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Investigations on phosphorus doped amorphous/nanocrystalline silicon films deposited by a filtered cathodic vacuum arc technique in the presence of hydrogen gas

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ABSTRACT

Phosphorus doped amorphous/nanocrystalline silicon (a-Si:H/nc-Si:H) thin films have been deposited by a filtered cathodic vacuum arc (FCVA) technique in the presence of hydrogen gas at different substrate temperatures (T_s) ranging from room temperature (RT) to 350 °C. The films have been characterized by using X-ray diffraction (XRD), Raman spectroscopy, Fourier transform infrared (FTIR) spectroscopy, dark conductivity (σ_D), activation energy (ΔE), optical band gap (E_g) and secondary ion mass spectroscopy. The XRD patterns show that RT grown film is amorphous in nature but high temperature (225 and 350 °C) deposited films exhibit nanocrystalline structure with (111) and (220) crystal orientations. The crystallite size of higher temperature grown silicon film evaluated was between 13 and 25 nm. Raman spectra reveal the amorphous nature of the film deposited at RT, whereas higher temperature deposited films show crystalline nature. The crystalline volume fraction of the silicon film deposited at higher temperatures (225 and 350 °C) was estimated to be 58 and 72%. With the increase of T_s, the bonding configuration changes from mono-hydride to di-hydride as revealed by the FTIR spectra. The values of σ_D, ΔE and E_g of silicon films deposited at different T_s were found to be in the range of 5.37×10^{-4}–$1.04\ \Omega^{-1}\ cm^{-1}$, 0.05–0.45 eV and 1.42–1.83 eV, respectively. Photoconduction of 3.5% has also been observed in n-type nc-Si:H films with the response and recovery times of 9 and 12 s, respectively. A n-type nc-Si:H/p-type c-Si heterojunction diode was fabricated which showed the diode quality factor between 1.6 and 1.8.

1. Introduction

The silicon based thin film solar cells have drawn interest to a great extent. These solar cells have the superior properties over the first generation crystalline Si (c-Si) solar cells such as large area deposition, low manufacturing cost and made a large share in the global market [1]. But some disadvantages such as low power conversion efficiency [2] and light induced degradation so-called Staebler–Wronski effect [3] have also been manifested by the hydrogenated amorphous silicon (a-Si:H) thin film solar cells. Nanocrystalline silicon (nc-Si:H) thin film, a mixed phase material consisting of nanocrystals embedded in the amorphous matrix, is a subject of extensive research in the field of semiconductor thin film technology. nc-Si:H has been extensively applied for the

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fabrication of thin film devices such as solar cells, thin film transistors, sensors, etc. Optical and electrical investigations of nc-Si:H thin films have been carried out widely [4–9] which represented a strong optical absorption and a large photocurrent in nc-Si:H films. The nanocrystal grains in nc-Si:H thin films have better charge carrier conduction than a-Si:H thin films [10]. There are a number of reports to realize high efficiency and good stability of single-junction [11,12] and tandem [13,14] third generation nc-Si:H thin film solar cells. Different methods such as plasma enhanced chemical vapor deposition (PECVD), hot wire chemical vapor deposition (HWCVD) and electron cyclotron resonance chemical vapor deposition (ECR-CVD) have been extensively utilized in the fabrication of nc-Si:H thin films [15–18]. All these techniques deploy different gaseous sources like silane and for doping phosphine and diborane which are toxic, hazardous and not environment friendly, for the fabrication of nc-Si:H thin films. Uniform deposition over a large area is also one of the principal challenges in applying nc-Si:H thin film on an industrial scale.

However, a better alternative would be to use solid silicon as a source material for the fabrication of nc-Si:H thin film and to seek a different but an efficient process such as filtered cathodic vacuum arc (FCVA) that could effectively fabricate a high quality nc-Si:H thin film for various technological applications. FCVA is a plasma based popular industrial technology for the deposition of a variety of films like metals, ceramics, diamond-like carbon, tetrahedral amorphous carbon (ta-C) films, etc. [19–25]. It is a low voltage and high current process that takes place between the two electrodes. The FCVA method has been used earlier to deposit amorphous silicon thin films [26–29]. This technique has also been used to deposit boron doped ta-C film as a window layer in the inline production of large area hydrogenated amorphous silicon solar cell for improving the power conversion efficiency [30]. In this technique, the properties of films can be controlled by various process parameters such as arc current, substrate temperature and gaseous pressure in the reactive mode.

This paper reports the deposition and characterization of phosphorus doped amorphous/nanocrystalline silicon (a-Si:H/nc-Si:H) thin films by a FCVA technique in the presence of hydrogen gas. The effect of the processing parameters such as deposition temperature on the structural, electrical and optical properties of the doped a-Si:H/nc-Si:H thin films have been studied. Photoconduction and a heterojunction diode have been studied using the nc-Si:H film.

2. Experimental

Phosphorus doped a-Si:H/nc-Si:H thin films have been deposited by the FCVA technique. The schematic of the FCVA system is shown in Fig. 1. The detailed description of the system has been described elsewhere [22,24]. The FCVA process works on the principle of striking the arc (arc voltage of 35–40 V with an arc current of ~100 A) between the two electrodes. Here, one electrode is phosphorus doped silicon (0.55 Ω cm) cathode of 50 mm diameter and 5 mm thickness of purity 99.999% that works as a silicon source in order to deposit the thin film. Second electrode is a retractable high purity tungsten wire as an anode. The magnetic filter is energized using direct current (D.C.) power supply and a magnetic field of ~350 G is achieved inside the duct to remove the macro-particles generated from the plasma. Prior to the deposition, the chamber was evacuated to a base pressure of $\sim 10^{-6}$ mbar. The Si films were grown in the presence of hydrogen gas at different substrate temperatures (T_s) of RT, 225 and 350 °C at a fixed pressure of $\sim 2.5 \times 10^{-3}$ mbar.

The substrates used for the deposition of n-type a-Si:H/nc-Si:H thin films were 7059 corning glass for the optical, electrical, X-ray diffraction (XRD) and Raman studies and

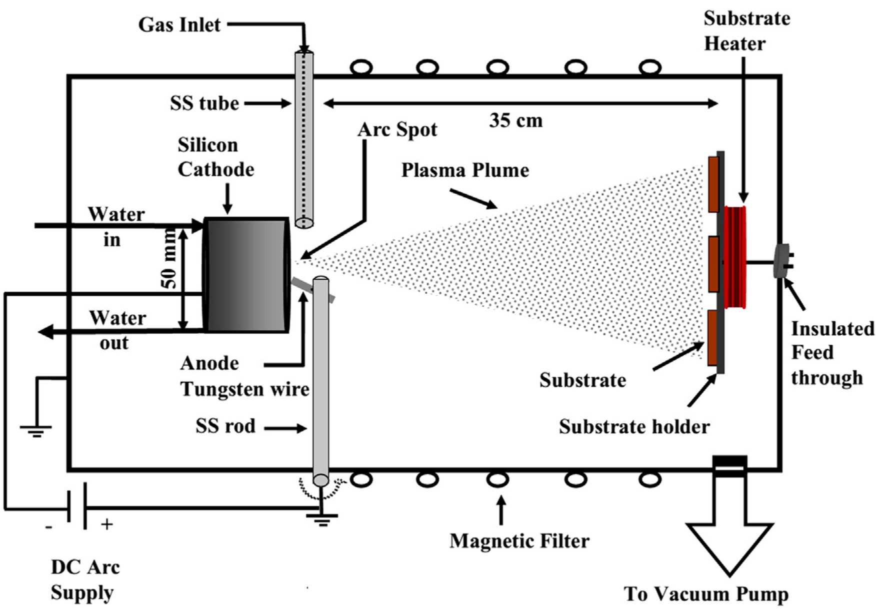

Fig. 1. Schematic of FCVA system used in the deposition of the film.