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Preparation and characteristics study of CdS/macroporous silicon/c-Si double heterojunction photodetector by spray pyrolysis technique

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ABSTRACT

In this paper, a thin film of undoped cadmium sulfide CdS was deposited on p-type macroporous silicon by spray pyrolysis technique. Porous silicon was synthesised by electrochemical etching at 30 mA/cm^2 for 15 min. The optical and structural properties of polycrystalline CdS sprayed at substrate temperature of 350 and 450 °C were investigated by using atomic force microscopy AFM, x-ray diffraction XRD and UV–vis spectroscopy. Scanning electron microscopy and optical microscopy were performed to study the structure of the porous silicon. XRD results confirmed formation of crystalline hexagonal CdS with preferential orientation along (002) plane. The electrical and optoelectronic characteristics of CdS/PSi/c-Si junction were investigated. The current-voltage characteristics of CdS/PSi/c-Si heterojunctions showed rectification characteristics and the ideality factor was greater than unity. The values of on/off ratio were 146 and 426 at 6 V for photodetectors prepared at 350 and 450 °C, respectively. The spectral responsivity results revealed that the CdS/PSi/c-Si junction prepared at 350 °C has two peaks of response located at 455 and 814 nm, while the peaks of response of CdS/PSi/c-Si photodetector prepared at 450 °C were located at 455 and 840 nm. The specific detectivity and carrier lifetime of the heterojunctions have been measured.

1. Introduction

Cadmium sulfide CdS is important and attractive semiconducting materials and has draw attention due to its optical and electrical properties [1–3]. It has n-type conductivity and energy gap of 2.4 eV at room temperature [4]. CdS has been used extensively in many applications such as solar cells, heterojunction photodetectors, window material for thin film heterojunctions, photoconductor, and logic gate [5–7]. Extensive works have been reported on the fabrication and characterization of CdS/Si heterojunction devices [8–10]. Studies on improvement of the performance of CdS/Si devices by post deposition annealing and by doping of CdS have been published [11–13]. It is reported that the figures of merit of CdS/Si devices were depend on the preparation conditions [14]. Many methods have been employed to deposit CdS films such as thermal evaporation, chemical bath deposition CBD, laser deposition, sol-gel, hydrothermal, successive ion layer adsorption and reaction SILAR, sputtering, electrodeposition, and spray pyrolysis [15–20]. Deposition of CdS film by spray pyrolysis

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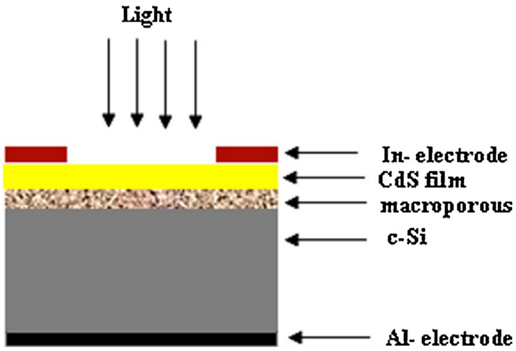

Fig. 1. Schematic diagram of cross sectional view of CdS/PSi/c-Si photodetector.

technique exhibits many advantages like cost-effective, no vacuum required, simple, large deposited area, high purity, good control on film morphology and composition, and low processing temperature [21]. Little data have been focused on the deposition of CdS on porous silicon PS [22–26]. Porous silicon structures have draw attention in optoelectronic applications due to their unique optical and electrical properties [27]. The size and morphology of porous structure were found to play a crucial role in determining the appropriate application field of porous silicon. Based on the superior features of porous silicon, high sensitivity Porous silicon photodetector fabricated by electrochemical method was reported [28,29]. The large surface to volume ratio and light trapping effect are considering the main parameters resulted in improvement the porous silicon photodetectors [30]. The present study aims to prepare and characterize of CdS/PSi/c-Si double heterojunction photodetector by low cost spray pyrolysis. Figures of merit of photodetector deposited at two substrate temperatures have been demonstrated and discussed.

2. Experiment

All the chemicals used in this study were analytical grade. In this study, p-type mirror-like silicon substrate was used having electrical resistivity of (3–5) Ω cm and (100) orientation. First, the wafer are cut into square pieces with area of 1 cm^2 and cleaned by standard method. Electrochemical method (anodization) was used to prepare porous silicon. Anodization was carried out by using a Teflon cell with an electrolyte containing 40% HF and 99.9% ethanol, 1:1 by volume. The silicon samples were anodized at a current density of 30 mA/cm^2 for 15 min. After anodization, the silicon samples were washed with deionized water for 10 min and dried using N_2 gas. CdS films were deposited on cleaned glass and porous silicon substrates by chemical spray pyrolysis technique. Aqueous solution of cadmium nitrate $Cd(NO_3)_2{\cdot}4H_2O$ and thiourea $CS(NH_2)_2$ of 0.1 M have been used as starting spray solution. The film deposition was carried out at substrate temperature of 350 and 450 °C ± 5 °C by using digital temperature controller. Nitrogen as carrier gas and the solution was sprayed with flow rate of 1 cm^3 min^{-1} along the entire experiment. The formation of CdS film can be taken place according to the chemical reaction:

$$Cd(NO_3)_2 + CS(NH_2)_2 + 3H_2O \rightarrow CdS \downarrow + 2NH_4NO_3 + CO_2$$

The optical transmittance of the CdS film deposited on glass substrate was measured using double beam spectrophotometer (Cintra-5-GBC Scientific). The structural properties of CdS film and porous silicon were examined using x-ray diffractometer using CuKα source with wavelength of 0.154 nm (Shimadzu, XRD-6000). The surface morphology of film and porous silicon was studied using atomic force microscope AFM (AA 3000 SPM). The morphology of CdS film and porous structure was investigated using scanning electron microscope (Tescan VEGA3). Hall measurement (Ecopia HMS-3000) was used to investigate the conductivity type of CdS film. To measure photodetectors properties, ohmic contacts were established on both CdS film and back side of silicon wafer by depositing of In and Al films, respectively, through special masks by thermal resistive technique. Fig. 1 shows the architecture diagram of CdS/PSi/c-Si photodetector structure. The dark and illuminated current-voltage characteristics of the photodetector were measured at room temperature. Capacitance-voltage characteristics have been investigated using RLC meter at frequency of 100 KHz. The spectral responsivity of the photodetector in presence of the external bias was estimated with aid of monochromator in the spectral region (300–900) nm after making power calibration. The lifetime of minority carriers of the photodetector was measured using flash light from stroboscope and digital storage oscilloscope with 100 MHz bandwidth.

3. Results and discussion

Fig. 2 illustrates the XRD patterns of CdS film deposited on glass substrate prepared at350 and 450 °C. Five diffraction peaks were noticed at 2θ = 22.93°, 24.16°, 25.97°, 41.5°, and 48.83° corresponding to (100), (002), (101), (220), and (311) planes, respectively. All these peaks are indexed to crystalline hexagonal wurtzite CdS structure of P63mc space group according to (JCPDS #01-077-2306) [31]. The high intensity of (002) reflection indicating the crystallites are well ordered along c-axis.