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OBSERVATION OF SCREW DISLOCATIONS IN SPUTTERED $YBa_2Cu_3O_{7-\delta}$ FILMS

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By imaging the as-grown surfaces of sputtered $YBa_2Cu_3O_{7-\delta}$ films with scanning tunneling microscopy (STM), we have directly observed spiral-shaped growth terraces that emanate from screw dislocations. This surface morphology has important implications for Josephson junctions and superlattices. The density of screw dislocations observed is in the range of $10^9\,cm^{-2}$. In addition to their importance as flux pinning sites, these screw dislocations act as growth centers by continually providing a growth step for the attachment of incident species by a step-propagation growth mechanism known as screw dislocation mediated growth. Growth parameters strongly influence the screw dislocation density: it decreases with increasing growth temperature, decreasing growth rate, and increasing substrate misorientation for $SrTiO_3$ surface orientations near {100}.

1. INTRODUCTION

Recently, it has been demonstrated that high-quality images of the as-grown surfaces of $YBa_2Cu_3O_{7-\delta}$ films can be obtained by STM.[1,2] Observations of sputtered[1,2] and laser-ablated[3] $YBa_2Cu_3O_{7-\delta}$ films by STM have revealed high densities of screw dislocations ($\approx 10^9\,cm^{-2}$), which are not only potentially strong vortex-pinning sites,[4] but also have a dramatic effect on film growth.[5] Screw dislocations are known to have a great impact on the crystal growth process by continually providing a surface step, which is an energetically favored attachment site for the depositing species.[6] As growth proceeds, this surface step winds up into a growth spiral—a towering staircase of atoms centered around the screw dislocation.

2. EXPERIMENTAL

The c-axis oriented $YBa_2Cu_3O_{7-\delta}$ films, 120-1500 Å thick, were grown by DC hollow cathode magnetron sputtering on vicinal $SrTiO_3$ {100} substrates (tilted by up to 3.5 degrees off <100>) at substrate heater block temperatures of 750-780 °C. Electrical transport measurements indicated typical $T_c(\rho=0)$ values of 87-90 K, resistivity ratios (ρ_{300}/ρ_{100}) of 2.5-3, and critical current densities $J_c = 1\text{-}8\times10^6$ A/cm^2 at 77 K and $J_c = 1\text{-}7\times10^7$ A/cm^2 at 4.2 K.

The as-grown $YBa_2Cu_3O_{7-\delta}$ films were investigated by STM at room temperature in air using mechanically prepared $Pt_{0.8}Ir_{0.2}$ tips, a tunneling current $I_T = 10\text{-}20$ pA, and a tip bias voltage $V_T = 0.5\text{-}1$ V. Further experimental details can be found in Refs. 1, 4 and 5.

3. RESULTS AND DISCUSSION

All of the sputtered $YBa_2Cu_3O_{7-\delta}$ films imaged by STM contained growth spirals induced by screw dislocations, an example of which is shown in Fig. 1. From this we conclude that these defects are an intrinsic property of sputtered $YBa_2Cu_3O_{7-\delta}$ films. The step height between successive turns of the growth spirals corresponds to the c-axis length of $YBa_2Cu_3O_{7-\delta}$, and the surface roughness of the films is typically 100-200 Å.

Controlling the surface roughness and defect densities, which occur as a result of screw dislocation mediated growth, is important for thin film device applications. The effects of growth rate, growth temperature, and substrate misorientation were

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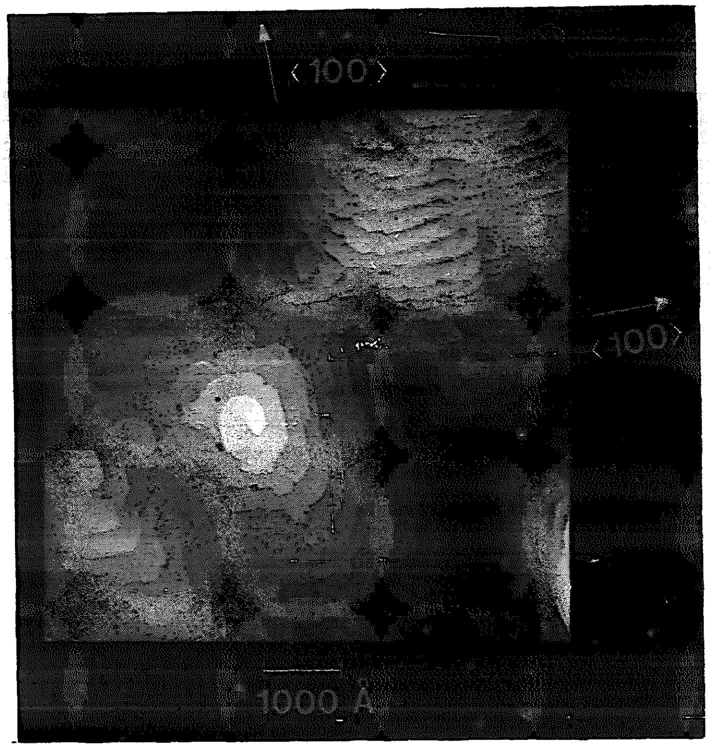

FIGURE 1. STM image of the as-grown surface of a 1500 Å thick sputtered $YBa_2Cu_3O_{7-\delta}$ film grown on $SrTiO_3$ {100} showing growth spirals emanating from screw dislocations. The in-plane < 100 > directions of the substrate are indicated. This film was grown at ≈755 °C and 0.5 Å/s and had a surface screw dislocation density of 8.5×10^8 cm^{-2}.

studied.[1,5] An increase in screw dislocation density was found to accompany increasing growth rate, whereas the screw dislocation density decreased for increased growth temperature and substrate misorientation away from {100}.

Screw dislocations may be particularly effective pinning sites when the flux lines are oriented parallel to the line of the dislocations, since pinning can then occur over a substantial fraction of the flux line length. We observe a correlation between the volume pinning force and the screw dislocation density in fields ($\mu_0\vec{H} \parallel c$) up to 8 T.[4] The observed density of screw dislocations is expected to provide a substantial fraction of the total volume pinning force in fields up to ≈ 0.01-0.1 T (at which the Lorentz force on the vortices exceeds the maximum available pinning force due to the screw dislocations), whereas in higher fields other correlated defects are believed to be responsible.[4] These as yet unidentified defects may be created during the coalescence of growth spirals.[2]

4. CONCLUSIONS

High densities (≈10^9 cm^{-2}) of screw dislocations have been observed in sputtered $YBa_2Cu_3O_{7-\delta}$ films grown under a wide range of conditions. These defects influence the resulting morphology and properties of sputtered and laser-ablated[3] $YBa_2Cu_3O_{7-\delta}$ films. The screw dislocation density, which influences the surface roughness and pinning properties of sputtered $YBa_2Cu_3O_{7-\delta}$ films, can be controlled by substrate temperature, misorientation, and growth rate. This ability is of importance for the fabrication of heterostructures such as superlattices and tunnel junctions.

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