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Growth temperature dependence of the properties including the Fe-atom locations in ferromagnetic-semiconductor GeFe

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Group-IV-based ferromagnetic-semiconductor (FMS) GeFe is expected to be an efficient spin injector and detector, which can suppress the spin-flip scattering at the interfaces with Si or Ge since it can be epitaxially grown on Si(001) and Ge(001) substrates[1,2]. However, the current problem of GeFe is its low Curie temperature (T_C), which is at the highest 170 K so far. In this study, we have investigated the growth temperature (T_S) dependence of T_C and the lattice constant of GeFe by using magnetic circular dichroism (MCD) and the X-ray diffraction (XRD) measurements. In addition, we employed channeling proton-induced X-ray emission (c-PIXE) characterizations to investigate the relationship between the T_C and the proportion of the substitutional Fe atoms. Here, $Ge_{1-x}Fe_x$ films (x = 0.065, 0.105) were grown at various T_S (160 - 280°C).

Figure 1 shows the T_S dependence of T_C estimated by the Arrott plots (MCD^2 - B/MCD) of the MCD-B curves of the $Ge_{0.935}Fe_{0.065}$ films (blue circles) and $Ge_{0.895}Fe_{0.105}$ films (red squares). In both cases of the Fe concentration, maximum T_C is achieved when T_S = 240°C. These maximum T_C values (100 K in $Ge_{0.935}Fe_{0.065}$ and 170 K in $Ge_{0.895}Fe_{0.105}$) are about 1.4 times larger than those obtained in the previous study (70 K in $Ge_{0.94}Fe_{0.06}$ and 120 K in $Ge_{0.905}Fe_{0.095}$[1]). In Fig. 2, the (004) diffraction peak of the $Ge_{0.935}F_{0.065}$ film is clearly seen on the higher-angle-side of the Ge(004) peak with clear fringes, which indicates the abrupt and smooth interface and high quality of the GeFe layer. The excellent crystallinity of the $Ge_{0.935}Fe_{0.065}$ films grown at T_S = 240°C is also confirmed by the XRD rocking curves (not shown). Figure 3 shows the lattice constant estimated by the XRD spectra of the $Ge_{0.935}Fe_{0.065}$ films (blue circles) and $Ge_{0.895}Fe_{0.105}$ films (red squares) as a function of T_C. The T_C increases with a decrease in the lattice constant of the GeFe films. This result indicates that the larger the amount of the Fe atoms is incorporated in the substitutional sites, the higher T_C becomes. This feature is one of the characteristic properties of FMSs. In our presentation, we will show the channeling-PIXE results to discuss the relationship between the T_C and the proportion of the substitutional Fe atoms.

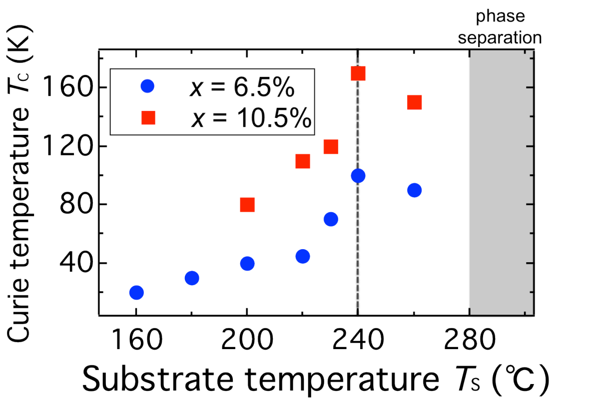

Fig. 1　T_S dependence of T_C of the $Ge_{0.935}Fe_{0.065}$ films (blue circles) and the $Ge_{0.895}Fe_{0.105}$ films (red squares) estimated by the Arrott plot (MCD^2 - B/MCD) with a photon energy of 2.3 eV, where B is the magnetic field.

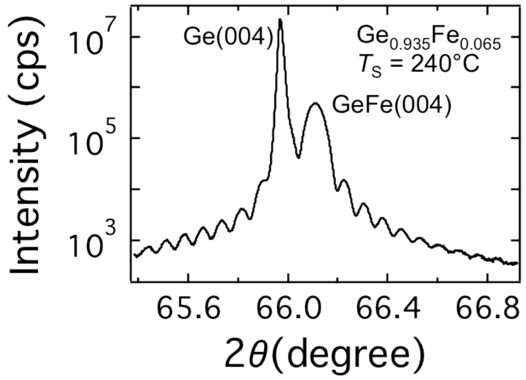

Fig. 2　XRD θ-2θ spectra of the GeFe (004) reflection of the $Ge_{0.935}Fe_{0.065}$ film grown at T_S = 240°C.

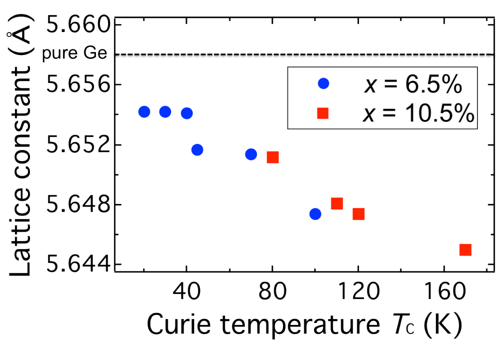

Fig. 3　Lattice constant estimated from the XRD spectra as a function of T_C of the $Ge_{0.935}Fe_{0.065}$ films (blue circles) and $Ge_{0.895}Fe_{0.105}$ films (red squares).

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1) Y. Shuto, M. Tanaka, and S. Sugahara, Appl. Phys, Lett. **90**, 132512 (2007).
2) Y. Shuto, M. Tanaka, and S. Sugahara, Jpn. J. Appl. Phys. **47**, 7108 (2008).