Effects of Laser Repetition Rate on the Structural and Superconducting Properties of YBCO films Deposited by PLD on NiW Tapes

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Abstract. YBa2Cu3O7-x (YBCO) films were fabricated at various laser repetition rates on CeO2/YSZ/CeO2 buffered Ni-W tapes by pulsed laser deposition (PLD). The dependence of structural and superconducting properties on the laser repetition rates was investigated. The microstructure and surface morphology of YBCO films were characterized by X-ray diffraction and atomic force microscopy. And the critical current (Ic) of YBCO films was measured by the conventional four-probe method. The results show that with increasing laser repetition rate the island density decreased and the island size increased. It was found that the texture and Ic of YBCO films were largely dependent on the laser repetition rate. And furthermore it was observed that the film thickness was not in directly proportional to laser repetition rate. Under optimum experimental condition, high quality YBCO films with critical current Ic above 500 A/cm at 77 K and 0T were obtained.

1. Introduction
YBa2Cu3O7-δ (YBCO) is one of the most widely studied superconductors because of its significant potential for practical applications. YBCO have been fabricated by various techniques, such as metal organic deposition (MOD) [1], pulsed laser deposition (PLD) [2], and metal-organic chemical vapor deposition (MOCVD) [3,4]. Since PLD technique was widely used in preparing thin films with precise control of films reproducibility, uniformity and simplicity, it has been regarded as one of the most promising methods [5]. The effects of texture, deposition temperature and thickness on the growth of epitaxial YBCO film with well c-axis orientation have been extensively studied [6]. However the effect of laser repetition has rarely been studied. Therefore, in order to achieve YBCO films with high critical current, it is necessary to understand the relationship between the laser repetition rate and performance of YBCO film.

The aim of the present work is to prepare the YBCO films on buffered Ni-W tapes at different laser repetition rates and hence to investigate the influence of repetition rate on epitaxial growth, surface morphology and superconducting property.

2. Experimental
YBCO films were deposited on Ni-W tapes by PLD. The in-plane and out-of-plane textures of Ni-W tapes used in this study were evaluated by the full width at half maximum (FWHM) values of the X-ray diffraction (XRD) φ-scan and ω-scan as Δφ = 8-9° and Δω = 6-7° , respectively. Prior to the
fabrication of YBCO films, the buffer layers of cerium oxide (CeO$_2$) and yttria-stabilized zirconia (YSZ) were well prepared as described in reference [7]. The thicknesses of CeO$_2$-seed layer, YSZ layer and CeO$_2$-cap layer were approximately 50 nm, 100 nm and 250 nm, respectively. During YBCO film deposition, a KrF excimer laser with a wavelength of 248 nm was used and the incident angle between the laser beam and the target surface was 45°. The distance between the target and the substrate was about 3 cm. The energy of the laser was 200 mJ and the oxygen pressure was 200 mTorr. The substrate temperature was 760-800 °C and the repetition rate of the laser was range from 30-180 Hz. After deposition, Ag films were deposited using DC sputtering system and then the tapes were annealed at 500 °C in O$_2$ pressure for one hour.

The structure of the film was studied by a general area detector diffraction system (D8 Discover with GADDS, Bruker Advanced X-ray Solutions, Inc.) with Cu Kα radiation. The generation voltage is 40 KV and tube current is 40 mA. The surface morphology and root mean square (RMS) surface roughness of the film were examined with atomic force microscope (AFM, BioScope, Veeco Instruments, Inc.) in tapping mode. The thickness of the film was measured by a stylus-type profilometer (Dektak XT). The critical current (I$_c$) was measured in liquid N$_2$ (77K) using a DC four-probe method with the criterion of 1μV/cm.

3. Results and discussion

3.1. The structure of YBCO films deposited at different laser repetition rates

| Repetition rate (Hz) | 30   | 60   | 90   | 120  | 150  | 180  |
|---------------------|------|------|------|------|------|------|
| Substrate temperature (°C) | 760  | 770  | 780  | 790  | 800  | 800  |

First we fabricated the YBCO films at different laser repetition rates and substrate temperatures. It was found that the optimum substrate temperature was dependent on the laser repetition rate. Table 1 shows the optimum substrate temperature of YBCO film deposited at different laser repetition rates. As shown in table 1, with increasing laser repetition rate the optimum substrate temperature first increased and then kept constant when the laser repetition rate increased to 150 Hz.

![Figure 1. XRD θ-2θ scans of YBCO films deposited at different laser repetition rates. (a) 30 Hz, (b) 60 Hz, (c) 90 Hz (d) 120 Hz, (e) 150 Hz, (f) 180 Hz](image-url)
X-ray diffraction (XRD) θ-2θ scans of the YBCO films were carried out to characterize the structure of the YBCO films deposited at optimum substrate temperature and different laser repetition rates. The XRD pattern of the YBCO films was shown in Fig.1. The appearance of peaks (00l) is observed, which shows that the YBCO film with a c-axis orientation was preserved. The peak intensity of the films increased and full width at half maximum (FWHM) decreased with increasing laser repetition rate. The crystallite size of the films was calculated using the Scherrer formula, and we found that the crystallite size increased with increasing laser repetition rate.

3.2. The surface morphologies of YBCO films deposited at different laser repetition rates

Fig.2 show the AFM images of the YBCO films deposited at various repetition rates. The images show the uniform distribution of crystallites with dense structure. The crystallite size, the particles and surface roughness increased with increasing laser repetition rate and the result is confirmed with our XRD pattern.

![AFM images of YBCO films deposited at various laser repetition rates](image)

Figure 2. AFM images of YBCO films deposited at various laser repetition rates. (a) 30 Hz, (b) 60 Hz, (c) 150 Hz, (d) 180 Hz

3.3. The superconducting properties of YBCO films deposited at different laser repetition rates

The thickness and \( I_c \) of YBCO film deposited at different laser repetition rates were measured by a stylus-type profilometer and the conventional four-probe method without microbridge patterning at 77 K and self field, respectively. Then we calculated the deposition rate and the critical current density \( J_c \) of the YBCO film, which were shown in table 2. As can be seen from table 2, with increasing laser repetition rate, the deposition rate decreased, and the \( J_c \) first increased and then decreased. The highest
Jc of $5.1 \times 10^6 \text{ A/cm}^2$ was obtained for the YBCO film deposited at 150 Hz. Then we fabricated 2 µm thick YBCO film at optimum condition, which has the highest $I_c$ of 520 A/cm and $J_c$ of $2.6 \times 10^6 \text{ A/cm}^2$ as shown in Fig.3.

Table 2. The dependence of deposition rate and $J_c$ of YBCO films on laser repetition rate

| Repetition rate (Hz) | 60   | 90   | 120  | 150  | 180  |
|----------------------|------|------|------|------|------|
| Deposition rate (nm/pulse) | 0.7  | 0.63 | 0.63 | 0.56 | 0.53 |
| $J_c$ (MA/cm$^2$, at 77K, 0T) | 3.9  | 4.1  | 4.3  | 5.1  | 4.7  |

**Figure 3.** End-to-end I-V characteristic of 2.0 µm thick YBCO film deposited at optimum experimental condition, tested at 77 K and self field.

4. Conclusion

YBCO films were grown on buffered Ni-W tapes by PLD at different laser repetition rates. As a result, the microstructure and the performance of YBCO were dependent on the laser repetition rate. With increasing laser repetition rate, the optimum deposition temperature, particles, surface roughness and grain size increased, but the deposition rate decreased. The $J_c$ first increased and then decreased  with increasing repetition rate. The highest $J_c$ of $5.1 \times 10^6 \text{ A/cm}^2$ was obtained at 150 Hz. High quality 2 µm thick YBCO film was obtained, which had $I_c$ of 520 A/cm and $J_c$ of 2.6 MA/cm$^2$ at 77 K and self field.

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