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Short communication

Characteristics of ZnO thin films fabricated by shock-consolidated ZnO target

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Abstract

Zinc oxide (ZnO) thin films were fabricated using pulsed laser deposition (PLD) at two substrate temperatures, room temperature (RT) and 400 °C using a shock-consolidated ZnO target with relative density of 99%. The root mean square (RMS) roughness, transmittance, energy band gap, and surface morphology of the shock-consolidated ZnO thin films were investigated and compared to those of conventional ZnO thin films fabricated using a commercial sintered ZnO target with relative density of 95.7%; it was found that the RMS roughness and deposition rate were larger for the former than for the latter. Morphology, crystallinity and band gap of the shock-consolidated ZnO thin film exhibited almost the same properties as those of commercial sintered ZnO thin film under the same deposition condition.

Keywords: Underwater shock compaction; ZnO thin film; Pulsed laser deposition

1. Introduction

Many kinds of ceramic target materials are used in transparent thin film depositions. In particular, zinc oxide (ZnO) and related materials have been widely applied due to their many possible applications such as solar cells [1], flat panel displays, gas sensors and varistors [2]. These ceramic target materials are usually manufactured by means of a conventional sintering method with a prolonged thermal treatment [3,4], an electric-assisted sintering method [5,6], or a microwave sintering method [7].

Underwater shock compaction [8–11] holds promise as a simpler, faster and less expensive method for the fabrication of ceramics because it allows for one-stage densification and a very fast consolidation process of a material and can easily fabricate denser ceramics by high shock pressure (≥1 GPa).

In this study, we compared two ZnO thin film targets – one, bulk fabricated by the underwater shock compaction method [8] and the other, commercial sintered – in order to investigate their respective properties following deposition by the PLD method. Film properties such as root mean square (RMS) roughnesses, transmittances, energy band gaps and surface morphologies were measured and compared.

2. Experimental procedure

The laser ablation of the shock-consolidated ZnO target (relative density, 99% and purity, 99.9%) and the commercial sintered ZnO target (relative density, 95.7% and purity 99.99%) was carried out using KrF excimer laser (Lambda Physik Compex 205, wavelength of 248 nm, maximum energy of 650 mJ) with laser fluence of 2 J/cm^2, repetition rate of 10 Hz and 9000 laser pulses. The vacuum chamber was evacuated by a turbo-molecular pump to the base pressure of 4.7×10^{-3} Pa and filled with O_2 gas at a flow rate of 20 sccm. ZnO thin films were deposited on glass substrates at two different substrate temperatures, room temperature (RT) and 400 °C. The substrates were installed at a position of 45 mm apart from the target surface. For ZnO thin film characterization, surface morphologies, crystal structures and transmittances were measured by atomic force microscopy (SII, SPM3800N), X-ray diffraction (RIGAKU, RINT 2100) and multichannel spectrometer (Ocean Optics, HR4000), respectively.

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3. Results and discussion

3.1. Surface morphologies

Fig. 1 shows surface morphologies of ZnO thin films deposited on the substrates at room temperature (RT) and 400 °C, respectively. In the ZnO thin films fabricated from both commercial sintered and shock-consolidated ZnO targets at RT, grains of about 100 nm were found in most areas, as shown in Fig. 1(a and c). In the ZnO thin films prepared at the substrate temperature of 400 °C grain boundaries and grain growth were clearly observed. The surface morphologies of the ZnO thin films fabricated from both commercial sintered and shock-consolidated ZnO targets at the temperature of 400 °C were quite similar. Table 1 shows the thin film thickness, deposition rate and RMS roughness of each ZnO thin film sample. The ZnO thin films fabricated using the shock-consolidated ZnO target exhibited higher deposition rate, larger RMS roughness and greater film thickness than those of the ZnO thin films fabricated using the commercial sintered ZnO target. This indicates that the shock-consolidated ZnO target is ablated much more than the commercial sintered ZnO target because its structural characteristics – small-sized grains, micro-cracks, and lattice defects – allow the atomic-sized particles to be more easily extirpated by the high pulse energy of the PLD method. Fig. 2 shows still images of plasma plumes produced by laser ablation of the ZnO targets. The plasma plume from the shock-consolidated ZnO target was larger and more intensive than that from the commercial sintered one. It seems that the higher density and hardness of the shock-consolidated ZnO target [8] allows a stronger plasma plume.

3.2. Structural properties

Fig. 3 shows X-ray diffraction patterns of ZnO thin films prepared at RT and 400 °C using the shock-consolidated and the commercial sintered ZnO targets. The ZnO thin film fabricated at RT using the shock-consolidated ZnO target, shown in Fig. 3(b), reveals a peak (0 0 2) of ZnO at a diffraction angle of 33.63° as well as a peak broader than that of the film prepared using the commercial sintered ZnO target, shown in Fig. 3(a). The peak (1 1 0) of ZnO was also observed. The broadened peak is caused by the lattice defects in the film transferred from the shock-consolidated ZnO target. As shown in Fig. 3(d), the film's FWHM peak (0 0 2) decreased; the peak (1 1 0) was not apparent in the film deposited at 400 °C. The crystallinity of the

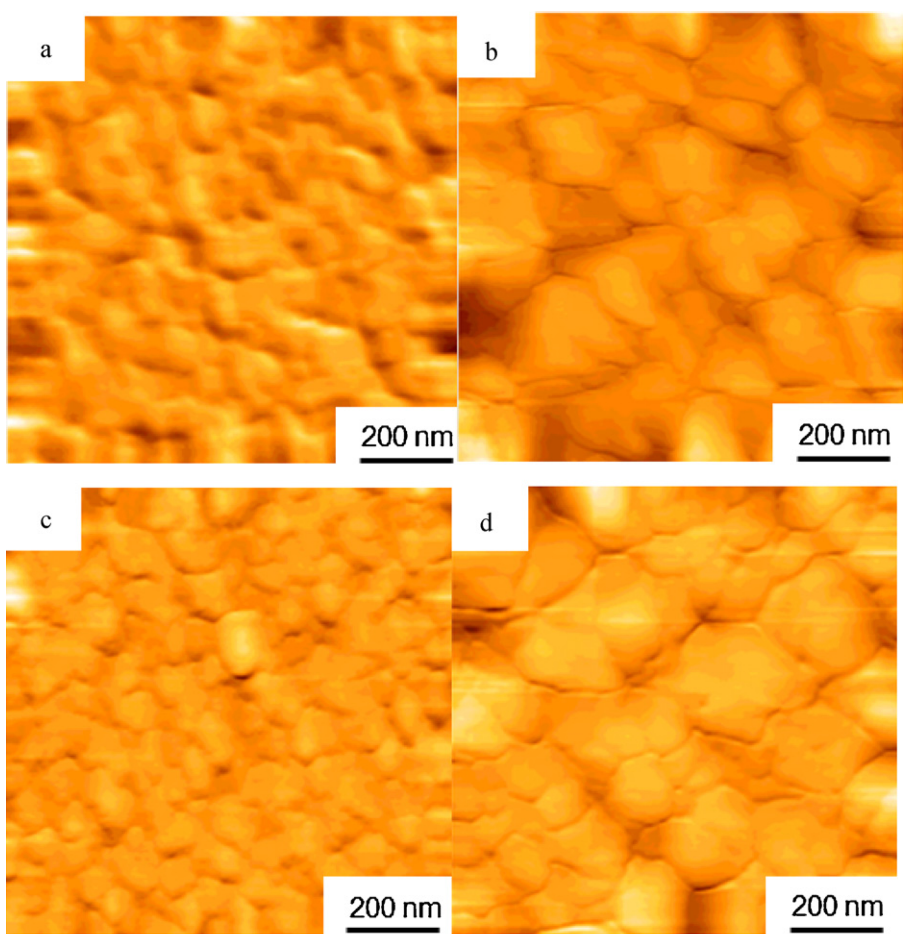

Fig. 1. AFM images of surface morphology; (a) and (b) are the ZnO thin films fabricated by the shock-consolidated ZnO target at room temperature (RT) and substrate temperature of 400 °C, respectively. (c and d) The ZnO thin films fabricated by the commercial sintered ZnO target at room temperature (RT) and substrate temperature of 400 °C, respectively.

Table 1
Estimated film thickness, deposition rate and RMS roughness.

Sample	Film thickness (nm)	Deposition rate (nm/pulse)	RMS roughness (nm)
Shock-ZnO target	960	0.107	4.2 (RT), 8.0 (400 °C)
Commercially sintered ZnO target	674	0.075	2.4 (RT), 4.8 (400 °c)

ZnO thin film was confirmed to have been significantly improved by substrate heating; furthermore, no difference was found between the ZnO thin films prepared at 400 °C using the shock-consolidated target and the sintered commercial target.

3.3. Optical properties

Fig. 4 shows optical transmittance spectra of the ZnO thin films fabricated using the shock-consolidated and commercial sintered ZnO targets at RT and 400 °C, respectively. It was confirmed that transmittances of the ZnO thin films prepared at RT were relatively lower in the visible region than those of the ZnO thin films prepared at 400 °C; the absorption property depends on the crystallinity of the thin film, and in the case of the ZnO thin films prepared at 400 °C, a high transmittance of over 80% was achieved.

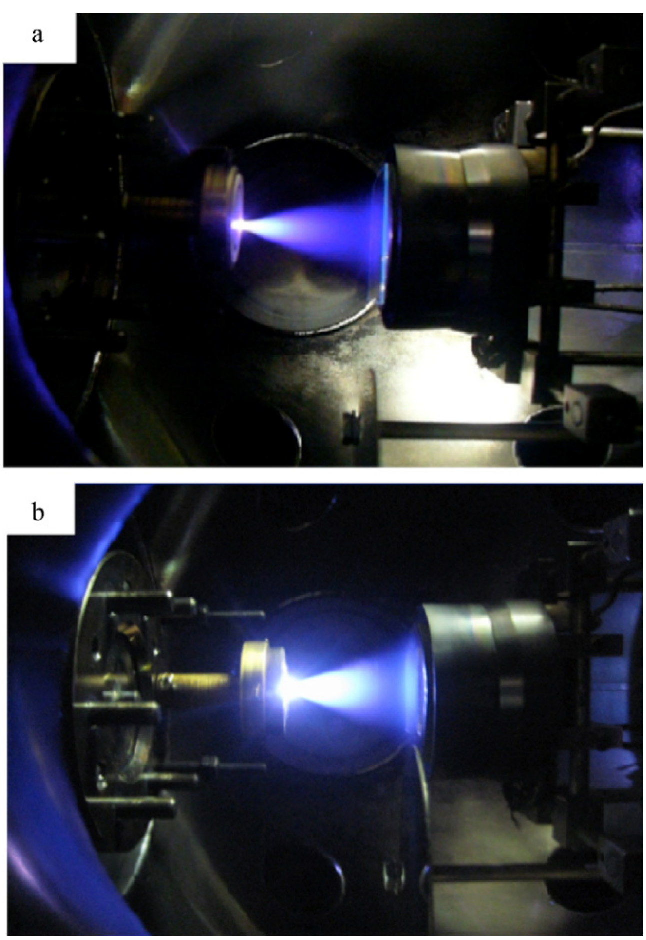

Fig. 2. Still images of plasma plume produced by laser ablation of (a) commercial sintered ZnO target and (b) shock-consolidated ZnO target.

Fig. 5 shows Tauc's plots of each ZnO thin film fabricated by the shock-consolidated and commercial sintered ZnO targets at RT and 400 °C, respectively. As seen in Fig. 5(a), the band gaps of both samples prepared at RT were of almost the same value (3.23 eV); however, their absorption edges were not as sharp in as those prepared at 400 °C. The optical band gaps of ZnO thin films prepared at 400 °C were also 3.23 eV, but the sharp absorption edges were ascribed to crystallinity improvement, as shown in Fig. 5(b). We have confirmed that there was no

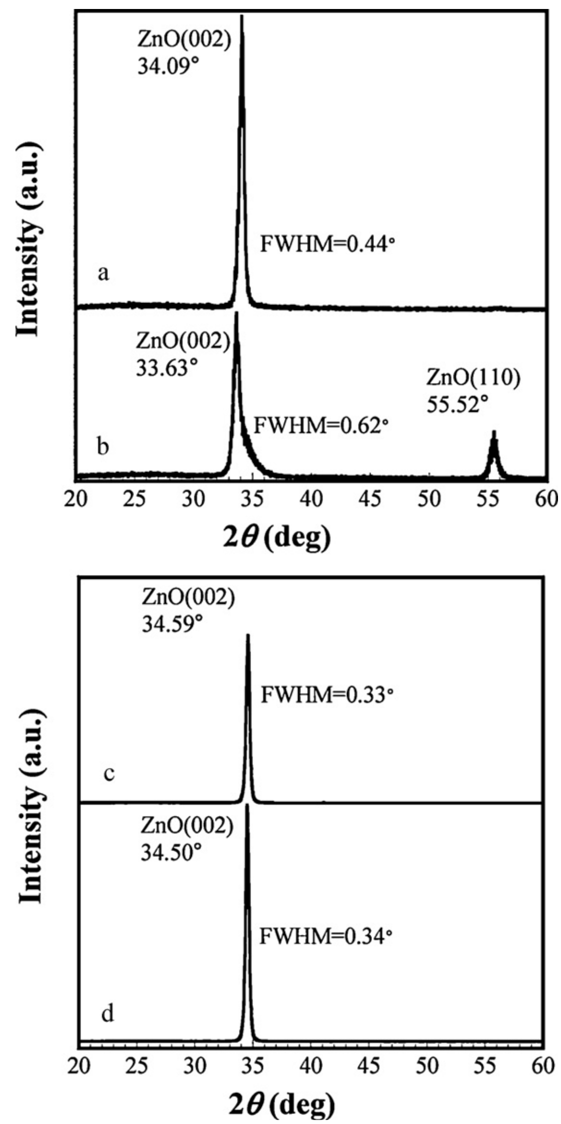

Fig. 3. X-ray diffraction patterns; (a and c) the ZnO thin films fabricated by the commercial sintered ZnO target at room temperature (RT) and substrate temperature of 400 °C, respectively; (b and d) the ZnO thin films fabricated by the shock-consolidated ZnO target at room temperature RT and substrate temperature of 400 °C, respectively.

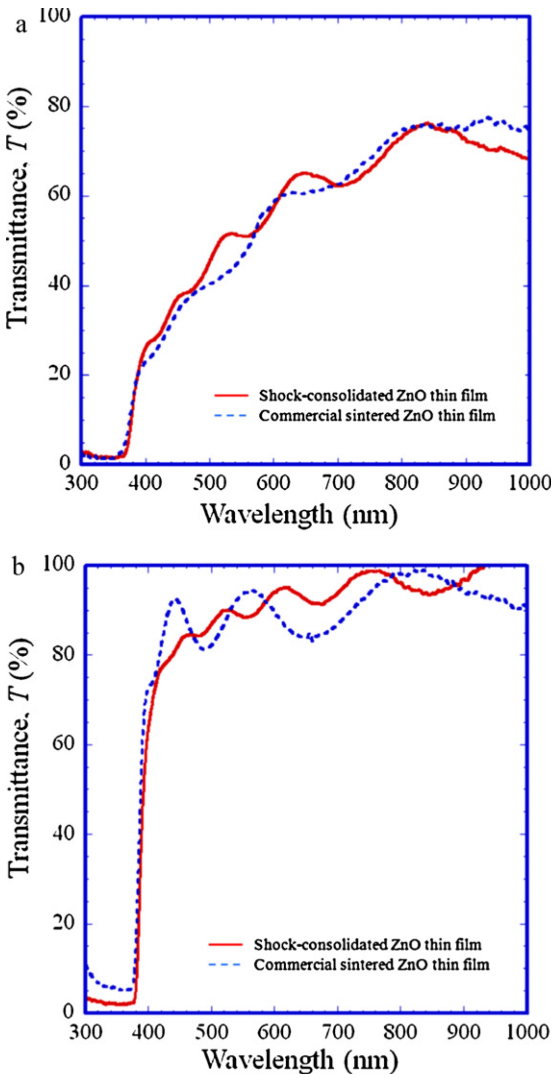

Fig. 4. Optical transmittances of ZnO thin films deposited on glass substrates using the shock-consolidated and commercial sintered targets at (a) room temperature (RT) and (b) substrate temperature of 400 °C.

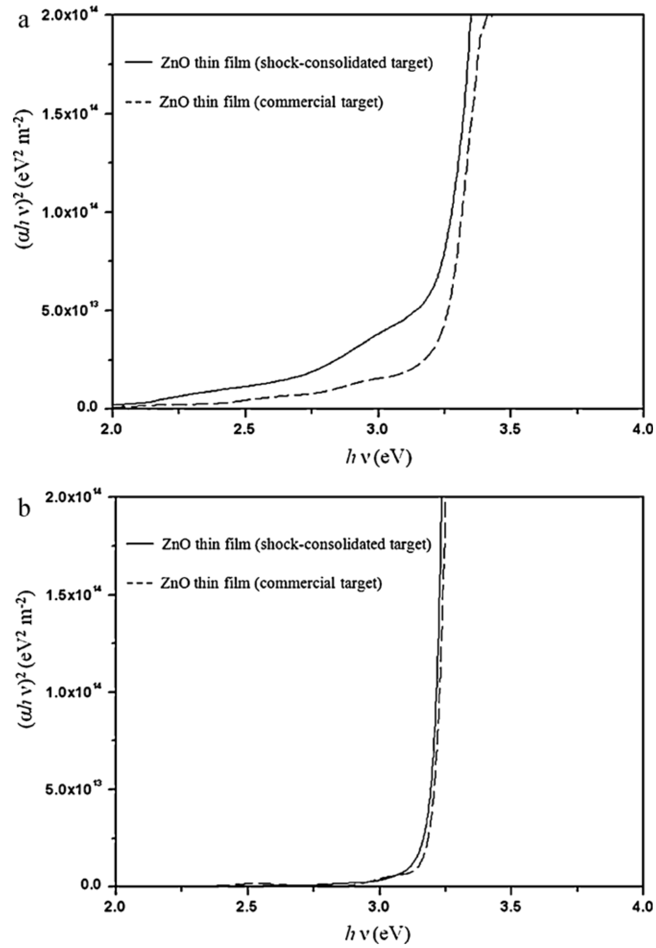

Fig. 5. Tauc's plots of the ZnO thin films fabricated by shock-consolidated and commercial sintered ZnO targets at (a) room temperature (RT) and (b) substrate temperature of 400 °C, respectively.

remarkable difference on the absorption characteristics between ZnO thin films fabricated by the shock-consolidated and commercial sintered ZnO targets at 400 °C.

4. Conclusions

ZnO thin films were fabricated using a shock-consolidated ZnO target at RT and 400 °C and compared to ZnO thin films fabricated using a commercial sintered ZnO target. The main conclusions of this investigation are as follows:

(1) Surface morphologies of ZnO thin films: ZnO thin films fabricated using the shock-consolidated ZnO target displayed the RMS roughness, film thickness and deposition rate which were greater than those fabricated using the commercial sintered ZnO target. This is because the shock-consolidated ZnO target is ablated much more than the commercial sintered ZnO target due to the effects on its atomic-sized particles by high pulse energy.

(2) X-ray analysis: the ZnO thin film prepared at RT exhibited a broadened diffraction peak due to the lattice defects of the shock-consolidated ZnO target, whereas substrate heating of 400 °C led to improvement of crystallinity of the thin film.

(3) Optical transmittance spectra analysis: the ZnO thin film prepared at 400 °C exhibited a high transmittance of over 80%, whereas the transmittance of the ZnO thin film prepared at RT was relatively low in the visible region. The band gaps of ZnO thin films exhibited almost the same value (3.23 eV) as that of ZnO thin films fabricated using the commercial sintered ZnO target.

These results confirm that shock-consolidated ZnO targets are applicable to fabrication of ZnO thin film at elevated substrate temperatures.

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