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Effects of deposition temperature on the structural and morphological properties of SnO_2 films fabricated by pulsed laser deposition

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ABSTRACT

Tin oxide (SnO_2) thin films were grown on Si (1 0 0) substrates using pulsed laser deposition (PLD) in O_2 gas ambient (10 Pa) and at different substrate temperatures (RT, 150, 300 and 400 °C). The influence of the substrate temperature on the structural and morphological properties of the films was investigated using X-ray diffraction (XRD), atomic force microscopy (AFM) and scanning electron microscopy (SEM). XRD measurements showed that the almost amorphous microstructure transformed into a polycrystalline SnO_2 phase. The film deposited at 400 °C has the best crystalline properties, i.e. optimum growth conditions. However, the film grown at 300 °C has minimum average root mean square (RMS) roughness of 3.1 nm with average grain size of 6.958 nm. The thickness of the thin films determined by the ellipsometer data is also presented and discussed.

1. Introduction

Tin oxide (SnO_2) is an n-type semiconductor that is widely used under various forms in a broad range of important applications, ranging from solid-state gas sensors to liquid crystal displays, photovoltaic cells and transparent conducting electrodes. SnO_2 is a promising candidate for such applications due to its high sensitivity to various gases, high transparency in the visible wavelength range, high stability and low cost [1–5].

There are many different techniques used for depositing SnO_2 films: r.f. sputtering [6], dc-magnetron sputtering [7], thermal evaporation [8,9], ion beam deposition [10], chemical vapour deposition [11–15], spray pyrolysis [16], successive ionic layer deposition (SILD) [17] and other chemical methods [18,19]. Sberveglieri [20] has presented a review of the techniques applied for SnO_2 films deposition. As it is shown there, all methods discussed require high substrate temperature or post-deposition annealing in order to fabricate good-quality polycrystalline films. High temperature, however, damages the surface of the films and increases the interface thickness, which has negative effect on the optical properties especially on the waveguiding.

Pulsed laser deposition (PLD) technique was successfully applied for growing of quality thin SnO_2 films [21–23]. They were produced by ablation of either Sn target in oxidizing oxygen atmosphere [21] or SnO_2 target [23]. PLD offered many advantages of reduced contamination due to the use of laser light, control of the composition of deposited structure and in-situ doping. It is a versatile and powerful tool for production of nanoparticles with desired size and composition only by varying the experimental deposition conditions [24].

The reported literature [25,26] has shown that higher substrate temperature is needed for the growth of polycrystalline SnO_2 on Si substrate. However, recent studies [27–30] indicate room-temperature growth of SnO_2 thin films on glass or alumina substrate. But no one has achieved low-temperature growth of polycrystalline SnO_2 film on Si substrate. For an extensive use in commercial applications SnO_2 films prepared at lower substrate temperature is preferable. Si is used as a substrate, because it is the material of choice for integrated circuits and low-power semiconductor electronic devices for the past 50 years. Silicon processing is quite simple and inexpensive and so it is the material of choice for most applications.

In this paper, we report results on the deposition of SnO_2 thin films on Si substrates obtained at different substrate temperatures by PLD technique. We also investigated the influence of the substrate temperature applied during the deposition process on the structural and morphological properties of the films.

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2. Experimental details

Preparation of the thin films was carried out by a typical PLD high-vacuum system [31]. Before each deposition event, the vacuum chamber was evacuated to a residual pressure less than 10^{-5} Pa. During this time the chamber walls were heated to facilitate the desorption of water vapour and other contaminants. The quality of the vacuum was monitored with a quadruple mass spectrometer.

Ablation of the target was achieved using an UV XeCl excimer laser source ($\lambda = 308$ nm, pulse duration of 30 ns, repetition rate of 10 Hz). In order to deposit one film, 20,000 subsequent laser pulses were applied. Before each successive deposition event, the target surface was cleaned by applying 3000 laser pulses. To avoid the deposition of the ablated material from the first layers of the target, which can contain contaminants, a shutter was interposed between the target and the collector. An MgF_2 lens with 300 mm focal length was used. In order to avoid drilling and to ensure surface cleanness, the target was rotated at a frequency of 3 Hz.

We used a target of SnO_2 (99.99%). The laser beam impinging on the target at an angle of 45° with respect to the surface normal led to the growth of SnO_2 film. The incident laser fluence was held constant at 10 J/cm^2 during the deposition processes. The deposition of the films was performed in dynamic pressure of O_2 (10 Pa). Ablated material was collected on Si (1 0 0) substrates maintained at RT, 150, 300 and 400 °C during the deposition. Substrates were placed parallel and in front of the target at a distance of 6 cm. All substrates were cleaned in an ultrasonic bath before deposition.

The crystalline structure of the SnO_2 films was characterized by X-ray diffraction (XRD) technique using a Philips X'Pert-MRD X-ray diffractogram with Cu-Kα radiation ($\lambda = 1.54$ Å) at a glancing incident angle of 2°. Diffractograms were recorded from 20° to 80° with a step of 0.05°. Surface morphology was characterized using scanning electron microscopy (SEM). The observations were

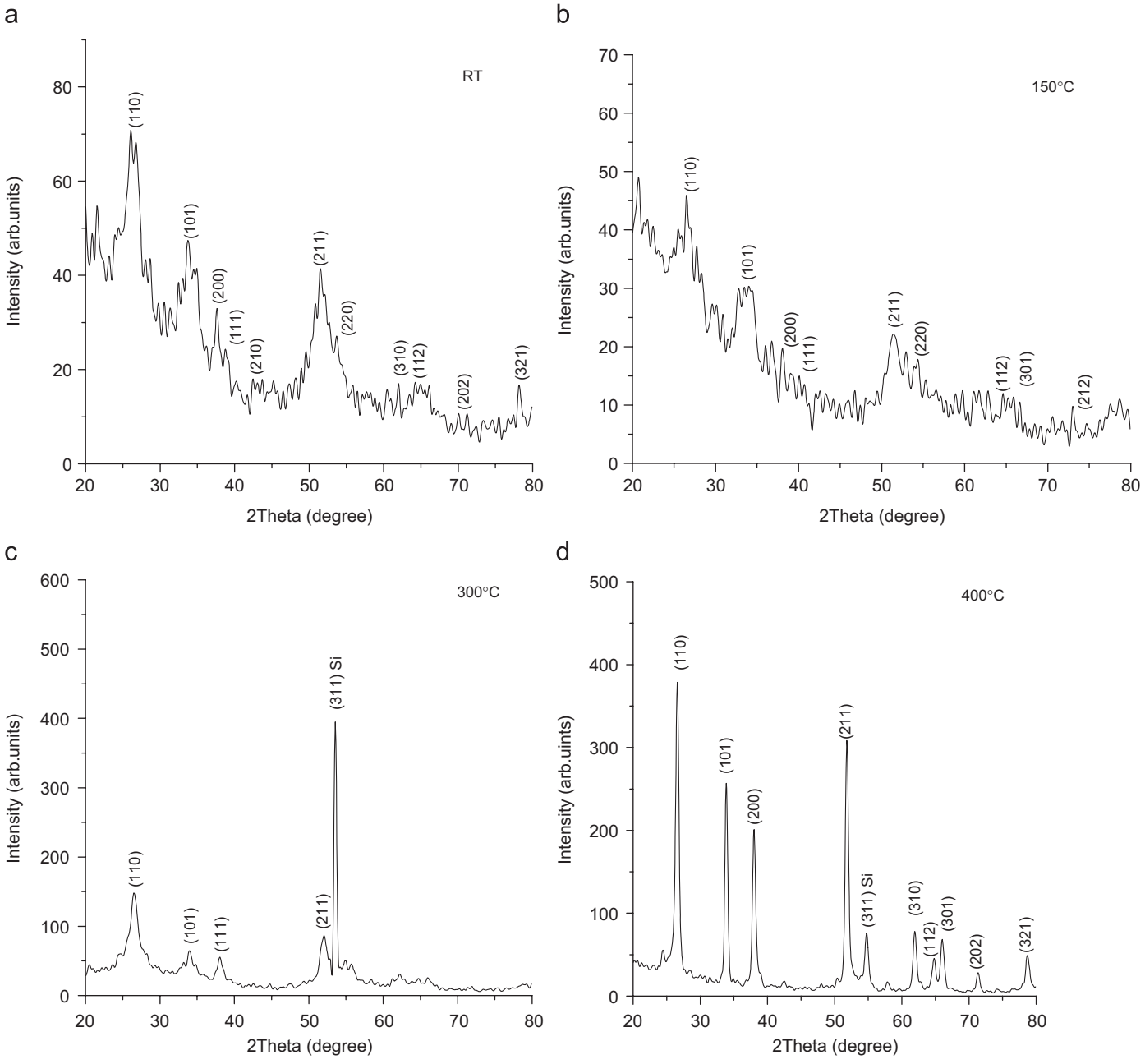

Fig. 1. XRD spectra of the SnO_2 film deposited at (a) RT, (b) 150 °C, (c) 300 °C, (d) 400 °C.