Magnetic response of surface plasmon polaritons in silver / Co$_2$FeSi$_{0.6}$Al$_{0.4}$ Heusler alloy / silver films

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Abstract. Reflectivity change caused by an excitation condition of surface plasmon polaritons (SPPs) by an external magnetic field is important for a magnetic sensing technique to use the SPPs. The magneto-plasmonic effect utilizing the Co$_2$FeSi$_{0.6}$Al$_{0.4}$ Heusler alloy, which is one of candidates for the high spin-polarized material even at room temperature for spintronic devices, as a magnetic responsible layer was investigated. The SPPs were excited in the Co$_2$FeSi$_{0.6}$Al$_{0.4}$ Heusler alloy by using a sandwiched structure between two silver layers. The maximum value of absolute magnetic activity $|\Delta R|_{\text{max}}$ of 0.14 were obtained.

1. Introduction
It is important for realizing a magnetic sensor using magnetic response of surface plasmon polaritons (SPPs) that a large reflectivity change caused by an excitation condition of SPPs is observed by an external magnetic field. The magnetic response of SPP, which is called magneto-plasmonic effect, has been reported using films combined a noble metal with a ferromagnetic material [1-6]. Although half-metallic ferromagnetic materials, such as Heusler alloys, are paid attention to spintronic devices because of their high spin polarization [7, 8], their magneto-plasmonic effect has not been reported yet. Therefore, the magneto-plasmonic effect using a Co$_2$FeSi$_{0.6}$Al$_{0.4}$ Heusler alloy, which is one of candidates for the high spin-polarized material even at room temperature [8,9], as a magnetic responsible layer was investigated for development of a spintronic and magneto-plasmonic device.

2. Experimental procedure
Film structure for magneto-plasmonic effect was a glass substrate / Ag / Co$_2$FeSi$_{0.6}$Al$_{0.4}$ / Ag. Film thicknesses of Ag and Co$_2$FeSi$_{0.6}$Al$_{0.4}$ layers were varied from 3 to 30 nm and from 1 to 4 nm, respectively. The specimens were fabricated by rf magnetron sputtering at ambience temperature on a glass substrate. Base pressure and process Ar gas pressure of sputtering were less than 1 × 10^{-4} Pa and 1 Pa, respectively. Deposition rates of Ag and Co$_2$FeSi$_{0.6}$Al$_{0.4}$ layers were 1 and 2 nm/s, respectively. The specimens were annealed at 500 °C in 1 × 10^{-3} Pa of nitrogen during 0.5 hours after air exposure.

The SPPs were excited by the attenuated total reflection (ATR) method in the Kretschmann-Raether configuration [10] using light with wavelength of 700 nm. External magnetic fields of 4 and 0 kOe were applied normal to the film plane using a permanent magnet. This is Voigt configuration in Cyclotron Resonance Inactive (CRI) mode. The reflectivity in the configuration, which strongly depends on the boundary condition of the SPP excitation, is magnetically changed by a change of diagonal component, which is parallel or perpendicular to the magnetization direction, in dielectric tensor of a magnetic
the films, same magnitude as shown in Fig. 4
loop and XRD were measured. The magnetic properties of the films were measured using a vibrating sample magnetometer (VSM) applied normal to the film plane.

3. Results and Discussion

A reflectivity \( R \) for a \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) Heusler alloy single layer film as deposited with 35 nm-thick fabricated on a glass substrate as a function of incident angle \( \theta \) is shown in Fig. 1. Wavelength \( \lambda \) is 700 nm. The reflectivity is monotonously decreased at the angle higher than the critical angle of 42.4°. The reflectivity dip, which corresponds to the excitation of SPPs, cannot be observed in the profile. This fact indicates that a large amount of light is absorbed in the \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) Heusler alloy film.

Therefore, a thinner \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) Heusler alloy layer was sandwiched between two silver layers, which can easily excite SPPs. The thickness of the \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) layer varied from 3 to 7 nm. The reflectivities \( R \), for a glass sub. / Ag (25) / \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) (\( d \)) / Ag (5 nm) multilayer films as a function of incident angle \( \theta \), are shown in Fig. 2. All reflectivity curves show a steep dip at around 43.5° by using the Ag layers as the SPP excitation layer. The difference between the maximum and minimum reflectivities, \( R_{\text{max}} - R_{\text{min}} \), and the maximum absolute inclination of the reflectivity curve, \( |\text{d}R/\text{d}\theta|_{\text{max}} \), for the \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) with 5 nm-thick sandwiched film are 58.8 % and 56.8 %, respectively.

The magnetic activities \( \Delta R \), which is calculated using the formula (1) by the reflectivity profiles measured at \( \lambda = 500 \) and 700 nm, for the glass sub. / Ag (25) / \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) (5) / Ag (5 nm) film are shown in Fig. 3. The maximum values of absolute magnetic activity \( \Delta R_{\text{max}} \) measured at 500 and 700 nm show 0.11 and 0.14, respectively. The maximum values of absolute magnetic activity \( \Delta R_{\text{max}} \) of 0.14 is not so high compared with previous reports [5, 6]. One of the methods to increase \( \Delta R_{\text{max}} \) is to adjust the layer thickness because it can improve plasmonic properties of the film.

To confirm the magnetic and structural properties of the \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) films, magnetic hysteresis loop and XRD were measured. A magnetic hysteresis loop of the glass sub. / Ag (25) / \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) (5) / Ag (5 nm) multilayer film measured by a VSM with a magnetic field normal to the film plane is shown in Fig. 4. The magnetization of the \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) layer is almost saturated at 4 kOe, which is as same magnitude as the applied field at ATR measurement. The XRD profiles for the \( \text{Co}_2\text{FeSi}_{0.6}\text{Al}_{0.4} \) films with 200 nm-thick fabricated on a glass substrate to examine the crystal orientation and degree of
order are shown in Fig. 5. One is annealed at 500 °C and the other is as-deposited. Diffracted lines can be observed at around 2θ = 44.3° which corresponds to the diffraction angle from the Co₂FeSi₉₀₆₆Al₀₄ (220) plane in both profiles. The diffracted line intensity from the (220) plane of the annealed film is stronger than that of the as-deposited film. There are, however, no diffracted lines originated from the ordered phase with B2 and L₂₁ structures even in the annealed film. Both Co₂FeSi₉₀₆₆Al₀₄ films are oriented (220) plane with the A₂ disordered structure. Magneto-plasmonic effect of the ordered B2 and L₂₁ structures of Co₂FeSi₉₀₆₆Al₀₄ should be also examined for development of a spintronic and magneto-plasmonic device.

4. Conclusion
Plasmonic and magneto-plasmonic properties for a Co₂FeSi₉₀₆₆Al₀₄ Heusler alloy film were investigated for a magnetic sensing technique to use the SPPs. The SPPs were excited in the Co₂FeSi₉₀₆₆Al₀₄ Heusler alloy by using a sandwiched structure between two silver layers. The maximum value of absolute magnetic activity |AR|ₘₐₓ of 0.14 were obtained.

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Acknowledgement
This work was partially supported by MEXT-Supported Program for the Strategic Research Foundation at Private Universities, 2013-2017.