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Synthesis of nanostructured Al-doped zinc oxide films on Si for solar cells applications

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Al-doped ZnO thin films have been prepared by a novel successive chemical solution deposition technique. The variation in morphological, structural, electrical, and optical properties of nanostructured films with doping concentration is investigated in details. It was demonstrated that rapid photothermal processing (RPP) improves the quality of nanostructured ZnO films according to the enhancement of resonant Raman scattering efficiency, and the suppression of the visible luminescence with the increase of RPP temperature. It was found from the *I–V* characteristics of ZnO/Si heterojunction that the average short-circuit current density is about 8 mA/cm^2. For 1%Al-doped ZnO/SiO_2/Si structure, the short-circuit current density is about 28 mA/cm^2. The improvement shown in the characteristics may be assigned partially to the reduction of the defect density in the nanostructured Al-doped ZnO films after RPP. The correlations between the composition, microstructure of the films and the properties of the solar cell structures are discussed. The successive chemically deposited Al-doped ZnO thin film offers wider applications of low-cost solar cells in heterojunction structures.

1. Introduction

Solar power as a clean and economical energy source plays an important role in the 21st century in a low greenhouse gas future. Although the sun provides about 12×10^4 TW of solar energy, the whole earth needs to consume about 12–14 TW. Thin film-based solar cells hold greater opportunity to reduce the solar energy cost.

Different types of solar cells have been studied, but among them heterojunction thin film solar cells on single-crystalline Si are preferred due to their high conversion efficiency ($>24\%$). In order to overcome one shortcoming of these cells, high cost, transparent conducting semiconductor/Si heterojunction is investigated. Among the various semiconducting metal oxide materials, the most convenient conducting oxide for solar energy applications is zinc oxide.

The compound semiconductor zinc oxide has a direct bandgap of 3.37 eV (at 300 K), a high melting point of 2248 K, and a large exciton binding energy (60 meV) and wurtzite structure similar to GaN [1]. ZnO is a multifunctional semiconductor material that can be used in many applications such as antireflection coatings, window material for displays, piezoelectric transducers, surface acoustic wave devices, and sensors [1,2]. Zinc oxide can be used as nanostructured electrodes for solar cells [3] because its physical and electrical properties can be controlled by appropriate doping either by cationic (Al, In) or by anionic (F) substitution [4], as well as by deposition parameters and post-growth annealing. Studies on nanostructured semiconducting oxide films for nanotechnology applications [5,6] demonstrated that the photocurrent can be improved by increasing the effective surface area of the ZnO electrode [6–8]. The high conversion efficiency of nanostructured ZnO films based on Al-doped crystallites [8,9] triggered investigations of novel synthesis techniques for fabrication of nanocrystalline ZnO for efficient solar cells. Recently, Al-doped ZnO thin films have attracted attention as a replacement for ITO (tin-doped indium oxide) due to their low resistivity, high transmission, non-toxicity, and low-cost. In addition, zinc oxide production is compatible with current microelectronic technology.

In this context, chemical deposition at low temperatures [2,10–17], and especially the successive chemical solution deposition (SCSD) method [12,15,16] is emerging as a possible alternative to vapor deposition techniques in vacuum or the sol–gel

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