STATIC AND TIME DEPENDENT MAGNETIZATION STUDIES OF

Y1Ba2Cu3O7 THIN FILMS*

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ABSTRACT

Thin films of Y1Ba2Cu3O7 (YBCO) were deposited by electron-beam coevaporation of Y, Cu, and BaF2 onto single-crystal substrates of SrTiO3 and KTaO3. Various oxygen annealing protocols produced different epitaxial alignments of the films, which were then studied using vibrating sample (VSM) and SQUID-based magnetometry. The magnetization behavior and the critical current density Jc(H,T) deduced from the magnetic hysteresis is observed to be quite sensitive to the substrate orientation as well as to annealing procedures that result in variations of the film morphology as evidenced by x-ray diffraction and and SEM techniques. Flux creep effects are also observed over short time intervals in VSM studies and examined quantitatively over longer periods with a SQUID magnetometer.

INTRODUCTION

A large body of work has established that the superconducting properties of thin Y1Ba2Cu3O7 films prepared by electron-beam evaporation or sputtering techniques followed by annealing procedures are very sensitive to the substrate on which they are deposited. In some cases, a severe degradation in the superconducting properties is observed due to formation of reactive layers at the interface between the YBCO film and substrate (e.g., Al2O3, ZrO2, and Si).1,2 Such interfacial reaction effects are particularly severe in those formation methods requiring thermal anneals in the temperature range near 850°C. Interdiffusion across film-substrate interfaces presumably also occurs, but to a lesser degree, with the use of single-crystal SrTiO3 and KTaO3 substrates,3 but in these cases the transition temperatures Tc of the YBCO films remain high at ~90 K and with a transport critical current Jc that depends critically on the epitaxial growth that, in turn strongly depends on substrate orientation.4

Accordingly, in the present work magnetic studies of high T_c films formed by coevaporation onto single-crystal SrTiO_3 and KTaO_3 substrates were undertaken in order to evaluate these materials for use in electronic devices and other possible applications.

EXPERIMENTAL TECHNIQUES AND APPARATUS

Thin films of YBCO ~350 nm thick were formed by e-beam coevaporation of Y, Cu, and BaF_2 onto single-crystal substrates that previously had been ultrasonically machined into circular discs ~6 mm in diameter. The Y1Ba2Cu3O7 phase was formed by a high-temperature reaction in wet oxygen. The substrate materials in this case were single-crystal SrTiO_3 with (001) and (110) surfaces and KTaO_3 with a (001) surface. Preparation of the samples has been reported elsewhere.3,4 It is worth noting that the deposition of films on the (001) and (110) SrTiO_3 substrates was made in the same run and was followed by identical annealing procedures. The morphology of these films can be summarized as follows: (1) on a (001) SrTiO_3 substrate, the film consisted predominantly of domains with the c-axis perpendicular to the substrate surface and with the a- and b-axes approximately aligned with the in-plane [100] axes of the substrate (sample A), (2) by suitable heat treatment, the film on (001) KTaO_3 consisted of comparable fractions of grains with either the a-axis or c-axis perpendicular to the surface (sample B), and (3) on a SrTiO_3 (110) substrate, a mixture of finely divided domains (~1 x 1 \mu m^2) was observed with [110]- and [103]-type orientations relative to the surface (sample C).

Magnetic properties of these samples were investigated in the temperature range from 1.5 K to 100 K in a vibrating sample magnetometer (VSM) and a commercial SQUID magnetometer. The static magnetic field capability was 8.0 T and 5.0 T respectively for these studies. The circular disc samples were oriented with the plane of the disc normal to the applied field and to first order can be considered as oblate spheroids with demagnetization factor D ~ 1. Isothermal magnetization data were obtained using both types of magnetometry. With the VSM, the applied field was ramped at ~100 Oe/sec and periodically stopped to observe the early stages of flux relaxation which can be quite large. The same procedure was followed while ramping the magnetic field back to zero. Similar magnetization investigations were made on these samples with the SQUID magnetometer. While the earliest stages of flux creep could not be probed with this apparatus, it did offer the ability to study flux creep rates over extended periods of time. In addition to high-field magnetization measurements, constant low applied magnetic fields (~10 Oe) were used to obtain zero-field cooled data while varying the temperature in order to determine T_c. The 10% onset of the T_c values was found to be 89.1 K, 88.4 K, and 71.2 K, respectively, for samples A, B, and C. The low value of T_c for sample C is not understood but it may be related to the granularity of this film. At 10 Oe no Meissner flux exclusion was observed in field-cooled studies for any of the samples because of significant volume and boundary flux pinning.

MAGNETIZATION RESULTS

Figure 1 shows the isothermal magnetization curves at 4.2 K for the YBCO film A with the c-axis normal to the (001) surface and parallel to the