Magneto-optic ellipsometry characterization of Co and SmCo thin films

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Abstract—Magneto-optic ellipsometry in the longitudinal Kerr configuration was performed to determine the complex permittivity tensor of the Co and SmCo thin films within the spectral range from 400nm to 1000nm. The Co film was a middle layer in an Au/Co/Au trilayer structure. Magneto-optical response was analyzed in terms of Mueller matrix elements. Reduced magneto-optical response of the Co layer is explained by the influence of the gold top layer of the trilayer structure.

Magneto-optical (MO) properties of ferromagnetic metals and their alloys are of great interest because of applications in data storage devices [1] and magneto-plasmonic (MP) sensors [2-5]. The enhancement of MO activity has been reported as surface plasmon resonance (SPR) excitation in Au/Co/Au trilayers in the Kretschmann configuration [6-7]. This gives rise to Magneto-Optic Surface Plasmon Resonance (MOSPR) sensors [2] which reveal better sensitivity better than standard SPR biosensors. Such sensors benefit from the intense MO activity of a ferromagnetic layer and exceptional plasmonic properties of noble metal layers. The plasmon enhancement of MO activity is essential for active photonic devices [8] as well.

The MO properties of Co must be known for modeling and optimization of optical response of multilayer structures under applied magnetic field. For a very thin Co film, few nanometers, these MO properties depend on a deposition technique, film thickness, and impurities which penetrate from the adjacent layers inside the structure.

Recently, magneto-optical generalized ellipsometry (MOGE) has been developed to characterize the MO properties of thin films and multilayers [9-11], which are described in terms of off-diagonal elements of a complex permittivity tensor [12]. In this work we report the results of MOGE measurements of the complex permittivity tensor for the Co layer inside an Au/Co/Au three-layer, with a designed thickness suitable for the MOSPR sensor [4]. The MO properties of the SmCo thin film are reported for the first time and are compared with the properties of pure Co.

The Au/Co/Au samples have been grown in a molecular beam epitaxy system on an SF10 glass substrate covered with a 2nm Cr layer at the pressure 10^{-8} Pa (see details elsewhere [13]). The nominal thicknesses of Au-bottom, Co, Au-top layers are 25nm, 6nm, and 15nm, respectively.

A polycrystalline SmCo film (composed of Sm and Co in the ratio 1:1) has been fabricated by a pulsed laser deposition technique on an Si (111) substrate at the chamber pressure 10^{-1} Pa and substrate temperature 600K [14]. The nominal film thickness is 8nm.

Samples characterization has been carried out at room temperature by a J.Woolam Variable Angle Spectroscopic Ellipsometer (VASE). A detailed description of this technique can be found in [15]. The setup has been equipped with a permanent magnet, consisting of two NdFeB discs (Supermagnete) 30mm and 15mm in diameter, placed at a distance of 35mm as shown in the inset of Fig. 1.

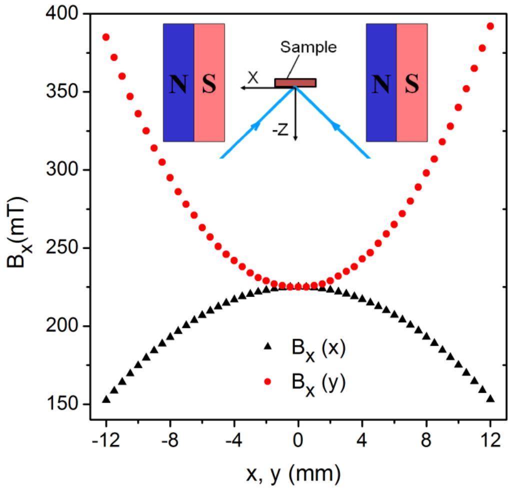

Fig. 1. Distribution of the x-component of magnetic flux density along the *x*- and *y*-axis. The inset explains sample orientation relative to the magnet and the coordinate system.

The magnetic field is applied along the *x*-axis. Hence it lies in the sample plane and that of incidence (corresponding to the longitudinal Kerr effect). The field direction can be inverted by rotation of the magnet about the *z*-axis. The longitudinal and transversal distribution of the *x*-component of magnetic flux density is depicted in Fig. 1. The uncertainty of magnetic field is less than 1.8% for beam lateral dimensions of 1.5mm and 2mm along the *y*- and *x*-axis, respectively, which correspond to an incidence angle of 45°.

Note that the used magnetic field of 0.225T was large enough to saturate in-plane magnetization of ferromagnetic films, as confirmed by the MOKE measurements.

For such complex systems, the normalized Mueller matrix (MM) representation is needed [16]. The $M_{ij}=m_{ij}/m_{11}$ elements, where m_{ij} are the MM ones, i=1,2,3 and j=1,2,3,4, were measured for reflected light from 400nm to 1000nm, for opposite magnetic field directions. The angle of incidence was fixed at 45°. The MM elements are functions of the sought-for parameters which are complex permittivity tensor elements and layer thickness.

The sought-for parameters are obtained using a numerical regression procedure which is standard for ellipsometry [15], and implies the fit of simulated M_{ij} elements to the experimental data. For complex permittivity tensor elements, we use the notation $\varepsilon_{kl} = Re(\varepsilon_{kl}) + i \cdot Im(\varepsilon_{kl})$, where $k,l=x,y,z$, and assume that $\varepsilon_{xx} = \varepsilon_{yy} = \varepsilon_{zz} = \varepsilon$ holds for diagonal elements.

We fitted together the experimental M_{13}, M_{24}, and M_{31} data for opposite magnetic field directions, as these elements reveal the largest MO response for the longitudinal Kerr effect [11]. The differences between normalized MM elements for opposite magnetizations $\Delta M_{ij} = M_{ij}(H_x^-) - M_{ij}(H_x^+)$, where H_x^+ and H_x^- indicate two opposite field directions, are depicted in Fig. 2. The precision of ΔM_{ij} measurements is about 10^{-4}. The experimental data are in good agreement with the simulated curves for both the Au/Co/Au and SmCo samples.

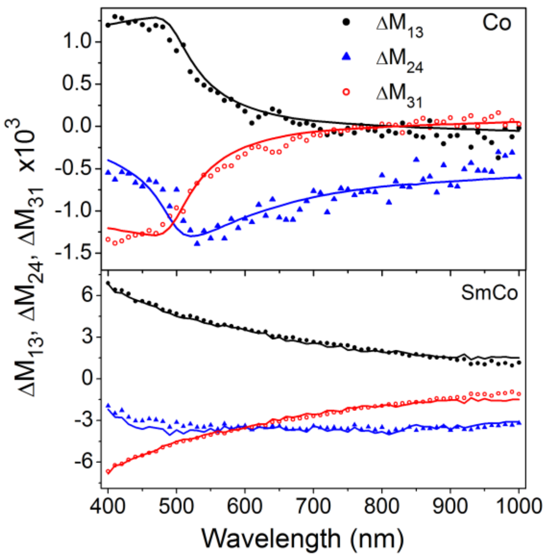

Fig. 2. The experimental (symbols) and simulated (lines) normalized Mueller matrix element differences for Au/Co/Au (top) and SmCo (bottom) samples.

In the visible wavelength range, ΔM_{13} and ΔM_{31} values for the Au/Co/Au sample are half the values obtained elsewhere [11] for the 8nm thick Co film on a sapphire substrate. In the infrared, the corresponding ratios are even less. In our case, the smaller MO response is caused by two reasons: the slightly smaller Co film thickness and, which is more important, the presence of a top Au layer. In particular, the Au layer reflects the impinging light, and also partially absorbs the light which interacts with the Co film.

The MO response of the SmCo film is more than twice that of the Co film with the same thickness [11]. However different substrates (the Si one in our case and the sapphire one in [11]) hinder comparison of the MO responses.

The diagonal elements of a permittivity tensor for the Co and SmCo films are depicted in Fig. 3, as obtained from the fit of the all measured 11 M_{ij} elements. The permittivity of Sm [17] is presented for comparison as well. The SmCo curves are reasonably situated between the corresponding curves for Co and Sm.

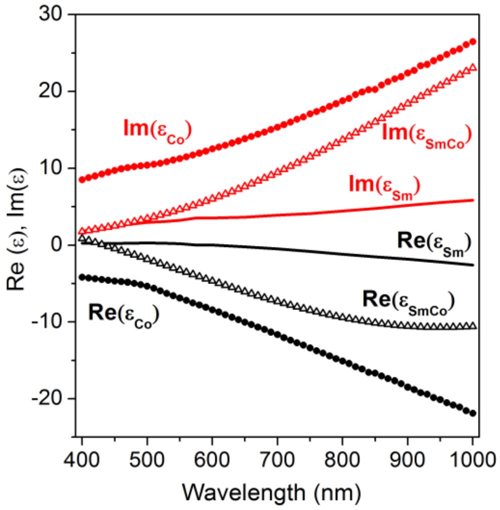

Fig. 3. The diagonal elements of the permittivity tensor for the Co and SmCo films (symbols) and the data taken from Ref. [17] for Sm (lines).

The off-diagonal elements $\varepsilon_{yz} = -\varepsilon_{zy}$ for the Co and SmCo films are shown in Fig. 4. These are obtained from the fit of data presented in Fig. 2. The off-diagonal MM elements of the SmCo film are smaller than those of the Co film.

However, the substitution of the Co layer with the SmCo one in the Au/ferromagnetic/Au structure can be promising for MOSPR sensors. Indeed, we obtained a 50% increase in ΔM_{13} and ΔM_{31} values when we simulated the MO response of the Au/SmCo/Au multilayer on an SF10 substrate using measured permittivity tensor elements for SmCo.

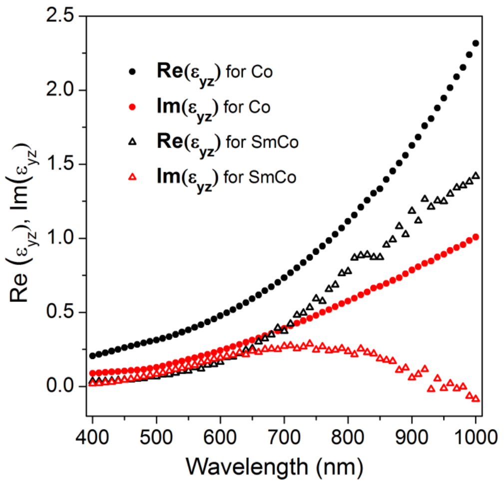

Fig. 4. The off-diagonal elements of the permittivity tensor for the Co and SmCo films.

In conclusion, we have measured the MO response of the Au/Co/Au and SmCo thin films in terms of the Mueller matrix elements. The top Au layer reduces strongly the MO response of the Au/Co/Au trilayer and complex permittivity tensors for Co and SmCo thin films are obtained. The simulations of the MO response allow us to assume the Au/SmCo/Au trilayer to be promising for MOSPR sensors.

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