Materials Science in Semiconductor Processing 26 (2014) 677–680

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Study of growing zinc oxide on polycrystalline silicon/glass substrate prepared by aluminum-induced crystallization of amorphous silicon

J.D. Hwang *, W.J. Yan, J.H. Chen

Department of Electrophysics, National Chiayi University, Chiayi City 60004, Taiwan

ARTICLE INFO

Available online 27 September 2014

Keywords:
ZnO
Polycrystalline silicon
Aluminum-induced crystallization
Epitaxial silicon

ABSTRACT

Zinc oxide (ZnO) was grown on a polycrystalline silicon (pc-Si)/glass substrate prepared by the aluminum-induced crystallization (AIC) of amorphous silicon. ZnO directly grown on the AIC-pc-Si exhibits many defects with a distribution unlike that of conventional ZnO; the defect density is highest near the conduction band and decreases near the valence band. The defects can be greatly suppressed by depositing an epitaxial silicon (Epi-Si) layer on the AIC-pc-Si. The resulting defect distribution is similar to that of ZnO grown on a crystalline Si (c-Si) substrate. X-ray diffraction shows that the epitaxial silicon layer can improve the crystallization of ZnO. However, the AIC-pc-Si and Epi-Si/AIC-pc-Si substrates exhibit rougher surfaces; consequently, the ZnO has a more random structure and lower density than that grown on a c-Si substrate. X-ray photoelectron spectroscopy demonstrates that as compared to the ZnO grown on the AIC-pc-Si, the defect ratio could be dramatically reduced from 0.70 to 0.56 by depositing an epitaxial silicon layer on AIC-pc-Si, and the defect ratio is about the same as that (0.55) for the ZnO grown on a c-Si substrate.

1. Introduction

Zinc oxide (ZnO) has attracted considerable interest because of its wide direct band gap (3.37 eV), high exciton binding energy (60 meV), and high radiation resistance; it is potentially useful in various optoelectronic applications, including photodetectors [1–4] and light-emitting diodes [5,6]. However, a reproducible, reliable p-type ZnO is still not available for several reasons, such as the deep acceptor levels, low solubility of the dopants, and self-compensation process [7]. Therefore, instead of ZnO-based homojunctions, p-Si/n-ZnO heterojunction diodes have been developed because the crystalline Si (c-Si) material is inexpensive and suitable for fabricating integrated circuits [8–10]. Nevertheless, in this case, the ZnO was deposited on a c-Si substrate. Compared to a glass substrate, the c-Si substrate is still expensive and nontransparent, making it unsuitable for application in optoelectronic devices. Thin film technology using a transparent, low-cost glass substrate has been developed to fabricate optoelectronic devices, such as thin film solar cells and thin film transistors in liquid-crystal displays.

Aluminum-induced crystallization (AIC) of amorphous silicon (a-Si) has been proposed as the crystallization process for the formation of a continuous polycrystalline silicon (pc-Si) thin film on glass because AIC is a true low-temperature process with annealing temperatures ranging from 350 to 500 °C [11,12]. AIC was employed by annealing the a-Si/Al/glass structure at a temperature (350–500 °C) below the eutectic temperature of the Al-Si system.

* Corresponding author. Tel.: +886 5 2717958; fax: +886 5 2717909.
E-mail address: jundar@mail.ncyu.edu.tw (J.D. Hwang).

http://dx.doi.org/10.1016/j.mssp.2014.09.018
1369-8001/

Through annealing, the a-Si is crystallized into pc-Si; in addition, the Al and Si films exchange their positions, yielding an Al/pc-Si/glass structure. After the top Al layer is removed, the resulting AIC-pc-Si is p-type owing to Al doping during AIC [13]. The AIC-pc-Si film prepared by AIC demonstrates a highly crystalline orientation and large grain size, resulting in fewer grain boundaries and aiding the subsequent epitaxial growth of the crystalline silicon [14,15]. In this work, ZnO was grown on the AIC-pc-Si using a hydrothermal (HT) method. In addition, an epitaxial silicon (Epi-Si) layer was deposited on the AIC-pc-Si to improve the characteristics of the ZnO.

2. Experimental details

The p^+-type poly-Si layer was prepared by AIC technology as follows. First, a thin Al (300 nm) layer was deposited on a glass substrate (Corning 1737) by direct current sputtering. Next, the sample was exposed to air for 1 h to form an AlO_x layer on the surface of the Al film as a membrane of silicon atoms diffuses into the Al layer. An amorphous silicon (300 nm) layer was deposited on the substrate by a plasma-enhanced chemical vapor deposition system. The resulting substrate (a-Si/Al/glass) was subjected to thermal annealing in a conventional furnace at 500 °C for 1 h. After AIC, the positions of the Al and a-Si layers were exchanged, and the a-Si was crystallized into a pc-Si film, yielding an Al/pc-Si/glass structure. The Al layer on top of the pc-Si was removed using an Al etching solution. Hall measurement shows that the obtained AIC-pc-Si is p^+-type with a concentration of 2×10^{18} cm^{-3} and a hole mobility of 72 $cm^2/V\,s$ owing to the Al doping. Some AIC-pc-Si was deposited as an epitaxial silicon layer (about 1 μm) using a hot-wire chemical vapor deposition system at a substrate temperature of 450 °C and a hot-wire temperature of 1500 °C. Finally, ZnO was grown on the AIC-pc-Si or Epi-Si/AIC-pc-Si substrate using the HT method. The process of ZnO grown by the HT method is as follows. Aqueous solutions of zinc nitrate hexahydrate [$Zn(NO_3)_2 \cdot 6H_2O$, 0.05 M] and hexamethylenetetramine ($C_6H_{12}N_4$, 0.05 M) with equal concentrations were mixed in a pyrex glass bottle. Then, substrates were dipped in the mixture for 40 min at 90 °C to prepare a ZnO seed-layer. Annealing at 450 °C was performed in a N_2 atmosphere for 10 min and next, the same mixed solution was used to grow ZnO for 3 h at 90 °C. Photoluminescence (PL) using 266 nm Nd:YAG laser and triax 320 spectrophotometer, X-ray diffraction (XRD) of Bruker D8 Discover, Scanning electron microscopy (FE-SEM) of JEOL 7401F, transmission electron microscopy (TEM), atomic force microscopy (AFM), and X-ray photoelectron spectroscopy (XPS) (Kratos Axis Ultra DLD) were used to investigate the properties of the ZnO grown on the AIC-pc-Si and Epi-Si/AIC-pc-Si substrates.

3. Results and discussion

Fig. 1 shows cross-sectional TEM images of the Epi-Si/AIC-pc-Si/glass structure. As shown in Fig. 1(a) and (b), clear electron diffraction patterns are observed in the AIC-pc-Si and Epi-Si layers, respectively. Hence, each grain in these regions consists of a crystalline phase of mainly a single domain. This result confirms that the AIC-pc-Si and Epi-Si layers prepared at a low temperature have a highly crystalline structure. Fig. 2 shows the room temperature photoluminescence spectra of ZnO grown on the AIC-pc-Si and Epi-Si/AIC-pc-Si substrates; that of the ZnO grown on the c-Si substrate using the same HT method is also shown for comparison. For the ZnO grown on the AIC-pc-Si, ultraviolet light emitted at 378 nm appears owing to the band-to-band recombination of ZnO. Additionally, a high broadband signal extending from 400 to 700 nm is observed; the broadband signal is generally attributed to radiative recombination of defects in the band gap [16]. These defects originate from intrinsic defects in ZnO, such as zinc vacancies V_{Zn}, oxygen vacancies V_O, interstitial zinc Zn_i, interstitial oxygen O_i, and antisite oxygen O_{Zn} [17]. However, the defect distribution is unlike that of conventional ZnO material, which is centered at about 500–600 nm. The defect density is highest near the conduction band and decreases near the valence band. The defects can be greatly reduced by depositing an epitaxial silicon layer on the AIC-pc-Si. The ZnO grown on the Epi-Si/AIC-pc-Si substrate exhibits fewer defects than that grown on the AIC-pc-Si, implying that the epitaxial silicon layer can effectively suppress the defects. Also from the figure, the defect distributions of ZnO grown on the Epi-Si/AIC-pc-Si and c-Si substrates are similar, ranging from 500 to 600 nm, which is the conventional defect distribution of ZnO material [8]. The behavior suggests that the epitaxial

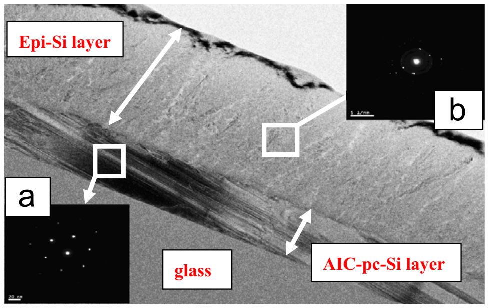

Fig. 1. Cross-sectional TEM images of Epi-Si/AIC-pc-Si/glass structures. (a) and (b) Diffraction patterns of AIC-pc-Si and Epi-Si layers, respectively.

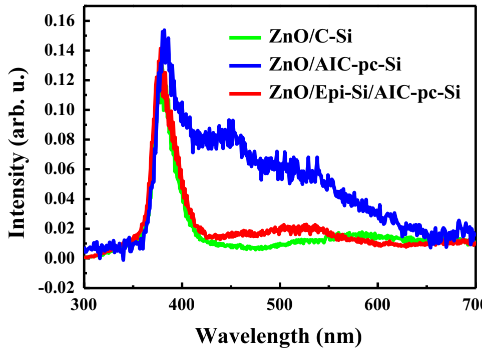

Fig. 2. Photoluminescence spectra measured at room temperature for ZnO grown on various substrates.