Selective Resputtering-Induced Magnetic Anisotropy in High-Density Magnetooptic Media

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Amorphous rare earth-transition metal films (a-RETM) are employed as materials in magneto-optic (MO) sensors and as media for high-density MO disks. They possess perpendicular magnetic anisotropy (PMA), a unique property that allows for written bits of information to align perpendicular to the plane of the storage disk. This orientation allows for a much higher density of information per unit area. Conventional magnetic storage media (e.g. Zip and computer hard drive media) have bits that lie in the disk plane and therefore occupy a larger amount of space.

Discovered in 1973 by IBM researchers P. Chaudhari, J.J. Cuomo, and R.J. Gambino [1], these materials ushered in the modern era of high-density magnetooptic storage and remain to this day the industry's mainstay material. For their discovery, these authors were awarded the 1995 National Medal of Technology. [2]

Remarkably, although these materials have been used in commercial magnetooptic devices, the physical mechanism underlying their most important properties have never been made clear. In amorphous materials, unlike their more common crystalline cousins, atoms are disordered in their relative placement to each other. As such, a magnetic property that is traditionally determined by crystalline order, such as the magnetic anisotropy energy that preferentially aligns the magnetization vector within a material, becomes very small. In the amorphous rare earth containing alloys (e.g. a-TbFe), however, this property is often large and spontaneously aligns perpendicular to the film plane. Since the rare earth atom's shape, determined by its valence charge cloud, is non-spherical (for Tb it is more football like), some form of local electrostatic anomaly had been proposed as the source of this property. In 1992, NRL researchers measured the presence of local atomic arrangements in a-TbFe and showed that they provide such an electrostatic anisotropy and give rise to PMA via a crystal field interaction [3]. The anisotropic atomic structure was described as a statistical preference for like atom pairs to align parallel to the film plane with a corresponding preference for unlike pairs to align perpendicular to this plane. This preference was of the order of 5-8% from the ideal isotropic amorphous environment and is broadly referred to as a pair-order anisotropy (POA) in reference to the model first proposed by van Vleck [4]. We have recently focused our efforts to discover the growth mechanism responsible for such anisotropic atomic arrangements.

By examining the energy of the RF plasma used in magnetron sputtering of a-TbFe, and comparing this to the energy required to remove atoms from the growing film, deposition conditions were determined in which atoms are selectively removed from the growing film. The conditions for *selective resputtering* are defined in terms of a plasma energy envelope, where plasma energies between 34 eV $\leq E_{Ar} \leq$ 65 eV result in the *selective* removal of one species of adatom versus another from the surface of the growing film, resulting in POA.

Extended x-ray absorption fine structure (EXAFS) measurements were performed at beamline X23B on several films grown using different working gas pressures (Ar gas) and RF power. These growth conditions allow for the systematic change of the plasma energy

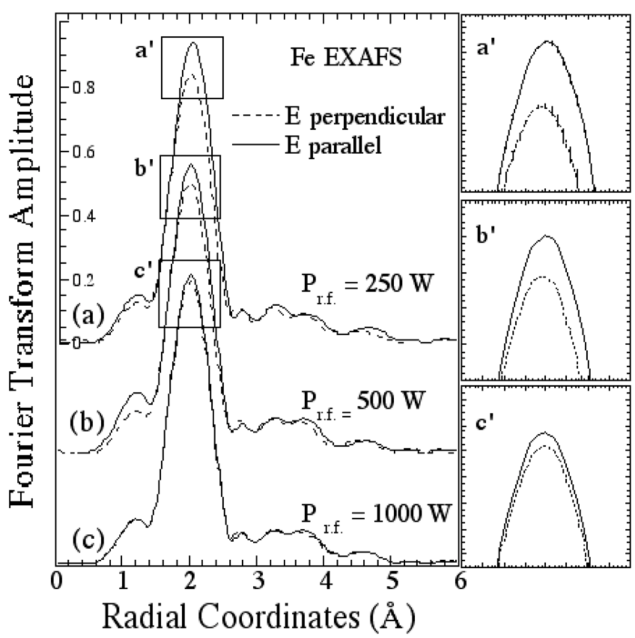

Figure 1. *Fourier transformed Fe EXAFS data for samples grown with increasing RF power. The amplitudes of the peaks are proportional to the occupancy and atomic disorder while its center reflects the bond distance uncorrected for electron phase shift.* ***E*** *is the electric vector of the incident radiation and identifies the direction along which the structure is sampled. The atomic structural anisotropy is most evident in the nearest neighbor amplitude (see insets a', b' and c'). [6]*

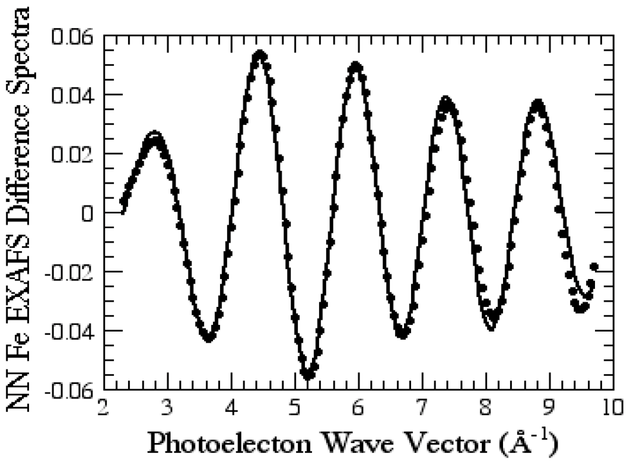

Figure 2. Fourier-filtered (FF) nearest neighbor (NN) Fe EXAFS difference spectrum (as symbols) for the sample grown using 250 W and 7.6 mTorr Ar gas. The best fit, determined using a nonlinear least square fitting of FEFF data, is shown as the solid curve. The difference spectrum is obtained by subtracting the out-of-plane data (E⊥ from the in-plane data (E||). [6]

to different regions of the energy envelope, thereby allowing for an increase in POA and PMA. The in-plane and out-of-plane atomic environments of Fe atoms for a subset of these samples are plotted in Figure 1 as Fourier-transformed EXAFS data. Comparison of the in-plane and out-of-plane structure clearly shows that the POA changes as a function of the RF power. This POA, seen most clearly in the near neighbor environment, was determined by modeling the difference spectrum (i.e. the difference of the in-plane and out-of-plane data sets) using data generated from the FEFF codes of Rehr et al. [5]. A representative best fit is illustrated in Figure 2 for the sample whose FT EXAFS data is presented as Fig. 1a'.

In Fig. 3, the PMA is plotted as a function of both POA and Ar ion energy (E_{Ar}). A strong positive correlation exists between the Ar ion energy and both the PMA and the POA. The projection of this curve onto the three two-dimensional planes indicates an exponential relationship between PMA and both POA and E_{Ar} , with a linear relationship between E_{Ar} and POA.

After nearly three decades of research, both the source of PMA and the mechanism by which it is incorporated in sputtered films are now understood. This advancement will directly lead to improved processing of MO materials for sensor and media applications. Furthermore, the improved understanding of the growth dynamics of sputtered films will allow for greater optimization in materials processing as well as an improved understanding of the role of anisotropic atomic structure in a broad range of materials systems.

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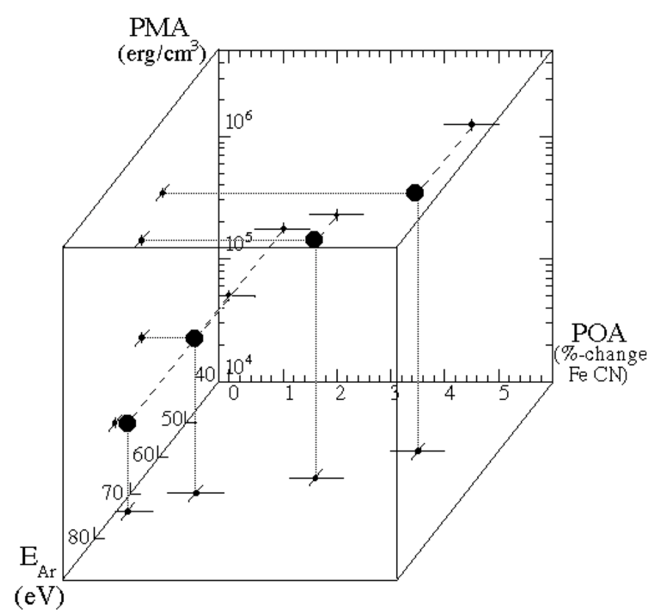

Figure 3. Magnetic anisotropy energy (PMA) plotted against the POA metric, defined as the percentage change in the Fe-Fe bond length between the in-plane and perpendicular directions, as a function of Ar ion energy (E_{Ar}). The data points are projected onto the two-dimensional planes illustrating the exponential relationships between PMA and both POA and E_{Ar}. [6]