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High Resolution Magnetic X-ray Microscopy Study of the Magnetization Reversal in CoCrPt Alloy Thin Films

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Magnetic transmission soft X-ray microscopy has been used to study element-specifically the magnetization reversal behavior of $(Co_{84}Cr_{16})_{87}Pt_{13}$ alloy thin films with a lateral resolution of 35 nm. Our results indicate that the magnetization switching is carried out by a random nucleation process that can be attributed to the reversal of individual grains. We found evidence of a large distribution of the switching fields at the nanogranular length scale, which has to be considered seriously for applications of CoCrPt systems as magnetic high density storage materials.

Key words : nanogranular CoCrPt films, magnetization reversal, magnetic X-ray microscopy, perpendicular magnetic recording

1. Introduction

CoCr-based alloy films have received significant attention as possible high-density magnetic recording media because of their strong magnetic anisotropy and low media noise due to the decoupling of exchange interaction between the magnetically isolated grains via the compositional segregation at grain boundaries [1, 2]. In particular, CoCrPt alloy films have attracted considerable interest, since they provide desirable magnetic properties such as high coercivity and strong perpendicular magnetic anisotropy (PMA) for high-density recording [3, 4].

In order to achieve high-density magnetic recording media, the magnetization reversal behavior on a submicron length scale is crucial since it is closely related to the size and irregularity of grains and eventually stability of written domain [5, 6]. So far, most of the studies on CoCrPt alloy films concentrated on the control of the grain size and the grain size distribution which is essential to media processing and to suppress the media noise by reducing the intergranular exchange interaction between the neighboring grains [7-9]. Studies of magnetization reversal of CoCrPt alloy films published so far have been performed by macroscopic measurement techniques as well as by theoretical magnetization reversal models [10, 11]. Therefore, no experimental evidences are available on magnetization reversal behavior in CoCrPt alloy films at the nanogranular size level, which is mainly due to the resolution limitation of the microscopic measurement techniques employed.

Magnetic soft X-ray transmission microscopy (MTXM) combining X-ray magnetic circular dichroism as huge element-specific magnetic contrast mechanism with soft X-ray microscopy offering a high lateral resolution provided by Fresnel zone plate optical elements has been established recently [12, 13].

Here we report results of experimental studies on magnetization reversal behavior in CoCrPt alloy films on a length scale of the underlying nanogranular structure obtained with MTXM.

2. Experimental Details

We have used the full-field magnetic transmission soft X-ray microscope (XM-1) at the Advanced Light Source in Berkeley, which has a lateral resolution down to 21 nm [14] The experimental setup of this X-ray microscope is described elsewhere [15]. To record the images, first circularly polarized radiation emitted off-orbit from a

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bending magnet is monochromatized by a condensor (CZP) and a pinhole close to the sample due to the wavelength dependence of the focal length of the CZP. Second, the radiation passes through the ferromagnetic sample and is projected through the micro zone plate acting as the lens onto a 2048×2048 pixel array of a backside illuminated CCD camera. With a 1400-fold magnification and a physical pixel size of 13.5 μm, one pixel corresponds to 9.6 nm. Since the magnetic contrast is given by the projection of the magnetization onto the photon propagation direction, the CoCrPt sample with a pronounced PMA was mounted with its surface normal parallel to the photon beam direction. To study the magnetization reversal in the CoCrPt films the images have been recorded in varying external magnetic fields pointing perpendicular to the film plane. A solenoid allows to generate field strengths up to 5 kOe. To distinguish structural contrast (defects, inhomogeneities, etc) from magnetic contrast, the images have been normalized to images taken in an external field sufficiently high to saturate the thin films.

50 nm thick $(Co_{83}Cr_{17})_{87}Pt_{13}$ alloy films were prepared on 40 nm thick Ti buffer layers using dc magnetron sputtering of a CoCr alloy target with Pt chips at a base pressure of better than 8×10^{-7} Torr and a sputtering Ar pressure of 3 mTorr. A 200 nm thick Si_3N_4 membrane was used as substrate in order to allow for sufficiently high transmission of soft x-rays. To achieve a better (002) hcp crystallographic alignment of the CoCrPt alloy film, the Ti buffer layer was first deposited onto the substrate. The sample was prepared at ambient temperature without heat treatment. The magnetic anisotropy and the macroscopic magnetic properties were characterized using a torque magnetometer and a vibrating sample magnetometer (VSM), respectively. The sample exhibits a PMA energy of 1.58×10^6 erg/cc and a saturation magnetization of $M_s = 362$ emu/cc. The average grain size of the sample determined from analyzing TEM images using particle-analysis software was about 35 nm (Fig. 1).

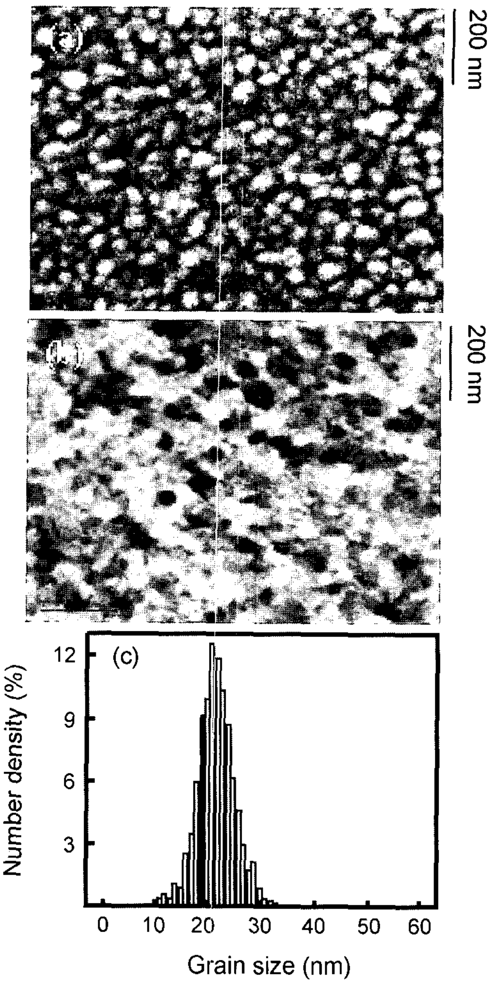

Fig. 1. (a) Scanning electron microscopy (SEM) image of the microstructure. (b) Transmission electron microscopy (TEM) image showing the granular structure. (c) Number density distribution determined from the TEM image.

3. Results and Discussion

The MTXM images have been recorded at the Co L_3 edge (777eV), therefore the magnetic structures seen in the data represent the local Co magnetization. Due to the high lateral resolution of MTXM, insight into the reversal mechanism can be obtained [16]. In Fig. 2, MTXM images taken at subsequent applied magnetic fields are shown together with magnetization data obtained by VSM for the identical sample. The arrows indicate the location of magnetic microstructure within the hysteresis cycle. Starting at a fully saturated sample at a large positive field value corresponding to a fully white contrast in the MTXM image, at +400 Oe (Fig. 2(a)) several small nucleation sites can be observed as dark spots showing up at stochastically distributed positions in the sample.

The smallest features that can be observed in Fig. 2(a) are at the resolution limit of the X-ray optical components used here. Thus, according to the grain size distribution deduced from the TEM measurements it can be concluded that the nucleation process starts with the reversal of individual grains in the sample.

The stochastical character of the reversal of individual grains is furthermore supported by repeated imaging of the nucleation process. In Fig. 3(a), (b) the onset of the nucleation was imaged in two subsequent hysteresis cycles at the same value of the applied field. It can be seen that the location of the nucleation spots is not

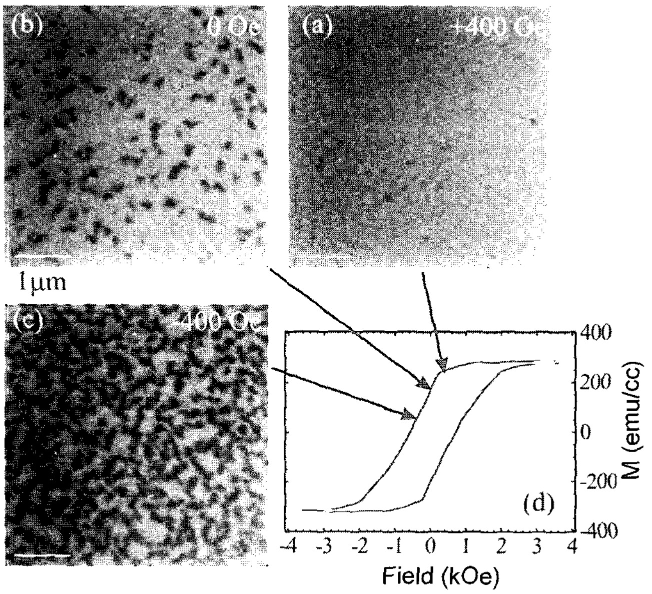

Fig. 2. MTXM images of the magnetic domain structure in a 50-nm thick $(Co_{83}Cr_{17})_{87}Pt_{13}$ alloy film recorded at the Co L_3 absorption edge (777eV) in an external field of (a) +400 Oe, (b) 0 Oe and (c) -400 Oe. (d) M vs H hysteresis loop obtained via VSM measurement. The arrows indicate the location of the domain structure within the reversal cycle [16].

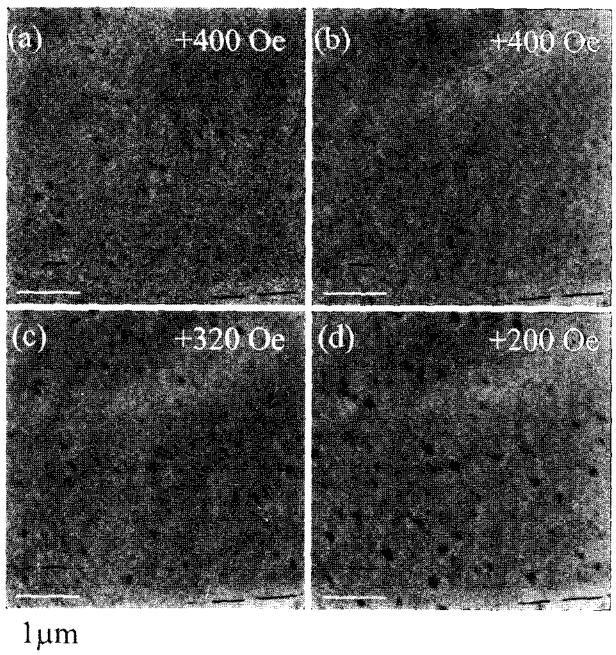

Fig. 3. (a) Start of nucleation at +400Oe after saturation. (b) Repeating the nucleation as in (a) in a subsequent magnetisation cycle. (c)-(d) More stochastically distributed nucleation sites revers at +320 Oe and +200 Oe, resp.

resembled twice, which is also verified by a correlation analysis of the images.

The nucleation dominated reversal scenario dominates the initial stage of the reversal process as can be seen by comparing Fig. 2 and 3(c), (d). At +320 Oe (Fig. 3(c)) and +200 Oe (Fig. 3(d)) further individual nucleation spots show up at irregularly distributed locations. Contiguous domain structures consisting of more individual dots and forming irregular shapes commence at an external field close to 0 Oe (cf. Fig. 2(b)), however there is no evidence that intergrain interactions is the driving force for that behaviour. At -400 Oe (Fig. 2(c)), which is close to the coercive field these irregular domain structure scenario is dominating. Although a correlation analysis at this stage can not fully exclude intergrain interactions that could yield some clustering of reversed regions, the dominant contribution to the reversal mechanism of the CoCrPt nanogranular alloy films is still of stochastical character.

The shape of the hysteresis loop, measured by VSM and shown in Fig. 2(d) indicates a rather large distribution of switching fields for the individual grains. This is consistent with the observation that close to saturation magnetization there are still some individual grains that have not been switched [16].

4. Conclusion

Considering CoCrPt alloy systems for future high density storage media their magnetization reversal at a granular length scale has to be taken seriously into account. The elemental specific magnetic domain reversal behavior has been characterized using MTXM with high lateral resolution. It is found that the nucleation starts with the reversal of individual grains in the CoCrPt alloy film and the switching field distribution for the individual grains is relatively large.

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