Magnetooptical properties of iron based Heusler alloy
epitaxial films on Ge(111)

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Abstract

We have examined the LMOKE of some Heusler alloy films Fe4Si, Fe3Si, Fe2CoSi, Fe2MnSi (21at and 9at%Mn), Co2FeSi epitaxially grown on Ge(111) and found that Fe3Si, Fe4Si and Fe2CoSi films have larger Kerr rotation and smaller coercive fields than the amorphous Fe film and that they may be promising materials for magnetophotonic applications.

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1. Introduction

Magnetooptical Kerr effects (MOKE) have been applied to some optical modulating or isolating devices and magnetooptical (MO) disk memories. Recently, photonic crystals (PhC) consisting of dielectric periodic structures have been attracted because properties of propagating lights can be designed by photonic band-gaps depending on the periodic structures. We have investigated application of iron silicides with a high refractive index to the PhC on Si [1, 2]. This work brought us a new PhCs with a light modulating function based on the MOKE in the case that we fabricate ferromagnetic periodic structures named magnetophotonic crystals (MPhC).

Novsad et al. [3] have reported a magnetic grating (i.e., one dimensional MPhC) of amorphous Fe3Si film. They demonstrated modulation of diffracting light due to its transverse Kerr effect. Iron based Heusler alloys have been predicted theoretically to have properties of high spin polarization which is adapted to enhancement of the MOKE. The MOKE has been known to be dependent upon spin polarization of ferromagnetic materials [4]. Fe based-Heusler alloys [5, 6] can be expected to have higher spin polarization and larger MOKE than bcc-Fe.

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In this study, we examine the MOKE of some Fe-based Heusler alloy films epitaxially grown on Ge(111) and discuss available materials for magnetophotonic applications.

2. Experiments

Heusler alloy films were deposited on Ge(111) substrate with a Ge buffer layer by low temperature molecular beam epitaxy (MBE) below 200 °C. The details are reported in ref. [3]. The film thickness employed in this study was 50 nm. The MOKE was evaluated by a longitudinal MOKE (LMOKE).

Figure 1 shows the experimental set-up for measurements of the LMOKE spectrum (Fig. 2) and magnetooptic hysteresis loops (Fig. 3). The configuration of PMSA (Polarizer (P=45°) of a Glan-Thompson prism (GT) / photoelastic modulator (HINDS PEM 100™ with an optical retardation of δ0 /Sample mounted on a positioning stage /Analyzer (A=0°) of a GT prism mounted on a rotating stage), and the incident angle of polarized light of 28°, were employed. Electrical equipments with the a PEM driver, a Si, Ge or InGaAs photoreceiver at each responsible wavelength region, an electromagnet with a bipolar power source, signal recovery systems for three signals S0(f), S1(2f) and S2(2p) responsible to f, p, and 2p Hz, a wavelength driver for a monochromator, a rotating stage driver for the polarization analyzer, a magnetic field meter were connected and controlled with PC with LabVIEW™ programs. The magnetic filed was applied perpendicular to the (111) plane along the direction of <110>. The calibration of a Kerr rotation angle was carried out by using a plane silver mirror [7].

Fig. 1 Experimental set-up for measurements of LMOKE (Kerr rotation and magneto-circular dichroism: RMCD) spectra and magnetooptic hysteresis loops at each wavelength.

3. Results and Discussion

Figure 2 shows spectra of Kerr rotation for Heusler alloy films, DO3-Fe4Si with off-stoichiometric composition and stoichiometric Fe3Si, L2,-Fe2CoSi, Fe2MnSi with a composition of either 21at% or 9at%Mn, Co2FeSi and an amorphous Fe film. It was observed that the Fe3Si, Fe2Si and Fe2CoSi films showed larger Kerr rotation angles near 2 eV than Fe and Co2FeSi films and both films of Fe2MnSi. The MOKE of Fe based alloys near 2eV may be attributed to a transition of electron between up and down spin states [5]. Therefore, we speculate that these observed differences in the Kerr rotation near 2eV correspond to differences in spin polarized states between them.

Figure 3 shows magnetooptic hysteresis loops for Fe3Si, Fe2Si, Fe2CoSi, and Co2FeSi films. These hysteresis loops presented relative values of magneto-circular dichroism (RMCD) at 633 nm and coercive magnetic field (Hc) as shown in Table I. Their hysteresis loops showed a good square property as shown in Fig. 3 and very small or no change of them with changing the direction of in-plane magnetic field. This result indicates that crystal anisotropy (difference between magnetic easy or hard axes) of magnetization on the (111) plane of the Heusler alloy films may be very small. This less magnetic anisotropy will be useful for homogeneous design of characteristics of
magnetophotonic crystals. The $H_c$ values of Fe$_3$Si, Fe$_4$Si and Fe$_2$CoSi films were smaller than those of Co$_2$FeSi and amorphous Fe films. The $H_c$ dominates a minimum magnetic field energy necessary for modulation of polarized states of light. The Heusler alloys Fe$_3$Si, Fe$_4$Si and Fe$_2$CoSi films with smaller $H_c$ are appropriate for magnetooptical modulating devices.

Contrary to our expectations, the Fe$_2$MnSi films with 21at% and 9at%Mn showed small Kerr rotation and evident MOKE hysteresis loops. Theoretical prediction teaches us that this Fe$_2$MnSi may have half-metallic properties (completely spin-polarized material). One of the reasons may be small magnetization of the film at room temperature, since this stoichiometric bulk material has been known to have a curie temperature $T_c$ lower than 300 K [8]. However, we cannot explain the fact that the low Mn content film (which may have higher $T_c$ than 300 K) shows the smallest Kerr rotation in the films. Probably we need further discussion on electronic states of full Heusler alloys to understand these observed differences in MO properties.

![Kerr rotation spectra for DO$_3$ Fe$_3$Si and off-stoichiometric Fe$_4$Si and L2$_1$ Fe$_2$MnSi with 21at% and 9at%Mn, Fe$_2$CoSi and Co$_2$FeSi films of 50 nm in thickness.](image)

**Fig. 2** Kerr rotation spectra for DO$_3$ Fe$_3$Si and off-stoichiometric Fe$_4$Si and L2$_1$ Fe$_2$MnSi with 21at% and 9at%Mn, Fe$_2$CoSi and Co$_2$FeSi films of 50 nm in thickness.

![Magnetooptic hysteresis loops for DO$_3$ Fe$_3$Si and Fe$_4$Si and L2$_1$ Fe$_2$CoSi and Co$_2$FeSi films of 50 nm in thickness. The $H_c$ means a coercive field in a direction parallel to the <110> axis on the (111) planes.](image)

**Fig. 3** Magnetooptic hysteresis loops for DO$_3$ Fe$_3$Si and Fe$_4$Si and L2$_1$ Fe$_2$CoSi and Co$_2$FeSi films of 50 nm in thickness.
4. Conclusions

We have examined the LMOKE of some Heusler alloy films Fe$_3$Si, Fe$_4$Si, Fe$_2$CoSi, Fe$_2$MnSi (21at and 9at%Mn), Co$_2$FeSi epitaxially grown on Ge(111) and found that Fe$_3$Si, Fe$_4$Si and Fe$_2$CoSi films have larger Kerr rotation and smaller coercive fields than the amorphous Fe film. These Heusler alloy films may be promising materials for magnetophotonic applications. Moreover, we found effects of film thickness on the Kerr rotation in 50nm and 100nm thick films of Fe$_3$Si. The thinner film indicated a larger Kerr rotation angle. This effect may be attributed to interference effects of lights reflected at the film surface and the interface with the Ge substrate.

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