PROCEEDINGS OF THE INTERNATIONAL CONFERENCE
NANOMATERIALS: APPLICATIONS AND PROPERTIES
Vol. 4 No 1, 01NTF06(2pp) (2015)

Strain Properties of Thin Films Based on Ni and Ag in External Magnetic Field

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(Received 10 June 2014; published online 29 August 2015)

The paper describes the research results of influence of an external magnetic field with 200 mT induction on the longitudinal gauge factor of nano-crystalline film systems of Ni and Ag with different thickness of non-magnetic layer of Ag (or Ni) within elastic deformation up to 1% are presented. Considered methods of forming double- and triplex-layer structure based on thin films Ni and Ag and research of the structure and phase composition of the obtained samples. The correlation between the factor value of the longitudinal gauge factor, structural-phase state of film systems and total thickness is estimated.

Keywords: Strain Effect, Gauge Factor, Phase Composition, Film Systems.

PACS numbers: 68.60.Bs, 73.63.Bd, 75.80.+q

1. INTRODUCTION

Modern nano-electronics development connects to the new technologies of magnetic memory devices, intellectual sensors and actuators [1-2]. As a practical usage of the sensor technical devices it is necessary to determine the materials which provide the most significant sensitivity values which react to the external factors: magnetic field, deformation, temperature, etc. The sensor instrumentation device's electronic elements and assemblies are in most cases functioning in external magnetic field conditions. Therefore, determination and prediction the physical regularities of such elements behavior and properties allow to formation the new technology of the films electro-physical characteristics controllable regimes. Also, it gives the opportunity to use these films as the sensitive elements of control-measure devices (checkers). Based on the foregoing, investigation and comparison of physical effects in presence and absence of the external magnetic field have a practical matter.

The study of the magnetic field influence on strain properties of ferromagnetic materials is devoted in works [3] where it was shown that for such materials is presented the additional contribution in the elastic properties (so-called ΔE - effect). These magneto-elastic (ME) properties are connected with the magnetic order influence on elastic characteristics and are due to the magnetostriction effect. In paper [4] are presented the investigation of ME influence (100 mT) on the Ni, Co and α-Fe gauge factor (GF) values. So, as Co films are nano-crystalline the GF value is increased on 17% ($d \approx 10$ nm) or on 8% ($d \approx 100$ nm), in dispersed Ni films took place the analogue GF value increasing from 34% ($d \approx 20$ nm) to 25% ($d \approx 100$ nm). Authors named this phenomenon as a magneto-deformation effect. These authors proposed in the framework of phenomenon approaching the theoretical ratios of the metal films longitudinal and cross GF magnetic coefficients.

2. EXPERIMENTAL

Thin-film materials were obtained by thermal-resistive evaporation in single technological cycle using the typical VUP-5M (SELMI, Ukraine) vacuum equipment at room temperature (residual gases pressure was ~ 10^{-3} Pa). Films thickness during the deposition was calculated by quartz resonance technique and was checked by the optical interferometry method using the Linnick interferometer (MII-4 device) that allows the measurement error no more than 5%.

To determine the film system's structure and phase composition were carried out transmission-electron microscopy (TEM) and electron-graph investigations (PEM–125K microscope, SELMI, Ukraine).

To deformation the film/substrate system was used specially designed device (deformation machine) that allows to estimate the tension operation with step 0.05 % and to determine films electrical resistance. For GF measurement it is carried out from 5 to 7 "load-throwing-out load" deformation cycles in cases of 1) the magnetic field to 200 mT induction in perpendicular-plane geometry; 2) while the magnetic field is absent. The magnetic field is formed by special system consisted of Neodymium magnets.

3. RESULTS AND DISCUSSION

Considering the probability of the phase composition and components structure influence on Ni (Ag) films strain properties there were investigated mono-layer Ni and Ag films. Selected-area electron diffraction (SAED) analysis shown that Ag films have fcc-lattice structure. Their average lattice parameter is $\bar{a}$(Ag) = 0.408±0.001 nm. The average crystalline size is L=40 nm. Ni mono-layer films also have fcc-lattice and its average lattice parameter is $\bar{a}$(Ni) = 0.352±0.001 nm. Measured lattice parameters values have a good agreement with the reference values of the bulk patterns a_0(Ag) = 0.409 nm and a_0(Ni) = 0.352 nm [5]. It is also should be noted that the average Ni and Ag films crystalline size is sensitive to film's thickness (Fig.1).

The Ag-Ni diagram state shows that this system is a simple mono-tectic. The maximal Ag-in-Ni solubility is ~1% at. % and decreases at the temperature decreasing. Carried out SAED investigations of double- and triplex-layered systems based on Ni and Ag films confirm their double-phased composition. On the diffraction graphs are observed rings which are connected to these metals. So, after condensation the layers individuality is preserved.

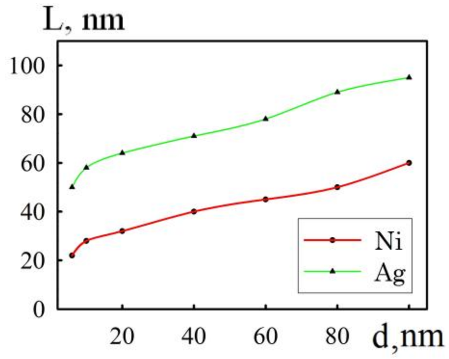


Fig. 1 – Average crystalline size vs thickness of Ni and Ag films

It was estimated that the longitudinal GF value reaction of Ni mono-layer films on the external magnetic field. At the film thickness d_{Ni} = 30 nm it was observed the significant increasing of γ_l in all magnetic field valued range (Fig. 2 a). The general GF increasing was ~ 25%. Thicker patterns GF (65 nm) are in weak react in the magnetic field in general to 5%. The similar view was observed for films with thickness 15 nm.

To determine the laws of influence the magnetic and non-magnetic layers on their GF in external magnetic field it was carried out the investigation of double-layered systems based on nickel and silver where at first was fixed the Ni film thickness (Ag layer's thickness was 10 nm), after that the Ag thickness was determined at constant Ni film thickness.

It was observed that in Ni(10)/Ag(d_{Ag})/Substrate film systems while the Ag layer d_{Ag} was increased from 10 to 30 nm GF value is lesser sensitive to the external magnetic field, so the γ_l increasing is no more than 10% (Fig. 2 c). While the Ag film thickness is more than d_{Ag} = 45 nm, the GF is not react on the magnetic field and is in the range of 5 units. At the Nickel film thickness varying the GF increasing in magnetic field is observed in all thicknesses range and was 25-40 % (Fig. 2 b).

It was seen that in Ni(10)/Ag(d_{Ag})/Substrate film systems at silver layer thickness increasing d_{Ag} from 10 to 30 nm the GF value is less sensitive to external magnetic field and γ_l increasing is no more than 10% (Fig. 2 c). At d_{Ag} layer thickness is more than 45 nm the film system GF value is not react on the magnetic field and lays in the range of 5 units. While the Nickel film's thickness is varied the GF increasing in magnetic field is observed in all thicknesses ranges and is 25-40 % (Fig. 2 b).

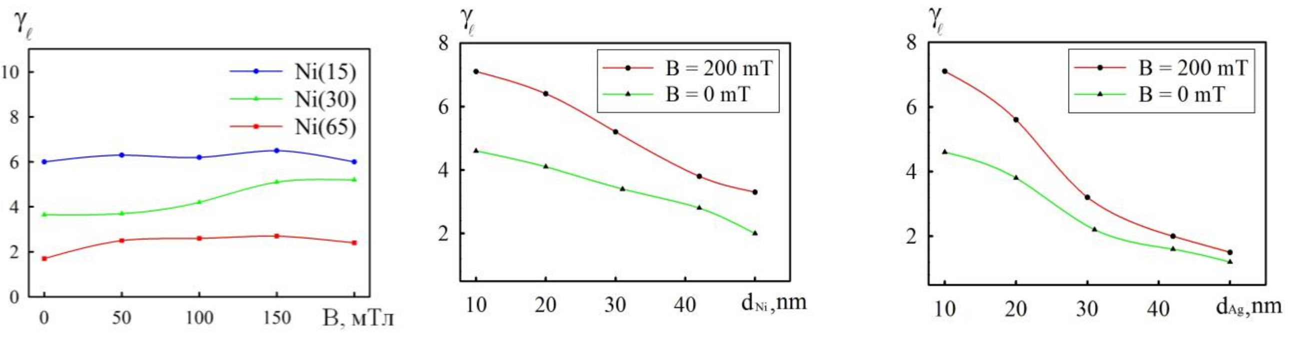
Estimated study of the Ni(10)/Ag(x)/Ni(30)/Substrate film system strain properties shown that GF value is a dimensional-depend on the silver layer thickness and is decreased while its thickness is increased. When this system is replaced in the external perpendicular-plane magnetic field with 200 mT induction it is observed GF value increasing regardless on the layer's thickness

4. CONCLUSIONS

Ni and Ag based films systems are perspective to formation the multi-functional sensors, and double-(triplex) layered systems are more sensitive to the deformation and magnetic field influence.

It was estimated that a formation of the films systems with a controlled grain (crystalline) size allows to controlling their electro-physical properties and their considering at their junction from single- to multi-layer nature.

The correcting of Ni and Ag films GF value in magnetic field is real while the Ni layer thickness is varied.



a b c

Fig. 2 – γ_l *vs* external magnetic field induction dependencies for Ni (a) and double-layered Ag(10 nm)/d_{Ni}/Substrate (b) and d_{Ag}/Ni(10 nm)/Substrate (c) film systems

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