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Photoconductive characteristics of ZnO: Al network films sputter-deposited at different deposition temperatures

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ABSTRACT

50 nm-thick ZnO: Al network films were sputter-deposited on nanochannel Al_2O_3 substrates at 300 K, 423 K and 623 K. A photoconduction of the network films was measured by using a metal–semiconductor–metal planar configuration with Ag contact electrodes. Both the dark current and the photocurrent increase linearly with the applied voltage, meaning an ohmic contact between ZnO: Al network film and Ag electrode. The photocurrent of the network films increases with increasing deposition temperature. The network films show a slow photo-response. The rising process time constant is almost independent of deposition temperature. The photosensitivity of the network films decreases with increasing deposition temperature.

1. Introduction

ZnO and ZnO-based films have attracted considerable attention for their potential applications in optoelectronics, magnetoelectronics, piezoelectric devices and chemical sensors [1–3]. Al-doped ZnO (ZnO: Al) films are often used as transparent conductive electrodes and have been actively investigated for scientific and practical interests. Besides, a few studies on the photoconductive characteristics of ZnO: Al films have been reported. Xu et al. [4] used a sol–gel method to prepare ZnO: Al films and obtained a photocurrent of 58 μA at a bias voltage of 6 V. Mamat et al. [5] prepared ZnO: Al films with different Al doping concentrations by the sol–gel method. They found that the film with 1 at% Al had the highest photocurrent under ultraviolet illumination. Mamat et al. [6] prepared nanorod–nanoflake ZnO: Al network films by ultrasonic-assisted sol–gel and immersion methods. They found that the photo-response of the network film was higher than that of the continuous film. Ganesh et al. [7] prepared ZnO: Al films with different Al concentrations by sol–gel spin coating. An optimal Al doping concentration for photoconductive applications was 1–2 wt%.

As mentioned above, the chemical methods were used to prepare the ZnO: Al films for the photoconductive applications. On the other hand, nanochannel Al_2O_3 is an attractive template to prepare nanomaterials [8]. Recently, we have sputter-depo sited ZnO: Al network films on nanochannel Al_2O_3 substrates [9]. A photoluminescence of the network film was better than that of the continuous film. In the present work, photoconductive characteristics of the ZnO: Al network films sputter-deposited on nanochannel Al_2O_3 substrates are studied as a function of the deposition temperature. The photoconductive ZnO: Al films have potential applications in optoelectronic devices. This work reports the photocurrent and the photosensitivity of the sputter-deposited ZnO: Al network films. It is significant for fundamental and practical viewpoints.

2. Experimental procedure

The DC magnetron sputtering system with the target inclined to the substrate at an angle of 45° was used [9]. The commercial nanochannel Al_2O_3 substrate (Whatman) had an average pore diameter of 100 nm. The ZnO: Al films were sputter-deposited on nanochannel Al_2O_3 substrates at 300 K, 423 K and 623 K using a sintered ZnO+2 wt% Al_2O_3 target (99.99% purity). Prior to deposition, the working chamber was evacuated to a pressure of 4×10^{-4} Pa by a turbo molecular pump. The distance between target and substrate was 100 mm. During sputter-deposition, the Ar gas (99.9995% purity) pressure was 0.4 Pa and the sputtering power was 150 W. The deposition rate was 13 nm/min. The substrate holder was rotated by using a stepping motor during deposition in order to obtain the uniform films.

Field emission scanning electron microscope (FE-SEM) of SUPRA 55 (Zeiss) was used to observe the film structure. The film thickness measured by the cross-sectional FE-SEM microphotograph of the film is 50 nm. Photoconductive characteristics of the

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network films were measured by using the metal–semiconductor–metal planar configuration with Ag contact electrodes. The Ag electrodes were prepared on the film surface by Ag paste. The distance between the Ag electrodes was 5 mm. A relationship of current and voltage (*I–V*) was measured by Keithley 4200-SCS system (Keithley) in order to determine the dark current and the photocurrent. ENF-280C/FE light source, which had a wavelength of 365 nm and a power of 0.47 mW/cm^2, was used to obtain the photoconductive behaviors of the films. A relationship of photocurrent and time (*I–t* curve) was measured by using an electrochemical instrument SI1287 (Solartron Analytical), which was used as the voltage source and the current monitor.

3. Results and discussion

Figure 1 shows FE-SEM microphotographs of the ZnO: Al films grown on nanochannel Al_2O_3 substrates at 300 K, 423 K and 623 K. As shown in Fig. 1, all the films have a network structure. For the films grown at 300 K and 423 K, the network is formed by connecting granules. The granule consists of many small grains. For the film grown at 623 K, the network is formed by connecting grains. The grain size increases with increasing deposition temperature. The high deposition temperature enhances the surface diffusion of adatoms, promoting the grain growth and the decrease in vacancies.

Figure 2 shows dark and photo-illuminated *I–V* characteristics of the ZnO: Al network films grown at various deposition temperatures. As shown in Fig. 2, all the network films exhibit the photoconductive behavior. Furthermore, both the dark and photo-illuminated currents increase linearly with increasing bias voltage, indicating that the Ag electrode forms the ohmic contact on the ZnO: Al film. It was reported that the Schottky contact was formed between Ag and n-type ZnO [10,11]. Furthermore, the Schottky contact could become the ohmic contact with increasing the carrier concentration in the ZnO film [11]. Thus, in the present work, the ohmic contact between the Ag electrode and the ZnO: Al film can be attributed to the high carrier concentration in the film. Moreover, according to the *I–V* relationship of the dark current, it is said that the resistivity of the ZnO: Al network film decreases with increasing deposition temperature. It is attributed to the increase in the grain size and the decrease in the vacancies with the deposition temperature.

It was reported that the oxygen chemisorption mechanism was used to explain the photoconduction of the ZnO and ZnO-based films [6,11,12]. The oxygen molecules adsorbed on the film surface play an important role in the oxygen chemisorption mechanism. In the present work, the ZnO: Al network films have a large ratio of surface area to volume. The large surface area of the network films leads to a large number of oxygen molecules on the film surface. As the network film is illuminated by the ultraviolet light, its photoconductive behavior can be explained by the oxygen chemisorption mechanism.

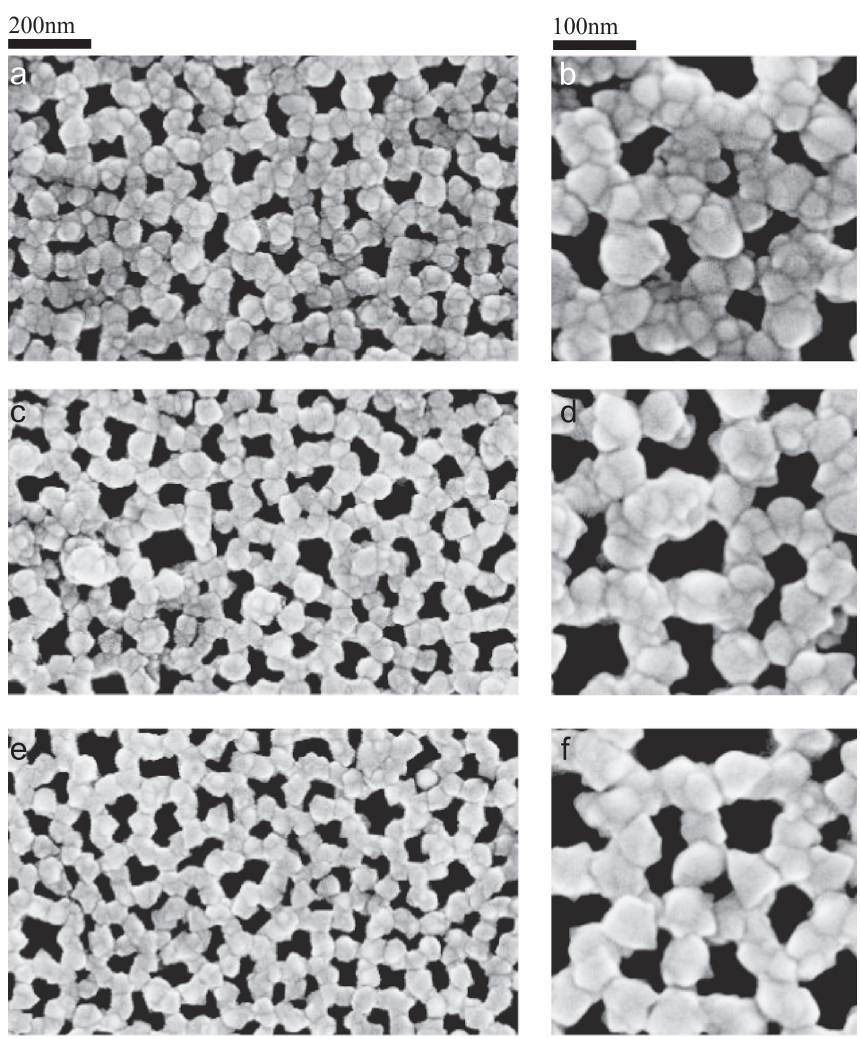

Fig. 1. FE-SEM microphotographs of the ZnO: Al films grown at (a, b) 300 K, (c, d) 423 K, and (e, f) 623 K.