

Resolving magnetic and chemical heterogeneity using soft x-ray resonant scattering

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At LBNL's Advanced Light Source we are developing and applying resonant scattering techniques to resolve magnetic structure and its relation to chemical structure in a variety of heterogeneous systems [1]. These techniques can be broadly classified as resolving structure in depth in layered thin films [2-6] or laterally in systems involving lateral heterogeneity [7-14]. To date we have used primarily the L edges of magnetic transition metals (500 – 1000 eV) to gain resonant sensitivity to magnetism in those species, although M edges of magnetic rare earth species (850 – 1600 eV) are also generally of interest in the soft x-ray range. Strong resonance in charge and magnetic scattering factors at these edges can literally raise signals from below noise levels, yielding sensitivity to very small sample volumes. Scattering techniques complement microscopy techniques operating at the same wavelength, because their higher effective numerical aperture allows them to resolve smaller features. While most measurements have been made in the so-called incoherent mode, coherent magnetic scattering techniques have been developed to quantify magnetic memory on the microscopic level [9].

Depth-resolved magnetic structure has been studied in exchange-spring systems comprised of different hard/soft exchange couples. These reflection geometry studies are entirely analogous to visible MOKE techniques where both intensity and polarization changes can be measured. In the FePt/NiFe system [2] depth sensitivity was obtained by inserting ultrathin Co layers at different depths in to soft NiFe layer and at the hard/soft interface and tuning to the Co L_3 edge. In the Sm-Co/Fe system depth sensitivity was obtained in the soft Fe layer by both modeling the shape of hysteresis loops of Kerr rotation [3] and by varying energy near to Fe L_3 edge to vary the penetration depth [4]. Direct sensitivity to the deeply buried hard layer was obtained by tuning to the Co edge. These studies reveal both the expected twist structure in the soft layers, and also that part of the hard layers begin reversal as soon as the soft layer begins to reverse, consistent with exchange softening of the hard layer and with possible lateral heterogeneity in these layered structures. In other systems, q -resolved studies [5] including standing wave effects [6] have been used as probes of buried interfaces.

Lateral magnetic structure has been studied extensively in Co/Pt multilayer films having perpendicular anisotropy that form stripe domains providing strong magnetic scattering centers [7]. When domains are present, they produce strong magnetic peaks that are purely magnetic in origin (Fig. 1). When the magnetization is saturated, a weaker peak at much higher q remains that is due to chemical heterogeneity associated with the polycrystalline grain structure of these films. When using linear incident polarization this scattering reflects the magnetic-magnetic and charge-charge correlations, but not their cross-correlation. Coherent magnetic scattering studies have found that the microscopic domain memory is sensitive to the strength of this chemical peak and hence to the degree of chemical heterogeneity in these films [8]. Resonant scattering has also been used to study domain structure through reversal in hybrid films based on the Co/Pt

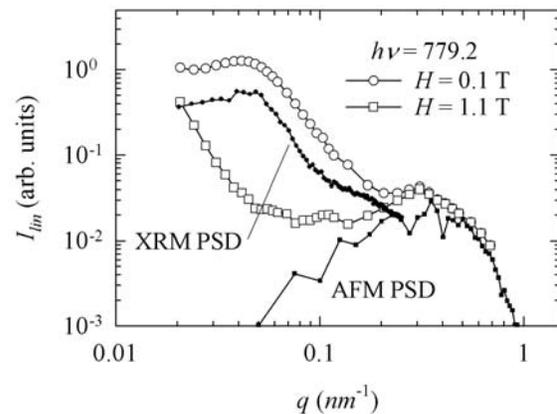


Figure 1

system, including exchange bias [9] and indirect antiferromagnetic exchange coupling [10]. Details of domain structure and wall motion during reversal have been studied by following the behavior of higher magnetic scattering harmonics of aligned stripe domains [11].

Resonant scattering has provided the first direct measurement the magnetic correlation length in granular alloy films that constitute longitudinal (in-plane) magnetic recording media [12]. This is demonstrated in Figure 2 that shows scattering data for three different alloy films that represent a historical progression of recording media. Co is the predominant magnetic constituent of these alloys, and scattering data at the Co L_3 edge contains both magnetic and chemical information. Cr is a nominally nonmagnetic constituent, and data collected at the Cr L_3 edge contains primarily charge-charge correlations. Scaling these data at high q and subtracting, then, leaves a spectrum reflecting largely magnetic correlations. For the CoCr and CoPtCr alloys, the magnetic (Co – Cr) peak indicates that magnetic correlations are 4-5 times longer than the chemical grain size, while addition of B shifts the magnetic peak to higher q and thus significantly reduces the magnetic correlation length, in agreement with improved recording density. We have found that modeling the energy spectra at the chemical grain peak provides a meaningful measure of the chemical composition difference between the magnetic grain centers and non-magnetic grain boundaries in these systems [13]. These resonant scattering techniques will be valuable in correlating chemical structure, magnetic structure, and recording performance in future generations of recording media such as perpendicular alloy films [14], and in assessing the potential of more exotic recording materials such as magnetic nanoparticle assemblies.

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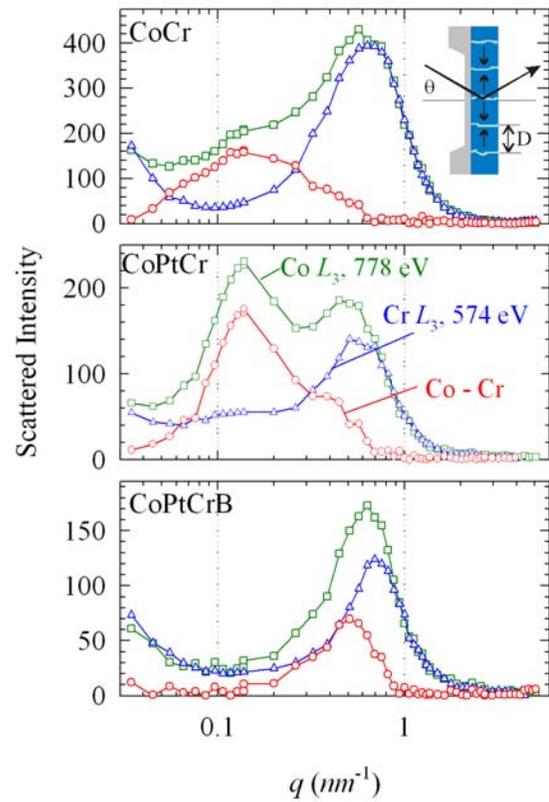


Figure 2