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Highly luminescent columnar ZnO films grown directly on *n*-Si and *p*-Si substrates by low-temperature electrochemical deposition

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ABSTRACT

In this study, nanocolumnar zinc oxide thin films were catalyst-free electrodeposited directly on *n*-Si and *p*-Si substrates, what makes an important junction for optoelectronic devices. We demonstrate that ZnO thin films can be grown on Si at low cathodic potential by electrochemical synthesis. The scanning electron microscopy SEM showed that the ZnO thin films consist of nanocolumns with radius of about 150 nm on *n*-Si and 200 nm on *p*-Si substrates, possess uniform size distribution and fully covers surfaces. X-ray diffraction (XRD) measurements show that the films are crystalline material and are preferably grown along (0 0 2) direction. The impact of thermal annealing in the temperature range of 150–800 °C on ZnO film properties has been carried out. Low-temperature photoluminescence (PL) spectra of the as-prepared ZnO/Si samples show the extremely high intensity of the near bandgap luminescence along with the absence of visible emission. The optical quality of ZnO thin films was improved after post-deposition thermal treatment at 150 °C and 400 °C in our experiments, however, the luminescence intensity was found to decrease at higher annealing temperatures (800 °C). The obtained results indicate that electrodeposition is an efficient low-temperature technique for the growth of high-quality and crystallographically oriented ZnO thin films on *n*-Si and *p*-Si substrates for device applications.

1. Introduction

Zinc oxide thin films have been particularly attractive due to interest in studying its fundamental physical properties and potential applications in optoelectronic devices operating at low currents and high temperatures [1,2]. The excellent optical properties of ZnO such as its wide and direct band gap of 3.37 eV (at 300 K) and its large free exciton binding energy (60 meV) [3] are of interest for the integration in Si-based high-performance optoelectronic devices. Other ZnO properties such as high mechanical and thermal stabilities [4,5], decomposition at high temperatures (about 1950 °C) [6,7], and radiation hardness [8–10] endow it as promising material. The combination of ZnO thin films and single crystalline Si is of much interest for integration of ZnO-based devices with current Si-based technologies [11–14]. However, according to previous reports, the direct growth or deposition of ZnO on Si was found to be difficult [11–15]. High optical quality ZnO thin films are very difficult to grow on Si(1 1 1) substrates (especially *p*-type) based on different lattice constants and crystal structure, which can affect the material quality and device performances. To overcome such problems different techniques have been reported for surface pre-treatment, like deposition of ZnS [16], GaN [17], nitridation of the Si surface [18], CaF_2 [19], etc. Note that the introduction of the insulating layer (e.g. SiN or CaF_2), will affect the electrical properties of ZnO/Si junction [11–14]. Only few studies concerning the growth of catalyst-free ZnO thin films on Si substrates by different techniques have been performed, due to inherent problems encountered in the growth process [11,12]. Electrochemical deposition (ECD) is known to be a simple, low temperature, and cost-effective large-area deposition technique for groups II–VI semiconductors such as ZnO on conductive substrates. High quality ZnO films grown by ECD on FTO substrates have been reported [20–24], which can be easily scaled up for optoelectronic devices fabrications, e.g. light emitting diodes [11–13]. However, several very important issues have to be explored like the microstructural and the optical properties of ZnO thin films grown on Si substrates. Another issue is the effect of thermal annealing on these ECD ZnO thin films grown on Si. Answers to these questions are extremely important for further improvements of ECD techniques, because the thin films properties are determined by the phenomena at the atomic level and by crystallographic uniformity, which ensure stable function of high-performance devices based on.

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