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Fabrication of textured FeCo(110) and FeCo(200) films by DC magnetron sputtering

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The results of study of bias voltage U_b and substrate temperature T_s influence on the texture of FeCo films with the thickness of 180 nm deposited on Si/SiO$_2$ substrates by DC magnetron sputtering are presented. It is shown that the change of U_b from -250 V to 80 V leads to the growth of films with (110) texture. Further change of U_b from 80 V to 250 V causes the growth of films having (200) texture. Films deposited at $U_b = 0$ and $T_s = 60-300°$C have (200) texture. Further increase of T_s results in the change of film texture to (110).

Keywords: FeCo films, magnetron sputtering, texture, coercitivity.

1. Introduction

To increase the recording density on hard disk drives, the use of recording heads with soft magnetic materials and high saturation magnetization is required. These properties are possessed by films of FeCo alloy that, in addition, have the highest values of magnetostriction, magnetic permittivity, and Curie point, which promotes their application in various microelectronic devices. The high coercitivity of these films prevents them from being widely used, thus various methods are applied to improve soft magnetic properties (low coercitivity and magnetic anisotropy) of the films by applying additional seed layers resulting in film texture change or decrease in grain size [1–5]. However, the use of additional layers complicates the technology and makes difficult the large-scale production, which stimulates the search for alternative methods to produce soft magnetic films of FeCo. Thus, in [6], Vopsaroiu at al. have shown the possibility to reduce coercitivity of FeCo with a thickness of 20 nm from 120 down to 12 Oe by controlling the deposition rate, which results in grain size decrease from 17 down to 7.5 nm. The improvement of soft magnetic properties of films as a result of thermal treatment is shown in [7] and explained by a number of factors, such as the decrease in stresses resulted from recrystallization, the decrease in grain size, and the texture change. The impact of internal stresses and texture of films on their soft magnetic properties is described in [8–10].

This paper reports the possibility of producing textured films of FeCo(110) and FeCo(200) by selecting bias voltage or temperature of the substrate in the process of film deposition without additional layers.

2. Experiment

FeCo films were deposited by d.c. magnetron sputtering in VUP-5M vacuum plant with a base pressure of $6 \cdot 10^{-4}$ Pa at an Ar working gas pressure of ~ 0.4 Pa. A Co$_{50}$Fe$_{50}$ target with a purity of 99.95% (Kurt J. Lesker) was used for the sputtering. Plates of single-crystal silicon Si(111) with thermal oxidized layer of SiO$_2$ with a thickness of 300 nm were used as substrates. Before being placed into the working chamber of VUP-5 vacuum plant, the substrates were cleaned in an ultrasonic bath with acetone at a temperature of $\sim 50°$C. Immediately before the sputtering, the substrates were degased by heating up to $350-400°$C for 30 min. The target-to-substrate distance was 75 mm. With a working current of 150 mA and a power input of ~ 60 W, the rate of film deposition was ~ 15 nm/min.

To study the crystal structure of films, the method of X-ray diffraction was used (DRON-4 diffractometer, CuK$_\alpha$ radiation) and the PCPDFWIN database of the International Centre for Diffraction Data. The interplanar spacing $a_{[hkl]}$ along the crystal axis [hkl] was determined by Bragg−Volf formula: $2a_{[hkl]} \sin\Theta = n\lambda$, where Θ — incident angle of X-ray radiation measured from the film plane, $\lambda = 0.15418$ nm and $n = 1$. The magnetization reversal processes were studied and hysteresis loops were built using vibration magnetometer in a magnetization geometry tangent to the film surface. The microstructure of films was studied by means of scanning electron microscope (SEM) (Auriga, Carl Zeiss). All measurements were performed at room temperature.
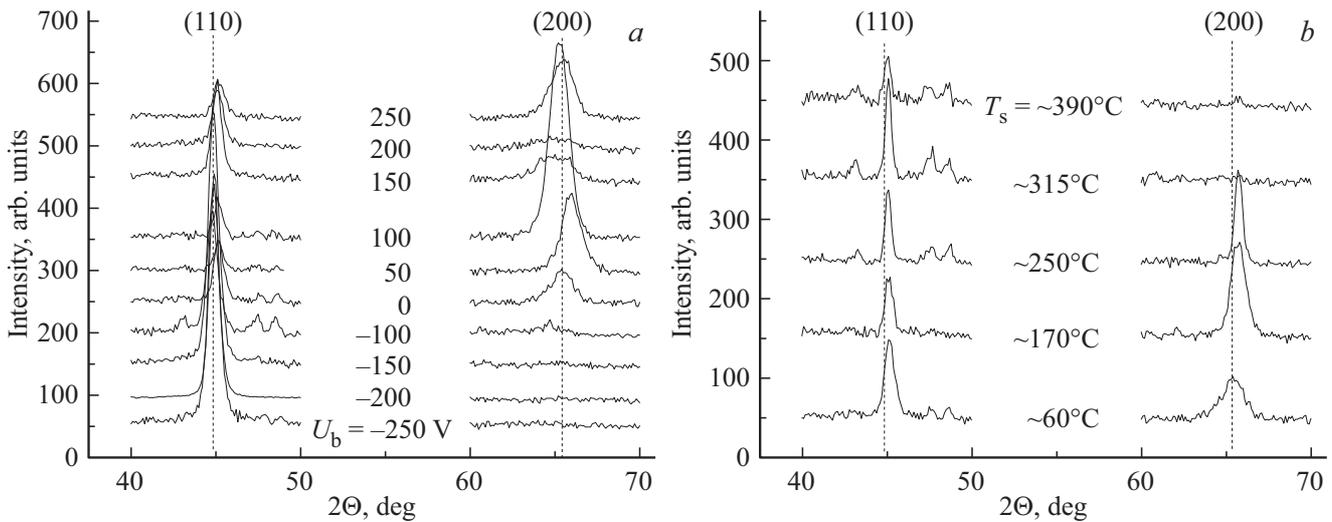
Figure 1. Diffraction patterns of films with a thickness of ~ 180 nm, deposited a) at different bias voltages U_b and b) on a substrate heated to T_s.
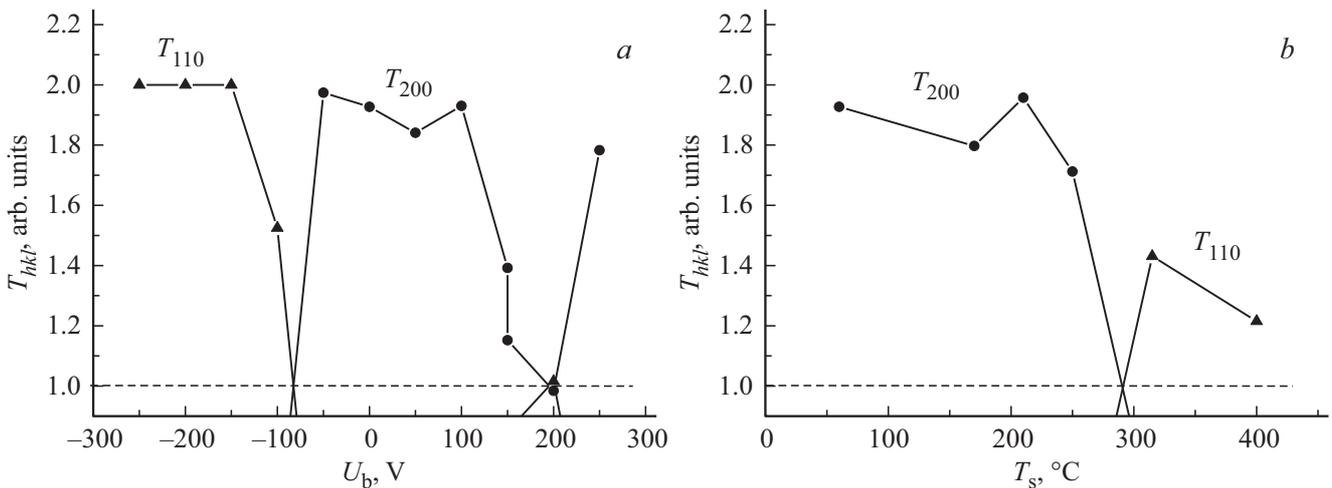
Figure 2. Texture coefficient T_{hkl} as a function of a) bias voltage U_b and b) substrate temperature T_s.

3. Results and discussion

Figure 1 shows diffraction patterns of films deposited at various bias voltages U_b (Fig. 1, a) and deposited on a substrate heated to T_s, (Fig. 1, b).

The presented results were used to calculate the texture coefficient T_{hkl} (Fig. 2) by the following formula [11]:

$$T_{hkl} = \frac{I_{hkl}/I_{hkl}^0}{1/N \sum I_{hkl}/I_{hkl}^0},$$

where I_{hkl} — measured intensity of the diffraction line hkl, I_{hkl}^0 — intensity of powder CoFe from JCPDS cards, and N — number of reflections used. Moreover, values of T_{hkl} more than 1 correspond to (hkl) texture.

It can be seen (Fig. 2, a), that the increase in U_b from ~ -80 to -250 V amplifies the (110) texture. With the change in U_b from ~ -80 to 250 V a growth of films with (200) texture is observed. Maximum values of T_{200} are observed for the films deposited at U_b varying from -50 to 100 V.

With $U_b = 0$, the deposition on a substrate at ambient temperature results in growth of films with (200) texture. The increase in T_s to 250°C results in decrease of (200) texture coefficient. Further increase in T_s to 400°C results in film texture change from FeCo(200) to FeCo(110).

Thus, FeCo(200) films can be produced either by deposition on a substrate heated to a temperature of $\sim 60-250$°C, or by deposition at a bias voltage from ~ -80 to 250 V. In both cases, the changes in texture is related to the increase in surface diffusion of atoms of the deposited metal due to the substrate heating. In other cases, the grown films have (110) texture.
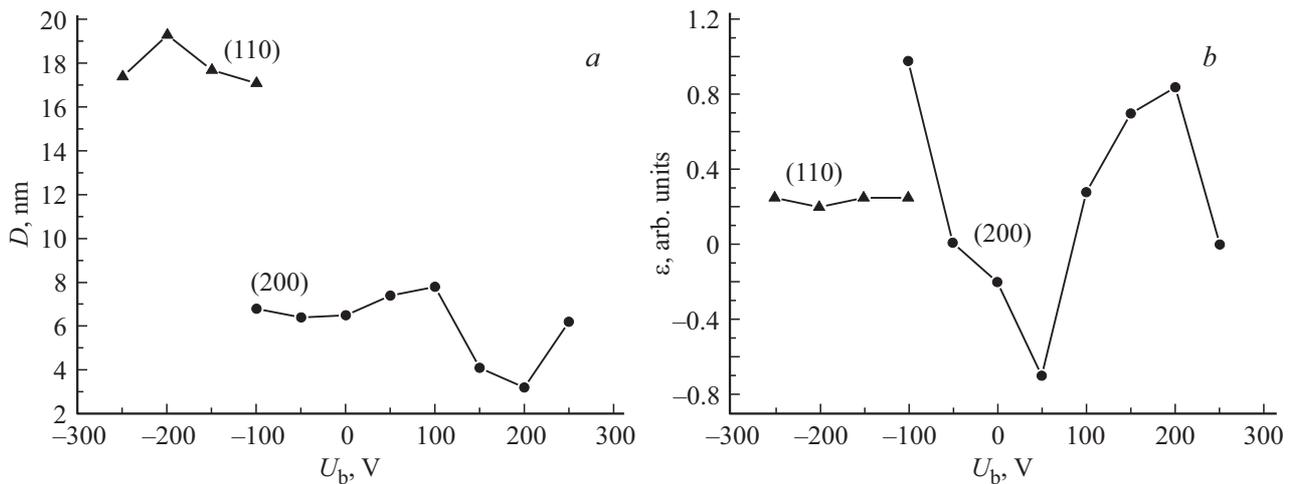
Figure 3. Bias voltage U_b as function of a) grain size D and b) strain ε of FeCo films with (110) and (200) textures.

Figure 3 shows the results of X-ray structural analysis of films deposited at various values of U_b. Grain size (Fig. 3, a) was determined by Scherrer formula: $L = \lambda/\beta\cos\theta$, where β — diffraction line broadening. The interplanar spacing $a_{[hkl]}$ along the crystal axis $[hkl]$ was determined by Bragg−Volf formula: $2a_{[hkl]}\sin\theta = n\lambda$, where θ — incident angle, $\lambda = 0.15418$ nm and $n = 1$. U_b as a function of internal strains $\varepsilon = (a_{exp} - a_{ref})/a_{ref}$ in the specimens under examination is shown in Fig. 3, b. Value of a_{ref} is taken from the PCPDFWIN database of the International Centre for Diffraction Data.

It can be seen that the grain size of films with (110) texture is bigger than that of films with (200) texture. A change in U_b results in a nonmonotone change in grain size for both texture types. FeCo(200) films undergo compression strains at U_b in the range from -50 to ~ 80 V and tension strains out of this range. FeCo(110) films undergo tension strains slightly varying under a change in U_b.

Grain size for the films deposited on a heated substrate is not more than 50 nm, which prevents from the use of Scherrer formula for the calculations. According to the results of structural analysis, films deposited on a heated substrate do not undergo strains.

Figure 4 shows coercivity H_c as a function of bias voltage U_b (Fig. 4, a) and substrate temperature T_s (Fig. 4, b).

It can be seen that minimum coercivity in FeCo(200) films is ~ 60 Oe at $U_b = 0$ (Fig. 4, a). The U_b increase to -250 and to 200 V results in nonmonotone growth of coercivity of FeCo(200) films, which may be caused by change in the strain (Fig. 3, b). Absence of strains in the films deposited at $U_b = 250$ V results in H_c decrease , down to ~ 90 Oe. The change in U_b from -250 to $+250$ V results in growth of residual magnetization M_r and change in the shape of hysteresis loop from „fusiform“ to rectangular form (Fig. 5).

The abrupt increase in coercivity at $U_b = -100$ and 150 V is related to formation of the stripe domain structure and columnar microstructure as evidenced by the transition from the rectangular hysteresis loop to supercritical one (Fig. 5) and scans of cross-section of films (Fig. 6). Yu et al. [12] explained the increase in coercivity with growth of negative U_b by contamination of the growing
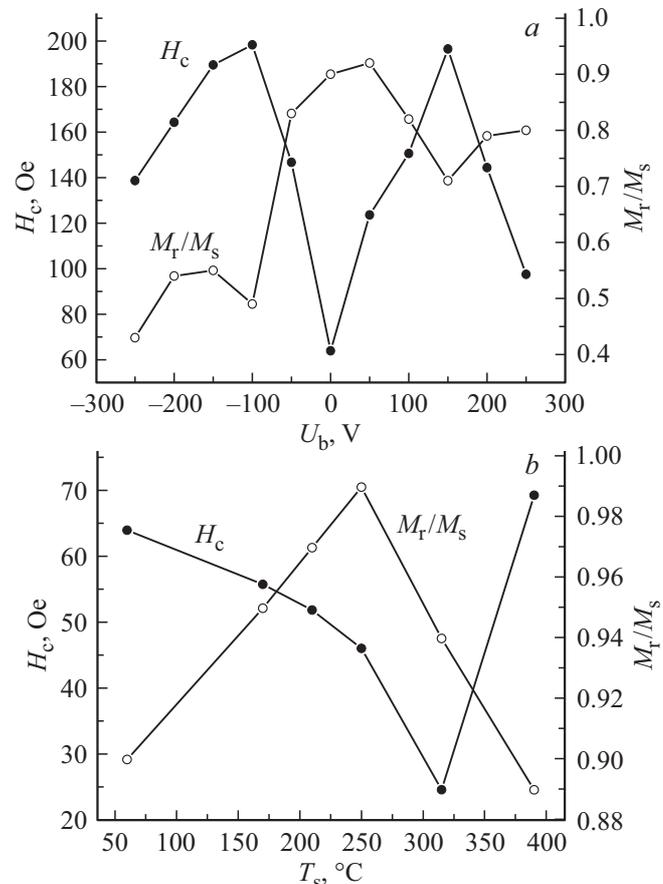
Figure 4. Coercivity H_c and ratio of residual magnetization to saturation magnetization M_r/M_s a) as functions of bias voltage U_b and b) substrate temperature T_s.
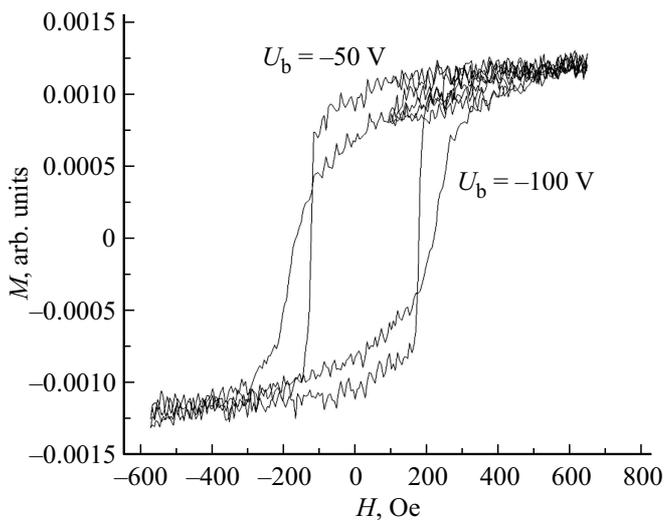
Figure 5. Hysteresis loops of films deposited at $U_b = -100$ and -50 V.

film by FeO and CoO oxides, in addition, resulting in grain size decrease due to division of grains. In the same way, the growth of coercivity with decrease in grain size for the films grown at positive U_b can be explained.

The increase in substrate temperature to $\sim 310°$C at $U_b = 0$ leads to H_c smooth decrease down to ~ 20 Oe

(Fig. 4, b). Further increase in T_s to $400°$C increases H_c to ~ 70 Oe.

It can be seen in Fig. 6 that films with (110) texture are characterized by columnar structure, while films with (200) texture have quasihomogeneous structure.

4. Conclusion

The presented results demonstrate a method to produce FeCo(110) and FeCo(200) textured film on Si/SiO$_2$ substrates without additional seed layers by d.c. magnetron sputtering. Minimum coercivity of ~ 20 Oe have the films with (110) texture, grown on a substrate heated to $T_s \sim 300-350°$C at $U_b = 0$. For FeCo(200) films the minimum value of $H_c \sim 60$ Oe is obtained at $U_b = 0$. Increase in U_b to ± 250 V results in nonmonotone growth of H_c to ~ 200 Oe, which can be explained by contamination of the growing film with FeO and CoO oxides, as well as by formation of the columnar microstructure.

Conflict of interest

The authors declare that they have no conflict of interest.
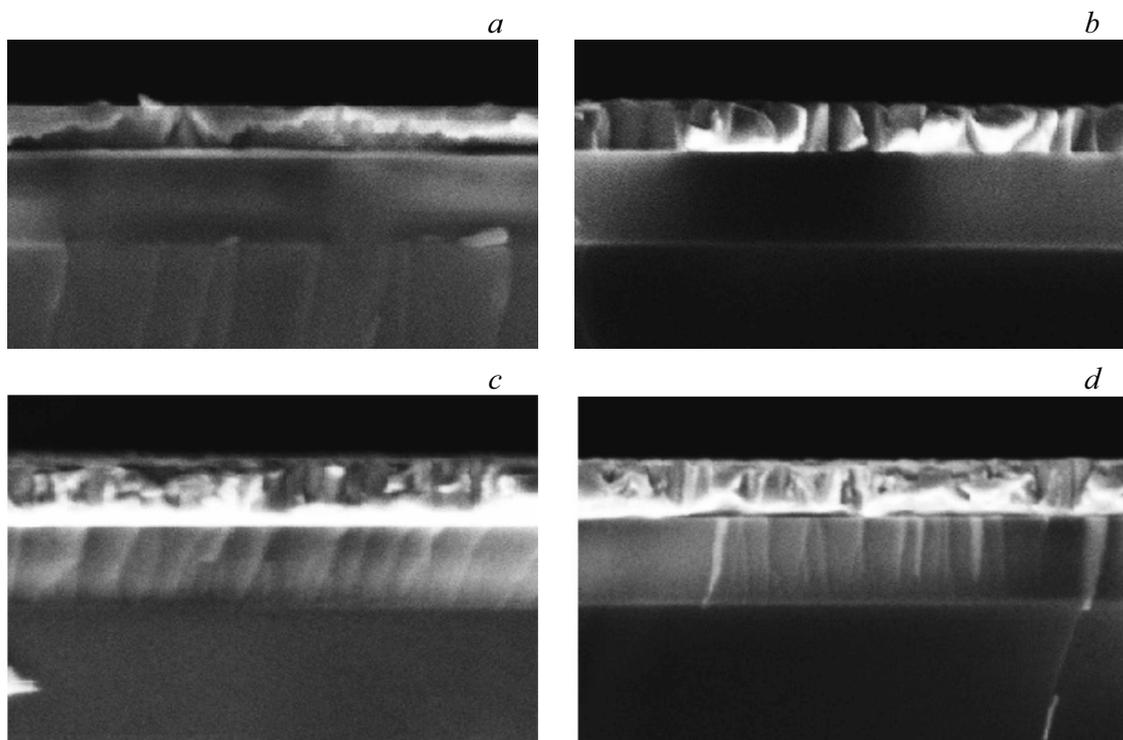
Figure 6. Cross-section scans of films grown at $U_b = 0$: a) $T_s = 480$ K, FeCo(200), b) $T_s = 590$ K, FeCo(110), and films grown at ambient temperature: c) $U_b = 250$ V, FeCo(200) and d) $U_b = -200$ V, FeCo(110).

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