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Determination of Basic Magnetic Unit Size in CoCrTa/Cr Magnetic Disk Media

Bunsen Y. Wong and David E. Laughlin

Abstract— **The magnetic transition region in a CoCrTa/Cr hard disk has been studied with high-resolution Foucault-mode Lorentz microscopy. It was found that the amplitude of the zigzag transition increases significantly at the track edges. Imaging results show that the CoCrTa grains behave magnetically in a clustered manner, forming domains of varying sizes at the transition. The dimension of the smallest grain cluster [or the basic magnetic unit (bmu)] has been determined by studying a pair of antiparallel domain contrast images in this medium. Investigations also reveal that each bmu consists of six to eight CoCrTa hcp grains, giving an average bmu unit size of about 80 ± 12 nm. Furthermore, the magnetic domain images indicate that the mechanical texture induced by polishing does not break up this intergranular coupling.**

Index Terms— **Basic magnetic units, grain size, magnetic domain, media noise, transition region.**

I. INTRODUCTION

MEDIA noise remains one of the principal obstacles on the road to achieving 10-Gbit/in^2 magnetic recording density. The solution must begin with a better fundamental understanding of the physical factors which are responsible for generating the noise [1]. The main source of media noise stems from the transition region where bits with antiparallel magnetization converge. By considering the problem in one dimension [2], the demagnetizing field limited transition width, a has been defined as

$$a \propto M_r t / H_c$$

where

M_r	remanent magnetization;
t	film thickness;
H_c	media coercivity.

In reality, this demagnetizing effect in two dimension results in a zigzag transition structure [3], [4] (Fig. 1). Such transitions cause jitter and uncertainties in the output signal pulse shape, position, amplitude, and width (PW50). These uncertainties together register as noise in the output spectrum. In the worst case, such a zigzag transition profile fosters interactions between successive transitions at high recording density. This phenomenon, known as percolation, leads to a superlinear increase in media noise.

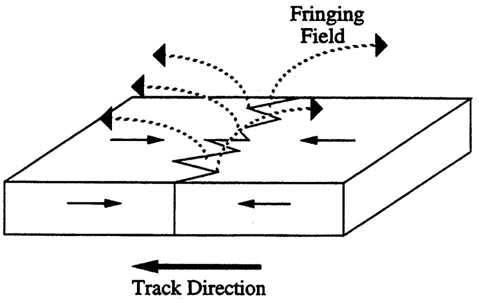

Fig. 1. A schematic of the bit transition structure.

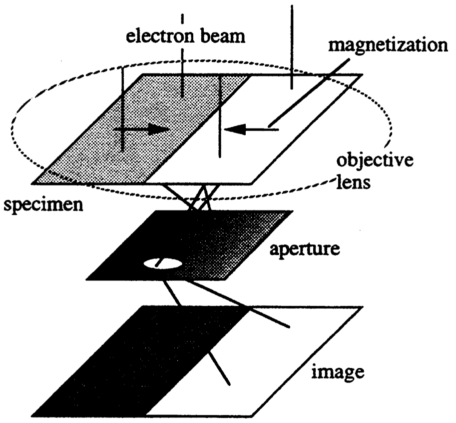

Fig. 2. A schematic of the principle behind Foucault-mode Lorentz microscopy.

The amplitude of this zigzag-transition region is determined by two factors: the write-head field gradient and the intergranular coupling. The former is associated with the head–disk interface design while the latter is an intrinsic media property which consists of a magnetostatic component and, more importantly, an exchange component between the grains. As a consequence of this intergranular coupling, grains respond to external magnetic fields in a clustered manner [5] instead of individually. This behavior leads to local variation in H_c and M_r, thus causing ambiguity in the transition position. The minimum size of such a grain cluster can be defined as a basic magnetic unit (bmu) which is an indirect means of measuring the coupling correlation length in disk media. The *bmu* has fundamental implications as it dictates the minimum

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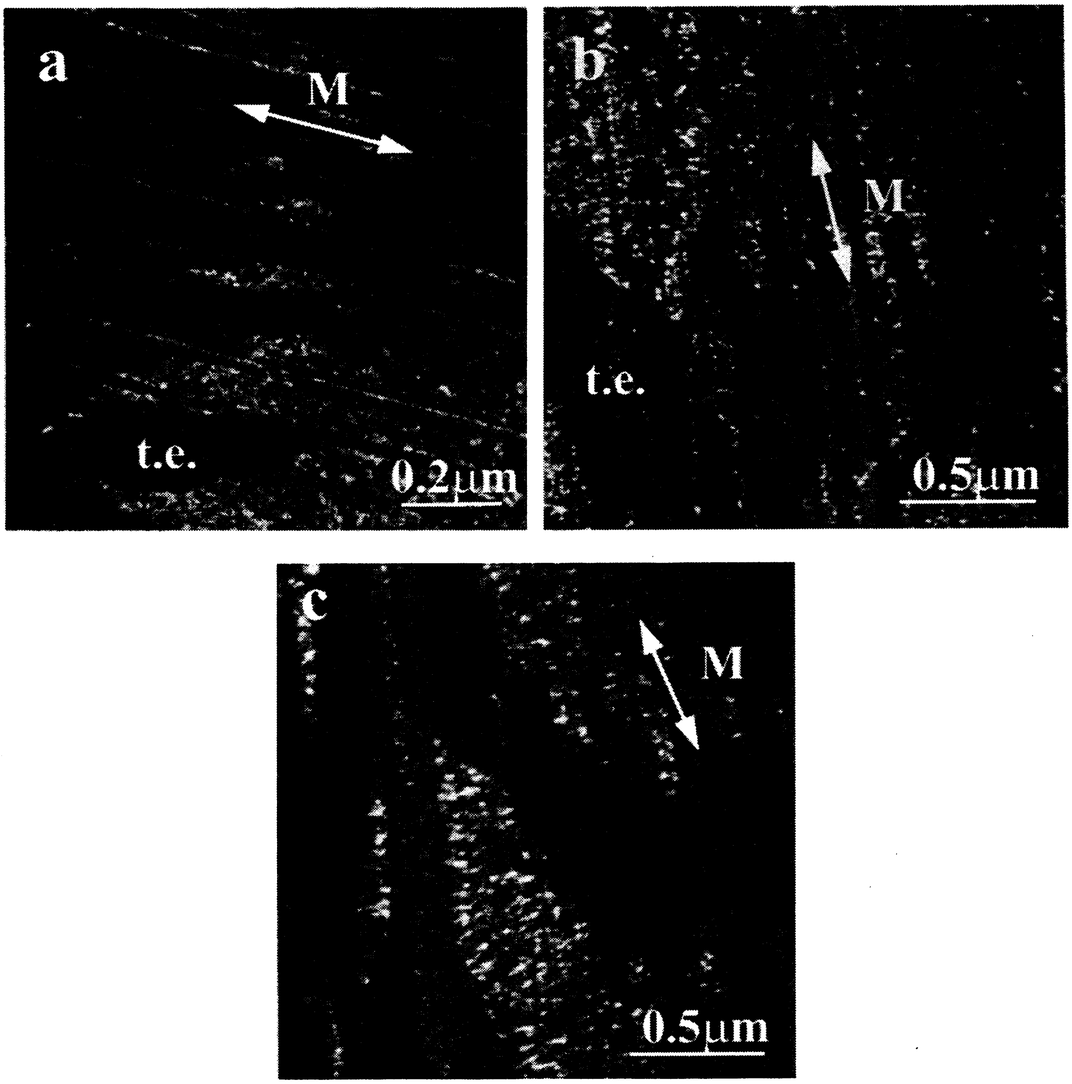

Fig. 3. (a)–(c) Magnetic domain structure of the magnetization component parallel to the track direction. (t.e.: track edge, M: magnetization component imaged.)

amplitude of the zigzag transition and plays an important role in the eventual design of the 10-Gbit/in^2 magnetic drive.

A number of previous investigations have studied the recorded bits and the transition region using Lorentz microscopy [6]–[10]. Correlation between the magnetic structure and the noise properties has been demonstrated. However, due to the resolution limit, it was not feasible to explore the relationship between the nanoscale microstructural features in thin-film media and the corresponding magnetic domains. Recently, we have utilized a high-resolution Foucault-mode Lorentz microscopy technique [11] which can resolve fine magnetic features in the nanometer range. In this work, we apply this technique to study the transition region of a CoCrTa/Cr medium in order to investigate its magnetic characteristics and determine the dimension of its bmu.

II. EXPERIMENTAL PROCEDURES

The hard-disk specimen used in this study has an H_c of 578 Oe, $M_r t$ of 3.6 memu/cm^2 and an S^* of 0.8. The TEM specimen was prepared by first separating the CoCrTa/Cr/NiP layers from the Al substrate through chemical etching. Final specimen thinning was achieved by employing the window technique in which the NiP substrate was removed chemically with a 50–50 mixture of HNO_3 and HCl. The specimen was studied with Foucault-mode Lorentz microscopy using a JEOL 4000EX transmission electron microscope operating at 400 kV. The microscope is equipped with a Gatan Image Filter (GIF) which provided an additional magnifying lens beyond the screen plane. The Foucault mode utilizes the fact that electrons are deflected by the specimen's local magnetization vector which causes a splitting of the diffracted electron beams (Fig. 2). Hence, magnetic contrast can be obtained in the image by using an aperture to intercept the portion of the diffraction spot which is associated with the magnetization component of interest.

III. RESULTS AND DISCUSSIONS

The domain structures of the magnetization component along the track in the recorded disk is shown in Fig. 3. The bit

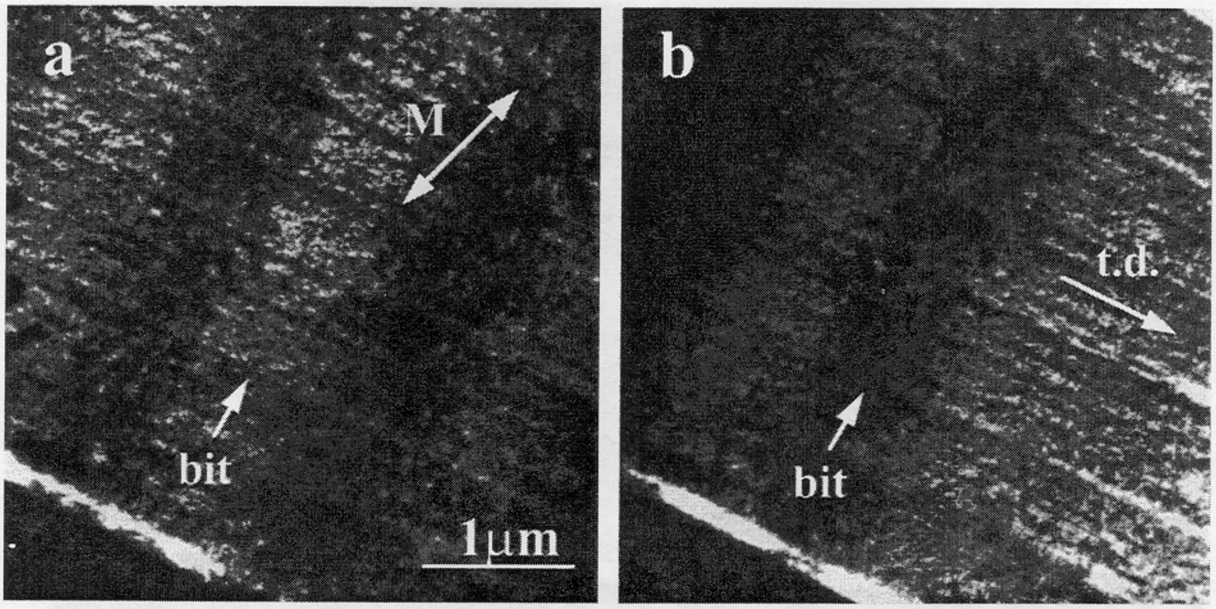

Fig. 4. (a) and (b) Magnetic domain image pair of the magnetization component close to the cross-track direction. The white bit in (a) becomes black in (b) as the aperture is moved to block the other half of the diffracted beam. (M: magnetization component imaged.)

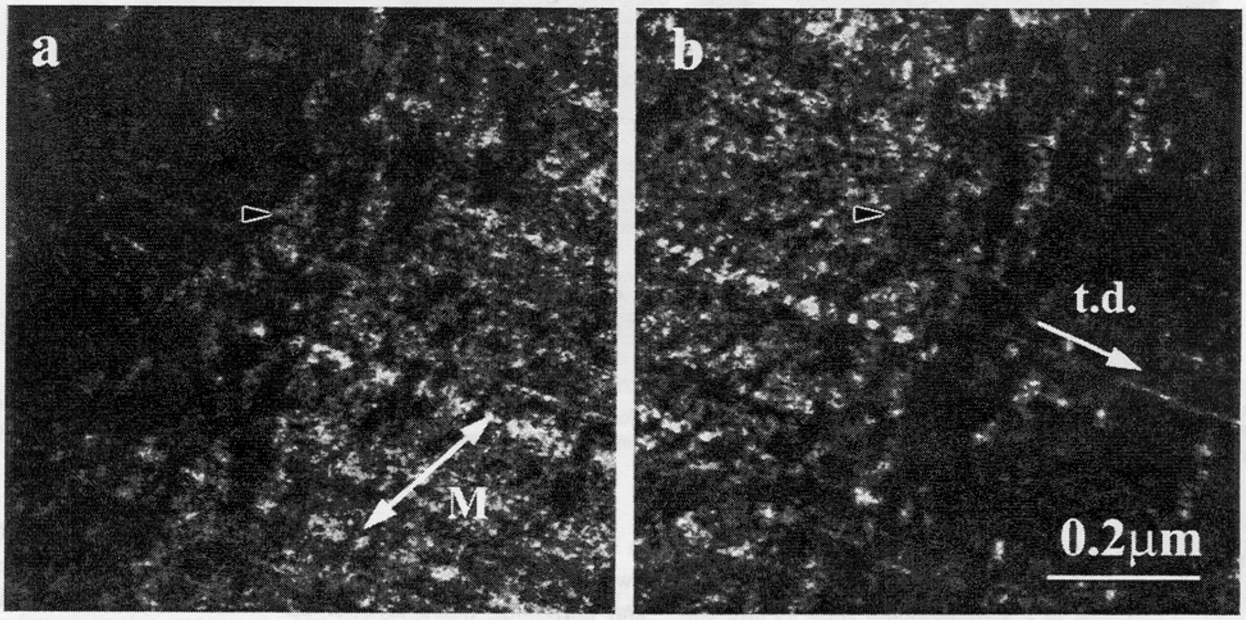

Fig. 5. (a) and (b) Magnetic domain image pair of the transition region. The black arrow marks a domain which switches contrast in the two figures. (t.d.: track direction; M: magnetization component imaged.)

size is approximately 1 μm × 7 μm and the transition has the expected zigzag characteristic. The amplitude of the zigzag increases near the track edges [Fig. 3(a) and (b)], which is probably due to the leakage of the write-head field, causing a reduction of head-field gradient. The side band registered by this leakage can be seen in Fig. 3(c).

In general, it is difficult to observe the magnetization component along the track because of the antiparallel fringing field which effectively reduces the net deflection of the electrons, making the magnetic contrast from the recorded bits difficult to resolve (Fig. 1). In view of this, we have minimized the effect of the fringing field by tilting the specimen 10° along the track direction. A pair of domain images of the magnetization component at approximately 85° with respect to the track direction is shown in Fig. 4. A white bit (arrow) in Fig. 4(a) becomes a black bit in Fig. 4(b) as the position of the aperture is moved. A reference deep polishing groove can be observed in the bottom left-hand corner. Although this black–white domain contrast from the antiparallel bits is evident, the zigzag feature at the transition is no longer present. This is because the primary magnetization component under investigation is perpendicular to the track direction. This component reveals

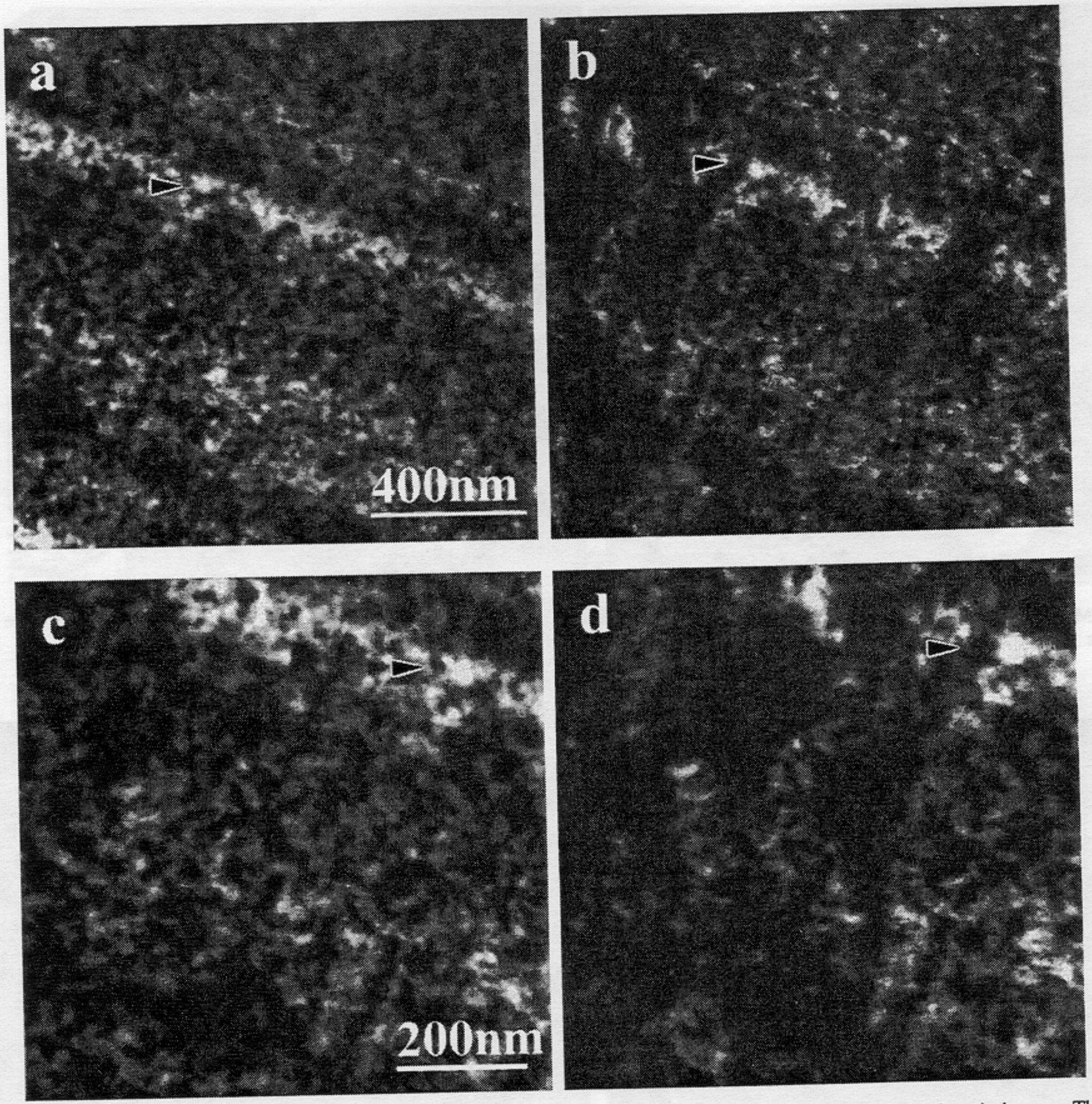

Fig. 6. (a) and (c) Bright field images of the transition region at higher magnification. (b) and (d) Corresponding magnetic domain images. The magnetization component imaged is the same as Fig. 5, which is close to the cross-track direction. A reference area of interest is marked by the black arrows.

better domain contrast as it is not compromised by the fringing field [10].

The transition region is in a demagnetized state locally and is broken into a collection of domains; one such domain is marked by arrows in Fig. 5(a) and (b). Elongated domains of varying sizes are evident and their shape is due to the local magnetostatic coupling between individual bmu clusters [4], [12]. There is no evidence that the polishing grooves (mechanical texture) break up intergranular coupling, as the domains clearly extend across the deep grooves.

Successive magnified bright field images [Fig. 6(a) and (c)] and their corresponding magnetic domain images [Fig. 6(b) and (d)] of an area of interest within the transition region are shown in Fig. 6. A reference area near the tip of an elongated domain is marked by arrows in all the images. Fig. 7(a) and (b) shows a magnified antiparallel domain image pair of the area of interest illustrated in Fig. 6. The corresponding bright field image revealing the individual CoCrTa grains is shown in Fig. 7(c); the average grain size was measured to be 29 nm. Two reference grains in the images are marked by the vertical and horizontal black arrows. The black and white intensity in Fig. 7(a) and (b) is a combination of both the magnetic and the crystalline diffraction contrast, whereas Fig. 7(c) is composed solely of the latter. Hence, it is possible to identify the size of a bmu by studying the contrast variation between Fig. 7(a) and (b) compared to that of Fig. 7(c). The white arrow in Fig. 7(a) depicts an example of the smallest magnetic domain (bmu), white in contrast, which has been observed in this specimen. One can find a diffracting CoCrTa grain (dark) within this cluster, and this grain is marked by the white arrow in Fig. 7(c). In Fig. 7(b), the contrast of this cluster has now switched to black and is also marked by the white arrow. Fig. 7(d) outlines the boundaries of two bmu's found in this medium. Various reference grains are also depicted.

From the measurement results, the cluster has an average diameter of 78 nm. The average value measured from a

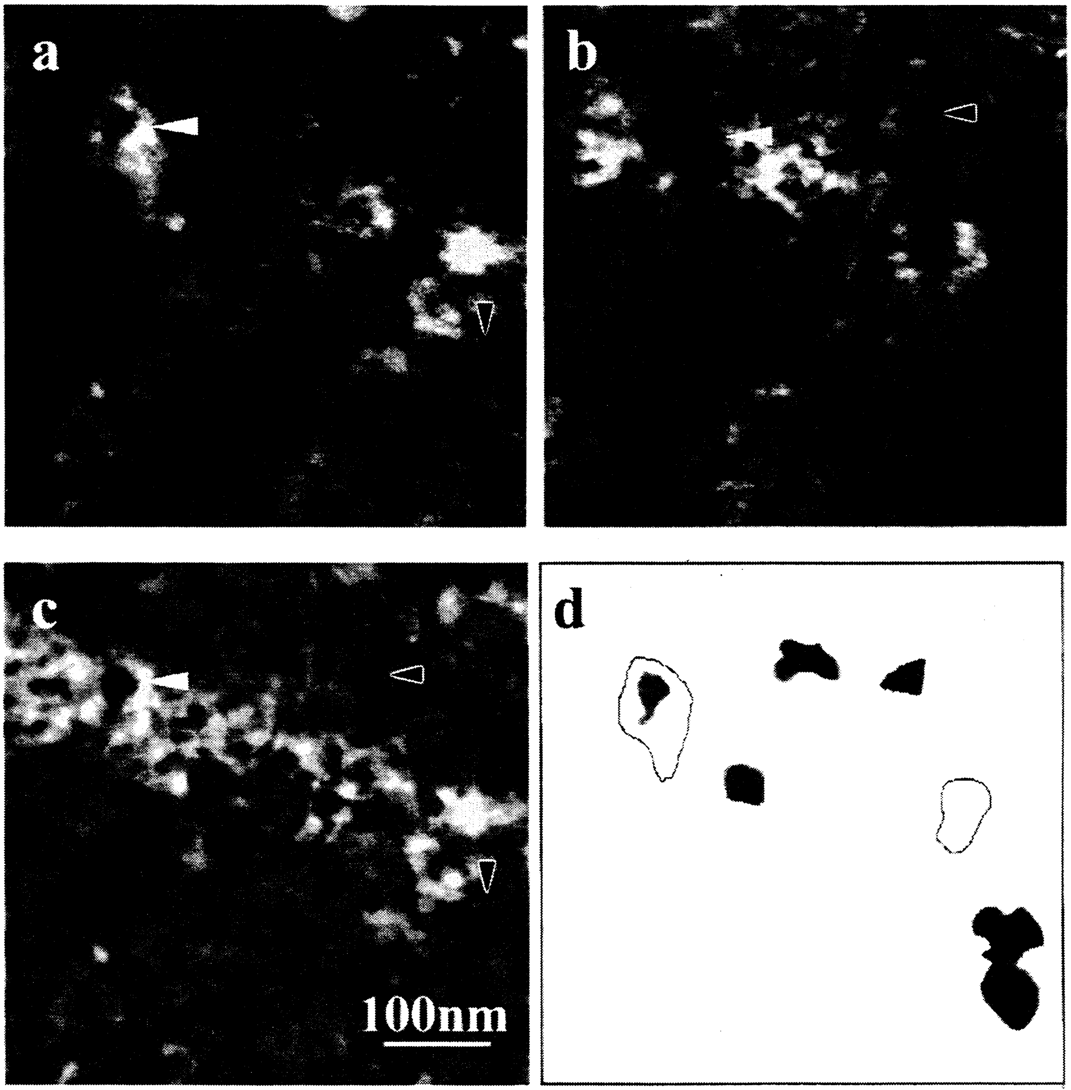

Fig. 7. (a)–(b) Magnetic domain image pair of the transition region. The magnetization component imaged is close to the cross-track direction as in the previous figure. (c) Corresponding bright field image. Two reference grains are marked by the black arrows in the corresponding images. (d) A schematic marking the various reference grains and the bmu observed.

collection of magnetic clusters is 80 ± 12 nm. This translates to about six to eight grains of the Co-alloy in each cluster/bmu. No magnetic unit which has the size of an individual grain has been found in this specimen. The physical reason determining the size of bmu, such as chemical inhomogeneity and orientation variation, is currently under investigation.

IV. CONCLUSIONS

High-resolution Foucault-mode Lorentz microscopy was able to reveal the fine magnetic domain structure at the transition region and the track edges of recorded bits in a CoCrTa/Cr hard disk. The CoCrTa grains coupled with each other magnetically and formed domains of different sizes at the demagnetized transition region. The smallest such clustered domain (bmu) observed was found to consist of six to eight CoCrTa grains which translate to an average bmu size of 80 ± 12 nm. In addition, the polishing grooves do not seem to promote morphological decoupling, as the domain extends across these groves.

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