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Magnetic and structural properties of dc magnetron sputtered CoCr thin films

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Thin films of CoCr are considered to be the most promising media for high-density perpendicular magnetic recording. It is shown that when depositing single CoCr layers onto a Si substrate by dc magnetron sputtering excellent magnetic and morphological properties can be achieved. The growth of nodular defects hindering a small head to medium spacing is characterized by cross-sectional TEM and discussed on the basis of a shadowing model treated by computer simulations.

1. Introduction

Thin films of CoCr are still considered to be the most promising media for high-density perpendicular magnetic recording. Recently it has been demonstrated that recording densities over 600 kFRPI are possible[1]. Despite the excellent properties, however, the CoCr medium could not achieve great success in mass production until now. Apart from some technical peculiarities connected with a new data channel for the perpendicular recording mode there are a number of more fundamental problems which have to be considered.

One of them is to obtain CoCr films with sufficient magnetic and morphological properties under conditions appropriate to mass production, e.g. without using a complicated multilayer structure.

Initial layers with remarkable in-plane magnetization, low remanence ratios S_P/S_L ($S_{P,L} = M_{P,L}/M_S$ with $M_{P,L}$ as the perpendicular and longitudinal remanent magnetization, respectively, and M_S as the saturation magnetization), too low perpendicular anisotropy and coercive force as well as too large grains or too broad grain size distributions hinder high recording performance.

Another problem, and this one is of steadily growing importance, is to avoid growth of nodular defects to realize very small head to medium spacings in the range of 0.1 to 0.2 μm necessary to achieve a sufficiently high output level.

The aim of our paper is on the one side to represent CoCr single layers exhibiting excellent magnetic as well as morphological properties and on the other side to enlighten the understanding of the growth of nodular defects generated in these films during the vacuum deposition process.

2. Experimental

The CoCr thin films were deposited onto Si(100) layers and glass substrate by dc magnetron sputtering in a diffusion pumped vacuum system. The substrates were heat treated in the vacuum chamber prior to the film deposition for 30 min at about 470 K. During deposition the substrate temperature could be chosen between 320 K (no additional heating) and 470 K. The magnetic and structural properties of the films have been investigated by VSM, cross-sectional and plane-view TEM, respectively. Special care was taken to prepare samples allowing TEM characterization of nodular defects[2].

3. Results

Figure 1 shows the dependence of the in-plane remanence ratio S_L on film thickness and how this dependence is affected by the type of substrate and the substrate temperature. The S_L is a sensitive measure for the existence of magnetic easy axis components parallel to the film plane. As revealed by X-ray diffraction investigations the latter can be correlated with a certain scatter in the crystallographic c-axis orientation perpendicular to the film plane (characterized by the $\Delta\theta_{50}$ value of the (002) peak) or with undesired other textures[3].

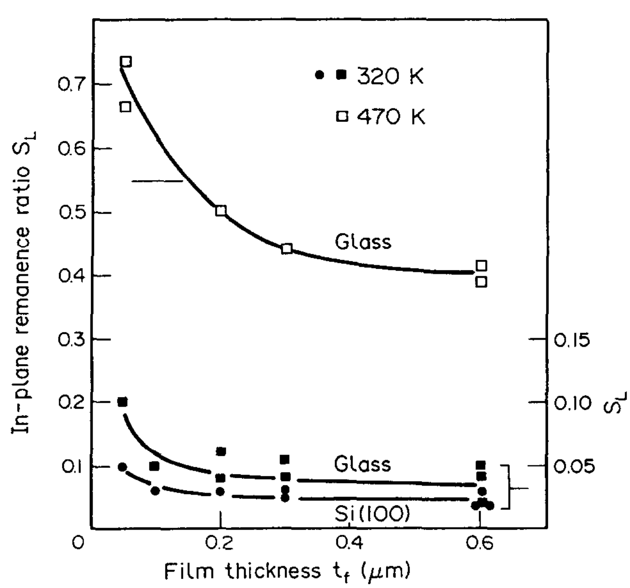

Figure 1. In-plane remanence ratio S_L vs film thickness t_f of Co-23at% Cr layers on different substrates.

Thus, at low substrate temperature the fast achievement of small S_L values with increasing film thickness can be interpreted in terms of a fast developing (001) texture, resulting in a strong perpendicular magnetocrystalline anisotropy. For increased substrate temperature the texture formation is retarded giving rise to a so-called initial layer containing a remarkable number of crystallites with *c*-axis orientations deviating from the film normal.

The influence of the type of substrate on the texture formation velocity and the final degree of texture also becomes visible in Figure 1. The lowest final S_L values down to 2% could only be reached on Si substrates. For a high quality perpendicular recording medium S_L, as one of the most important parameters, should be smaller than about 5%.

Whereas the CoCr films deposited in the lower temperature region show a low coercivity in the range of 10–15 kA m^{-1}, high temperature deposition leads to essentially higher H_C values which have been proved to be advantageous for a high recording performance. By a special temporal regime of the substrate temperature during deposition we succeeded in combining both low S_L values (smaller than 5%) and a reasonable coercivity (40–55 kA m^{-1}). Because of the small S_L the remanence ratio S_P/S_L for those samples is in the range between 2 and 5.

In Figure 2 a cross sectional view of a 0.7 μm thick CoCr film deposited onto a Si(100) surface under the above mentioned special regime is represented. The film has a well defined columnar microstructure with grain diameters in the range of 30 nm with an excellent (001) texture as indicated by the diffraction pattern ($\Delta\theta_{50}$ about 5°). No initial layer can be seen in the TEM micrograph. However, such a layer with a thickness of about 100 nm can be identified when the film was deposited at low substrate temperature as well as at increased substrate temperature. In the latter case this layer can be correlated with the initial layer found by magnetic measurements (see Figure 1), whereas at low substrate temperature this zone does not remarkably affect S_L. The origin of the increase in H_C with temperature is not recognizable in the TEM micrographs. According to ref 4 it is due to an accelerated Cr segregation into the grain boundaries of the film not visible in TEM.

Having in mind the magnetic and morphological properties these optimum CoCr films should be well suited for high-density perpendicular magnetic recording. But to be acceptable for recording applications, it has to be proved whether the optimum deposition regime can be applied to substrates generally used in

Figure 3. Cross sectional view of a 0.7 μm Co-15at% Cr layer deposited onto Si(100) at 320 K with growth hillocks, HVEM.

drives, e.g. NiP covered Al disks, or not and that the surface of the films will be flat in dimensions smaller than 100 nm. Here the most serious problem seems to be the formation of nodular defects projecting essentially the otherwise flat surface[5].

Figure 3 shows a TEM view across nodular defects (or hillocks) which grew in a CoCr film. As can be seen the hillocks as a whole are cone-shaped and have fairly open boundaries. Furthermore, the microstructure of a hillock deviates from that of the surrounding film. Both consist of well defined and densely packed grains, but within the hillock the grains are conically shaped arising from a strongly distorted 'transitional' layer, and they do not show any texture. The origin of the hillocks could not be clearly identified in our micrographs, but it is assumed that they are caused by any imperfections of the substrate surface like debris, scratches or dust particles[2], and that their growth is due to the shadowing effect as described in ref 6.

Here, we only give an impression how simple geometric shadowing works if a spherical asperity residing on the substrate surface is coated. In Figure 4 the growth of nodular defects is simulated by employing a modified geometric shadowing model and by considering the case where the atom beam is incident from two sources (two-dimensional equivalent of a sputtering source)[5]. This treatment only by coating a protrusion beyond the substrate surface gives some typical features of hillock growth, namely the conical shape of the hillock and the open boundaries between the hillock and the homogeneous film. Nevertheless,

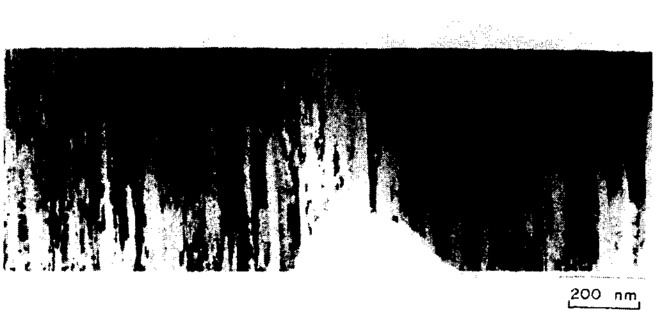

Figure 2. Cross sectional view of a 0.7 μm Co-23at% Cr layer deposited onto Si(100) under an optimum regime (substrate side: where the length unit is located).

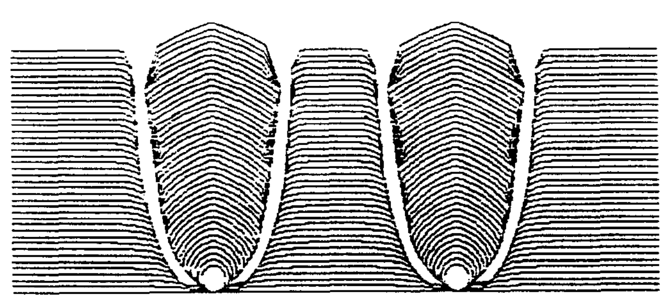

Figure 4. Pair of hillocks calculated in the 'global' shadowing model with incidence angles ϕ for the oncoming atoms in the range of $60° < |\phi| < 75°$ to the surface normal (lines represent the temporal development of the surface of the film as well as of the nodules).

such processes leading to the generally accepted runaway type of growth or allowing to describe the development of the microstructure are not included. To treat both these aspects further computer simulations are in progress taking into account the atomic nature of the oncoming particles as well as their mutual interaction[7].

4. Conclusion

It has been shown that without using any seed or sublayer and by using a special temperature regime during deposition excellent magnetic and morphological properties of single CoCr layers on Si(100) and glass substrates can be reached which are sufficient for high perpendicular recording performance. To be suited for recording applications, however, it has to be proved whether the optimum deposition procedure can be applied to the generally used substrates. Furthermore, the growth of nodular defects has to be prevented, mainly by avoiding any type of contamination and asperity on the substrate surface before deposition of the film.

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