Grain Alignment and Magnetization Anisotropy of Nd$_{1.85}$Ce$_{0.15}$CuO$_4$

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Procedures have been developed to make Nd$_{1.85}$Ce$_{0.15}$CuO$_4$ powders which have the c-axis of all the grains aligned in one direction. By rotating a powder sample mixed with liquid epoxy about an axis perpendicular to a strong applied magnetic field, the c-axis of the grains aligns with the axis of rotation. The procedure works for any material having the maximum room-temperature susceptibility perpendicular to the c-axis. Using this technique, we measured the magnetic anisotropy of this electron-carrier high-temperature superconductor.

KEY WORDS: superconductor; Nd–Ce–Cu–O; grain aligned.

1. INTRODUCTION

High-temperature superconductors are sufficiently anisotropic that measurements on samples with randomly oriented grains are difficult to interpret. Single crystals, of course, are the best if they can be properly oxygenated, but for even modest-sized crystals it is difficult to diffuse oxygen all the way through the crystal. As a substitute for single crystals, often, orientation-dependent data can be taken on composites of many single crystals if the individual crystals are sufficiently well aligned. As was first shown by Farrell and coworkers [1], Y$_1$Ba$_2$Cu$_3$O$_7$, Y(123), tends to fracture along grain boundaries and it is possible both to make powders of tiny single crystals and to grain-align them with a magnetic field. For Y(123) the susceptibility at room temperature is larger along the c-axis than it is along the a–b plane so there is a torque aligning the c-axis with the field. By mixing powders of Y(123) in a low-viscosity liquid epoxy and placing this composite in a large magnetic field, the magnetic torque will turn the grains so that

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529
the c-axis is parallel to the field. By letting the epoxy harden, a sample is obtained which is composed of tiny single crystals oriented with the c-axis parallel to the magnetic field $H$. Optical photographs of polished surfaces of the pellets under polarized light show that the particles are tiny single crystals separated from one another by epoxy and having the twin planes oriented. Further X-ray powder patterns and x-ray rocking curves show that the mosaic spread of the orientation is less than $2^\circ$ full width at half maximum (FWHM).

This is a broadly applicable technique but the direction of the c-axis may be either parallel or perpendicular to $H$ depending on the direction of maximum susceptibility. Hart and coworkers [2] and others [3] surveyed many high-transition-temperature, $T_c$, materials and found that substituting La, Nd, Pr, Sm, Dy, Ho, and Lu for Y in the (123) structure all give samples with the c-axis along $H$. This is to be contrasted with the substitution of Gd, Eu, Er, Tm, and Yb, for Y in Y(123) which gives samples with the c-axis perpendicular to $H$. In the $K_2Ni_1F_4$ or (214) structure, $La_2Cu_4O_4$, $Eu_2Cu_4O_4$, and $Gd_2Cu_4O_4$ align with the c-axis parallel to $H$ and $Nd_2Cu_4O_4$, $Pr_2Cu_4O_4$, and $Sm_2Cu_4O_4$ align with the c-axis perpendicular to $H$. Presumably crystal field effects and a combination of the magnetic moments on the Cu sites and the rare earth sites contribute to the anisotropy of the total susceptibility.

For the study of the superconducting properties of high-$T_c$ materials, it is generally better to have the c-axis of all the grains pointing in the same direction. The easy direction for supercurrent flow is in the $a-b$ plane, and it is essential to study the motion of vortices in the geometry where the axis of the vortex is parallel to the c-axis. Simply knowing a unique direction for the $a-b$ plane often is not very helpful. For these materials, the c-axis for various grains could lie anywhere in the plane perpendicular to the aligning field and there is no unique c-axis direction.

The $Nd_{1.85}Ce_{0.13}CuO_4$ superconductors are important because Hall effect studies show that there are a large number of electron carriers contributing to the normal state conduction process [4]. If these carriers also participate in the superconducting ground state, they might have critical current densities $J_c$ that are different from the hole-carrier materials such as Y(123). It is not really known how $J_c$ values for electron carriers might differ from hole-carrier materials. Electrons and holes, however, occupy different energy bands, and electron supercurrents might respond to weak-link barriers such as grain boundaries in a way different from the hole carriers. In any case, it is important to measure fundamental properties such as the anisotropy of the free-energy surfaces, the anisotropy in the upper critical field, $H_{c2}$, the lower critical field, $Hc1$, and the intragranular $J_c$ values.