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Report:

The atomic selectivity of X-ray magnetic circular dichroism (XMCD) offers a powerful method to probe the contribution of the individual elements in a heteromagnetic structure to the total magnetization curves of the material, an information not accessible by classical methods. To date, this technique has been used to measure selectively the magnetization-versus-field behavior of the ferromagnetic components in thin-film structures [1,2]. It is not surprising that the secondary magnetic properties, such as the coercive field and the remnant magnetization, which depend upon details of domain formation and reversal in the ferromagnetic sublayers, are quite different. We have probed the contribution of thin Ce layers to the overall magnetic hysteresis curves of Ce/Fe multilayers. In this cases the situation is different since magnetic order of the element addressed is induced by Fe in the heterostructure, and it is not clear a priori if the induced magnetization differs in its hysteretic behavior from that of its architect. Previous X-ray absorption spectra at the $2p \rightarrow 5d$ and $3d \rightarrow 4f$ excitation thresholds of Ce in this system have shown that on a depth of ~17 Å near the interfaces Ce adopts the highly correlated electronic structure of the a-phase, with delocalized 4f states, which in bulk Ce metal has a nonmagnetic ground state. In the multilayers with Fe, strong 3d-5d, 3d-4f and 5d-4f hybridization is effective. XMCD spectra reveal the presence of an ordered 5d and 4f magnetic moment (-0.1 μ_B) on Ce at room temperature. While the 4f polarization is limited to the immediate interface the 5d polarization extends over the entire a-phase-like part in the Ce layers [3].

The XMCD experiments were intended to probe the hysteresis of the magnetic 5d polarization of Ce. They were performed at the Ce-L_2 $(2p \rightarrow 5d)$ absorption edge on the energy-dispersive beamline ID24 in transmission mode at room temperature, with an external magnetic field (up to a few 100 Oe) as a free parameter and the multilayer in glazing angle position with respect to the field. Circularly polarized light was produced by a diamond quarter wave plate, and for a given magnetic field with fixed direction, the helicity of the photons was changed by flipping the quarter wave plate between two angular positions on either side of a suited Bragg reflection profile of the plate material [2]. The beam was focused to a diameter of 1.5μm on the sample. The multilayers had been prepared before on substrates of Kapton foil, with thin buffer and protective capping layers of Cr. Three samples [CeXÅ/Fe30Å]×n were investigated, with Ce-layer thicknesses of 20, 53 and 45 Å.

The results reveal a very special magnetization reversal on Ce which must be connected with the polarization characteristics of this material in the multilayers. An example is shown in the figure where the Ce-L_2 XMCD signal of the multilayer [Ce35Å/Fe30Å]×62 is compared to the overall magnetization curve measured by means of the magnetooptical Kerr effect (MORE). It is clear that the MOKE curve predominantly reflects the Fe-sublayer magnetization. Both curves have been normalized to 1 at saturation. The following points are noteworthy: (i) The Ce- and Fe-layer magnetizations are antiparallel. (ii) The coercive field, remnant and saturation magnetizations are distinctly smaller in the Ce layers with respect to the total multilayer MOKE curve. Qualitatively, the same behavior has been observed for the two other multilayers, the differences being less pronounced for the multilayer with the 45-Å-thick Ce layers.

The interpretation must await a more detailed analysis of the data, which were only collected recently, and additional XMCD experiments probing the magnetic hysteresis of the Ce-4f and Fe-3d states. But there is evidence that the 5d-state magnetization reversal in Ce occurs differently for the Ce atoms directly at the interface with Fe and for those more distant to it. Small-angle x-ray diffraction diagrams of these multilayers reveal an intermixture of Ce and Fe at the interface involving 1 atomic layer of each element [3]. According to ^{57}Fe Mössbauer spectra [4], Fe in this interfacial zone shows a 6 times smaller magnetic hyperfine field than in the center of the layers, as a result of the 3d-4f and 3d-5d hybridization. These interfacial Ce atoms are strongly correlated with Fe and will follow closely the reversal of its magnetization, while the more distant Ce atoms respond more easily to the external field which then appears as an overall softer magnetic behavior of the 5d states of this α-like Ce in the multilayers.

The beamtime available did not permit, as originally proposed, to perform the same measurements on the hydrided multilayers [CeH_2/Fe]×n, where the 4f states of Ce are y-phase like and localized. But an exploratory attempt (with insufficient statistics) revealed that the Ce-5d magnetization in this system seems to follows that of the MOKE curve, with no difference in the coercive fields and remnant magnetization.

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