

Pulsed Laser Deposition of Thin YBCO Films on Faceted YSZ Single Crystal Fibers

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Abstract. Flexible rods of single crystals of 9% Y₂O₃-stabilized ZrO₂ (YSZ) were used as substrates for deposition of high-critical temperature superconducting (HTS) thin films. YSZ fibers were prepared by mini-pedestal method with laser heating and had average diameter of 300 micrometers and 30 mm length. X-ray diffraction analysis demonstrated high crystalline quality of obtained fibers and also indicated the presence of 15° deviation of the fiber axis from the [001] YSZ direction. Thin YBa₂Cu₃O_{7-x} films were grown by pulsed laser deposition on YSZ rods using CeO₂ buffer layer. Films have shown high critical temperature of 90 K with sharp superconducting transition. Critical current density was estimated to about 3x10⁴ A/cm² at 80 K. Temperature dependence of critical current density suggests granular structure of films with grain size about several microns. Our results demonstrate feasibility of flexible YSZ fibers coated by HTS thin films for practical use.

Keywords: high-temperature superconductors, YBCO thin films, flexible substrates

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1. Introduction.

A significant progress in fabrication of high-quality high-critical temperature superconductors (HTS) power cables and ribbons could allow making HTS flux transformers. However, metal tapes used as substrates for fabrication of HTS cables are magnetic and conductive that are not compatible with superconducting quantum interference devices (SQUIDs) due to inserted magnetic noise and problem with realization of superconducting contacts [1, 2] to HTS thin-film multiturn input coil placed on the SQUID chip [3]. Therefore, flexible and non-magnetic non-conductive substrates should be used. Another important issue is providing a good superconducting contact between the HTS wire and the SQUID pick-up loop, if needed. Both problems have not been solved yet and represent a significant technological challenge.

To solve aforementioned problems, flexible single crystal fibers of different materials have been used as substrates for deposition of HTS thin films. Recently, YBa₂Cu₃O_{7-x} (YBCO) thin films with small width-to-thickness aspect ratio fabricated on sapphire faceted fibers by pulsed laser deposition (PLD) were reported [4]. Besides the sapphire, yttrium-stabilized zirconia (YSZ) could be used as a possible flexible substrate material for the HTS wires. The flexibility of the YSZ polycrystalline substrates in the form of thin sheets with thickness close to 50 μm has been shown previously [5]. Due to the cubic crystallographic structure it is much easier to obtain facets with correct orientation suitable for the YBCO thin film deposition. However, only few reports on fabrication of YBCO thick films by liquid phase



epitaxy [4] and hot-wall type metal-organic chemical vapor deposition [6] on YSZ fibers have been published.

2. Fabrication details.

High-quality single-crystal fibers were fabricated using mini-pedestal method with laser heating [7, 8]. Several fibers with length of about 30 mm and average diameter of about 300 μm were fabricated using this method and had at least one facet. Image of central part of one obtained faceted fiber is shown in figure 1 (a), and face image of the end of fiber is shown in figure 1 (b).

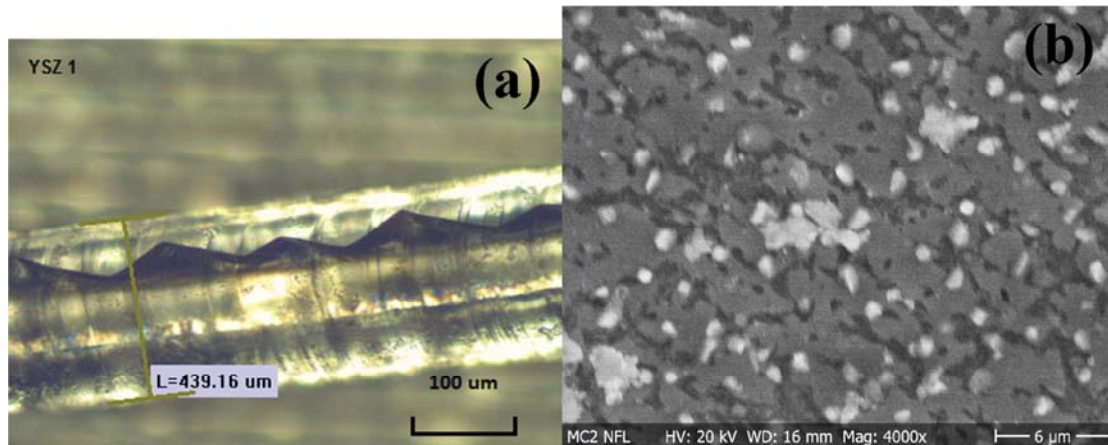


Figure 1. The images of the obtained YSZ faceted fiber. The long single-side facet is visible in fiber face – (a). Scanning electron microscopy images of the central part of the fiber with deposited film and silver-paint contacts placed on the holder - (b).

YSZ fibers were placed directly into the sapphire sample holder with 10×10 or 5×5 mm^2 open windows and covered by another 0.5 mm thick YSZ single crystal substrate to prevent deposition of film material on the heater. During the deposition, substrates were heated by SiC radiation heater from the back side.

25 nm thick CeO_2 buffer layers were deposited using RF sputtering at the temperature of 780 $^\circ\text{C}$. The layer was deposited with an RF source power of 100 W in a mixed argon-oxygen atmosphere (60% O_2 + 40% Ar) at a partial pressure of 0.1 mbar. Distance between target and sample was 30 mm. Sample was slowly (10 $^\circ\text{C}/\text{min}$) cooled down to a room temperature under 500 mbar oxygen pressure. After CeO_2 deposition, sample was transferred into the PLD chamber without breaking the vacuum.

YBCO films were deposited using pulsed laser deposition from a 3 inch stoichiometric target at the temperature of 880 $^\circ\text{C}$. Oxygen pressure during deposition was set to 0.6 mbar, repetition rate 10 Hz and laser energy density at the target 1.25 J/cm^2 . The substrate-to-target distance was set to 60 mm. 7500 laser pulses approximately correspond to YBCO thickness of about 360 nm.

The surfaces of the obtained YBCO films were investigated using scanning electron microscopy (SEM). Figure 1 (b) shows SEM image of the central part of the YSZ fiber with the deposited YBCO film. The size of grains was estimated about 5 μm .

3. Electrical characterization of the YBCO films.

Electrical measurements of deposited YBCO films were performed in the PPMS system (Quantum Design) in the temperature range 5 - 300 K and magnetic fields up to 8 T. Four electrical contacts were made along the fiber using gold bonding wire and additional silver glue reinforcement. Distance between contacts was about 1 mm.

Critical temperature, T_C of two deposited films was measured at zero magnetic field. Sharp superconducting transition at temperature about 90 K was observed in both samples. Residual resistance ratio between 300 K and 100 K was about 2. A small residual resistance below superconducting transition of the order 5Ω was observed in both samples. Estimated normal state resistivity at 300 K, ρ_n is close to $500 \mu\Omega\text{cm}$.

Magnetic field dependence of resistance, R , for one of the samples is shown in figure 2a. Obtained $R(H,T)$ dependence is typical for the case when magnetic field is oriented parallel to $(a-b)$ planes of the YBCO [9, 10]. Increasing the magnetic field does not only shift critical temperature but makes the transition wider. Broadening of the transition at high magnetic field can be explained by thermal activated flux-flow [11]. There is no shoulder in transition curve that is usually attributed to a lattice melting transition or giant thermal activated flux creep dissipation [10].

Temperature dependences of critical current for this sample are shown in figure 2b. $I_c(T)$ curve for the sample measured near the critical temperature is well-fitted to the Ambegaokar-Baratoff model corresponding to Josephson tunneling between film grains that is well approximated by $(1-T/T_c)$ dependence near T_c . In the case of low critical temperature granular thin film [12 - 15] such behavior corresponds to situation when supercurrent critical density is low and did not suppress the grain's gap parameter.

Due to the round shape of fiber and films it is rather difficult to estimate cross-section area of the YBCO film and corresponding critical current density. A reasonable assumption is that film covers uniformly facet surface with a width about 1/3 of fiber diameter. For the YBCO film thickness of about 300 nm, the critical current density, J_c can be estimated as $3 \times 10^4 \text{ A/cm}^2$ at 80 K for both samples.

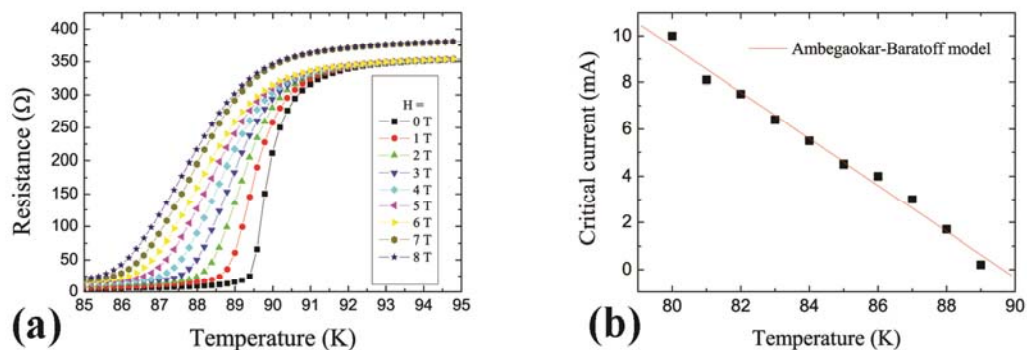


Figure 2. Temperature dependencies of YBCO film resistance at different magnetic fields (a). Experimental temperature dependence of critical current of YBCO films deposited on 10 mm long YSZ fiber (b).

4. Discussion

Our results show that YSZ faceted fibers can be used as substrates for pulsed laser deposition of YBCO thin films with good superconducting parameters (T_c about 90 K, reasonable critical current density). The residual resistivity below critical temperature can be explained by the presence of steps at the facet surface due to the presence of 15° deviation of the fiber axis from the [001] YSZ direction shown by XRD measurements. Large superconducting grains connected by normal metal (or semiconducting) inclusions could be formed here. This is further supported by the fitting of $I_c(T)$ curves that have behavior characteristic for granular films.

We note that these results have been obtained for fibers that did not have facets with proper crystallographic orientation suitable for epitaxial growth of YBCO films. Deviation of the fiber axis from the crystallographic [001] YSZ direction may be the main reason for granular structure of the YBCO films, formation of intergrain boundaries, and lower values of critical current densities. To fulfill the conditions of the epitaxial growth of the CeO₂ and YBCO layers the axis direction of the fiber should correspond to the <001> family of directions. In this case there should be the areas on the flank of the fiber corresponding to the directions [100], [010], [-100], [0-10] due to the cubic structure of the YSZ.

We used rather thick YSZ fibers that have been earlier demonstrated flexibility with typical bending diameter of 40 mm [16]. For practical applications it is important to grow fibers with smaller diameter of about 50 um that can significantly reduce the bending diameter to about 10 mm. It is also important to achieve proper facet formation conditions that would allow for well-oriented surface of the fiber and provide better conditions for the epitaxial growth of HTS films. We are currently working in this direction.

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