SCIENCE AND TECHNOLOGY OF SELF-ASSEMBLED MAGNETIC AND SUPERCONDUCTING NANO ARRAYS

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The research goals of this NIRT project are to develop a fundamental understanding of self-assembly growth process to synthesize ordered structures of nanomaterials with significantly improved properties and to create prototype devices using nanomaterials synthesized in the project. The NIRT members have recently discovered a pulsed laser deposition based method that is generic in nature for creating three-dimensional nanostructures of materials ranging from magnetic, to superconducting, to optical, to stronger metals and ceramics, and so on. In this report, we are briefly highlighting three of our major accomplishments.

I. Coherent nanostructures in superconducting thin film matrix: A controlled distribution of nanophase materials in a superconducting thin film matrix has been found to beneficially impact their physical properties and accordingly the performance of devices comprised of superconducting materials.[1] This benefit arises from their characteristic length scales such as coherence length and penetration depth are in the nanorange.

Figure 1(a) is a scanning transmission electron microscopy (STEM) image of an $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin film embedded with Y_2O_3 nanodots. The inset of Fig. 1(a) shows an electron diffraction pattern from this area where the YBCO (001) lattice vector has been highlighted with an arrow, while the Y_2O_3 (002) reflection has been marked with a circle, showing that they are perfectly aligned with each other. Nanodots in the image have been indicated with arrows. Figure 1(b) shows a high resolution Z-contrast STEM-Z image of one such Y_2O_3 nanodots. The Y_2O_3 nanoparticles are crystalline and coherent with the YBCO matrix. In this figure, Y atomic planes in YBCO have been highlighted with white dotted lines, evidencing that the interface runs parallel to the YBCO *ab*-plane, and consists of a Y plane shared between both materials.

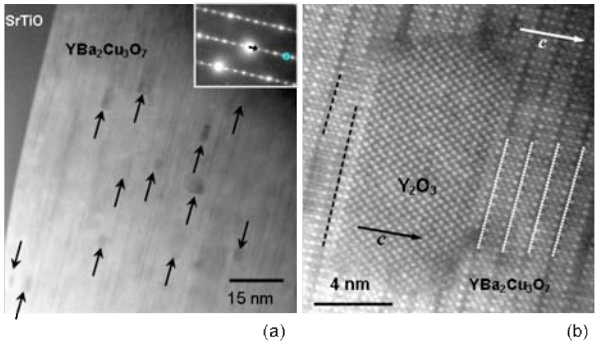

Fig. 1. STEM-images of (a) an YBCO film embedded with Y_2O_3 nanoparticles (indicated by arrows) and (b) a coherent Y_2O_3 nanoparticle in YBCO matrix.[1,2]

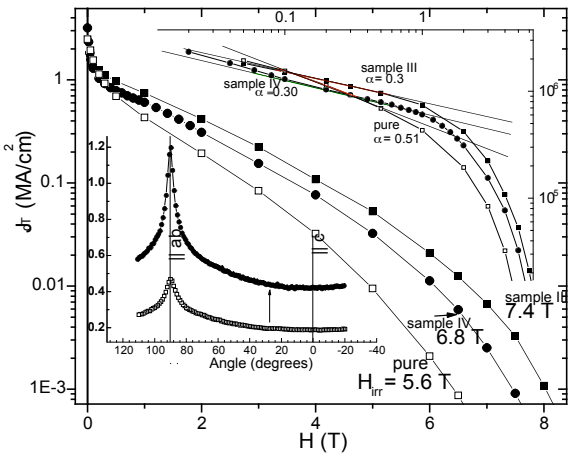

Fig. 2. Magnetic field dependence of transport critical current density J_{cT} at 77 K for B || c of multilayered film, YBCO/(Y2O3/YBCO) x 9.[2]

The improvement in $J_c(B)$ of YBCO films with inclusion of coherent Y_2O_3 nanodots (Fig. 2), each nanodot acting as a flux pinning center as evident from the upward shift of the irreversibility field H_{irr} (upper inset of Fig. 2), has been demonstrated on two substrates, a factor of three on $LaAlO_3$ and a factor of five for multilayers on $SrTiO_3$ substrates, at B = 5 T.[2] The absence of any "peak" (lower inset of Fig. 2) for orientations about the direction of the *c*

axis shows that the improvement in pinning is fairly isotropic and enhancement in J_{cT} occurs over a wide range of field orientations.

II. Self-assembled nanomagnetic particles in thin film matrices: By using our sequential processing, we have laid down the layer of the matrix which is followed by deposition and formation of nanodots of uniform size.[3] Fig 3 (a) shows 7 nm Ni nanodots in the alumina matrix by the simultaneous method, where Fig 3(b) shows detailed atomic structure of a nickel nanodots produced by our sequential method. With 7 nm nanodot size and assuming one bit of information is stored in the spin of a nanodot, we can store over 10 Terabits of information per square inch of the chip area, leading to 250 million page of information in a single chip.

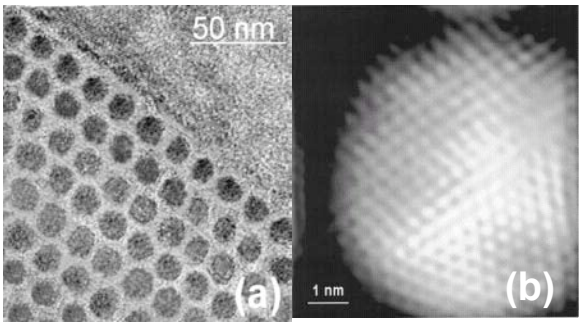

Fig. 3 (a) 3-D self-assembled Ni-nanoparticles in Al_2O_3 thin film matrix. (b) STEM-image of a single Ni-nanoparticle in Al_2O_3 thin film matrix.[3]

III. Surface Proximity Enhanced Magnetism of a Buried Magnetic Layer: Magnetism in reduced dimensions is strongly influenced by the proximity of interfaces and surfaces.[4] An understanding of these effects is essential to fully realizing the potential of nanostructured magnetic materials where such influences cannot be avoided because of large surface-to-volume ratios. We are studying the magnetic properties of ultra thin Fe films, 1.5 Å thick, buried a distance *x* from the top surface of 200 Å thick Pd films. Palladium as a non-magnetic host is advantageous for two reasons: (1) it protects the Fe from oxidation for *x* as small as 5 Å and (2) ferromagnetic moments can be induced on the Pd atoms in close proximity to the Fe layer. Systematically decreasing *x* from 50 to 5 Å results (Fig. 4) in pronounced increases in extrinsic (coercivity) and intrinsic (Curie temperature) magnetic properties.

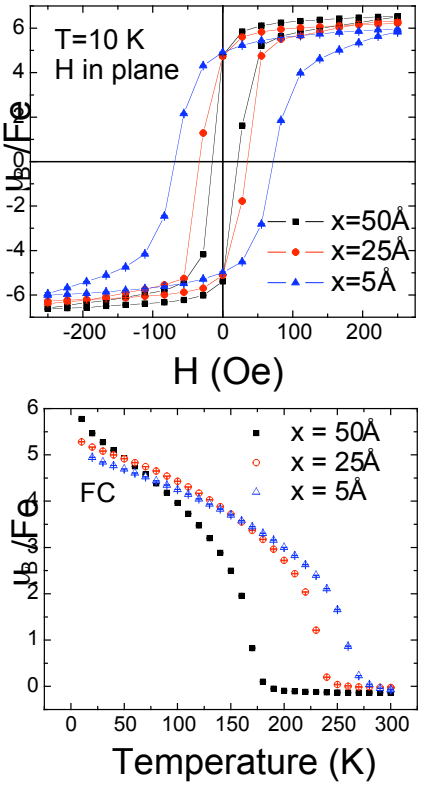

Fig. 4: Field (top) and temperature (bottom) dependence of normalized Fe moment Bohr magnetons) for different *x*. The coercivity increases by a factor of 3.8 and the T_c by a factor of 1.6. The saturated moment for all *x* is enhanced by a factor of ~3 over the value (2.1 Bohr magnetons) for pure iron.[4]

1. D. Kumar, "Science and technology of nanomagnetic and superconducting thin films" TMS Annual Meeting, March 14-18, 2005, San Francisco. (Invited Presentation).

2. A. Gapud, D Kumar, S K Viswanathan, C Cantoni, M Varela, J Abiade, S J Pennycook and D K Christen, "Enhancement of flux pinning in $YBa_2Cu_3O_{7-}$ thin films embedded with epitaxially grown Y_2O_3 nanostructures using a multi-layering process" Supercond. Sci. Technol. **18**, 1502-1505, (2005).

3. J. Narayan and A. Tiwari, "Novel methods of forming self-assembled nanostructured materials: Ni nanodots in Al_2O_3 and TiN matrices" J. Nanosci. Nanotechnol. **4**, 726-732 (2004).

4. A. Hebard, "The role of disorder in the suppression of long-range magnetic order in nanoscale systems," MRS 2005 Spring Meeting, San Francisco (Invited presentation).