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Effect of rapid thermal annealing on the characteristics of amorphous carbon/n-type crystalline silicon heterojunction solar cells

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ABSTRACT

Heterojunction solar cells were fabricated by the deposition of un-doped amorphous carbon on mono-crystalline n-type silicon wafer (a-C/Si) using a frequency doubled pulsed Nd:YAG laser under vacuum followed by rapid thermal annealing (RTA). Structural and optical properties were characterized by x-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive x-ray (EDX), atomic force microscopy (AFM), Fourier transformation infrared spectroscopy (FTIR), and UV–vis transmittance. Optical properties investigation showed a 2.2 eV optical band gap of the amorphous carbon. *I–V* characteristics indicated a good rectification of the a-C/Si heterojunction with an ideality factor of 3. The 30 s annealed a-C/Si solar cell at 600 °C showed the highest conversion efficiency ($\eta = 1.1\%$). The maximum open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) of the cells were 250 mV and 33.3 mA/cm^2 respectively. The photo-response of the cells was significantly improved after RTA.

1. Introduction

Diamond like carbon (DLC) film is a material of great interest due to its excellent mechanical properties and low negative electron affinity [1–3]. Its optical properties can be changed by varying the deposition conditions. DLC is an amorphous carbon (a-C) which shows a semiconducting nature and promotes its applications in the field of semiconductor technology as in heterojunction diodes and solar cells. Many methods are used to deposit DLC; these include radio frequency plasma enhanced chemical vapor deposition [4], pulsed discharge plasma chemical vapor deposition [5], microwave surface wave plasma chemical vapor deposition [6], magnetron sputtering [7], and pulsed laser ablation [8]. Many lasers were used for depositing amorphous carbon film; these include ruby laser, Nd:YAG laser, and excimer laser. The main advantage of using lasers in manufacturing DLC lies in the capacity of producing highly energetic carbon species with distinct kinetic energy and almost the same stoichiometry of the film and the target material [1]. Laser can produce films without hydrogen and with high degree of diamond-like properties [9]. Amorphous C/p-Si heterojunction solar cell with efficiency of 0.28% fabricated by laser ablation was reported by Seong et al. [9,10]. In the current study, structural, morphological and optical properties of carbon films prepared by laser ablation are presented together with the photovoltaic properties of a-C/Si heterojunction solar cells before and after RTA.

2. Experimental

Q-switched frequency doubled Nd:YAG laser, operating at 0.532 μm and 7 ns pulse duration, was used to deposit diamond like carbon film on n-type silicon substrates by irradiating a graphite target. Fig. 1 shows the schematic diagram of the pulsed laser deposition (PLD) system used

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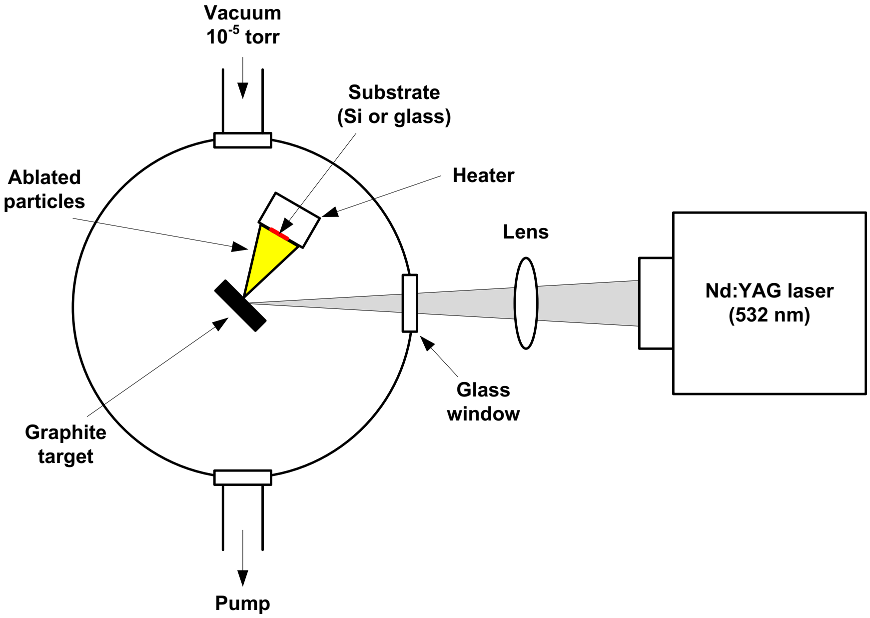

Fig. 1. Laser ablation system used for deposition of DLC.

in this study. The DLC films were grown on HF-etched single crystal Si (111) having an electrical resistivity between 1 and 3 Ω cm and also on cleaned glass substrates under a vacuum pressure of 10^{-5} Torr. The system has a facility of rotating the substrates as well as heating them to a 100 °C during the laser deposition process. The laser beam was focused on the graphite target to a spot diameter of 0.5 mm using a 10 cm positive lens. The laser fluence on the graphite target was fixed at a value of 10 J/cm^2. The DLC film growth (about 100 nm in thickness) was subjected to rapid thermal annealing (RTA) using a halogen lamp at 600 °C for 30 s under high purity argon gas. RTA at 400 °C, 500 °C, 600 °C, and 700 °C annealing temperatures and 10 s, 20 s, 30 s, and 40 s annealing times were tested but optimum properties of the film growth were only obtained at 600 °C for 30 s. XRD studies were carried out to investigate the structure of the DLC films. The transmittance of the DLC films deposited on glass substrates was recorded by a spectrophotometer in the range of 350–900 nm (SP8001Meteric.Inc.). The morphology of the DLC films was tested by using a field emission scanning electron microscope (Jeol JSM 7600F FESEM) while their topography was studied by using an atomic force microscope AFM (SPM AA 3000 Angstrom Advanced Inc. USA). The AFM measurements were performed in a non-contact mode with a scan area of $20 \times 20\ \mu m^2$. Fourier transformation infrared spectrophotometer (Shimadzu IR Affinity-1) was used to investigate the chemical composition of deposited films. Four point probe measurements were employed to estimate the conductivity type of the DLC films. The front side (DLC film) and back side (n-Si) ohmic contacts were made by depositing Au electrodes through special masking using an electron beam evaporation technique. A schematic cross sectional representation of the a-C/Si heterojunction solar cell is given in Fig. 2.

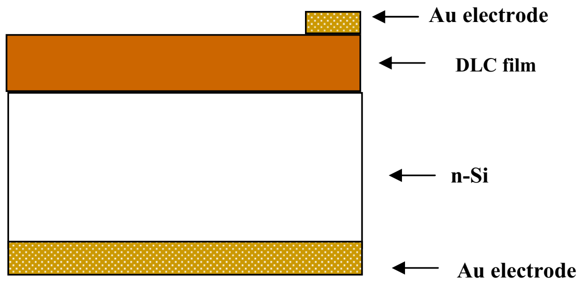

Fig. 2. Cross-sectional view of a-C/Si heterojunction solar cell.

A solar simulator was utilized to measure the photovoltaic properties of the cells at AM1.5 condition. The area of the solar cell was 3 cm^2 and all measurements related to DLC films and solar cells were carried out at room temperature.

3. Results and discussion

XRD measurements showed that the carbon films grown are amorphous before and after RTA; this is ascribed to the presence of dangling bonds and hydrogen atoms. No diffraction peaks related to the traces of any phases were observed except the one belonging to the silicon substrate. Fig. 3 shows the SEM images of the carbon films deposited on glass substrates before and after RTA. The morphology of the films indicates an amorphous carbon matrix with an embedded diamond-like carbon structure. The formation of aggregate-like structure can also be seen. The vertical and horizontal aggregate dimensions are around 80–95 nm and 130–145 nm, respectively. The aggregation of nanoparticles could be due to the