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Photovoltaic characteristics of phosphorus-doped amorphous carbon films grown by r.f. plasma-enhanced CVD

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Abstract

The phosphorus-doped amorphous carbon (n-C:P) films were grown by r.f. power-assisted plasma-enhanced chemical vapor deposition at room temperature using solid phosphorus target. The influence of phosphorus doping on material properties of n-C:P based on the results of simultaneous characterization are reported. Moreover, the solar cell properties such as series resistance, short circuit current density (J_{sc}), open circuit current voltage (V_{oc}), fill factor (FF) and conversion efficiency (η) along with the spectral response are reported for the fabricated carbon based n-C:P/p-Si heterojunction solar cell were measured by standard measurement technique. The cells performances have been given in the dark I–V rectifying curve and I–V working curve under illumination when exposed to AM 1.5 illumination condition (100 mW/cm^2, 25 °C). The maximum of V_{oc} and J_{sc} for the cells are observed to be approximately 236 V and 7.34 mA/cm^2, respectively for the n-C:P/p-Si cell grown at lower r.f. power of 100 W. The highest η and FF were found to be approximately 0.84% and 49%, respectively. We have observed the rectifying nature of the heterojunction structures is due to the nature of n-C:P films.

Keywords: Photovoltaic; Solar cell; Phosphorus doping; a-C:H; PECVD

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1. Introduction

Amorphous carbon (a-C) shows semiconducting nature, which promotes its application in the field of semiconductor technology, such as fabrication of photovoltaic solar cells [1]. A large variety of a-C thin films with and without hydrogen due to the difference in bonding and degree of disorder have been expected to become very important class materials because of their semiconducting properties. In the past decade, the application of a-C films on the semiconductor field were the subject of many investigations [1,2].

However, undoped a-C is weakly p-type [3] in nature and the complex structure and presence of high density of defects restricts its ability to dope efficiently and is the main barrier for its application in various electronic devices, and therefore, when we attempt to utilize such carbon as alternative material in opto-electronic devices, control of the conduction type through doping of carbon film is indispensable.

The doping mechanism of amorphous semiconductors has always been an interesting issue. Observations from literature showing that the semiconducting carbon films can be either intrinsic or they can be doped during or after the growth to make them extrinsic semiconductors. Effective doping can modify electronic properties, specially gap states, conductivity, etc. in semiconductor materials. Many attempts have been made to dope carbon films using various elements. It has been reported that, phosphorus (P) is the widely used n-type impurity in silicon [4] and is a possible alternative to N in carbon [5]. The optical, electrical and photovoltaic properties of phosphorus doped, which is thought to be promising for n-type conductivity control, a-C:H leading to the possibility of devices fabrication are studied. An attempt has been made on the device fabrication with P-doped amorphous carbon thin films (n-C:P) deposited on p-type Si (1 0 0) by r.f. plasma-enhanced chemical vapor deposition (PECVD).

2. Experimental

The P-doped n-C:P thin films were deposited in a 13.56 MHz r.f.-powered PECVD system, at room temperature, with CH_4 and H_2 as the source gas, in a clean room setup [6]. The distance between substrate stage and top plate was set at 49 mm. Substrate temperature was kept at 20 °C. Base vacuum was typically set at the pressure of lower than 2×10^{-4} Pa using a turbomolecular pump and oil diffusion pump. After that, the chamber pressure was allayed at setting pressure of 20 Pa and the flow rate of feed gas mixtures of CH_4 and H_2, respectively was optimized at 5 and 50 sccm. The r.f. power was the variable condition from 100 to 300 W. In order to dope, the pure solid phosphorus target of 100 g weight with 2–10 diameters were put at the distance of 20 mm on the top of the substrate. For comparison, the undoped a-C film was also deposited using the above deposition procedure without solid phosphorus target. All the films and photovoltaic cells were analyzed by using standard experimental characterization techniques [7].

3. Results and discussions

X-ray photoelectron spectroscopy (XPS) analysis is one of the most likely used techniques in the literatures to characterize the formation, bond types and useful information on the chemical environment [7]. XPS studies have shown the C 1s peak position of the n-C:P films grown up to 200 W is unchanged, constant at the same position