Doping Effect of PtCu/Co and PtAl/Co Multilayers

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The effect of doping Cu and Al into the Pt spacer layers on the polar Kerr rotation θ_K in the wavelength range of 4000Å~8000Å has been investigated for sputtered 8ÅPt/3ÅCo multilayers. It is found that the small concentrations of the doped atoms result in a large enhancement of θ_K at 7700Å (1.59eV) for PtCu/Co and at 6800Å (1.94eV) for PtAl/Co multilayers. Moreover, the polar Kerr rotation θ_K at this enhanced peak shows an oscillation behavior with the increasing concentrations of the doped atoms. To interpret the experimental results, we apply the formula of Zak et al. to calculate the magneto-optical properties of 600ÅPt_{1-x}Cu_x/20×(3ÅCo/8Å Pt_{1-x}Cu_x) multilayers, where x is in the range of 0 to 0.35, and find that the enhancement and its oscillation are mainly determined by the variation in the dielectric tensor of Co layers, which are caused by the diffusion of the doped atoms.

Key words: Pt/Co multilayers, magneto-optical Kerr effect, doping, thin film, computer simulation, magneto-optical recording

1. Introduction

The transition metal multilayer structures have been intensively studied in recent years due to the fundamental research interest and their potential for application¹⁾⁻⁴⁾. In particular, the magnetic and magneto-optical properties of Pt/Co multilayers, such as the perpendicular anisotropy⁵⁾ and the large Kerr rotation in the short-wavelength range^{1),4),6)}, are of great interest for magneto-optical storage devices. Magneto-optical measurements are also a valuable tool in the study on the magnetic properties and the electronic structure of magnetic materials.

In this article, the effect of doping Cu and Al into Pt spacer layers on the polar Kerr rotation θ_K of the 8ÅPt/3ÅCo multilayers has been investigated. To interpret experimental phenomenon, computer simulation on PtCu/Co multilayers has been realized.

2. Experiments

Two series of samples, 600ÅPt_{1-x}M_x/20×(3ÅCo/8Å Pt_{1-x}M_x) with M = Cu and Al in the range of x = 0~1, were sputtered onto glass substrate at 20 mTorr Ar of 99.99% purity. 600ÅPtM is an under layer, and the samples do not have any overcoated layers. The composition of the spacer layers was determined finally by the scanning electron microscope (Model S-4200, Hitachi) for PtCu, and the inductively coupled plasma-atomic emission spectrometry

(Model Tarrel-Ash AtomComp 96-786) for PtAl, respectively. The accuracy is better than 5 at.%. The crystal structure and multilayer character of these samples were analyzed by small and large x-ray diffraction(XRD). It indicates the sharp interfaces of our Pt/Co multilayers for which four small angle peaks have been found in the x-ray diffraction spectrum of 600ÅPt/20×(8ÅCo/15ÅPt) multilayers. Details of the x-ray diffraction analysis have been reported elsewhere [7]. From the sample surface, the saturation polar Kerr rotation at room temperature in the range of 4000Å ~ 8000Å incident wavelength were determined in magnetic field up to 1.2T *ex situ* by a Kerr spectrometer.

3. Results and Discussion

3.1 Experimental results

Figures 1(a) and 1(b) show the polar Kerr rotation

Fig. 1 The saturation polar Kerr rotation spectra in the range of 4000~8000Å incident wavelength for different doping concentrations in the spacer layers, (a) for PtCu/Co multilayers, and (b) for PtAl/Co multilayers

versus wavelength as a function of the doping concentrations, x , for $\text{Pt}_{1-x}\text{Cu}_x/\text{Co}$ and $\text{Pt}_{1-x}\text{Al}_x/\text{Co}$ multilayers, respectively. It is clear that the doping results in two pronounced effects: (1) the polar Kerr rotations θ_K decreases monotonously with the increase of the doping concentrations as a whole; (2) the large enhancement peaks of θ_K appear at 7700Å for 4% Cu doping and at 6800Å for 5% Al doping, and the θ_K at the enhancement peaks oscillate with the increasing concentrations of the doped atoms. Fig. 2(a) shows the variation of Kerr rotation θ_K at 5000Å incident wavelength versus the doping concentrations x in the Pt spacer layers for $\text{Pt}_{1-x}\text{Cu}_x/\text{Co}$ and $\text{Pt}_{1-x}\text{Al}_x/\text{Co}$ multilayers, and Fig. 2(b) is the plot of the θ_K at the enhancement peaks (7700Å for $\text{Pt}_{1-x}\text{Cu}_x/\text{Co}$ and 6800Å for $\text{Pt}_{1-x}\text{Al}_x/\text{Co}$ multilayers) versus x . Comparing fig. 2(b) with fig. 2(a), an oscillation behavior is easily found.

3.2 Computer simulation

The calculation of the magneto-optical response is based on the dielectric theory where the boundary conditions are matched at the interface by using two kinds of matrices, one to describe the effect of an interface and the other to describe propagation through a magneto-optically active material to the next interface. The explicit forms for these matrices are derived in Ref. 8. The matrices are combined into a film matrix representing the effect of one layer in multilayers. The series of film matrices are then multiplied together for a multilayer structure and a set of linear equations are solved for the magneto-optical Fresnel coefficients. These coefficients are used to calculate Kerr rotation, ellipticity, and the

Fig. 2 The variation of θ_K (a) at 5000Å, (b) at the enhancement peaks with x for PtCu/Co and PtAl/Co multilayers, where x denotes Cu and Al doping concentrations

Fig. 3 The calculated results (Kerr rotation, ellipticity, and reflectivity spectra) and the experimental Kerr spectra of Pt/Co multilayers

reflectivity.

The magneto-optical properties of a given material are described by the dielectric tensor $\tilde{\epsilon}$, which for an isotropic and perpendicularly magnetized thin film takes the form:

$$\tilde{\epsilon} = \begin{pmatrix} \epsilon_{xx} & \epsilon_{xy} & 0 \\ -\epsilon_{xy} & \epsilon_{xx} & 0 \\ 0 & 0 & \epsilon_{zz} \end{pmatrix}. \quad (1)$$

The diagonal element ϵ_{xx} can be connected with the optical constants:

$$\epsilon_{1xx} = n^2 - k^2, \epsilon_{2xx} = 2nk. \quad (2)$$

The off-diagonal element ϵ_{xy} leads to the magneto-optical effects given by Eq. 3 which presents the Kerr rotation in terms of components of the dielectric tensor.

$$\theta_K = \text{Re} \left(\frac{\epsilon_{xy}}{\epsilon_{xx}^{1/2} (1 - \epsilon_{xx})} \right). \quad (3)$$

The values of optical constants used in the calculation are taken from Ref. 9 for Cu, Ref. 10 for Pt and Ref. 11 for Co. The off-diagonal element for Co are taken from Ref. 12.

Figure 3 shows our calculation results, polar Kerr rotation, ellipticity, and reflectivity spectra of 8ÅPt/3ÅCo multilayers, and compares the polar Kerr spectra with the experimental data. It is found that (1) in the long-wavelength region the calculation data agree with our experiment very perfectly; (2) in the short-wavelength region experimental Kerr rotations are different with calculation data. We also find that our calculation results are different from the recent results in the short-wavelength range, for an example, the ellipticity changes its sign at about 3eV, the Kerr rotation and ellipticity peaks appear at about 3.8eV and 4.0eV respectively¹³⁾. Since the samples are rather thin, and are grown on the top of underlayers, part of experimental magneto-optical effect may be due to the optical interference. In our calculation, the underlayer and substrate are not

Fig. 4 Calculated Kerr spectra of PtCu/Co multilayers on the assumption that the variety in dielectric tensor in Pt spacer layers is in direct proportion to the concentrations of the doped atoms

considered. Maybe this is where the difference came from. But we notice that our calculation agree with our experiments in the long-wavelength range, and the Kerr rotation oscillations take place just in this region (1.59eV for PtCu/Co and 1.94eV for PtAl/Co). Considering this point, it is reasonable that we apply above-mentioned method to interpret our experimental results.

First of all, we assume that the dielectric tensor $\tilde{\epsilon}$ of non-magnetic layers is changed by the doped atoms, and calculate the polar Kerr rotation of PtCu/Co multilayers. Because the off-diagonal element ϵ_{xy} is zero for non-magnetic material, only the diagonal element ϵ_{xx} has been considered. The calculation, on the assumption that the variety in ϵ_{xx} is in direct proportion to the concentrations of the doped atoms, has been done and the result is shown as Fig. 4. After compared Fig. 4 with Fig 1(a), it is easily found that the calculation data are quite different with the experiments, and the variety in the dielectric tensor $\tilde{\epsilon}$ of non-magnetic layers can not explain the fact that small concentrations of the doped atoms result in a large enhancement of polar Kerr rotation at a special wavelength for PtCu/Co multilayers.

Considering that the thickness of Co layers (3Å) is very thin, only one or two atom layers, it is reasonable to assume that the dielectric tensor of Co layers is changed due to the diffusion of the doped atoms. We calculate the Kerr rotation at 7700Å for PtCu/Co multilayers according to this assumption. For magnetic materials, two components of the dielectric tensor $\tilde{\epsilon}$, diagonal element ϵ_{xx} and off-diagonal element ϵ_{xy} , contribute to magneto-optical effects. First of all, we assume that ϵ_{xy} is unchanged and ϵ_{xx} , substituted by optical constants in our calculation, varies. Figure 5 shows our calculation results, which are obtained by two steps, one to keep n of magnetic layer as a constant (n of Co) and calculate k according to corresponding experimental polar Kerr rotation θ_K , the other to keep k of magnetic layer as a constant (k of Co) and calculate n . Then we assume that

Fig. 5 Calculated optical constants (n , k) of magnetic layers versus the concentrations of Cu doped into Pt spacer layers of PtCu/Co multilayers according to the corresponding experimental polar Kerr rotation θ_K

ϵ_{xx} is unchanged and ϵ_{xy} varies, and the similar figure as Fig. 5 can be obtained. If the variation in dielectric tensor of Co layers follows certain laws, which has not been determined due to lacking of enough experimental data, such as ellipticity and reflectivity, the enhancement and its oscillation can be quantitative interpreted.

From the calculation, we can draw the conclusion that (1) the variety in dielectric tensor $\tilde{\epsilon}$ of non-magnetic layer, which is caused by the doped atoms, can not explain the experimental facts; (2) the enhancement and its oscillation are mainly determined by the variation in the dielectric tensor $\tilde{\epsilon}$ of the Co layers, which is caused by the diffusion of the doped atoms.

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