

## Measurement of individual bond magnetostrictive strain in a-TbFe<sub>2</sub>

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We have succeeded in measuring the magnetostrictive strain of Fe-Fe and Fe-Tb bonds in an amorphous film of TbFe<sub>2</sub>. This has been made possible thanks to recent developments in the field of synchrotron radiation based methods, which have enabled the measurement of femtometer atomic displacements [1]. Using linearly polarized synchrotron radiation and the energy dispersive X-ray Absorption Spectroscopy beamline ID24 at the European Synchrotron Radiation Facility [2] we have performed X-ray Magnetic Linear Dichroism (XMLD) at the Fe K-edge on a 6 μm thick a-Tb<sub>28</sub>Fe<sub>72</sub> film, and have measured an increase of 0.0006 Å and of 0.001 Å in the Fe-Fe and Fe-Tb bonds respectively when the electric field E of the synchrotron radiation is perpendicular to the direction of the applied magnetic field B compared with the case when E is parallel to B. This work represents the first application of these new methods to the investigation of amorphous matter. Previous work on polycrystalline matter may be found in references [1, 3, 4].

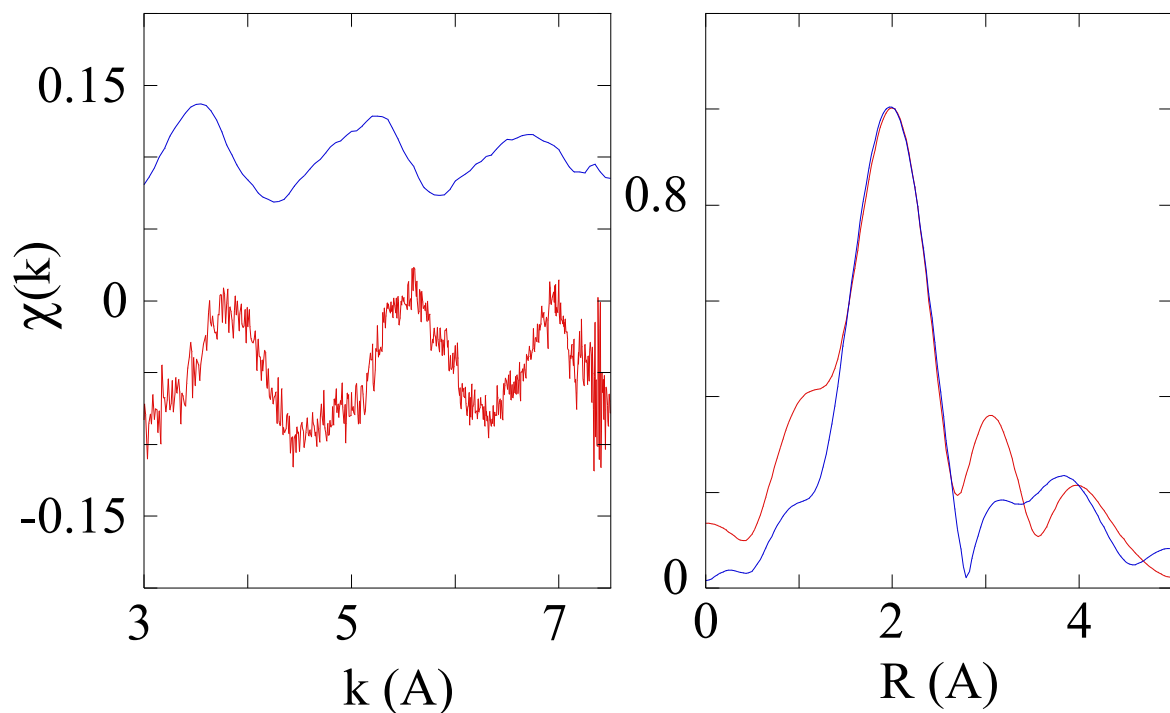
These results have been obtained in the framework of an Extended X-ray Absorption Fine Structure (EXAFS) study at the Fe K and rare earth (RE) L<sub>3</sub> absorption edges on amorphous RE-Fe<sub>2</sub> films such as TbFe<sub>2</sub>, DyFe<sub>2</sub> and TbDyFe<sub>2</sub> in the attempt to identify and eventually quantify magnetostrictive atomic displacements in these compounds. Such studies are aimed at elucidating the atomic origin of the giant magnetostriction observed in RE-transition metal compounds. It is well known for example that in RE-Fe<sub>2</sub> compounds, the huge anisotropy of the 4f electron cloud, the high moment, and the high Curie temperature, lead to large magnetostriction at room temperature [5]. In these systems, when the orientation of the magnetic moment of the 4f shell is rotated with respect to the crystallographic axes by an external magnetic field, it is assumed that the anisotropic 4f charge density is rigidly co-rotated and atomic displacements from the equilibrium positions are expected to occur. Internal distortions in TbFe<sub>2</sub> were predicted 40 years ago [6] but to date have not yet been detected.

In this perspective, the local character and the chemical sensitivity of XAS have the potential to shed light into the role played by the asymmetry of the rare-earth in the generation of such large strains. In an earlier attempt to use Extended X-ray Absorption Fine Structure (EXAFS) spectroscopy as a microscopic strain gauge to probe which atoms contribute to the observed magnetostriction of the giant magnetostrictive material Terfenol-D (Tb<sub>0.3</sub>Dy<sub>0.7</sub>Fe<sub>2</sub>), no internal distortions of the unit cell were observed to within ±0.003 Å [7].

The TbFe<sub>2</sub> film used in this experiment was grown by RF magnetron sputtering on a 200 μm vitreous carbon substrate using an Fe target with Tb chips. For this first attempt at detecting internal distortions, we have chosen to investigate TbFe<sub>2</sub> in its amorphous phase as the structurally isotropic nature of our films allowed to simplify the interpretation of the data.

From a technological point of view, the structural disorder inherent to these “thick” amorphous RE-Fe<sub>2</sub> films overcomes the system’s strong magneto-crystalline anisotropy and thus negates the main technological problem encountered when attempting to make magnetoelastic devices from their crystalline counterparts. Since the amorphous structure averages out local anisotropy, there is considerable interest in the applications of such amorphous materials, particularly if they possess high magnetostriction and require lower saturation fields than the corresponding crystalline materials.

To detect bond strain induced by magnetostriction the sample is magnetized by a saturating 0.5 T magnetic field applied in the film plane. We then measure changes in photoelectron scattering path length induced by local atomic distortions arising from a 90° rotation of the magnetic field. Analysis of the EXAFS oscillations from both edges reveals a local structure around Fe composed of a first shell of 6 Fe atoms at  $\sim 2.5$  Å and of a second very disordered shell of 6 Tb atoms at distances between 3 and 3.8 Å. A model with a split second shell (3 Tb at  $\sim 3.0$  Å and 3 Tb at 3.8 Å) reproduces the EXAFS oscillations very well. The left panel of the figure compares the Fe K-edge EXAFS signal (blue) to the XMLD signal multiplied by a factor 1000 (red). The Fourier Transforms of the two signals are shown in the right panel. A fit of the frequency region  $R = 1.5 - 3.0$  Å, which includes the contribution of the 6 Fe-Fe and of the 3 short Fe-Tb bonds, yields best fit strain values of the order of  $250 \pm 50$  ppm and  $380 \pm 100$  ppm for the Fe-Fe and Fe-Tb bonds respectively.



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