Nanoparticle Arrays of Ni, Fe, Co, CoPt, and FePt: Ion Beam Synthesis and Competing Magnetic Energy Scales

J. R. Thompson[a,b], K.D. Sorge[a,b], L.A. Boatner[a], J.D. Budai[a], T.E. Haynes[a], Hwee Kwan Lee[a], A. Meldrum[c], T.C. Schulthess[a], C.W. White[a], and S.P. Withrow[a]

[a]Oak Ridge National Laboratory, Oak Ridge, TN 37831
[b]University of Tennessee, Knoxville, Tennessee
[c]University of Alberta, Edmonton, Alberta, Canada

INVITED PRESENTATION

NANOMAT Congress 2003
European Academy of Sciences
Brussels, Belgium
October 22–24, 2003

prepared by
CONDENSED MATTER SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY
Managed by
UT-BATTELLE, LLC
under
Contract No. DE-AC05-00OR22725
with the
U.S. DEPARTMENT OF ENERGY
Oak Ridge, Tennessee

November, 03

"Nanoparticle arrays of Ni, Fe, Co, CoPt, and FePt: ion beam synthesis and competing magnetic energy scales" J. R. Thompson,[a,b] K.D. Sorge,[a,b] L.A. Boatner,[a] J.D. Budai,[a] T.E. Haynes,[a] Hwee Kwan Lee,[a] A. Meldrum,[c] T.C. Schulthess,[a] C.W. White,[a] and S.P. Withrow[a]

[a] Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6061 USA
[b] Department of Physics, University of Tennessee, Knoxville, Tennessee, 37996-1200 USA
[c] Department of Physics, University of Alberta, Edmonton, Alberta, Canada

We have investigated the synthesis and magnetic properties of a series of nanoparticle systems containing Ni, Fe, Co, CoPt, or FePt. A dispersed array of nanoparticles was formed by implanting ions of the elements into either single crystal hosts such as Al_2O_3 and yttrium-stabilized cubic zirconia (YSZ) or amorphous SiO_2, to fluences of $\sim 10^{17}$ ions/cm^2. Subsequent heat treatment precipitated metallic particles from the supersaturated solution, forming a buried layer of dispersed, electrically isolated particles with a peak concentration of ~10 % by volume. X-ray diffraction and transmission electron microscopy studies showed that the particles are often faceted and preferentially textured by a crystalline matrix, with typical particle dimensions of a few nm. For the FePt intermetallic, XRD showed considerable ordering into the high anisotropy $L1_0$ phase, while the ordering in CoPt was more limited.

Magnetic studies of these systems revealed a competition between at least four energy scales: the usual "Zeeman" interaction between a magnetic moment and an external field, a magnetocrystalline anisotropy, a magnetostatic inter-particle interaction, and the thermal energy. We have explored this competition by investigations of the magnetic response as a function of magnetic field *H*, temperature *T*, and orientation, for ferromagnetic materials (Ni, Fe,…, FePt) in which the bulk magnetocrystalline anisotropy varies by several orders-of-magnitude. For example, α-Fe nanoparticles in YSZ are dominated by magnetostatic interactions, which make the in-plane direction the easy axis and serve to stabilize the remanence to temperatures far above the expected "blocking" temperature where the magnetic 'memory' would be lost. The essential role of inter-particle interactions in stabilizing the remanent magnetization has been demonstrated by numerical simulations using the observed distributions and sizes of the particles. In contrast, ordered FePt nanoparticles are governed primarily by strong magnetocrystalline anisotropy up to temperatures near their measured Curie points, $T_c \approx 700\text{-}730$ K. These and related examples illustrate some of the rich diversity of magnetic phenomena in nanoparticle systems.

The Oak Ridge National Laboratory is managed by UT-Battelle, LLC for the United States Department of Energy under contract No. DE-AC05-00OR22725.

file: NANOMAT_abstract.doc for NANOMAT Congress (European Academy of Sciences, Brussels, 22-24 October 2003); invited presentation.