Numerical calculation of Kerr spectra for Co/Pt magnetic multilayered films

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The Kerr spectra as function of wavelength, incident angle and layer number are calculated with 4 × 4 matrix method. It is found that the calculated results are in good agreement with experimental ones for [Co (0.3 nm)/Pt (0.4 nm)]×43/glass (1.21 mm) and [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm). In addition, for [Co (0.3 nm)/Pt (0.4 nm)]×43/glass (1.21 mm), it shows a maximum Kerr rotation at $N = 10$. For [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm), the calculated Kerr rotation as a function of incident angle reveals maximum when the incident angle is 89°.

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There is currently great interest in the magnetic and magneto-optical (MO) properties of multilayered media because of their many potential applications. With the maturation of the MO recording technology, the search for media with high MO performance at short wavelengths has become the focus of many research groups. Up to now a lot of experiments are performed in order to search a series of magnetic materials with large Kerr rotation for high-density recording media in the next generation of MO memories[1,2]. But as another competing candidate, Co-based multilayers also increasingly attract more researchers[3-4]. Angelakeris *et al.* studied Co-Pt, Co-[CoPt] and Pt-[CoPt] multilayers grown on Kapton, Si and glass in UHV[5]. Recently, many classical and quantum theories on the Kerr rotation of the multilayered films came forth[6-10]. However for the Co-based multilayer, few theories have systemically expounded about it.

In this article, we calculate Kerr spectra as functions of the incident angle, laser wavelength and individual film thickness for Co/Pt multilayer by employing 4 × 4 matrix method. Especially, the Kerr spectra of [Co (0.3 nm)/Pt (0.4 nm)] and [Co (0.4 nm)/Pt (1.1 nm)]×53 with the variable wavelength are calculated. In addition, we also calculate the Kerr spectra as function of the layer number N of [Co/Pt] and the incident angle.

A 4×4 matrix technique, which was applied to solve the problems of the reflection and transmission for stratified anisotropic and low optical symmetry media, was introduced by Teilter and Henvis in 1970s. After then, many papers came forth to explain MO Kerr phenomena for some magnetic multilayered-films[8-10]. We have applied this method to get the calculated Kerr spectra which are in good agreement with measured ones for MnBi multilayers[10]. The propagation matrix L of the reflection for multilayered films can be written as[8-10]

$$\begin{aligned} L = D^{-1}(0) \times D(1) \times P(1) \times D^{-1}(1) \\ \times D(2) \times P(2) \cdots D(n)P(n), \end{aligned} \tag{1}$$

where $D(i)$, $P(i)$ $(i = 0, 1, 2, \cdots n)$ is described in detail in Refs. [8 – 10].

The complex Fresnel reflection matrix R can be written as[8-10]

$$R = \begin{bmatrix} r_{xx} & r_{xy} \\ r_{yx} & r_{yy} \end{bmatrix}, \tag{2}$$

where the elements of the reflection r_{xx}, r_{xy}, r_{yx}, and r_{yy} are defined as

$$r_{xx} = \frac{L_{21}L_{33} - L_{23}L_{31}}{L_{11}L_{33} - L_{13}L_{31}}, \tag{3}$$

$$r_{xy} = \frac{L_{41}L_{33} - L_{43}L_{31}}{L_{11}L_{33} - L_{13}L_{31}}, \tag{4}$$

$$r_{yx} = \frac{L_{11}L_{23} - L_{21}L_{13}}{L_{11}L_{33} - L_{13}L_{31}}, \tag{5}$$

$$r_{yy} = \frac{L_{11}L_{43} - L_{41}L_{13}}{L_{11}L_{33} - L_{13}L_{31}}. \tag{6}$$

The coefficients listed in Eqs. (3)−(6) can be used to calculate the reflectivity, the Kerr rotation, and the Kerr ellipticity for the relevant optical system. The Kerr rotation can be calculated as

$$\theta_x = \mathrm{Re}(r_{yx}/r_{xx}), \tag{7}$$

$$\theta_y = -\mathrm{Re}(r_{xy}/r_{yy}), \tag{8}$$

and the Kerr ellipticity can be calculated as

$$\eta_x = \mathrm{Im}(r_{yx}/r_{xx}), \tag{9}$$

$$\eta_y = \mathrm{Im}(r_{xy}/r_{yy}). \tag{10}$$

In a general way, all of the reflection coefficients are assumed to be complex.

A generalized 4 × 4 matrix method for solving the propagation of electromagnetic plane waves in optically isotropic and anisotropic stratified media has been extended to calculate the relative Kerr or Faraday intensities for most optical arrangements. For a given light scattering arrangement, the reflectivity, Kerr rotation, Kerr ellipticity, Faraday rotation, and Faraday ellipticity may be calculated as functions of the incidence angle, laser frequency, overlayer or underlayer thickness.

In this article, [Co (0.3 nm)/Pt (0.4 nm)]×N/glass (1.21 mm) and [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm) are chosen as studied subjects. It is assumed that room-temperature polar Kerr rotation and ellipticity dispersion curves were simulated at an angle of incidence of zero degree and the applied magnetic field was always sufficient to saturate the samples normal to the film. In this simulation, it is important to know the elements of the permittivity tensor and the dielectric tensor of media in each sample at various wavelengths. They have been obtained in Ref. [11] and [12].

At first we consider the [Co (0.3 nm)/Pt (0.4 nm)] $\times N$/glass (1.21 mm) multilayer film. It has 43 bilayers, which are deposited on glass substrate and have no overcoat and the nominal film thickness is 30.1 nm. According to Eqs. (1)−(10) and parameters in Ref. [11], we can calculate the MO polar Kerr rotation and Kerr ellipticity. Figures 1(a) and (b) show the calculated and measured Kerr rotation and ellipticity as a function of the wavelength for [Co (0.3 nm)/Pt (0.4 nm)] ×43/glass (substrate) with zero incident angle, respectively. From Fig. 1, it is found that the calculated results are in good agreement with the experimental ones[11]. Obviously Kerr rotation decreases monotonously with the increase of the incident wavelength while Kerr ellipticity shows the minimal value near the wavelength of 450 nm.

In another system the sample Co (0.4 nm)/Pt (1.1 nm), deposited on glass substrates, was fabricated in a UHV-compatible vacuum system[12]. In this film, the number of bilayer is fifty-three and the thickness of each period is about 1.57 nm. The structure of the sample is [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm). We can also use 4 × 4 matrix method to simulate the MO polar Kerr spectra of this system with the data in Ref. [12]. The simulated and measured Kerr spectra as a function of the wavelength for [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm) with zero incident angle are shown in Fig. 2. Obviously, the results calculated with 4 × 4 matrix method meet with the experimental curves well[12].

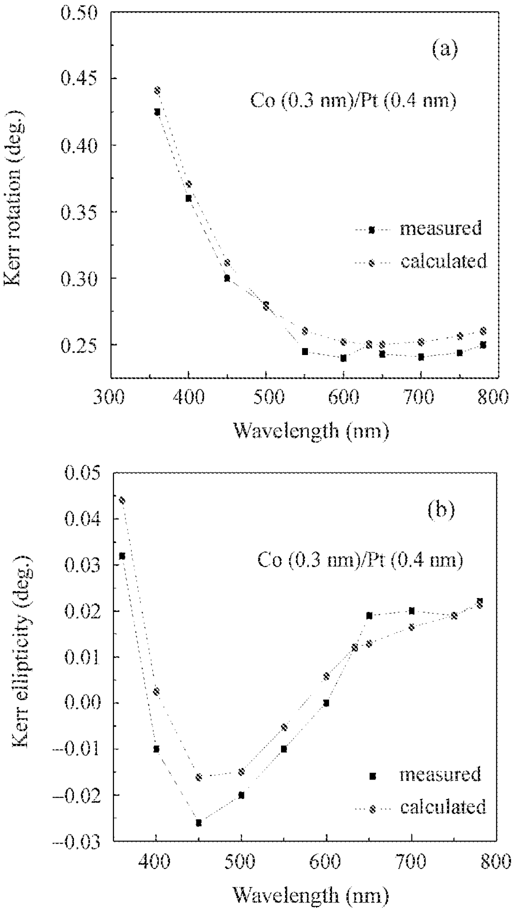

Fig. 1. The wavelength dependence of the calculated and measured Kerr spectra for [Co (0.3 nm)/Pt (0.4 nm)]×43 /glass[11].

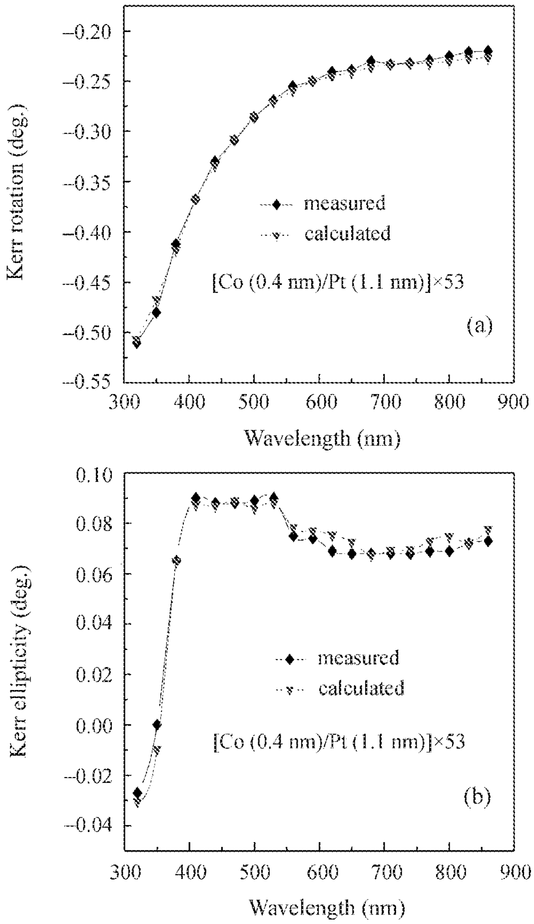

Fig. 2. The wavelength dependence of the calculated and measured Kerr spectra for [Co (0.4 nm)/Pt (1.1 nm)]×53 /glass (1 mm)[12].

Consistence between the simulated and measured spectra as a function of wavelength for two samples above indicates that the 4 × 4 matrix method illustrates its utility powerfully. Now we employ this method to calculate Kerr spectra as function of the incident angle for [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm). The thickness of magnetic layer (Co/Pt) is fixed in 79.5 nm and the wavelength of normal incident light is 620 nm.The calculated Kerr spectra curves for [Co (0.4 nm)/Pt (1.1 nm)]×53/glass (1 mm) as a function of the incidence angle are shown in Fig. 3. It is found that x-magnitude (θ_x) and y-magnitude (θ_y) of the Kerr rotation increase monotonically with the increasing incident angle. For Kerr ellipticity, η_x decreases slowly and is approximately a constant when the incident angle α varies from 0° to 70°. While η_y decreases slowly when varies from 0° to 50° and increases quickly to maximum from 50° to 89°.

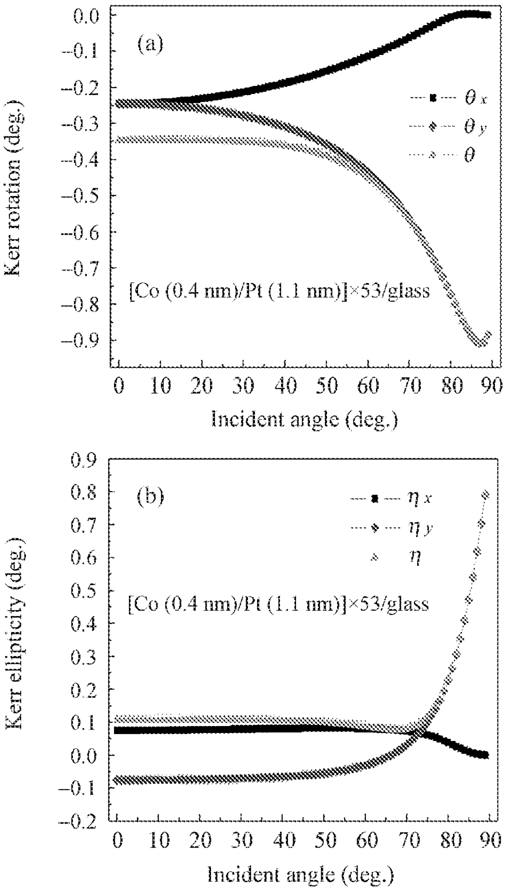

Fig. 3. Kerr spectra with the incident angle for Co/Pt (79.5 nm).

The Kerr spectra as a function of the number N of [Co (0.3 nm)/Pt (0.4 nm)] layer for [Co (0.3 nm)/ Pt (0.4 nm)]×N/glass (1.21 mm) are considered. It is assumed that the values of the permittivity tensor and the dielectric tenor of media do not change when the number of [Co/Pt] layer varies from 1 to 100. The calculated Kerr spectra are shown in Fig. 4. From Fig. 4, it is found that the Kerr rotation reach its peak value when the number of [Co (0.3 nm)/Pt (0.4 nm)] layer is equal to 10. When the number of layer is larger than 60, the rotation begins to saturate. However, the peak value of Kerr ellipticity appears at the number of layer $N \approx 4$.

In conclusion, 4×4 matrix method has been applied to simulate the Kerr spectra as a function of the wavelength, which is consistent with the measured ones. Furthermore we also employ this method to calculate the Kerr spectra with incident angle and individual thickness, which is important for material designation in the future.

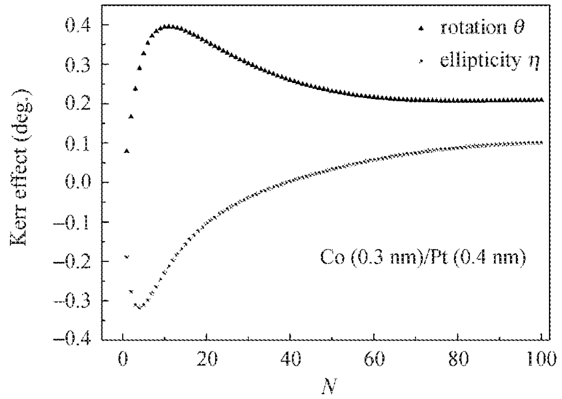

Fig. 4. The calculated Kerr spectra with the number of [Co (0.3 nm)/Pt (0.4 nm)].

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