Nanostructured Soft Magnetic Thin Film Materials: Nanograins in an Amorphous Matrix

Personnel: J.E.Snyder (Associate Scientist), D.C.Jiles (Senior Physicist), J.W. Anderegg (Assistant Scientist), C.C.H.Lo (Associate Scientist) and J.S.Leib (Graduate student)

Abstract:

This research aims to understand the interaction of competing energy contribution in determining critical magnetic phenomena. Of particular interest are systems where the characteristic structural dimension is of the order of the magnetic interaction lengths or the energy difference between crystalline states is of the same order as the energy difference between magnetic states.

Recent Results:

Reactive-sputtered FeSiAl(N) films have been investigated, and it has been observed that when the partial pressure of nitrogen exceeds a critical value, the structure of the film undergoes a transition from single-phase large, columnar grains to a two-phase nanostructure of bcc nanograins (≤ 10 nm diameter) in an amorphous matrix. Film stress was determined and correlated with the magnetic properties determined by vibrating sample magnetometry (VSM) and domain structure determined by magnetic force microscopy. Coercivity and film stress both decrease steeply at this transition. Films were characterized by X-ray photoelectron spectroscopy for composition and chemical bonding information, and results compared to predictions based on free energies of formation.

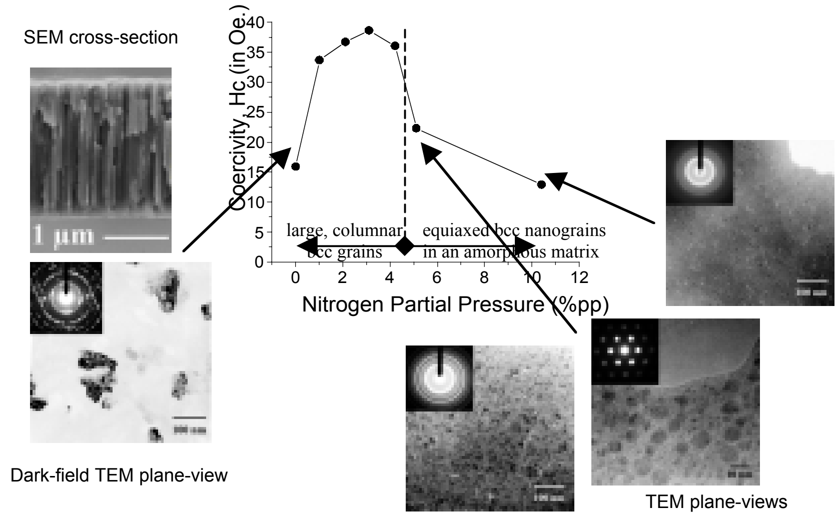

Fig. 1. Effect of Nitrogen on Micro/Nanostructure and Magnetic Properties of FeSiAl(N) Films

Magnetic force microscopy (MFM) has been used to obtain domain images in magnetic materials and this has formed a major thrust of the research effort into structure/property relationships in magnetic materials. Domain images obtained under applied fields have been correlated with structural information obtained by SEM and TEM and with magnetization data. MFM with *in situ* applied fields has been used to investigate magnetization reversal in magnetically soft nanostructured thin films. The FeSiAl(N) and CoFeHfO systems have both been investigated. In thin CoFeHfO films, for hard-axis applied fields, a ripple-like domain pattern formed and rotated gradually as reversed field was increased. These films have also been reported in the literature to consist of nanograins in an amorphous matrix, and furthermore to show spin-dependent transport in magnetic tunneling trilayer structures.

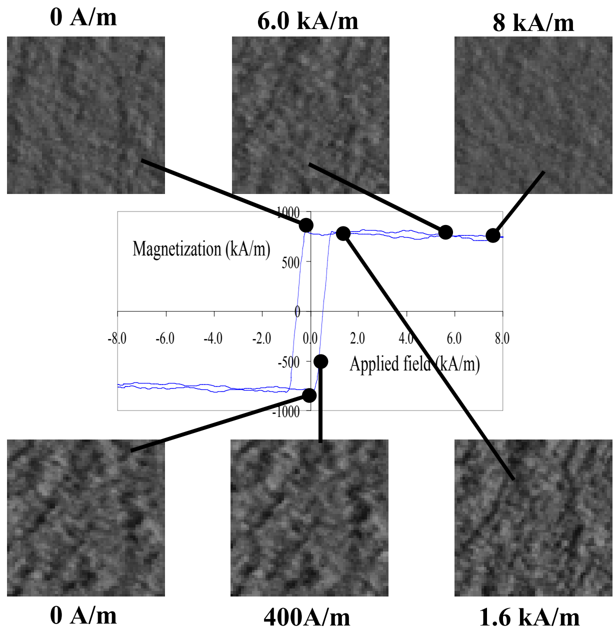

Fig. 2. Magnetic Force Microscopy images showing the domain structure evolution under the action of a magnetic field along the easy axis of a 10 nm CoFeHfO film.

Significance:

We have shown that dramatic changes occur in both nanostructure and properties of FeSiAl(N) films when nitrogen exceeds a critical value. N was shown to combine first with Al, then with Si, in order of the free energy of formation of the respective nitrides, and the nanostructural transition occurs at the point when the Al is all nitride and the Si is starting to react. Our results on the effect of composition and stress on magnetic properties have improved our understanding of the phenomenon through a combination of experimental measurements and modeling. Results have also been used to test predictive theory of the stress dependence of these magnetization processes. We have developed equipment for making MFM images under the action of applied magnetic fields at different temperatures so that we can study the evolution of domain configurations in these materials.

Future Work:

The magnetic coupling behavior of two-phased nanostructured soft magnetic thin films will be investigated by temperature dependent DC magnetization and AC susceptibility methods, varying nanograin size and separation by varying film growth conditions. A new laboratory for the preparation of nanostructured magnetoelectronic and spintronic materials has been established through non-BES funding. This includes a state-of-the-art ion beam deposition system and extends our research into two different types of nanostructured magnetic materials: nanostructured soft magnetic thin films, and magnetoelectronic multilayers.

Interactions:

Collaboration with R.W. McCallum of Ames Laboratory on temperature-dependent characterization, I.Tomas, Czech Academy of Science, Prague, Czech Republic, M. Pasquale, Galileo Ferraris Institute, Turin, Italy, H. Hauser, Technical University of Vienna, Austria