MICROSTRUCTURAL STUDY OF SPUTTERED CoCr-FILMS AND THE EFFECT OF NUCLEATION LAYERS FOR PERPENDICULAR RECORDING MEDIA

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With the aim of improving the *c*-axis oriented columnar growth, the nucleation of CoCr crystallites on various underlayers has been studied. Transmission electron microscopy was especially employed in order to elucidate the microstructure and the nucleation process of CoCr-films. This is discussed in terms of the Stranski–Krastanov crystal growth model.

1. Introduction

The structural anisotropy of CoCr with the hexagonal c-axis direction oriented perpendicular to the film surface, which is the easy axis of the magnetization, is a necessary requirement for vertical magnetic recording [1]. In order to obtain a well-oriented column-like CoCr-structure by sputtering the sputtering parameters such as argon-pressure, temperature, bias voltage and power need to be adjusted carefully [1–4]. Furthermore, the choice of the nucleation layer is very important.

In our experiments, Si as a seed-layer proved to lead to the best oriented columnar growth of CoCr, i.e., the columns were oriented nearly parallel to the normal direction of the film. Glass substrates or keeper-layers like NiFe, CoNbZr without an additional seed-layer caused a less well oriented growth of the CoCr columns.

In this work we pursue the obvious questions as to why Si is the best underlayer, which nucleation mechanisms are responsible for the excellent orientation, and why it differs therefore from other materials.

2. Experimental procedure

CoCr-films with 20 wt% Cr were produced by dcmagnetron sputtering at a sputtering rate of 50 nm/min, with a power of 1000 W, and at an argon-pressure of 3 mTorr. The substrate temperature was varied between 30 and 160°C. As underlayer materials Si, NiFe, CoNbZr and glass were used. Cross-sectional specimens of these samples were prepared and investigated in the Transmission Electron Microscope (TEM) at 200 kV with bright field and dark field imaging. Especially for the analysis of the interfacial zone between the underlayer and CoCr, Auger depth profile measurements (AES) were performed. In order to define the misorientation of the columnar CoCr-crystallites, the $\Delta \theta_{50}$ -value (half-width angle of the rocking curve [1]) was determined by X-ray diffraction for all samples. This angle represents the dispersion of the [001] direction

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(*c*-axis) of the hcp structure around the normal to the film plane.

3. Results and discussion

The cross-sectional view in the TEM micrograph of fig. 1 shows clearly that uniform columnar CoCr-crystallites are formed here from the beginning of the growth. Basically, continuous CoCr-columns are observed. A so-called "initial layer", i.e., an originally fine-crystalline and desoriented layer does not exist [5,6]. One observes columns stretching mainly straight upwards which have a constant diameter throughout the column length. Only in some cases the columns are conical either at their bottom or at their top.

In fig. 2 an intermediate layer about 4 nm thick (darker region) at the interface between CoCr and Si is clearly observed. During sputtering a new phase is formed here by a solid state reaction. Futamoto et al. [5] have observed a separate zone interface in Ge/CoCr.



Fig. 1. Cross-sectional TEM-micrograph of sputtered CoCr on amorphous Si.



Fig. 2. TEM-micrograph of the interfacial zone between CoCr and Si.

They considered it to be either a crystallized region due to an interaction of Ge with deposited CoCr or a Ge layer containing Cr and/or Co atoms which diffused into it from the CoCr film. In our experiments an AES-depth profile analysis confirmed our original presumption that a Co- and/or a Cr-silicide has been formed. Mainly Co was found in the amorphous Si. The solubility as well as the diffusion coefficient are both larger for Co in Si than for Cr in Si [7]. Therefore, we conclude that a Co-silicide with a minor portion of Cr was formed. The silicide is amorphous, and thus no constant stoichiometry may occur. The AES-analysis shows a Co concentration gradient in the amorphous silicide beginning at the CoCr, it stretches from Co₂Si continuously to CoSi₂.

This silicide layer which is clearly observed is responsible for the well-oriented growth of the CoCr-columns. The answer for the original question as to why Si behaves differently from other underlayers lies in this Co-Si-reaction layer. This situation corresponds to the Stranski-Krastanov-model [8–10] for nucleation and crystal growth (see fig. 3). This model describes a mechanism where first one or more atomic layers are formed. Then islands grow without covering the full film, which finally coalesce and grow upwards. The first layer is here the silicide layer on which the CoCr-nuclei and crystal columns are growing. This reaction interface leads to an optimal wetting of the deposit and the substrate material, the wetting angle is 0° at the very beginning.

This silicide thus causes uniform lateral conditions for the nucleation islands formed onto it. The heterogeneous nucleation occurs uniformly on the silicide surface and is not disturbed by micro-roughness. The small



Fig. 3. Stranski-Krastanov model for nucleation and crystal growth.

wetting angle of CoCr on silicide results in large nucleation islands which grow vertically and which form the CoCr-columns. This explains the lack of an initial layer which appears often with other growing processes performed by sputtering.

The silicide layer has here yet another function. The diffusion interface is a continuous transition in chemical composition, in lattice parameters, and in the inner stresses of the substrate and the film material. A transition layer stretching over a few atomic layers is compensating a crystallographic lattice misfit.

Another underlayer is shown in fig. 4: CoCr on CoNbZr. The difference to Si as a seed-layer is obvious. The CoCr-columns are significantly less well oriented. Measurements of rocking curves exhibit $\Delta\theta_{50}$ -values of 10°-15° as compared to Si with about 2°. The TEM-micrographs clearly show as well that the columns are slanted and are not uniform. A reaction layer between CoCr and CoNbZr cannot be discovered.

From observations of the interface CoNbZr/CoCr it can be recognized in some cases that the orientation of the *c*-axis direction depends on the surface roughness of



Fig. 4. Cross-sectional TEM-micrograph of CoCr on amorphous CoNbZr.



Fig. 5. TEM-dark field (right) and bright field image (left) of the top view in (100) of 20 nm CoCr on amorphous Si.

the substrate. The CoCr-columns are poorly oriented from the beginning and grow obliquely through the following process. A so-called sealed effect of substrate and keeper-surface which provides a flat surface with uniform lateral conditions cannot be found at the Co-NbZr-surface. A heterogeneous nucleation on the rough surface occurs dominantly at defect locations and it adapts to the local inclination of the surface roughness.

It is also apparent that the stacking faults (horizontal stripes within a column) are slanted within a relatively upright column. This means here that the column itself is growing parallel to the film normal and in the sputtering direction, but the crystallographic *c*-axis direction deviates from this growth direction. Upright columns with slanted orientation grow vertically. The thickness of the Si-layer has no effect on the column growth as we could confirm in many experiments. Only a uniformly continuous Si-layer seems to be important.

For further observation of the nucleation state, very thin (10, 20 and 40 nm) CoCr-films were sputtered onto different underlayers and were investigated in the TEM in bright field and dark field imaging with respect to their nucleation phase. In TEM-dark field images shown in fig. 5 a texturing of the a-b-base plane is observed if Si, Ge, C or Ti is the underlayer [11]. The individual CoCr-crystallites are oriented already at the very beginning and are thus influenced by the neighbouring crystallites. In the case of some other underlayer materials such as SiO₂, NiFe, Al, AlN, Cu, this phenomenon cannot be recognized. They behave as individual nuclei in the beginning and their orientation is more or less dependent on the roughness of the substrate surface.

4. Conclusions

By means of TEM-cross-sectional images, straight CoCr-columns without an initial growth-layer are observed with Si as a seed layer. A silicide layer as reaction layer causes optimal wetting of deposited and substrate material. It supports a uniform nucleation and can act as a transition layer over several atomic layers which also compensates any crystallographic misfit. The nucleation process corresponds to the Stranski-Krastanov model. With materials which do not form an interface reaction layer significantly worse CoCr-column growth is obtained. It can be concluded generally that the underlayers that form a reaction transition zone with CoCr lead to well oriented column growth. This also correlates with many previous results since materials such as Ge, C, Ti [1,5,6] cause a well oriented growth. It can therefore be assumed that these materials form germanides, carbides and titanides, respectively.

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