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AFM surface analysis of ZnO layers prepared by pulsed laser deposition at different oxygen pressures

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A B S T R A C T

Polycrystalline thin films of zinc oxide were deposited by pulsed laser deposition onto silicon substrates at different oxygen partial pressures in the range of 1–35 Pa. For ablation of the sintered zinc oxide target a pulsed Nd:YAG laser was used. Other processing parameters such as laser pulse energy, pulse repetition rate, substrate temperature and deposition pressure were identical. The effect of oxygen pressure on the structural properties of the films was systematically studied by using atomic force microscopy. The surface morphology, average roughness S_a, root mean square S_q, and mean size of grains on selected places with $2 \times 2\ \mu m^2$ area of prepared samples were evaluated. Detailed structural analysis confirmed that partial oxygen pressure leads to the modification of surface morphology. Mean grain size in height and lateral direction decreases with raising oxygen pressure from 1 to 5 Pa while the further increase of oxygen pressure from 5 to 35 Pa results in grain size enlargement. The zinc oxide film formed at oxygen partial pressure 5 Pa shows smallest values of evaluated parameters ($S_a = 0.6$ nm, $S_q = 0.7$ nm and mean size of grains 50 nm).

1. Introduction

In the last ten years zinc oxide (ZnO) based materials, thin films, nanostructures, and devices have received much attention because of their attractive features [1–3]. The assorted physical properties such as electro-optical, acousto-optical, piezoelectrical, and luminescence characteristics render ZnO a liable material for a variety of applications [4,5]. ZnO is an n-type II-VI semiconductor with a wide and direct band-gap ($E_g \approx 3.3$ eV at room temperature). It has a wurtzite-type crystal structure with a hexagonal symmetry, lattice constants $a = 0.325$ nm, $c = 0.521$ nm and melting point 2248 K. The electron Hall mobility at 300 K reaches 200 $cm^2\,V^{-1}\,s^{-1}$ ($m_e^* = 0.24$) and hole Hall mobility 5–50 $cm^2\,V^{-1}\,s^{-1}$ ($m_h^* = 0.59$). The refractive index of ZnO is in the interval 2.008 ~ 2.029 [6]. ZnO has a high exciton binding energy ($E_B = 60$ meV). Due to the wide E_g and high E_B, ZnO is a promising candidate for optoelectronics devices of short wavelength at room temperature. ZnO-based structures have been used for development of UV/blue LEDs [7], laser diodes (LDs) [8], UV photodetectors (Schottky, MSM) [9,10], transparent field-effect transistors (TFETs) [11], biomedical sensors, solar cells [12] and SAW filters [13]. Furthermore, it is possible to utilize ZnO-based multilayer structures and ZnO nanostructures to design and construct completely new integrated devices, such as tunable RF devices and multifunctional sensors. Pure ZnO is transparent in the wavelength range from 400 to 700 nm and is electrically conductive which makes it a promising alternative material to transparent conducting indium thin oxide (ITO) for many optical devices like solar cells, flat panel displays, heat mirrors, organic LEDs [14], because of the low cost of raw material, non-toxicity and better patterning characteristics. The surface morphology and conductivity of ZnO thin films depends upon several factors, such as the preparation technique, the in situ preparation parameters, the substrate type, the doping agent, and the annealing conditions [15–18].

Polycrystalline ZnO thin films have been fabricated by using pulsed laser deposition (PLD) onto silicon substrates held at a temperature of 673 K, at defined Nd:YAG laser pulse energy, pulse repetition rate, deposition pressure, and at different oxygen partial pressures in the range of 1–35 Pa. General interests of the investigations were connected with roughness and grain analysis of the deposited thin films as a function of oxygen pressures. An Atomic Force Microscope (AFM) was employed for surface characterization of prepared samples. This paper reports on the PLD optimum growth conditions for successful integration of ZnO layers with other materials, especially GaN for optoelectronic applications [19].

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2. Zno thin film preparation

Various deposition techniques such as PLD, RF/DC magnetron sputtering [20], reactive evaporation, spray pyrolysis, solution growth, molecular beam epitaxy (MBE), metal organic chemical vapour deposition (MOCVD) and plasma-enhanced chemical vapour deposition (PE CVD) have been employed for the growth of ZnO films. Among numerous deposition techniques, extensive and successful efforts have been made for thin film growth of ZnO using PLD since it is an attractive choice for the preparation of stoichiometric and high quality ZnO films for various applications. The PLD technique also has several other advantages including its ability to create high-energy source particles, permitting high quality film growth at low substrate temperatures, a simple experimental setup, and operation in high ambient gas pressures. In particular, low temperature deposition using the PLD growth method is capable of solving the VI-element vacancy problem. The physical properties of ZnO films prepared by PLD mainly depend on the

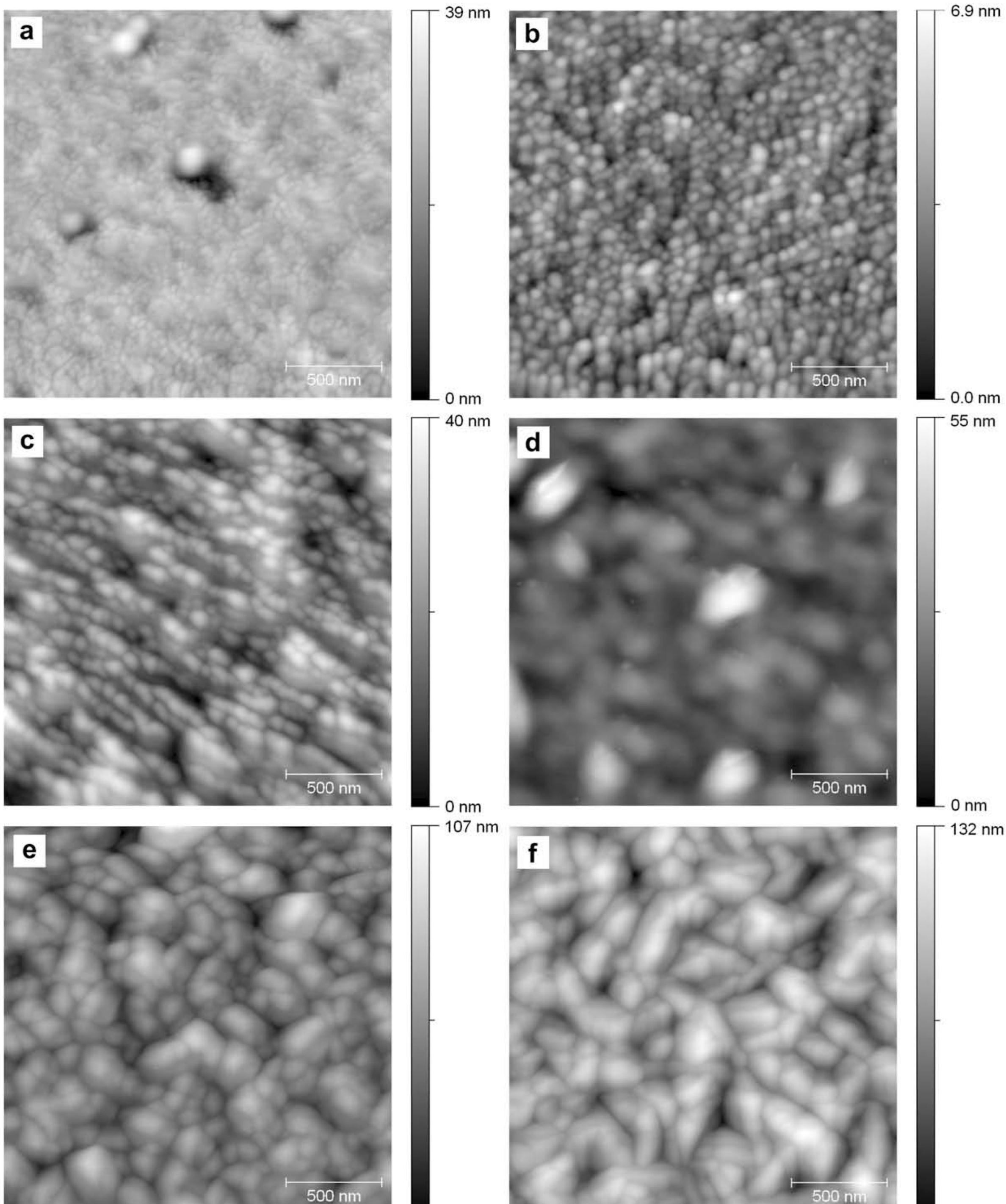

Fig. 1. Surface morphology of ZnO thin films prepared by PLD on Si substrates at oxygen partial pressure of (a) 1 Pa (b) 5 Pa (c) 10 Pa (d) 15 Pa (e) 25 Pa and (f) 35 Pa.