Field effect control of magneto-transport in Si epitaxial films doped with Ce by novel doping method using surface reconstruction

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【Introduction】

External field control of magnetism is one of the most attractive techniques in diluted magnetic semiconductors[1] (DMSs). However, because magnetic impurity dissolved Si films usually include a large amount of defects that cause donor generation, electrical field control of magneto-transport in Si-based DMS has not been reported yet. We have been interested in rare earth, Ce, doped Si films because ferromagnetic behavior appears in p-type Si:Ce films[2]. In spite of low solid solubility limit of Ce in Si in thermal equilibrium, Si:Ce epitaxial films with smooth surface and high crystallinity could obtain by novel doping technique using surface re-construction[3]. To discuss spin-hole interaction in Si:Ce, carrier modulation and control of magneto-transport by field effect have been tried. Here, gate voltage dependence of magnetoresistance (MR) in Si-based DMS is demonstrated by using organic ferroelectric-gate field effect transistors (FeFETs) on the top of Ce doped Si channel layer.

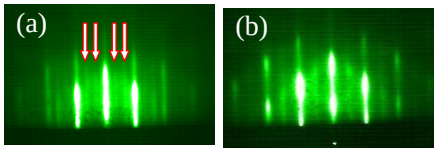
【Experiments and results】

15 nm-thick Si:Ce films with surface re-construction were fabricated on (001) silicon substrate by solid source MBE. The flux rates of Si, Ce 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 as shown in Figs. 1. FeFETs using organic ferroelectric, P(VDF-TrFE) as a gate dielectric was fabricated.

Fig. 2 shows gate voltage dependence of MR measured at 20 K. Negative component of MR is clearly recognized. Magnetic impurity doped semiconductors usually show negative MR due to the suppression of spin-scattering by ordering localized magnetic moments. In that case, magnetic field dependence of MR is given by

$$MR = \frac{-J_{sd}{}^2}{V^2}\langle S_Z\rangle\left[4\langle S_Z\rangle + cot\frac{\alpha}{2} + \frac{\alpha}{sinh^2\,{}^{\alpha}/_{2}}\right]$$

where J_{pf} is exchange coupling constant, $<S_Z>=2coth(\alpha)-coth(\alpha/2)$, V is the field independent part of the potential. In this case, the fitting parameter, α is determined by $\alpha=g\mu_B B/k_B(T-T_C)$ with g being g factor, μ_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, $MR=(a_1B^2)/(1-a_2B^2)$ with a_1 and a_2 are constant (fitting parameters). Our experimental results are well explained by these models as shown in Fig. 2 (solid lines). The spin-hole interaction in Si-based DMS will be discussed in my presentation.



Figs. 1 In-situ RHEED images of Si:Ce films with (a) and without (b) 3-folded surface reconstruction.

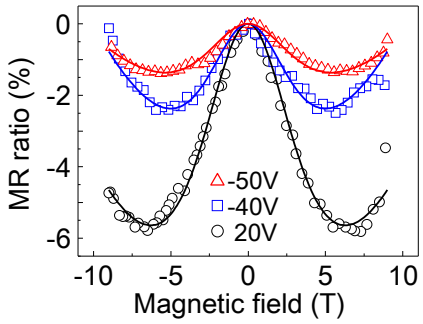


Fig. 2 Gate voltage dependence of transverse MR evaluated at 20 K. Solid lines mean the fitting results using spin-ordering model.

【References】

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