MAGNETIC AND MAGNETO-RESISTANCE PROPERTIES OF SPIN-VALVES BASED ON Co AND Cu OR Au FILM SYSTEMS

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ABSTRACT

The construction of module for automation measurement of magnetoresistance (MR) and coercitivity force (B_c) in spin-valve structures based on Co and Cu or Au film systems was proposed. The peculiarities of dependences of MR and B_c from angle α between substrate plane and direction of external magnetic field induction were studied. The abrupt changes of MR and B_c in the range α=70-90°were determined. The dependence character of MR from α describes as a level of solution of atoms of bottom ferromagnetic layer Co(3 nm) or Co(20 nm) in layer Cu(6 nm) as long as atoms Co(3 nm) have a practically full solution but Co(20 nm) – only limited solution. In this case magnetization of magnet layers of Co(20) and solid solution (s. s.) – [Cu, Co(3)] and layers of Co(20-x)+s.s. – [Cu, Co(x)] realize in different ways. This fact is cause of increase or decrease of MR.

Key words: spin-valve, induction of magnetic field, coercitivity, angle between induction and substrate plane.

INTRODUCTION

Giant magnetoresistance (GMR) was detailed studied based on different film systems (Fe/Cr, Co/Cu, Co/Au, Co/Ag, Co/Ru, Ni/Cu etc.). The investigation of GMR effect in spin-valve structures is the most important researcher's interest [1-3]. The angle of direction of applied external magnetic field has the most significant influence on magnetoresistance properties of thin film systems. There are two geometries of applied magnetic field: FIP (lines of magnetic induction are parallel to film plane) and FPP (lines of induction are perpendicular to sample).

On the basis of theoretical conception the research of the dependence MR and coercitivity from angle between substrate plane and direction of applied external magnetic field was the aim of the work.

METHODS OF SAMPLE MANUFACTURING AND ANALYSIS

The studied samples were spin-valve structures and were prepared by thermal vacuum evaporation method under the pressure of residual atmosphere 10^{-7} Pa. Deposition was provided by electron beam evaporation on single-crystalline silicon substrate with dioxide silicon surface layer. The layer thickness was controlled by quartz resonator method. MR measure at temperature 300 K using updating complex. Working methodic was described in work [4].

The automated measurement module was developed for research magnetoresistance in spin-valve structures subject to angle of external magnetic field direction with minimal changing step 1°. The system controlled with using software that was developed within graphical programming environment LabVIEW 2010 SP1. Structural scheme of developed complex showed in *fig. 1*. Hardware module mounts between limb of magnet (fig. 1 pos. 1) and consists of console (pos. 4), contact holder (pos. 3), sample holder (pos. 2) and stepper motor (pos. 5) that controlled with DAQ NI USB 6008 (pos. 6). Gold contact pins have minimal resistance and round tip that couldn't destroy thin film. Contact probes mount in special way that allows changing geometry of current flow without changing spin-valve position in sample holder.

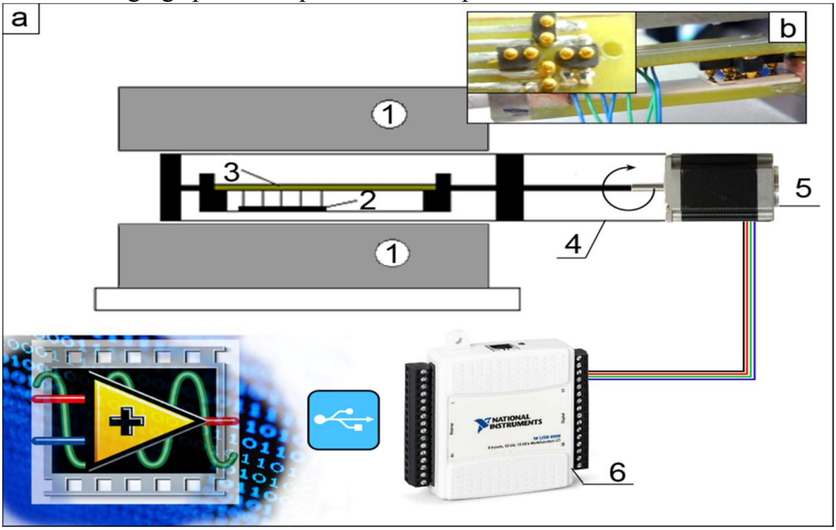

Fig. 1 – Scheme of developed hardware complex with mechanism for sample rotation (a) and image of contacts holder (b): 1 – limb magnet; 2 – sample; 3 – contacts holder; 4 – console of rotation mechanism; 5 – stepper motor; 6 – DAQ NI USB 6008

The possibility of automated MR measurement in thin film systems in the frame of different geometries of applied external magnetic field direction was the principle feature of developed system. The possibility of sample rotation during measurement realized in the system in the angle range of ±180° with minimal step 1°.

RESULTS AND DISCUSSION

The magnetoresistance properties were researched on the basis of spin-valve systems with CIP geometry of current flowing:

Au(1)/Co(**3**)/**Au**(6)/Co(**20**)/SiO_2/Si (spin-valve №1);
Au(1)/Co(**3**)/**Cu**(6)/Co(**20**)/SiO_2/Si (spin-valve №2);
Au(1)/Co(**20**)/**Au**(6)/Co(**3**)/SiO_2/Si (spin-valve №3) та
Au(1)/Co(**20**)/**Cu**(6)/Co(**3**)/SiO_2/Si (spin-valve №4),

where the layer thickness showed in the brackets. The peculiarity of studied spin-valve systems is the difference of nonmagnetic intermediate layer material (Cu or Au) and also thicknesses of magnetic layers Co.

The typical dependences of MR from magnetic induction with different angles α between substrate plane and induction direction in samples with CIP geometry current flowing showed in the *fig. 2*.

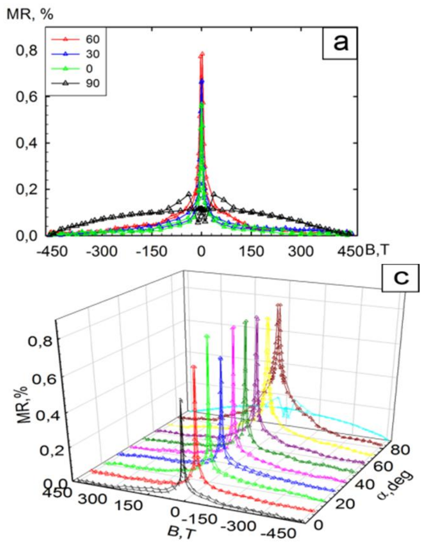

Fig. 2 – Dependence MR of multilayered film system Au(1)/Co(3)/Au(6)/Co(20)/SiO_2/Si from external magnetic field induction at different angles α between substrate plane and direction of magnetic induction. α, deg: 0°, 30°, 60°, 90° (a); 90°- 85°, 80° (b) and 0° – 90° (c)

The most interesting peculiarities are MR value not depend from angle α in the range of α=0°-70°. In the range of 70°-90° MR jump decrease in case of spin-valves Au(1)/Co(20)/Au(6)/Co(3), Au(1)/Co(3)/Au(6)/Co(20) and Au(1)/Co(3)/Cu(6)/Co(20) or vice versa jump increase in case of spin-valve Au(1)/Co(20)/Cu(6)/Co(3). This fact illustrated in the chart dependences of MR and B_c from magnetic field value at different angles sample orientation relative to the substrate plane (*fig. 2* and *3a*). The coercitivity force (fig. 3b) also practically did not depend from angle α in the range of α=0°-70°, but in the range of α=70°-90° jump increased in the case of all type of spin-valve systems. This fact could be interpreted by anisotropy of Co layers in the substrate plane.

Spin-valve (1) and (2) had “standard” structure in which fixed ferromagnetic layer Co(20) was hard layer and layer Co(3) was soft. The upper soft layer become to magnetized under the smaller value of magnetic induction in compare with hard layer Co(20). The jump changes were in the range of angles α=70°-90°. It could be connected with magnetized both layers Co(3) and Co(20). Layer changing in case of spin-valves (2) and (3) did not change the character of the dependence MR and B_c from angle α. Otherwise there was jump dependence in case of spin-valve (4). The peculiarity of this spin-valve was the interface between bottom layer Co(3) and non magnetic Cu(6). In this case the solid solution with absolutely solution and granule elements was obtained [5]. Magnetization of solid solution led to "anomaly" dependence MR from α. In the case of nonmagnetic layer Au(6) the solid solution with limited solution was obtained [5] that had not influence on magnetization Co(3).

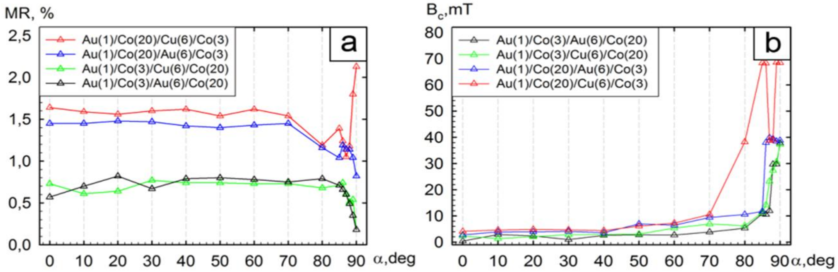

Fig. 3 – Dependences of MR (a) and coercitivity force (b) from angle of external magnetic field direction

CONCLUSIONS

The research of MR and coercitivity force in four spin-valve systems based on Co and Cu or Au was provided in the dependence from angle α between substrate plane and external magnetic field direction. The fact of jump changes of MR and B_c in the range of α=70°-90° was established. The dependences had a similar character in the case of three systems. The anomaly jump change was observed when atoms Co(3) diffused into Cu(6).

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