# Spin-related magneto-transport in semiconducting Ce doped p-type Si epitaxial films

○Yusuke Miyata, Takeshi Yoshimura, Atsushi Ashida and Norifumi Fujimura

E-mail: m-yusuke@pe.osakafu-u.ac.jp

## 【Introduction】

We have been interested in the effect of Ce doping on magneto-transport characteristics in Si epitaxial films because p-type Ce doped Si (Si:Ce) films show ferromagnetic behaviors[1)]. Up to now, the spin-related phenomenon has been investigated in Si:Ce films co-doped with B (Si:Ce,B) to obtain p-type conduction because low temperature growth induces donor generation due to point defects[2)]. However, the p-type Si:Ce,B exhibits degenerated state and metallic conduction. To observe the spin-dependent transport phenomena, a decrease of donor concentration for semiconducting p-type conduction might be essential. Eventually, the p-type Si:Ce films with semiconducting conduction were successfully obtained. In this talk, the spin-related negative magnetoresistance (MR) in p-type Si:Ce films is demonstrated for the first time.

## 【Experiments and results】

15 nm-thick Si:Ce,B films were fabricated on (001) silicon substrate by solid source molecular beam epitaxy. The flux rates of Si, Ce and B were controlled by the temperature of each Knudsen-cell. In-situ surface morphology and the reconstructed surface structure were observed by Reflection of High Energy Electron Diffraction.

Figure 1 shows change in the sheet resistivity of two Si:Ce,B films with the same Ce concentration of 1.0 at.% and the different sheet hole concentration of $1.2\text{x}10^{13}$ (sample A) and $4.0\text{x}10^{13}$ (sample B) $cm^{-2}$, respectively. Semiconducting conduction is recognized below 50 K in sample A while sample B shows degenerated hole conduction. Fig. 2 shows longitudinal MR of each sample evaluated at 10 K. Negative MR is clearly recognized in sample A, which shows semiconducting conduction. The origin of negative MR is considered as weak localization or spin ordering effect. However, negative MR caused by weak localization is should not be theoretically exceeded by -1.0 % using conventional parameters. The magnetic field dependence of MR due to spin ordering effect is given by[3)].

$$\mathrm{MR} = \frac{-J_{pf}^{\ 2}}{V^2} B_j(\alpha)\left[4B_j(\alpha) + coth\frac{\alpha}{2} - \frac{\alpha}{2sinh^2 \alpha/_2}\right]$$

where $J_{pf}$ is exchange coupling constant, $V$ is the field independent part of the potential and $B_j$ is Birillouin function. In this case, the fitting parameter $\alpha$ is determined by $\alpha=g\mu_B B/k_B(T\text{-}T_C)$ with $g$ being g factor, $\mu_B$ Bohr magnetic moment, $B$ magnetic field, $k_B$ Boltzmann constant, $T$ measurement temperature and $T_C$ Curie temperature. The positive component of MR is described using empirical expression, $MR=(a_1B^2)/(1\text{-}a_2B^2)$ with $a_1$ and $a_2$ are constant (fitting parameters). Our experimental result is well explained by these models as shown in Fig. 2 (broken line). Based on above discussion, we can conclude that the negative MR observed in sample A should be originated in the ordering of $Ce^{3+}$ magnetic moment dissolved in Si epitaxial film.

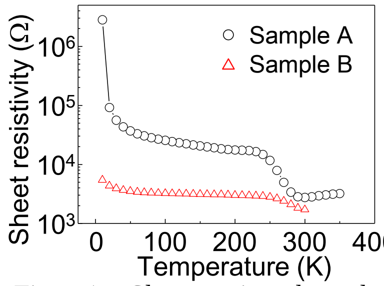


Fig. 1 Change in the sheet resistivity as a function of temperature.

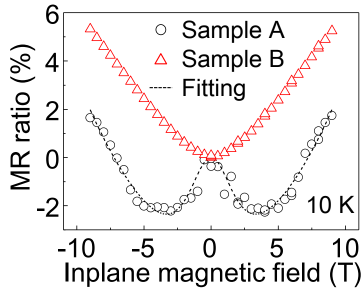


Fig. 2 Longitudinal MR evaluated at 10 K.

## 【Reference】

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3) L. Hartmann *et. al.*, J. Phys. D. Appl. Phys. **39**(2006)4920.