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Physica B 284–288 (2000) 1025–1026

PHYSICA B

www.elsevier.com/locate/physb

On-axis YAG:Nd^{3+} laser deposition of smooth high-T_c $YBa_2Cu_3O_{7-\delta}$ films

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Abstract

Velocity filtration of laser-induced plasma from droplets and solid particles has been successfully realized for infrared exciting radiation. Special approaches to preparation of targets and substrates as well as laser beam profiling have been proposed. Those new conditions enable reproducible on-axis deposition of particle-free $YBa_2Cu_3O_{7-\delta}$ films with high-T_c by pulsed YAG : Nd^{3+} lasers. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Laser deposition; YBaCuO films

Conventional on-axis (as opposed to off-axis [1]) pulsed-laser deposition is a convenient method of growing films of high-temperature superconductors (HTS) [2,3]. A large number of droplets and other particles generated by the laser beam is the main problem of the method. Use of fast shutters for velocity filtration of plasma streams induced by short-wave excimer laser radiation (wavelength 308 nm or shorter) has been found to provide protection of films from being hit by the particles [4].

As compared to the excimer lasers, YAG : Nd^{3+} lasers are cheaper to use and handy, but radiation densities across their beams usually are non-uniform. Furthermore, they produce radiation of longer (1.06 μm) wavelength and generate much more droplets and solid particles.

In this paper we study new conditions of on-axis YAG : Nd^{3+} laser deposition of $YBa_2Cu_3O_{7-\delta}$ (YBCO) films.

We deposited our films in oxygen at a pressure of 0.3 mbar on $ZrO_2 : Y_2O_3$ (YSZ) and $SrTiO_3$ single-crystal substrates heated to a temperature of 680°C and placed at a distance 5.5 cm from a rotated ceramic target. A disc-chopper installed between the target and the substrate at a distance 3.8 cm from the target was used as a fast shutter. An opening of 2.5 cm diameter was performed 6 cm off the disk center. The YAG : Nd^{3+} laser pulses (of 10 ns duration, 0.1–0.4 J energy, and about 14 Hz repetition rate) were triggered by a phase-adjustable electronic device when the opening was situated opposite the substrate. Critical temperature T_c of the films was measured as the temperature of the AC susceptibility transition midpoint ($\chi' = -0.5$).

YBCO films grown with targets of $YBa_2Cu_3O_{7-\delta}$ composition had a low-T_c and had large amount of precipitates on their surfaces. The highest T_c and no precipitates had YBCO films of nearly stoichiometric (or with a small Ba deficit) composition. We found, however, that their preparation required targets of about $YBa_{1.5}Cu_2O_x$ composition.

Ordinary on-axis deposition of 200 nm thick films with YAG : Nd^{3+} laser infrared exciting radiation led to

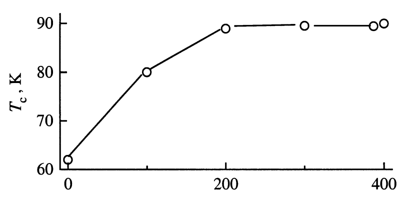

Fig. 1. T_c of YBCO films grown on YSZ substrates versus rotation frequency n of the disc-chopper.

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PII: S0921-4526(99)02367-4

Table 1

Beam profile	●	●	▽	×	○
Substrate	YSZ	$SrTiO_3$	YSZ	$SrTiO_3$	$SrTiO_3$
T_c (K)	77.0	81.4	90.1	91.3	91.0
	86.1	88.0	90.2	90.8	91.4
	82.7	89.2	89.9	91.0	90.3
	87.1	77.5	90.0	90.7	90.2

extremely large number of droplets (up to 10^8 cm^{-2}). As the mean size of the particles was about 1 μm, they covered the film surface almost completely and caused dramatic T_c reduction. The disc-chopper rotated with a revolution rate higher than 200 Hz demonstrated excellent separation of fast vapor streams and slow particles by time of flight, making the film surface shiny and T_c higher (see Fig. 1). The chopper rotated faster than 300 Hz reduced the number of particles by a factor of 10^6, at least.

We revealed also dramatic T_c reduction with increasing non-uniformity of the radiation density. So far as highly uniform beam profile was difficult to achieve and maintain, we increased the mean pulse energy density from 5–8 to 10–20 J/cm^2, so reducing vapor composition fluctuations due to complete evaporation of the less-irradiated target zones. It led however to ball-like plume shape and bad transfer of the evaporated material to the substrate. By various multimode adjustment of the laser resonator or using a mask we changed the beam profile to get sharp and bright lines (▽, ×, ○) or several bright spots instead of the ordinary (●) filled-circle shape. As a result, we got both high energy density and large size of irradiated target area, so providing oblong shape of the laser plume as well as effective vapor transfer [5]. The foregoing conditions enabled us to realize reproducible growth of YBCO films of high quality (see examples in Table 1 and Fig. 2).

Since our films grown on highly (1 0 0)-oriented substrates had reduced T_c (85–87 K), to all appearance due to the terrace epitaxy disturbance [6], slanting cuts 2–20° off the (1 0 0) plane were used.

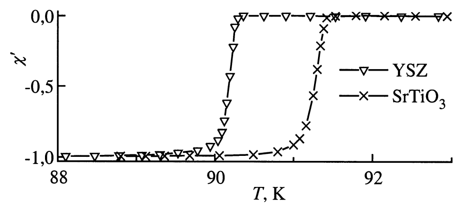

Fig. 2. Alternating-field screening curves of YBCO films grown on YSZ ((▽) profiled beam, $n = 400$ Hz) and $SrTiO_3$ ((×) profiling, $n = 380$ Hz) substrates.

In conclusion, by means of the plasma filtering with the beam profiling and the target composition correction on-axis YAG:Nd^{3+} laser deposition of HTS films of high quality has been realized.

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