Introduction

Nuclear resonance inelastic x-ray scattering (NRIXS) of synchrotron radiation at the 14.4125 keV nuclear resonance of $^{57}$Fe is an efficient and unique method for the direct measurement of the Fe-projected vibrational density of states (VDOS) of thin films that contain this Mössbauer isotope. In this contribution we will demonstrate that the VDOS is a sensitive probe of the crystallographic structure in nanoscale multilayers (MLs). Our samples are UHV-deposited Tb/Fe MLs with different layer thicknesses ($t_{Tb} = 14$-$50$ Å, $t_{Fe} = 10$-$50$ Å). Tb/Fe MLs may exhibit perpendicular magnetic anisotropy and are known to undergo an amorphous-to-crystalline structural transition upon increasing layer thickness.

Methods and Materials

The following types of Tb/Fe MLs (labeled A-F, respectively) were prepared in UHV by thermal evaporation on Si(111) substrates held at 300K:

- A: [Tb(50 Å)/Fe(10 Å)]*20
- B: [Tb(50 Å)/Fe(20 Å)]*10
- C: [Tb(50 Å)/Fe(35 Å)]*8
- D: [Tb(50 Å)/Fe(50 Å)]*8
- E: [Tb(14 Å)/Fe(20 Å)]*10
- F: [Tb(14 Å)/Fe(35 Å)]*10

The pressure during growth was $< 1 \times 10^{-9}$ mbar. All Fe layers were enriched with 20% $^{57}$Fe. X-ray diffraction and Mössbauer spectroscopy (CEMS) confirm that crystallographic structure of the Fe depends on the Fe layer thickness.

The inelastic nuclear resonant absorption experiments were performed at the undulator beamline 3-ID of SRI-CA at the Advanced Photon Source. Details of the technique are described in refs. 2-5. The synchrotron radiation had an energy bandwidth of 2.3 meV after monochromatization.

Results and Discussion

Distinct differences in the VDOS have been observed by varying $t_{Tb}$ and $t_{Fe}$ (Fig. 1). For larger $t_{Fe}$ values (samples C, D, and F), the VDOS exhibit the typical phonon peaks between 23 to 28 meV (transverse phonons) and 36 meV (longitudinal phonons) of bcc-Fe, and the derived Debye-Waller (f-) factor is close to its bulk value. For the thinnest Fe layers (samples A, B, and E), the VDOS extends up to ~40 meV and shows a maximum at ~20 meV, and the broad and structureless feature is similar to that observed in amorphous (a-)$Tb_{1-x}Fe_x$ alloy films, yielding a smaller f-factor. With increasing Fe layer thickness, the VDOS provide evidence for the typical amorphous-to-crystalline transition of Fe near $t_{Fe} = 25$ Å. The VDOS does not depend on the Tb layer thickness in this thickness regime (compare samples B and E, and F and C, respectively).

Summarizing, we have demonstrated that NRIXS is a useful method for the measurement of the structural state in multilayer samples. Vibrational dynamics opens a new domain in thin-film research.

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References