High resolution imaging of magnetic domains in TbFeCo MO disks with M-TXM at XM-1

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INTRODUCTION

Nowadays the magnetism in systems of low dimensionality as ultrathin magnetic films, multilayers or magnetic nanostructures attracts increasing interest in technological applications like current developments in information storage technology as magneto-optics, the use of GMR/CMR based read-out technologies, magnetic sensors or magneto-electronics (MRAM) combining semiconductor physics and magnetism. In all these fields there is a rapid decrease of the relevant length scales of the magnetic structures down to the sub-100nm range. However, serious questions arise about the physical limitation in the miniaturisation process or the relation between the observed or tailored macroscopic behaviour and the microscopic domain structure. A variety of techniques to image magnetic domains have been developed in the past including both electron (e.g. SEMPA, Lorentz microscopy), optical microscopies (e.g. SNOM, Kerrmicroscopy) and magnetic force microscopy. The requirement these techniques should meet are high spatial resolution, high sensitivity combined with a huge contrast, element-selectivity and imaging in applied fields.

A new concept to image magnetic domains is the combination of the X-ray magnetic circular dichroism as huge magnetic contrast mechanism in combination with a high resolution transmission X-ray microscope (M-TXM) [1]. Here we report on the first experiments with M-TXM obtained at the XM-1 beamline at the ALS where the domain pattern in real magneto-optical systems of FeTbCo could be imaged with high resolution

MAGNETIC TRANSMISSION X-RAY MICROSCOPY

The X-ray magnetic circular dichroism (X-MCD) in core-level absorption detects the magnetization dependence of the absorption coefficient in the vicinity of element-specific absorption edges of circularly polarized radiation. Absorption coefficients are conveniently detected in the transmission mode by counting the incoming and transmitted photon intensity. Due to the limited penetration depth of X-rays in matter, however, the information depth is limited to about 100nm for the soft X-ray regime below 1keV.

In the absorption process of a circularly polarized photon the spin-orbit interaction in the initial core level and angular momentum conservation causes the photoelectron to act as a spin and orbital polarized probe of the polarisation properties of the unoccuopied levels above the Fermi energy. Thus the (spectroscopic) X-MCD signal can be related to local magnetic moments. The huge magnetic contrast that can be obtained in technological relevant transition metals (Fe,Co,Ni) where large dichroic effects with values up to 50% occur at the $L_{2,3}$ edges [2] can be used to image magnetic domains if combined with a transmission X-ray microscope. This has been demonstrated for the first time recently at BESSY I in Berlin [1,3].

RESULTS

In 1999 this technique was applied for the first time also at the XM-1. Circularly polarized X-rays were obtained by viewing the off-orbit contribution emitted from the bending magnet. The sensitivity of the huge magnetic contrast on the component of the magnetization along the propagation direction of the ferromagnetic species makes M-TXM an ideal technique for systems with a pronounced out-of-plane anisotropy like in magneto-optical recording media. Real magneto-optical systems consisting of TbFeCo films, where the thermomagnetic writing process has been varied to obtain diverse bit patterns, were investigated by taking images at the Fe L_3 edge at a photon energy of 706eV.

Due to the fully computer based sample positioning and energy tuning at these beamline large areas of the sample and also a large spectral range can be addressed automatically. Thus up to a tile of 4x4 individual images were taken representing a large area on the sample. The recording time for the whole image (i.e.15x15mm^2) was in the min range. The on-line contrast of more than 20% allows to distinguish clearly dark and light areas, which can be attributed to magnetic domains, where the direction of the local Fe magnetization points in/out of the paper plane.

Thermomagnetic recording was done for films prepared on a polycarbonate substrate with and without Al heat sink layer. The recording was made using laser pumped magnetic field modulation (LP-MFM) method. The wavelength and numerical aperture (N.A.) of the optical head were 635nm and 0.55 respectively. The designed mark and space length is in between 0.8 and 0.05 μm as written beside the images. After the thermomagnetic recording, the films were peeled off from the substrate. One of the issues that can be addressed with M-TXM studies in MO systems is, how reliable the smallest bits can be written. As our results show, the crescent shaped bits could be written in these systems with good quality extended down to 100 nm in mark length, which is still far above the resolution limit of about 30nm. The images taken from the sample with an Al heat sink layer is clearer than without the Al layer. The Al layer seems to make the temperture gradient steeper and as a result the domain edges more clearly shaped.

An inherent feature of the M-TXM is the element-selectivity, which allows to address a single element in a multicomponent system. Thus information on the chemical morphology, which influences drastically the behaviour of the global magnetization in the presence of external fields can be obtained. Thus M-TXM images had been recorded at the Fe $L_{3,2}$ and the Co L_3 edge. The observed change in contrast between the L_3 and the L_2 edge originates in the opposite spin-orbit coupling in the respective $2p_{3/2}$ and $2p_{1/2}$ inneratomic levels. The unique property of X-MCD spectroscopy to address separately spin and orbital moments by applying the magneto-optical sum rules [4] to data from spin-orbit coupled edges as $L_{3,2}$ can thus be extended with the obtained lateral resolution in X-ray microscopy to deduce maps of the orbital moment, which will provide valuable insight into e.g. the origin of perpendicular anisotropy.

OUTLOOK

The combination of a high resolution TXM with the X-MCD as huge magnetic contrast mechanism allows to image element-specific magnetic domains [5]. The major advantage of this element-specific technique is the possibility to record the images in varying external magnetic fields, which gives information on the magnetization dependent evolution of magnetic domains within a complete hysteresis loop. Quantitative information can be obtained due to the relation of the X-MCD with the local magnetic moment.

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This work was supported by the University of Würzburg.

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