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Magneto-optical Properties of Spin-Valve Systems on the Basis of Au/Fe/Au/Co/Si

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This paper presents the results of investigation of magneto-optical Kerr effect in pseudo spin-valve systems on the basis of Fe, Co and Au. The significant dependence of coercetivity on such parameters as relative position of ferromagnetic layers, their thicknesses and surface morphology was shown. The investigation was carried out with AFM and TEM methods. Coercitivity value is greater for Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si system. This is explained with different transitional metals growth mechanisms on the substrate and on non-magnetic layer and with more varied surface morphology of films with thickness about 3 nm because of three-dimensional islands in Stranski - Krastanov growth mode.

Keywords: Spin-valve, Kerr effect, magnetic anisotropy, Spin-dependent scattering, Fe/Au/Co.

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1. INTRODUCTION

Multilayer film systems on the basis of magnetic materials are widely used in electronics as element base for magnetic carriers, read heads, electric current, position and rotation sensors, spin-transistors, magnetic compasses and etc. Spin-valves formed with ferromagnetic layers separated with non-magnetic interlayer are among such structures. Fe and Co are often used as magnetic layers because of their soft magnetic films with high sensitivity. Besides in the film systems based on Au/Co layers remain their individual properties and they have the biggest magneto-resistance (MR). That is why this paper is related to multilayer film systems on the basis of Fe, Co, Au. Such systems are considered to be pseudo spin-valves because of the absence of "pinned" layer and the difference in coercitivities (B_C) of magnetic layers appears due to usage of different materials and their thicknesses. Spin-valve systems are well known nowadays, however, there are still some unresolved questions, e.g. how annealing influences on magneto-resistive properties and how the process of magnetization reversal in three-layer structures with different combination of upper and lower layer parameters is carried out [1]. According to said above the purpose of this paper was investigation of variation magneto-optical properties in multilayer film systems with ferromagnetic layers rearrangement.

2. EXPERIMENTAL

The thickness of magnetic layer was chosen in the way to meet the condition that "soft" layer must be ≈ 16 % of the "hard" layer thickness that is why we chose 20 and 3 nm correspondingly [2]. Non-magnetic Au layer thickness was selected in the way to eliminate the appearance of displacement field that is the measure of ferromagnetic layer connection. This interaction can take place via vacancies inside the layer and through magneto-static connection that is caused by the surface morphology of the layer. Optimal interlayer thickness was ≈ 5 – 6 nm. In this case there are separate magnetization reversals of the layers and strict antiparallel arrangement of magnetizations in Fe and Co layers [3].

This way this paper presents the results of investigation of magneto-optical properties of pseudo spin-valve systems Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si and Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si.

The samples were built by thermal deposition method under the pressure of residual atmosphere of $7 \cdot 10^{-10}$ mbar (during deposition vacuum was decreased to $1 \cdot 10^{-9}$ mbar). Si(100) mono-crystals were used as substrate. They were cleaned by ultrasonic cleaning with acetone and then were annealed up to the temperature of 500° C during 30 min at the vacuum of $7 \cdot 10^{-10}$ mbar. The deposition rate was chosen in the way to eliminate the mixing of the layers: 0.32 nm / min for Co, 0.3 nm /min for Fe, 0.86 nm / min for Au. A quartz crystal was used to control the layer thicknesses. Phase structural sample's composition was investigated with help of TEM – 125 K, for studying the surface structure AFM Dimension Edge was used. Besides we carried out magneto-optical Kerr effect measurements in longitudinal geometry and ellipsometry research with Spectroscopic Ellipsometry EASE.

3. RESULTS AND DISCUSSION

The MOKE results for the systems described above are presented in Fig. 1. In both cases there is no shift of hysteresis curve along the field axis relative to B = 0, this means that there is no interaction between hard magnetic and soft magnetic layers via non-magnetic interlayer. The figures show that in both cases there is magnetic anisotropy. Coercitivity dependence on rotation angle in polar coordinates for Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si system (c) has typical for bulk Fe samples view [4]. The maximum value of coercitivity for those systems differs significantly: $B_{c\,max}$ = 20.5 mT and $B_{c\,max}$ = 3.9 mT correspondingly for the structures presented in Fig. 1 (a) and (b). Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/S system has typical structure for spin-valves when hard magnetic layer is built on the substrate.

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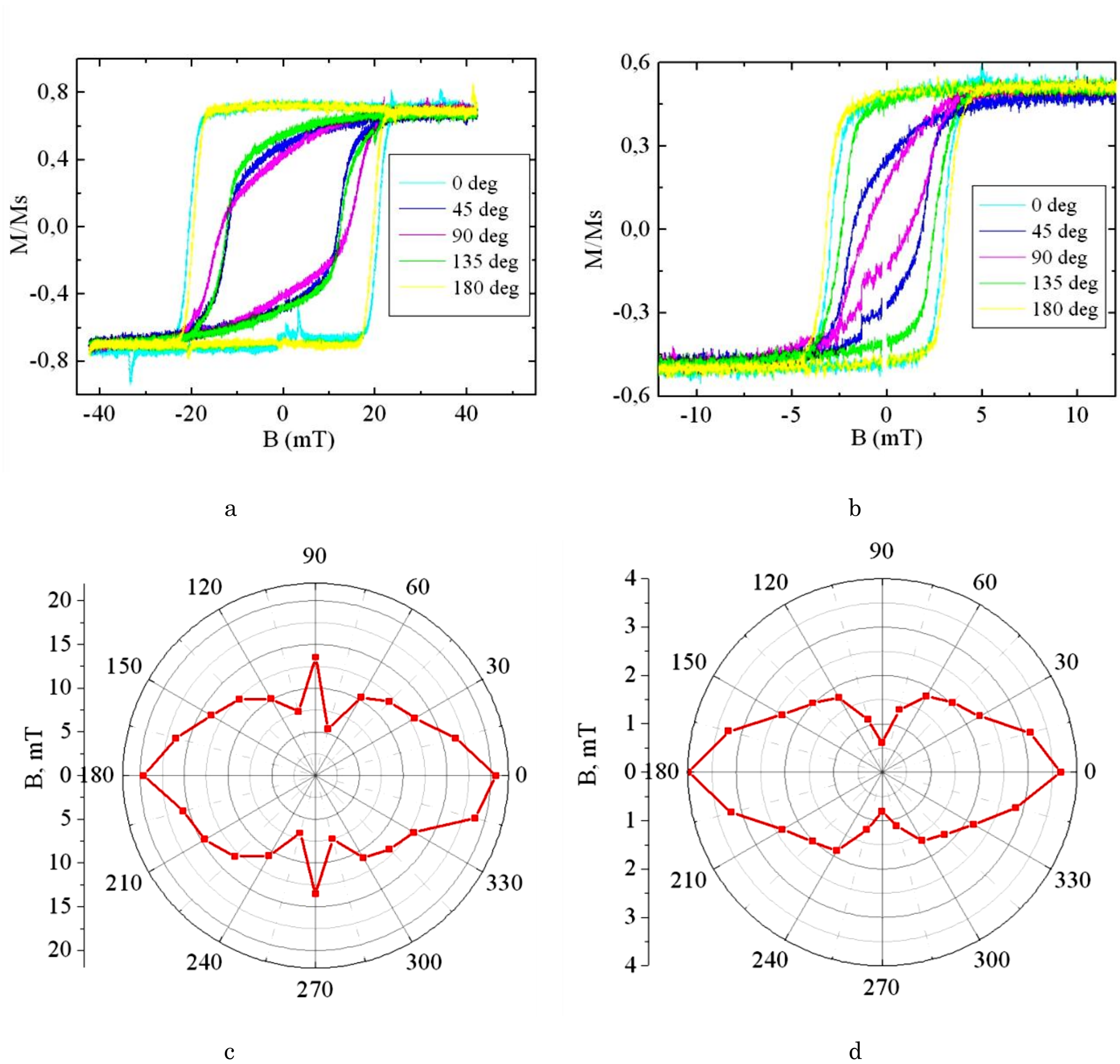


Fig. 1 – Magnetization curves in longitudinal geometry for Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si (a) and Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si (b) systems and coercitivity dependence on sample's rotation angle in polar coordinates for these systems (c) and (d)

On the example of those two systems one can see that not only hard magnetic layer influences on magnetic properties, because in this way coercitivity of Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si system was greater than for spin-valve with hard magnetic Fe (20 nm) layer, but in our case there is inverse relation. We can make a conclusion that the thin cobalt layer (3 nm) on the substrate surface leads to significant increase of coercitivity of whole the system. These facts are proved with the results in paper [5]. That paper presents the dependencies of magnetic properties of Co film on their morphology at different deposition rates. Due to quantum oscillations of energy of the interface between film surface and surface energy, during thin film growth (in particular of transitional metals) the transition of growth mechanism from layer-by-layer to island and back to layer-by-layer deposition is observed. For the thicknesses greater than 1.5 nm Stranski - Krastanov growth mode happens and three-dimensional islands are growing over two-dimensional layer. In this case the samples have great roughness value and therefore great imperfection which in its turn blocks domain-wall motion and leads to increase of sample's coercitivity. With further increase in thickness Co clusters are destructed and become smaller. This process decreases the roughness. When thickness value reaches ≈ 17 nm the roughness and coercitivity minima happens (see Fig. 2). Then films are growing layer-by-layer and with their thickness raise the grain boundaries are getting thicker that leads to monotonic increase of B_C.

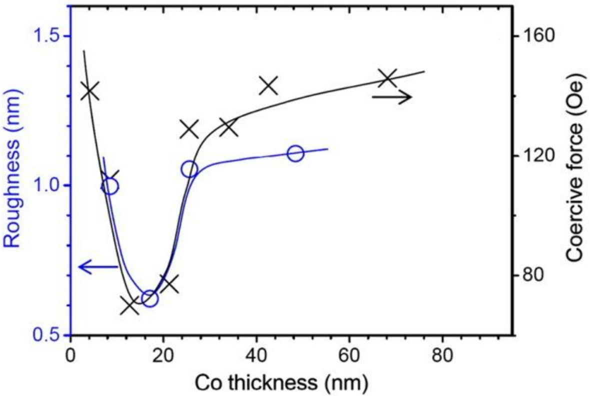


Fig. 2 – Roughness and longitudinal coercive force versus the Co thickness [5].

This way according to results presented in paper [5], Co films with thickness of 3 nm have coercive force ≅ 16 mT, and at d = 20 nm – 7 mT. Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si system in our case has B_C ≅ 18 mT (maximum value). Coercive force for Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si system is ≅ 4 mT. Upper ferromagnetic layers also have effect on magnetic properties of given pseudo spin-valves. First system has more hard magnetic Fe(20 nm) layer than Fe(3 nm) layer in the second system because transitional metals during deposition on non-magnetic Au layer grow like "terraces" [6] and have much smaller roughness than during growth on a substrate. Besides, if thin (≈ 3 nm) Co and Fe layers are compared then first one has significantly clearer texture [7] and therefore coercive force.

The investigation of the given pseudo spin-valves with AFM lets us define the roughness of upper ferromagnetic layers. Fig. 3 shows AFM pictures and profiles that indicates that roughness height is about ≅ 7 – 8 nm in both cases.

Diffusion processes that cause the formation of the interlayer also influence on magnetic properties of multilayer film systems. Because of this given spin-valve systems were investigated with help of TEM and afterwards the diffraction patterns were deciphered.

Fig. 4 presents micro picture and diffraction pattern for Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si system. The deciphering table is shown below. The analysis of diffraction pattern indicates that there is no solid solution formation and the layers remain their individuality. The same results were obtained for Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si system. Besides the ellipsometry research proves the absence of inter layer in given pseudo spin-valves.

According to facts above the main influence on magnetic properties of such systems is explained by thickness and surface morphology of ferromagnetic layers.

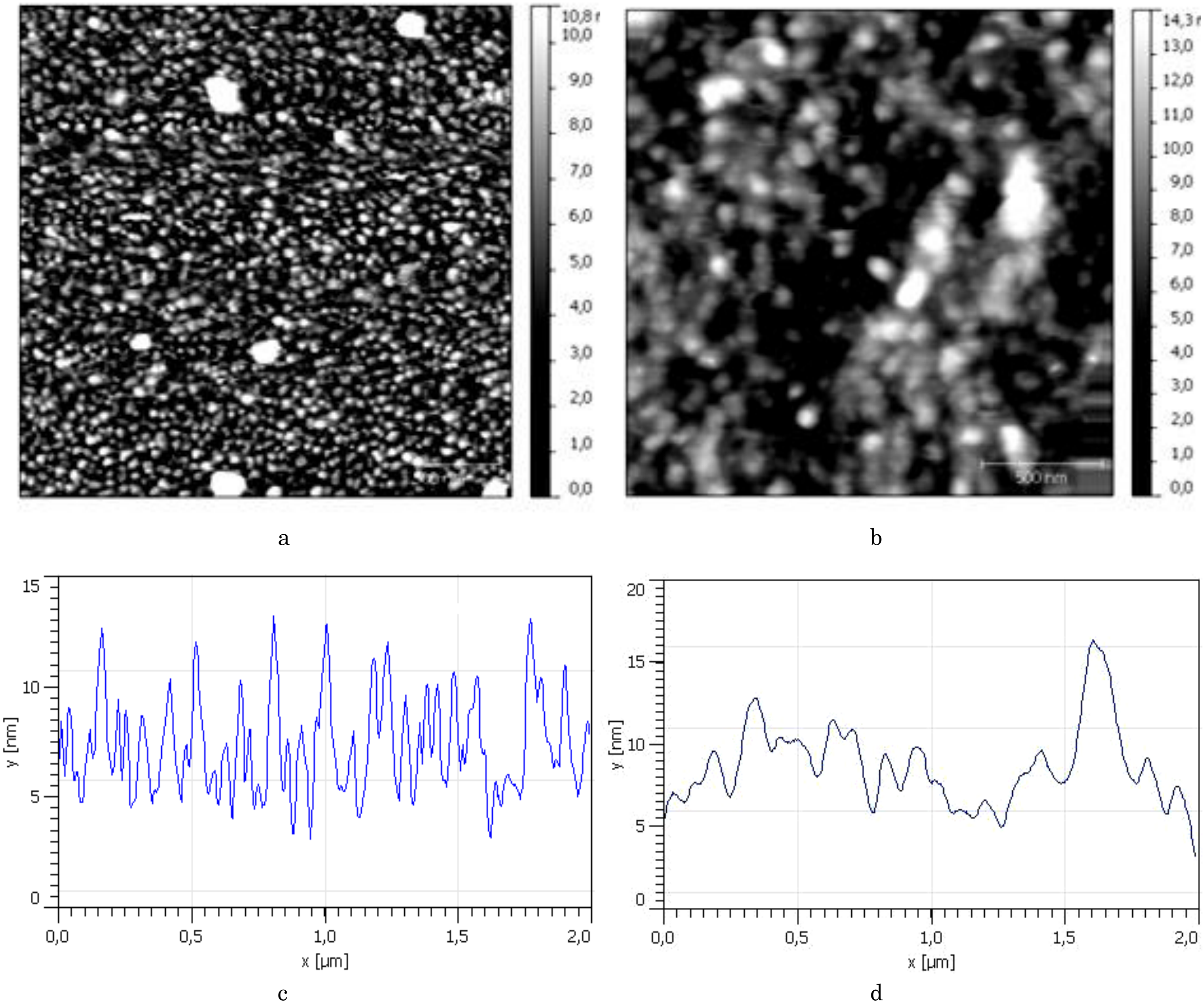
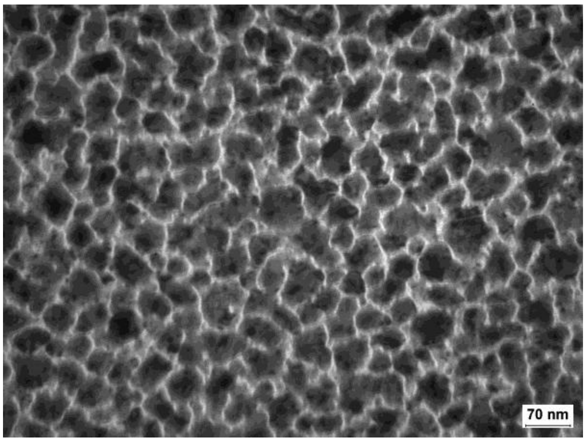
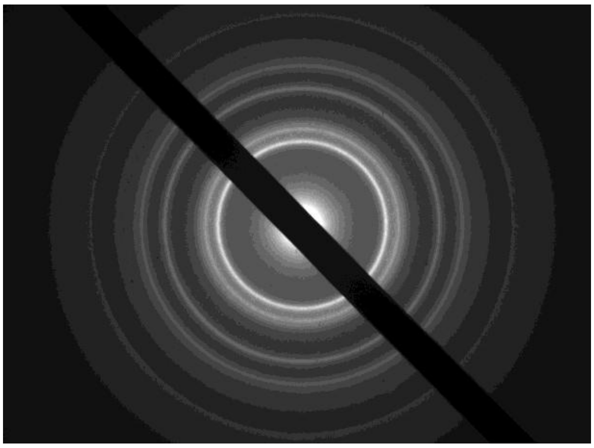


Fig. 3 – AFM pictures and profiles for Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si (a, c) and Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si (b, d)



a



b

Fig. 4 – Microstructure (a) and diffraction pattern (b) for Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si system

Table 1 – Diffraction pattern deciphering for Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si system

<table>
<tr><th>I, r.u.</th><th>d_{hkl}, nm</th><th>hkl</th><th>phase</th><th>a, nm</th></tr>
<tr><td>v.l.
1</td><td>0.236</td><td>111</td><td>fcc-Au</td><td>0,409</td></tr>
<tr><td>m.
0.6</td><td>0.204</td><td>200
110
111</td><td>fcc-Au
bcc-αFe
fcc-Co</td><td>0.408
0.288
0.353</td></tr>
<tr><td>l.
0.3</td><td>0.193</td><td>101</td><td>hcp-Co</td><td>-</td></tr>
<tr><td>m.
0.4</td><td>0.144</td><td>220
200</td><td>fcc-Au
bcc-αFe</td><td>0.407
0.288</td></tr>
<tr><td>m.
0.4</td><td>0.123</td><td>311</td><td>fcc-Au</td><td>0.408</td></tr>
<tr><td>v.l.
0.04</td><td>0.118</td><td>222
211</td><td>fcc-Au
bcc-αFe</td><td>0.409
0.289</td></tr>
<tr><td>v.l.
0.1</td><td>0.106</td><td>201</td><td>hcp-Co</td><td>-</td></tr>
<tr><td>l.
0.15</td><td>0.094</td><td>331
203</td><td>fcc-Au
hcp-Co</td><td>0.409
-</td></tr>
<tr><td>l.
0.15</td><td>0.091</td><td>420
310</td><td>fcc-Au
bcc-αFe</td><td>0.407
0.288</td></tr>
<tr><td>v.l.
0.03</td><td>0.083</td><td>422
222</td><td>fcc-Au
bcc-αFe</td><td>0.407
0.288</td></tr>
<tr><td colspan="2">a (Au) = 0.408 ± 0.001 nm
a_0 (Au) = 0.408 nm
Δa = ± 0.001 nm</td><td colspan="3">a (Fe) = 0.288 ± 0.001 nm
a_0 (Fe) = 0.289 nm
Δ a= ± 0.001 nm</td></tr>
<tr><td colspan="2">a (hcp-Co) = 0.250±0.001 nm
a_0(hcp-Co) = 0.251 nm</td><td colspan="3">a (fcc-Co) = 0.353±0.001 nm
a_0(fcc-Co) = 0.354 nm
Δa = ± 0.001 nm</td></tr>
</table>

b

4. RESULTS AND DISCUSSION

While carrying out this paper we investigate magneto-optical properties of spin-valve systems Au(3)/Fe(3)/Au(6)/Co(20)/SiO_2/Si and Au(3)/Fe(20)/Au(6)/Co(3)/SiO_2/Si. It was defined that both samples have magnetic uniaxial anisotropy. Besides greater coercitivity value is observed for the second system. This is explained with different transitional metals growth mechanisms on the substrate and on non-magnetic layer and with more varied surface morphology of films with thickness about 3 nm because of three-dimensional islands in Stranski - Krastanov growth mode. The films were deposited with low rate that let us eliminate the appearance of diffusion processes and interlayer formation with different magnetic properties. Ellipsometry research and deciphering of diffraction patterns prove these facts. Besides the absence of shift of hysteresis curves relative to B = 0 indicates the separate magnetization of upper and lower ferromagnetic layers of spin-valve systems that indirectly points on integrity of non-magnetic Au layer. So even small decrease of its thickness will lead to disappearing of antiparallel magnetization arrangement and appearing of displacement field.

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