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Magneto-optical investigation of Au/Cu-wedge/NiFe sandwiches

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The investigation of Cu-thickness dependence of magnetic and magneto-optical properties f Au/Cu-wedge/NiFe sandwiches were performed with help of the magneto-optical method with micron resolution. It was discovered that the magnitude of the transverse Kerr effect (TKE) oscillates, as Cu-wedge thickness is variable. It was found the period of these oscillations is equal to ~ 6Å. It was proved that TKE oscillations are caused by the influence of finite-size effect.

Key words: magneto-optical effect, sandwich, finite-size effect, quantum well states

1. Introduction

Recently, the study of the influence of finite-size effects (FZE) on physical properties of ultra-thin magnetic films and multilayers attracted a great deal of attention. FZE is caused by a small thickness of films or individual layers in multilayers. In ultra-thin films, due to the electronic potential discontinuities experienced by electron states at interfaces, the perpendicular wave vector is quantized, giving rise to resonance in the density of electronic states called quantum well states (QWS's) "Ref.1". Usually, the existence of QWS's appears in the oscillations of the measured properties with changing of the thickness of the films or a layer in multilayers. Direct experimental probe of QWS's in many systems is the method of photoemission spectroscopy. The data, received by using of this method, confirmed the existence of QWS's in Cu, Ag, Au overlayers on Co (001) and Fe(100) "Ref. 2 – 6" and in Fe (100), Co (100) magnetic overlayers on noble-metals "Ref. 2, 7, 8". Nowadays, it is proved that the oscillation period of the exchange coupling and the giant magnetoresistance in multilayers "Ref. 9 - 11" and also magneto-optical Kerr effects in the ultra-thin film of iron "Ref. 12 - 14" and cobalt "Ref. 14 - 16" can be explained when of QWS's take into account. At the same time analysis of the recent work showed that the influence of QWS's on magnetic and magneto-optical properties of sandwiches with noble-metal wedge is studied insufficiently. In order to obtain a better understanding of this problem we performed a study of the influence of finite-size effect on magnetic and magneto-optical properties of Au/ Cu-wedge/ NiFe sandwiches.

2. Experimental

The studied samples were prepared by the molecular beam epitaxy deposition technique with a background pressure in the 10^{-10} Torr range. Polished MgO (001) samples were used as substrates. Before deposition the substrates were heated to 950°C for 1 min in order to remove adsorption gases and stress introduced by the polishing process. After cooling down till room temperature a Cu-layer of 1000Å was deposited. On this layer a permalloy film was deposited. On its top Cu-wedge was created by moving the sample under a shutter during deposition. In order to avoid oxidation Cu-wedge was covered an Au-layer of 20Å. The slope of Cu-wedge was 1.35 Å/mm, its length was equal to 20 mm, the minimum and maximum thickness values t_{Cu} were equal to 4 and 31 Å, respectively. There were three samples with permalloy film thickness equal to 15, 20, 35 Å. A cross section of the studied samples is shown in the insertion of Figure 2. The investigation of hysteresis and magneto-optical properties of Au/ Cu-wedge/ NiFe sandwiches were performed with help of magneto-optical micro-magnetometer (in details described at "Ref. 17") by means of the transverse Kerr effect (TKE) – δ. Here $\delta=\Delta I/I_0$ where I_0 is the intensity of reflected light from the studied sample at M=0 (M is the sample magnetization) and ΔI is the change of I_0 caused by the magneto-optical effect at $M \neq 0$. We use a modulation method of registration of magneto-optical signals. In our case alternating magnetic field H with frequency f = 80 Hz was applied parallel to the sample surface (along the wedge length L) and perpendicular to a plane of light incidence. Local magnetization curves δ (H) ~ M (H) and dependencies δ (L) that is equivalent δ (t_{Cu}) were measured by using of XY recorder. The diameter D of light spot on the sample was equal to 30 μm. The scan of the light spot was done across a sample middle line situated along its length. Photon energy of incident light ħω was fixed. All magneto-optical measurements were performed at room temperature in open air.

3. Results and discussion

Figure 1 shows the typical local magnetization curves of Au/ Cu-wedge/ 15Å NiFe sandwiches (the sample №1) received at ħω = 2.7 eV. The curve 1 was measured on the sample local micro-part with t_{Cu} ~ 4Å. The curves 2, 3 and so on were measured as the light spot was shifted on 1mm interval along the sample length L. From Fig.1 one can see that the local magnetization curves differ strongly. At the same time a set of such curves allows to obtain the dependence of a local values of saturation field H_s and to find its maximum value (see Figure 2).
The dependencies δ(t_{Cu}) were measured for $H > H_s^{max}$ and a fixed ħω. Figure 3 shows the dependence of δ (t_{Cu}) received for the sample №1 for ħω = 2.7 eV (curve 1). From Fig. 3 one can see that TKE has a maximum value at t_{Cu} ~ 5.5 Å. In the range of t_{Cu} between 6 and 8Å TKE

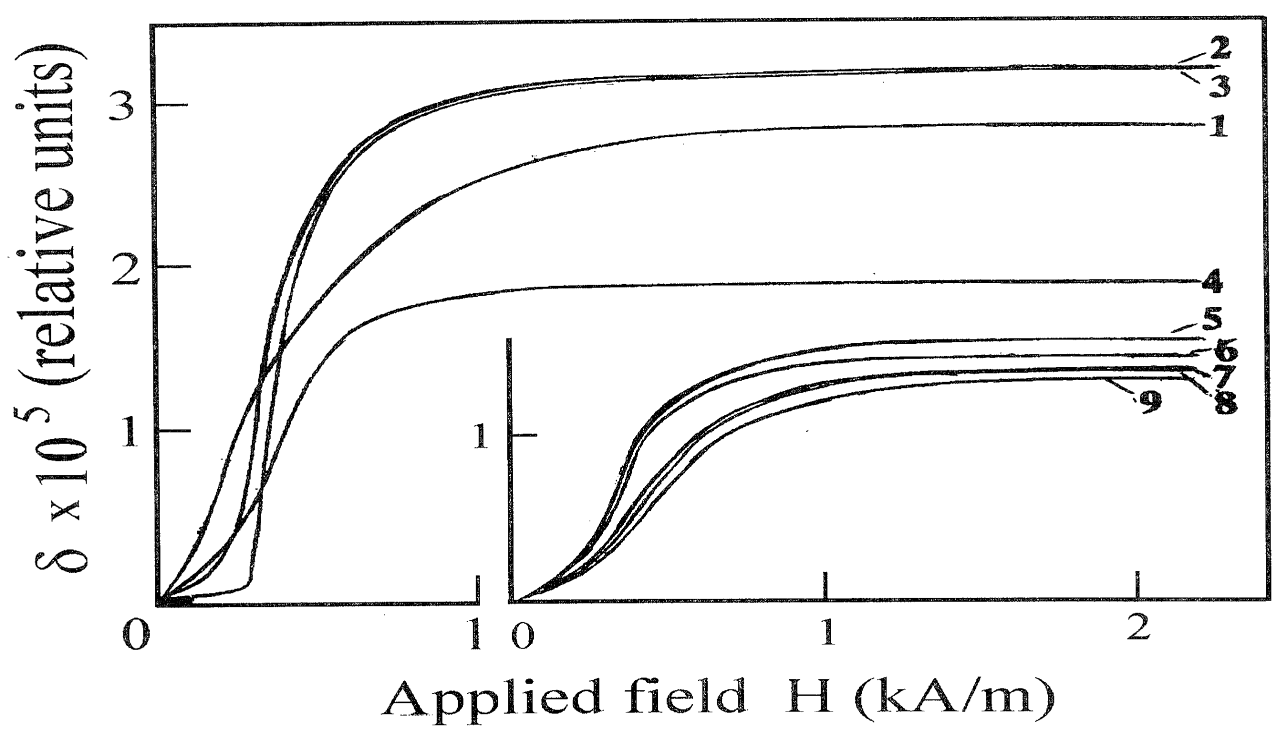

Fig.1 The typical local magnetization curves of Au/Cu-wedge/15 NiFe sandwich for spot size D = 30 μm (ħω=2.7 eV).

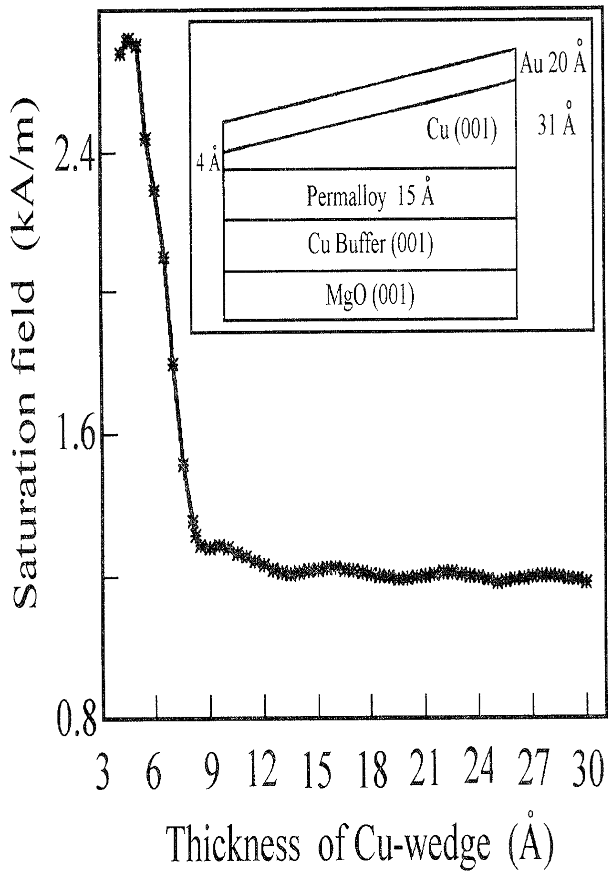

Fig.2 The dependence of the local values of saturation field on the Cu-wedge thickness received. The cross section of the studied sample is shown in the insertion.

decreases abruptly. At t_{Cu}. > 8Å TKE decreases slowly and small amplitude oscillations of δ-values are seen. The period of these oscillations is equal to ~ 6 Å.

Comparison of Fig. 2 and 3 (the curve 1) shows that the dependencies of H_s (t_{Cu}) and δ (t_{Cu}) are similar. Analogous measurements were performed at ħω = 2.5 and 3.2 eV and for the sandwiches with t_{perm} = 20 and 35Å. It was established that the change in the oscillation period of TKE is insignificant as the photon energy of incident light varies. This fact can be explained by a little amplitude variations of TKE. The dependencies of δ(t_{Cu}) received for the sandwiches with t_{perm} = 20 and 35 Å at ħω= 2.7 eV are presented in Fig. 3 (the curves 2 and 3, respectively). For a better clearing Figure 4 shows the curves 1, 2 at t_{Cu} > 8Å on an enlarged scale. From Fig. 3 and 4 one can see that the shape of the curves 1, 2 and 3 are similar but the values of TKE increase linearly and their oscillations become imperceptible with enlarging of t_{perm}. The explanation of the received data can be as following. According to the data of "Ref. 2 - 4, 7", photoemission spectra recorded from different thickness of Cu-overlayer on Co (100) and Fe (100) differ. The first additional peak in the above spectra showing the existence of QWS's appears at t_{Cu} ~ 1 ML. With increasing of t_{Cu} this peak decreases and shifts to Fermi level. The first Fermi level crossing for these states occurs at t_{Cu} ~ 5-6ML. The charge and the spin densities for states at the Fermi level in Cu on Fe (100) and Co (100) have nearly periodic dependence on t_{Cu}. The spin polarised photoemission studies showed that QWS's in Cu on magnetic substrates are strongly polarised preferentially with minority spin character. The presence of spin-polarised QWS's indicates that the copper atoms can carry a small magnetic moment depending

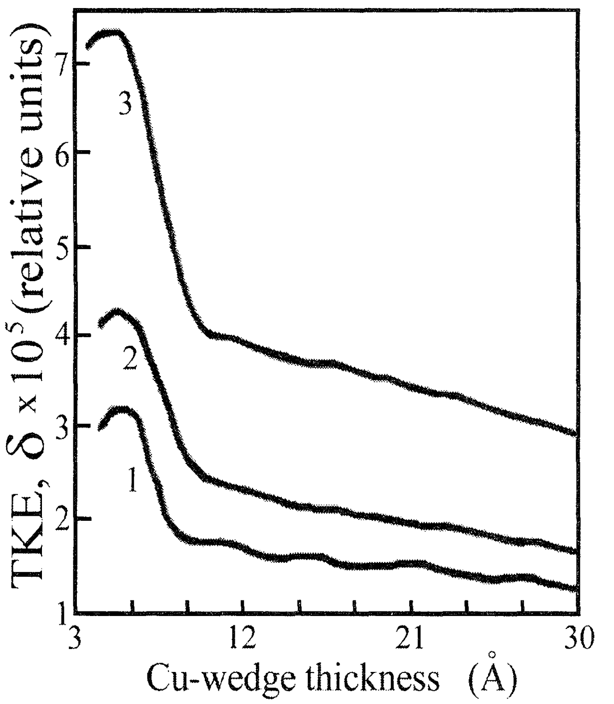

Fig.3 The dependence of transverse Kerr effect δ of Au/Cu-wedge/NiFe sandwiches on the Cu-wedge thickness (the curves 1, 2, 3 for t_{perm} = 15, 20, 35 Å, respectively).

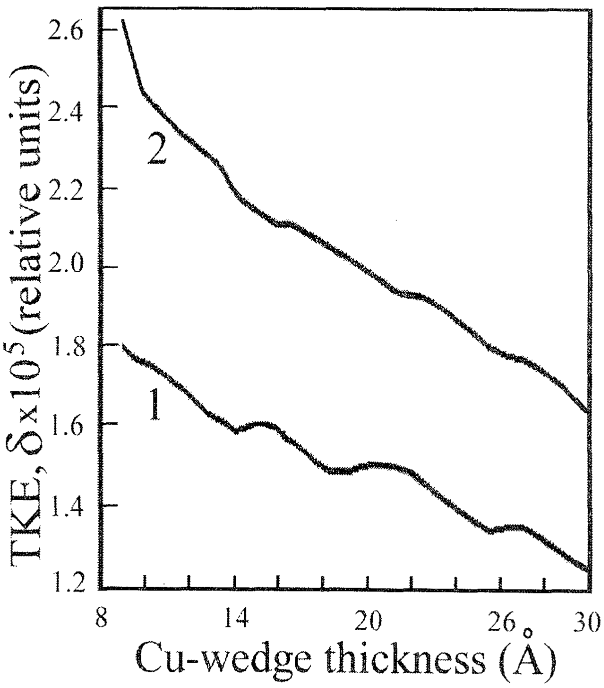

Fig.4 The dependence of transverse Kerr effect δ of Au/Cu-wedge/NiFe sandwiches on the Cu-wedge thickness (the curves 1, 2 for t_{perm} = 15, 20 Å, respectively) on an enlarged scale.

on Cu-thickness. However its value can not be assigned from the photoemission spectra. At the same time one can approve that the above-described peculiarities of electronic structure of copper ultra-thin film on the magnetic substrates should influence on the magnetic and magneto-optical properties of the last. More strong change of those should appear in the range of a small thickness of Cu-overlayer. For the sandwiches with Cu-wedge layer the dependencies of their local magnetic and magneto-optical properties on t_{Cu} should have an oscillating character. We did observe such behaviour of H_s (t_{Cu}) and δ (t_{Cu}). The reduction of the oscillation amplitude of δ with increasing of t_{perm} is caused probably by the decrease of the influence of QWS's on the measured properties. At last, the increase of δ-values with enlarging of t_{perm} correlates well with computation of "Ref. 18".

4. Conclusion

We observed the oscillations of the magnetic and magneto-optical properties of Au/ Cu-wedge/ 15Å NiFe sandwich versus the Cu-wedge thickness. The received data were explained by the influence of spin-polarised QWS's in Cu-wedge on the measured properties of the sample.

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