrarily, other research group suggests that the giant magnetoresistance can be explained by quasi-neutrality breaking of the space-charge effect [2-3]. Here we report on the measurement results of the magnetoresistance of n-type Si to explore the mechanism of the giant positive magnetoresistance of Si bulk crystal. To understand the underlying mechanism would be essential to enhance the magnetoresistive effect of Si for the applications of new magnetic-field sensors, which may further advance silicon technology.

2. EXPERIMENTAL

The Si:P lateral devices were fabricated from a 500 μm thick phosphor-doped silicon wafer (5 Ωcm, *n*-type 1×10^{15} cm^{-3}) produced by Se-Young Semitech. On top of the native surface oxide layer two indium electrodes of 4 mm wide, separated 7 mm from each other, are contacted by press. The magnetic field was aligned perpendicular to the plane of the substrate and swept from 0 to 1 T. Experimental data were taken by using a closed-cycle refrigerator which provided a base temperature of T = 3.0 K. To reduce the environmental noise, the measurement leads were connected to a two-stage low-pass RC filters with a cutoff frequency of 30 kHz and π-filters in series. The current-voltage (I-V) characteristic curves were obtained by sweeping the dc voltage source and measuring the current with Keithley Instruments.

3. DATA AND ANALYSIS

Figure 1a shows the I-V curves obtained from the Si:P lateral device at low temperature of T = 3.0 K. The I-V curve shows a non-linear behavior and the current flow is suppressed drastically under the application of the magnetic field of H = 1 T. The magnetoresistance (MGR) is defined as $(R(H)/R(0)-1) \times 100\%$, where R(0) and R(H) means the resistance at zero and applied magnetic field, respectively. The corresponding MGR is displayed in Fig. 1b, which exceeds 1,000 % at high bias voltage. To further explore the giant MGR effect, we have varied the angle of the magnetic field relative to the substrate, and found no pronounced anisotropy in the MGR. When the angle between the current and the magnetic field, the giant MGR remains with the same order of magnitude.

Temperature dependence of the MGR is shown in Fig. 2. When we increase temperature, the MGR decreases with temperature and almost vanishes above T = 35 K. Above T = 35 K, the I-V curves with H = 0 and 1 T are almost identical to result in zero MGR effect in our experimental range.

4. CONCLUSION

We have studied experimentally the magnetoresistive effect in Si:P single crystal. The magnetoresistance exceeds 1,000 % at low temperature. With increasing temperature, the MGR decreases rapidly with temperature and vanishes above T = 35 K. Enhancing the MGR performance up to room temperature would be critical for the device applications. To understand the underlying physical mechanism of the observed MGR, more extensive studies are needed.

5. ACKNOWLEDGMENT

This research was supported by Korea University.

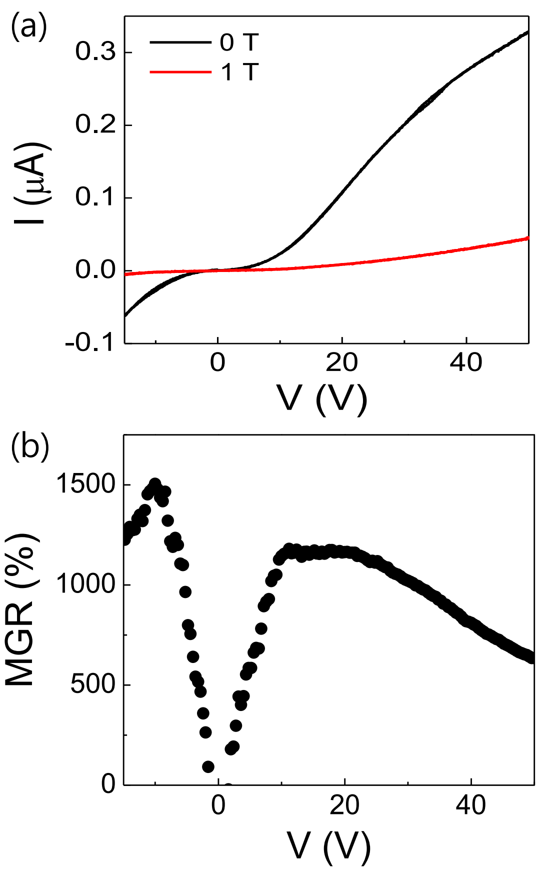

Figure 1. (a) I-V characteristics of Si:P (5 Ωcm) with different magnetic field at T = 3.0 K and (b) corresponding magnetoresistance as a function of bias voltage

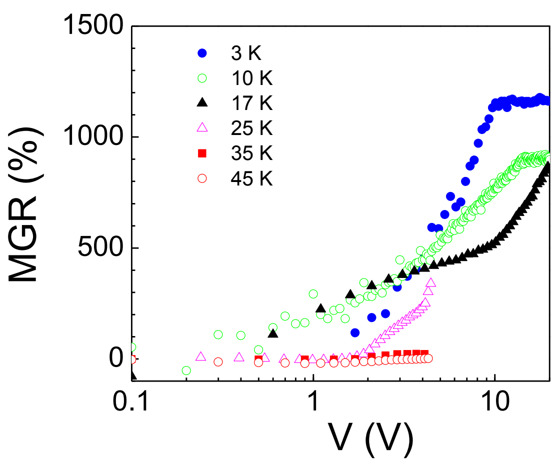

Figure 2. Temperature dependence of the magnetoresistance of Si:P with varying bias voltage

6. REFERENCES

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