

Permalloy thin films obtained by pulsed laser deposition: magnetic and galvanomagnetic behaviour

M. NEAGU*, M. LOZOVAN^a, M. DOBROMIR, L. VELICU, C. HISON^b, S. STRATULAT

"Al. I. Cuza" Univ., Faculty of Physics, 11 Carol I Blvd., 700506 Iasi, Romania

^aNational Institute of R&D for Technical Physics, 47 Mangeron Blvd., 700050 Iasi, Romania

^bCOHERENTIA CNR-INFM and PROMETE spin-off CNR-INFM, Università "Federico II",

P.le V. Tecchio 80, 80125 Napoli, Italy

Results concerning the bulk and surface coercivity as well as Hall voltage of Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin films, prepared by pulsed laser deposition, are presented. The samples were tested in as-deposited state as well as after thermal treatment in furnace, at temperatures between 330°C-370°C, for 30-60 minutes. For the as-deposited samples, the surface coercivity is up to about 14% higher than the bulk one. After thermal treatment, a decrease up to about 54 % of the bulk coercivity and an increase of about four times in the Hall voltage value are obtained.

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1. Introduction

The high structural and magnetic homogeneity, low coercivity and high magnetization are important characteristics of the magnetic sensor cores. The Permalloy thin films are intensively used for applications in sensors industry [1 - 5]. Therefore, the control of their magnetic behaviour is especially important in view of magnetic sensors miniaturization.

The pulsed laser deposition is a powerful tool for the production of soft magnetic thin films. One of the most important characteristics of this technique is the fairly good stoichiometric transfer of the target material to the growing film [1, 6 - 8].

In this paper, results concerning the magnetic (bulk and surface) as well as galvanomagnetic behaviour of Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin films prepared by pulsed laser deposition are presented.

2. Experimental details

The Permalloy films were deposited onto a glass microscope slide as substrate, using as parent material $\text{Ni}_{80}\text{Fe}_{20}$ plate sheet. The deposition was performed by means of a XeCl excimer laser, operating at 308 nm wavelength, with 30 ns pulse duration, 9 Hz repetition rate and 150 mJ maximum pulse energy. Before starting the target ablation, the deposition chamber was evacuated to 10^{-6} Torr. The substrates were placed at 30 mm distance from the target. The films were deposited using a circular shape mask of 10 mm in diameter placed on the substrate in order to ensure homogeneity in samples composition and thickness and minimize the demagnetising effect.

The composition of the obtained films was investigated using a scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDXS). The surface morphology was analyzed by scanning electron microscopy and atomic force microscopy (AFM).

An interferometric method was employed for the measurement of the films thickness.

The surface magnetic behaviour of the samples was investigated by means of longitudinal magneto-optical Kerr effect (MOKE) [3, 6, 7]. The surface hysteresis loops were obtained by measuring the change in the light intensity reflected by the film surface.

Axial hysteresis loops of the films were measured by a differential inductive method at 50 Hz, using an integrating fluxmeter.

The Hall voltage measurements were carried-out by five point contact method [9 - 11] using external magnetic induction values up to 2 T, Cu contact pads with silver paint soldered wires and dc sample biasing currents, I , between 2.5 and 10 mA. The Hall voltage was measured using a KEITHLEY nanovoltmeter.

The films were studied in as-deposited state, as well as after thermal treatments performed in furnace at temperatures between 330°C-370°C, for 30-60 minutes. The annealing was carried out in vacuum (10^{-6} Torr) to avoid the film oxidation.

3. Results and discussion

The interferometric measurements show that the thickness of the obtained films is ranging between 90-200 nm, as function of the deposition time.

The EDXS investigation demonstrates that the composition of the prepared films is very close to the target one. Therefore, it can be stated that the stoichiometry of the target has been achieved in the deposited films.

In Fig. 1 is presented a SEM mapping image of the Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin film.

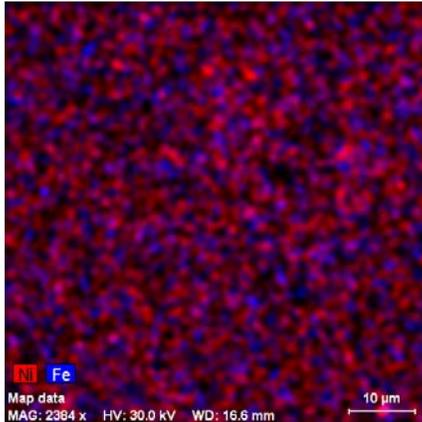


Fig. 1. SEM mapping image of Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin film.

SEM micrographs reveal the formation of droplets (typical of the pulsed laser deposition technique) on the films surface [8]. A typical AFM image of the surface morphology of the studied samples is presented in Fig. 2. For all investigated samples, the AFM analysis gives a surface roughness smaller than 25 nm.

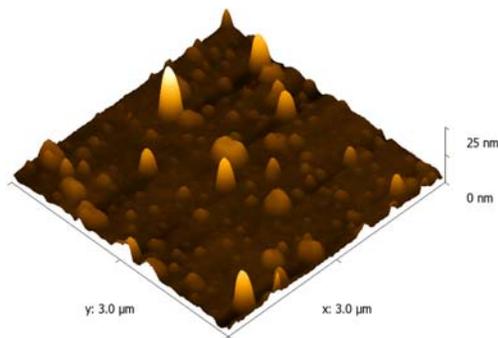


Fig. 2. Representative AFM image of Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin film.

Fig. 3 (a and b) presents the bulk hysteresis loops for the investigated Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin films (100 nm in thickness) in as-deposited state (Fig. 3a) and after 30 minutes annealing at 350°C (Fig. 3b). For the samples tested in as-deposited state, the bulk coercivity, H_c , is about 1000 A/m, while after annealing it becomes about 460 A/m.

Fig. 4 (a and b) shows the surface hysteresis loops for Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin film (100 nm in thickness) in

the as-deposited state (Fig. 4a) and after thermal treatment at 350°C for 30 minutes (Fig. 4b). In the as-deposited state the surface coercivity is with about 14% higher than the bulk one. As can be seen in Figs. 3(b) and 4(b), an important decrease (up to about 54% and 43% in the bulk and surface coercivity values, respectively) is obtained after thermal treatments.

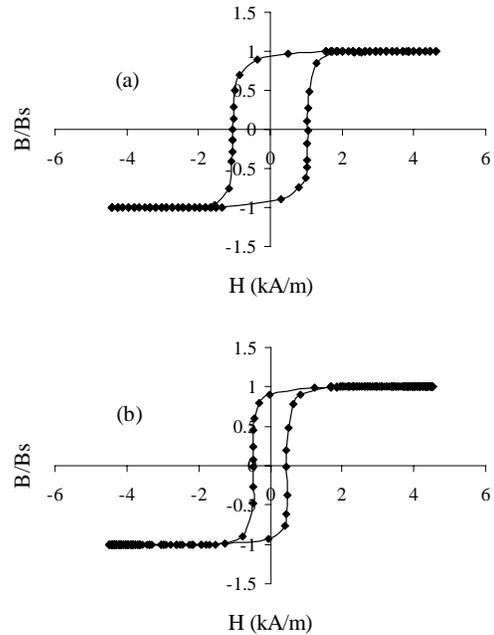


Fig. 3. The bulk hysteresis loops for Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin film (100 nm in thickness): (a) in the as-deposited state; (b) annealed 30 minutes at 350°C .

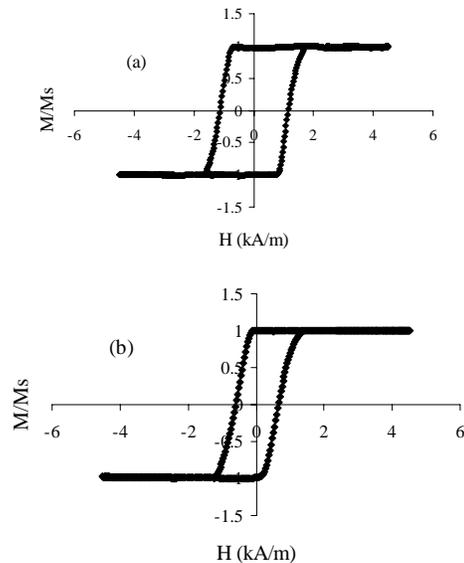


Fig. 4. Longitudinal MOKE hysteresis loops for Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$) thin film (100 nm in thickness): (a) in the as-deposited state; (b) annealed 30 minutes at 350°C .

In the studied range of treatment temperatures, the optimum temperature for the relaxation and improvement of the films magnetic properties was found to be at 350°C.

For the investigated range of films thickness, a small dependence of the coercivity on the thickness is observed.

Fig. 5 (a and b) shows the Hall voltage dependence, U_H , on the magnetic induction, B , for Permalloy ($Ni_{80}Fe_{20}$) thin films in as-deposited state (Fig. 5a) and after 350°C annealing at 30 minutes (Fig. 5b). The presented results are given for different sample biasing currents: 2.5 mA, 3.5 mA, 8 mA, 10 mA.

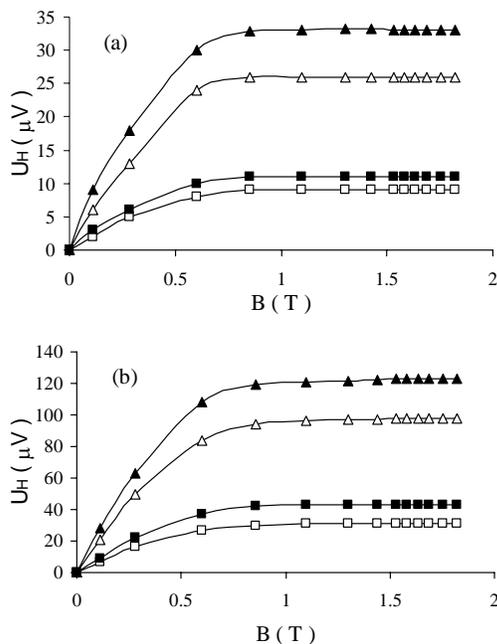


Fig. 5. The Hall voltage dependence on the magnetic induction for Permalloy ($Ni_{80}Fe_{20}$) thin films (\square $I=2.5$ mA; \blacksquare $I=3.5$ mA; \triangle $I=8$ mA; \blacktriangle $I=10$ mA): (a) in as-deposited state; (b) annealed 30 minutes at 350°C.

The Hall voltage absolute value increases continuously with the magnetic induction up to about 0.60 T and then it approaches saturation. The value of the Hall voltage is strongly dependent on the sample biasing current, increasing when the current value increases. An important increment in the Hall voltage is obtained after samples annealing. Practically, the Hall voltage for the films thermally treated at 350°C for 30 minutes increases of about four times.

4. Conclusions

The composition, morphology, surface and bulk coercivity as well as Hall voltage of Permalloy ($Ni_{80}Fe_{20}$) thin films, prepared by nanosecond pulsed laser deposition, were investigated. The samples were studied in as-deposited state and after thermal treatments. An

important decrease in the films surface and bulk coercivity values and a Hall voltage increase were observed after thermal treatments.

The obtained results are important in view of magnetic sensors design, where the composition reproducibility of the core material and the possibility to tailor its magnetic behaviour through thermal treatments are particularly interesting.

Studies concerning the magnetic annealing effect on the magnetic and galvanomagnetic response of the Permalloy ($Ni_{80}Fe_{20}$) thin films obtained by pulsed laser deposition are under work.

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*Corresponding author: mneagu@uaic.ro