ISSN 1330–0008
CODEN FIZAE4

SOME MAGNETIC AND MAGNETORESISTIVE PROPERTIES OF RF–SPUTTERED THIN NiFe–Si FILMS

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and

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Received 2 January 1993

Revised manuscript received 4 May 1993

UDC 538.955

Original scientific paper

The galvanomagnetic properties and some structural peculiarities of rf-sputtered alloy films $(\mathrm{Ni}_{80}\mathrm{Fe}_{20})_{100-x}\mathrm{Si}_x$ at $0 \leq x \leq 30$ at. % were studied and compared with the corresponding properties of evaporated films of the same thickness and composition. The content of silicon increased with the increasing of the velocity of deposition and led to the amorphousation of the films. Coercivity decreased with the velocity of growth but it did not depend on the thickness and on the velocity of film deposition. The magnetoresistance ratio $\Delta\varrho/\varrho$ of the sputtered films was about three times higher then that of the evaporated films.

1. *Introduction*

The investigation of the alloy films of Ni and Fe with the metalloids Si, Ge, B, C and P has increased in importance during recent years. In this paper samples of magnetic material – NiFe-Si – with a variety of properties were produced as thin films and some electrical and magnetic properties were investigated. The alloy films $(\mathrm{Ni}_{80}\mathrm{Fe}_{20})_{100-x}\mathrm{Si}_x$ $(0 \leq x \leq 30)$ were prepared by rf-magnetron sputtering at different velocities of growth. Coercivity as a function of the velocity of film growth was studied. The dependence of the resistivity and the magnetoresistance ratio on film thickness were measured and compared with those of evaporated films. The measurements were produced at room temperature.

2. *Experimental procedure*

The sputtered alloy $(\mathrm{Ni}_{80}\mathrm{Fe}_{20})_{100-x}\mathrm{Si}_x$ films were prepared by rf-magnetron sputtering of NiFe-Si alloy target by a Z-400 Leybold-Heraeus system in Ar-plasma at a pressure of 1 –10 Pa. The rf-sputtering parameters were: cathode voltage 1–2 kV, rf-generator's current 120–170 mA and rf-power applied to the target 2––8 $\mathrm{W\,cm^{-2}}$.

The films were deposited onto glass substrates and onto thermally oxidized Si-wafers with an oxide thickness of around 50 nm. The substrates were cleaned chemically and just prior to the deposition ion bombardment was used for final cleaning. No intentional heating was applied to the substrate during the deposition, but due to substrate contact with the plasma components substrate temperature increased to a value of up to 100°C. Films of two kinds were produced: (i) with a constant thickness (110 nm) at a different velocity of deposition; (ii) with a different thickness (from 30 to 200 nm) at a constant velocity of deposition (0.66 nm/s). The obtained films had random orientation of the easy axis of magnetization M. The samples were annealed after deposition. The annealing procedure consisted of two steps: (i) annealing of the samples in a H_2-atmosphere at 450°C for 15 min in order to reduce the number of defects which had arisen during the deposition; (ii) cooling the samples in a H_2-atmosphere with an external homogeneous magnetic field of 8 $\mathrm{kA\,m^{-1}}$ applied on the plane of the film [1].

The samples for galvanomagnetic measurements were prepared with rectangular geometry by means of photolitography. The 60 nm thick electrodes of copper were evaporated on the films. The chemical composition of the samples was determined by a "Philips 515" electron microscope and their crystal structure was observed by means of an electron diffraction using a Carl Zeiss EF-IV electron microscope.

The galvanomagnetic curves of the planar Hall-effect were measured. The first one was the field dependence $U(H)_{\Theta=\mathrm{const}}$, where U is the planar Hall voltage at different values of external magnetic field H, applied on the film plane at directions Θ with respect to the long side of the sample. The second one was the angular dependence $U(\Theta)_{H=\mathrm{const}}$, where U was the Hall voltage at fixed value of the planar magnetic field H, applied at different angles Θ. The measurements were carried out in the homogeneous magnetic field $H \leq 7.1$ kA m^{-1}, produced by Helmoltz coils. The angular rotation of the sample towards the magnetic field direction was controlled within an accuracy of 20′. The stabilized current source ensured a constant current j density through the sample. The changes of the Hall voltage were registered by an X-Y plotter [2].

The magnetoresistance ratio $\Delta\varrho/\varrho = (\varrho_{\parallel} - \varrho_{\perp})/2\varrho$ gives the relative difference between the longitudinal ($\varrho_{\parallel}$ at $M \parallel j$) and transverse ($\varrho_{\perp}$ at $M \perp j$) magnetoresistance. It was derived from the angular dependence $U(\Theta)$ at constant field $H = 7.1$ kA m^{-1} when the sample was saturated magnetically.

3. Results

The sputtered films deposited at different velocities of growth at constant thickness $t = 110$ nm were investigated first of all. The chemical composition measurements determined that the silicon content of the films depended essentially on the velocity of film growth. The Si-content increased from 1 to 29 at.% when film velocity of deposition V increased from 0.09 nm s^{-1} (Fig. 1). The small silicon content in the film at a low sputtering velocity could be explained with the lower velocity of the sputtering process of the silicon compared to the velocity of the Fe- and Ni-sputtering process under the same conditions [3]. The change of silicon content has a strong influence both on electron structure and on coercivity value.

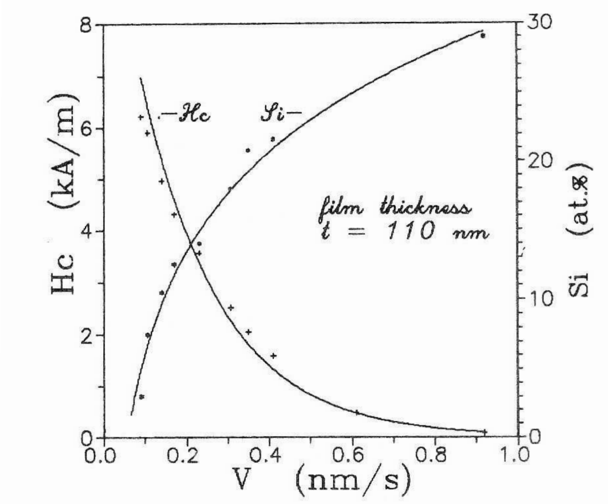

Fig. 1. Coercivity and silicon contents as function of the velocity of growth of sputtered NiFeSi *films.*

The structure of the $(NiFe)_{100-x}Si_x$ thin films was examined by electron diffraction patterns. The polycrystalline structure was observed in the samples with a silicon content of 3 or 7.5 at.%. The samples were amorphous completely when the silicon content was more than 20 at.%. The value of coercivity H_c was determined by the galvanomagnetic curves $U(H)_{\Theta=\mathrm{const}}$, when the direction of the external magnetic field coincided with the easy axis of the film. The measurements showed that H_c decreased with the increasing of the velocity of growth or with the increasing of the silicon content in the sample (Fig. 1). The magnitude of coercivity changes from 6 207 to 159 $\mathrm{A\,m^{-1}}$, when the velocity of deposition increases from 0.09 $\mathrm{nm\,s^{-1}}$ to 0.92 $\mathrm{nm\,s^{-1}}$. The content of silicon changed from 1 to 29 at.% when the velocity of deposition varied within the same limits. The decreasing of H_c could be connected with structural effects. The films grown at lower sputtering velocity formed a coarse-grained polycrystalline structure determining a higher value of the coercivity H_c. The magnitude of H_c decreases gradually with a decrease of the size of the grains and with the appearance of the amorphous structure which is due to the higher silicon content.

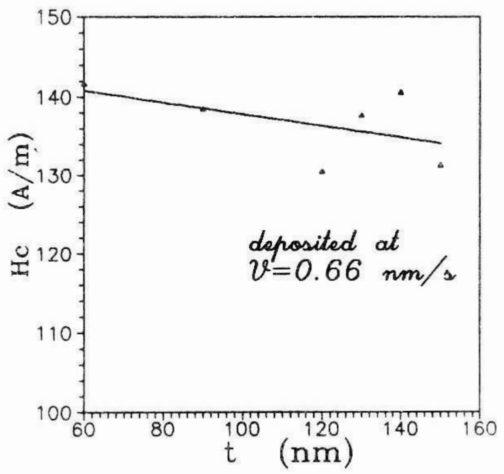

Fig. 2. Coercivity of sputtered films as a function of film thickness.

We investigated a second kind of NiFeSi films. They were prepared at relatively high velocity of deposition ($V = 0.66$ $\mathrm{nm\,s^{-1}}$). Then the content of silicon was high (about 25 at.%) and the structural measurements showed that the sputtered films were amorphous. These films with a different thickness were investigated and compared with vacuum evaporated films prepared at a pressure of 10^{-3} Pa. The evaporated films were deposited at the same velocity (0.66 $\mathrm{nm\,s^{-1}}$) and their thickness changed from 30 nm to 200 nm.

The galvanomagnetic measurements showed that the coercivity of the sputtered films was independent on film thickness and the value of H_c is around 135 $\mathrm{A\,m^{-1}}$ (Fig. 2). These results confirmed the relation between velocity of deposition, a silicon content and structural effects in the sputtered NiFeSi films. The coercivity was constant when the velocity of film growth was not changed and then the films were grown homogeneously. A similar dependence is reported for sputtered NiFe films deposited at a relatively low velocity of growth [4]. This behaviour was not observed in evaporated samples prepared at the same velocity of deposition. At the constant thickness of 80 nm the samples had different values of coercivity varying from 143 to 382 $\mathrm{A\,m^{-1}}$. The eventual annealing of the evaporated samples will reduce these values near the coercivity value of the sputtered samples.

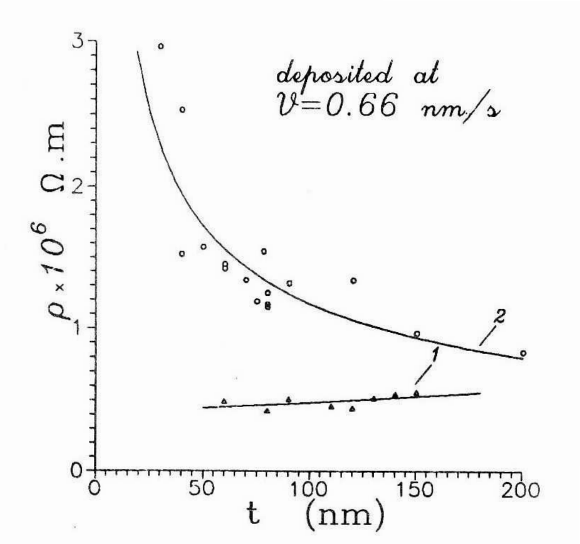

Fig. 3. Resistivity of sputtered (1) and evaporated (2) films deposited at constant velocity as function of the film thickness.

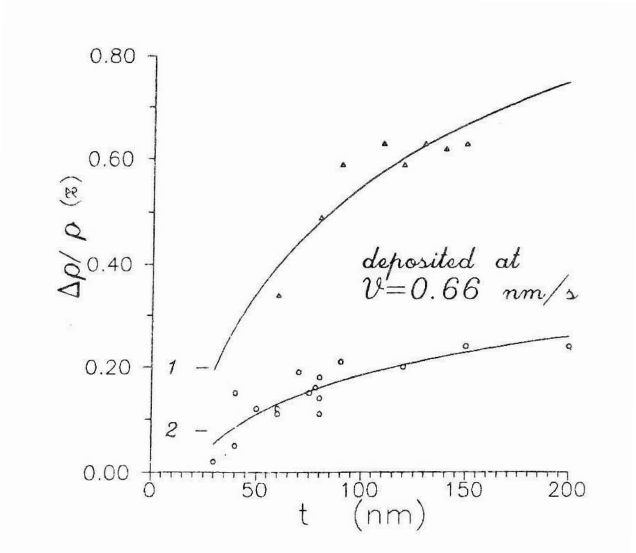

Fig. 4. Magnetoresistance ratio of sputtered (1) and evaporated (2) films deposited at constant velocity as a function of film thickness.

The resistivity and the magnetoresistance ratio of the sputtered and evaporated thin films prepared at a constant velocity of deposition were examined as a function of film thickness. The resistivities of sputtered films were nearly independent of the film thickness (Fig. 3) and their values were about $0.5 \times 10^{-6}\,\Omega\,\mathrm{m}$ (curve 1). The resistivities of the evaporated films decreased from 3×10^{-6} to $0.8 \times 10^{-6}\,\Omega\,\mathrm{m}$, when the thickness of the films increased from 30 nm to 200 nm (curve 2). This fact indicates that the structure of the annealing sputtered films is more homogeneous than that same of evaporated samples. The island structure of thinner evaporated films includes probably more gas defects in comparison with the annealed sputtered films. At the higher thickness the resistivity values of the both kinds of films are relatively close.

The magnetoresistance ratio is shown (Fig. 4) as a function of film thickness in the case sputtered and evaporated NiFeSi films prepared at a constant velocity of deposition. The ratio $\Delta\varrho/\varrho$ was about three times higher for the sputtered films and increased logarithmically with a tendency of saturation when $t > 80$ nm.

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MAGNETSKA I MAGNETOOTPORNA SVOJSTVA TANKIH SLOJEVA NiFe–Si NAČINJENIH RADIOFREKVENTNIM RASPRAŠIVANJEM

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UDK 538.955

Originalni znanstveni rad

Galvanometrijska svojstva i neke strukturalne osobenosti tankih slojeva legure $(\mathrm{Ni}_{80}\mathrm{Fe}_{20})_{100-x}\mathrm{Si}_x$ načinjenih radiofrekventnim rasprašivanjem sa $0 \le x \le 30$ atomnih postotaka eksperimentalno su proučavani i uspoređeni s odgovarajućima svojstvima naparenih slojeva jednake debljine i sastava. Sadržaj silicija je povećavan povećanjem brzine polaganja a slojevi su postajali amorfni. Koercitivnost slojeva se smanjivala s brzinom rasta, ali nije ovisila o debljini i o brzini polaganja sloja. Magnetootporni omjer $\Delta\varrho/\varrho$ raspršenih slojeva bio je oko tri puta veći nego za naparene slojeve.