Room-temperature local ferromagnetism and its nanoscale domain growth in the ferromagnetic semiconductor Ge\textsubscript{1-x}Fe\textsubscript{x}

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Group-IV-based ferromagnetic semiconductor (FMS) Ge\textsubscript{1-x}Fe\textsubscript{x} is expected to become efficient spin injectors and detectors in group-IV-based semiconductor devices, because it can be epitaxially grown on Si and Ge substrates and the conductivity can be controlled by boron (B) doping independently of the Fe concentration x [1]. Furthermore, \(T_c\) can be increased up to 210 K by annealing [2]; however, detailed microscopic understanding of the ferromagnetism is lacking. In this study, we investigate the local magnetic behavior of GeFe by using X-ray magnetic circular dichroism (XMCD) at various magnetic fields and temperatures.

We have carried out XMCD measurements of the Ge\textsubscript{0.935}Fe\textsubscript{0.065} films grown at 160°C \((T_c = 20 \text{ K})\) and 240°C \((T_c = 100 \text{ K})\) by low-temperature molecular beam epitaxy (LT-MBE) [3]. Figure 1 (a) shows the X-ray absorption spectroscopy (XAS) spectrum \([\mu^+ + \mu^-]\) at the Fe \(L_2\) \((~721 \text{ eV})\) and \(L_3\) \((~708 \text{ eV})\) absorption edges in the Ge\textsubscript{0.935}Fe\textsubscript{0.065} film grown at 240°C measured at 5.6 K with a magnetic field \(\mu_0H\) of 5 T applied perpendicular to the film surface. The main peak at around 708 eV is assigned to Fe\textsuperscript{2+} states in GeFe, which means that almost all the doped-Fe atoms are in the 2\(^\text{+}\) state. Figure 1 (b) shows the XMCD \((= \mu^+ - \mu^-)\) spectra at the Fe \(L_2\) and \(L_3\) absorption edges in the same sample measured at 5.6 K with \(\mu_0H = 0.1, 1, 3, \text{ and } 5 \text{ T}\). Figure 2 shows the effective magnetic-field \(H_{\text{eff}}\) dependence of the XMCD intensity at 707.66 eV for the Ge\textsubscript{0.935}Fe\textsubscript{0.065} film grown at 240°C measured at various temperatures. The total magnetization \(M (= m_{\text{spin}} + m_{\text{orb}})\) obtained by the XMCD sum rules is also plotted by filled red symbols.

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**References**

