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Characteristics of p-type nanocrystalline silicon thin films developed for window layer of solar cells

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Abstract

Different rf-power and chamber pressures have been used to deposit boron doped hydrogenated silicon films by the PECVD method. The optoelectronic and structural properties of the silicon films have been investigated. With the increase of power and pressure the crystallinity of the films increases while the absorption decreases. As a very thin p-layer is needed in p–i–n thin film solar cells the variation of properties with film thickness has been studied. The fraction of crystallinity and thus dark conductivity vary also with the thickness of the film. Conductivity as high as 2.46 S cm^{-1} has been achieved for 400 Å thin film while for 3000 Å thick film it is 21 S cm^{-1}. Characterization of these films by XRD, Raman Spectroscopy, TEM and SEM indicate that the grain size, crystalline volume fraction as well as the surface morphology of p-layers depend on the deposition conditions as well as on the thickness of the film. Optical band gap varies from 2.19 eV to 2.63 eV. The thin p-type crystalline silicon film with high conductivity and wide band gap prepared under high power and pressure is suitable for application as window layer for Silicon thin film solar cells.

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1. Introduction

In recent years intrinsic microcrystalline silicon has drawn considerable attention as the active layer of thin film solar cells due to its better stability and potential for higher efficiency compared to amorphous silicon. But prior to this, doped microcrystalline silicon films were developed and attempts were made to use these layers as window layer or interface layer in a-Si solar cells [1]. It has been reported that a-Si:H p–i–n solar cells prepared with μc-Si:H p-layer show an increase of V_{OC} by 50 mV and initial efficiency 7.7% [2]. Incorporation of microcrystalline fluorinated p^+ silicon having high dark conductivity and low optical loss in single and tandem amorphous silicon alloy based solar cells has resulted in increased open circuit voltage and conversion efficiency [3]. Sasaki studied the structures of thin μc-Si(p) layers as function of the substrate temperature (T_S) compared with the bulk films for solar cells [4]. Rath showed that single junction p–i–n cell could be made in superstrate configuration using p-type μc-Si as window layer directly on top of the SnO_2:F coated glass giving an efficiency of 9.63% [5]. Usually high band gap p-type amorphous silicon carbide layer is being used in high efficiency a-Si solar cell as window layer [6,7]. Yu reported that the a-$Si_{1-x}C_x$:H p-type films having high conductivity $\sim 10^{-6}\,(\Omega\,cm)^{-1}$ and wide band gap of ~2.8 eV provides an easy way to prepare high quality window layer [8]. Dasgupta stated that there is an optimum pressure, depending upon the other deposition parameters, to achieve high conducting doped μc-SiC:H film by controlling crystallinity in

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conjunction with doping efficiency [9]. Boron doped microcrystalline silicon has advantages of comparatively high conductivity, low activation energy and low absorption compared to its amorphous counterpart but it failed to produce better cell performance due to lattice mismatch with amorphous silicon [10,11]. Palit and Chatterjee have shown using theoretical simulation that response of a cell having p-μc-Si:H as window layer is comparatively less than that having p-a-SiC:H. This is because wide band gap p-a-SiC:H effectively blocks electron back diffusion current as the major part of the p/i band offset lies on the conduction band side resulting reduction of the recombination loss of p-layer. But large number of electrons produced by the absorbed short-wavelength light recombine with holes for μc-Si:H p-layer ($\Delta E_C = 0$) [12].

In case of p/i/n structure thin film solar cells where micro or nanocrystalline silicon is the active layer, nanocrystalline p-layer may be better option. Thin crystalline p-layer may help in nucleation of crystallites in the intrinsic layer. Lattice mismatch is expected to be less also. Structural and optoelectronic properties of Plasma Enhanced Chemical Vapour Deposited films depend critically on plasma excitation power and chamber pressure during deposition. Effect of these deposition parameters on the properties of p-type silicon layers have been studied in this paper. Usually characterizations are made on 3000–4000 Å thick films. But for solar cell application structural and optoelectrical character of thin p-layer is important. These properties also vary with the thickness of the films and the variations are different under different deposition conditions. For window layer of solar cells thin p-layer is necessary with good conductivity and low absorption. Thicker p-layer will absorb more sunlight and introduce less radiation into the active layer of the cell and thus produce less current. So objective of this paper is mainly to make thin nanocystalline p-layer with optoelectronic properties suitable for application in microcrystalline solar cells.

2. Experimental

p-type hydrogenated silicon (Si:H) films have been prepared using R.F. Plasma Enhanced Chemical Vapour Deposition technique using gas mixture of silane (SiH_4), diborane (B_2H_6) and hydrogen (H_2). The deposition system consists of load-lock and deposition chambers with an ultra-high vacuum facility. The base pressure for all the deposition chambers is in the range of $\sim 10^{-9}$ Torr, which provides an almost contamination- free environment for the film deposition. Three sets of p-Si:H films have been deposited under different rf power and chamber pressure; 10 W–1.4 Torr, 25 W–3 Torr and 40 W–4 Torr respectively varying the film thickness and keeping the substrate temperature (T_S) fixed at 200 °C. The hydrogen dilution of silane is 99% and B_2H_6 concentration in silane is 5.0×10^{-3} in gas phase.

The substrate used for the deposition of Si:H films is 7059 Corning glass. The dark conductivity (σ_d) is measured in a cryostat under a vacuum of the order of 10^{-6} Torr. The optical reflection and absorption of the films were measured by UV–VIS–NIR dual-beam spectrophotometer and from these data the band gap of the films have been estimated. The thickness of films was measured by Dektak Profilometer. X-ray diffraction was employed to investigate the crystallographic orientations of those films. Raman spectra have been taken on films with different thicknesses. High Resolution Transmission Electron Microscopy have been made on thin films deposited on carbon coated copper grid. Surface morphology has been studied by high resolution field emission Scanning Electron Microscope.

3. Results and discussion

3.1. Electrical and optical properties

The variations of dark conductivity (σ_d) of p-layer with the thickness of the films deposited under different power–pressure conditions are shown in Fig. 1. It is seen that σ_d increases with the increase of film thickness up to 3000 Å and then tends to saturate. The trend is same for films prepared under different power–pressure conditions but the rate of variations of conductivity with thickness are different. At the initial stage of growth the films are non-uniform and so carriers cannot get the percolation path. With the increase of film thickness some crystallites touch each other enhancing the carrier mobility and resulting higher conductivity. For crystalline growth in silicon film initially few nucleation layers are needed which are usually amorphous. It has been noted that σ_d of the thin films ($\sim$400 Å) deposited under 25 W–3 Torr and 40 W–4 Torr are 2.46 S cm^{-1} and 6.2 S cm^{-1}, respectively which are quite high compared to the conductivity ($\sim 10^{-3}$ S cm^{-1}) of p-type amorphous silicon film. Here the percolation paths of the charge carri-

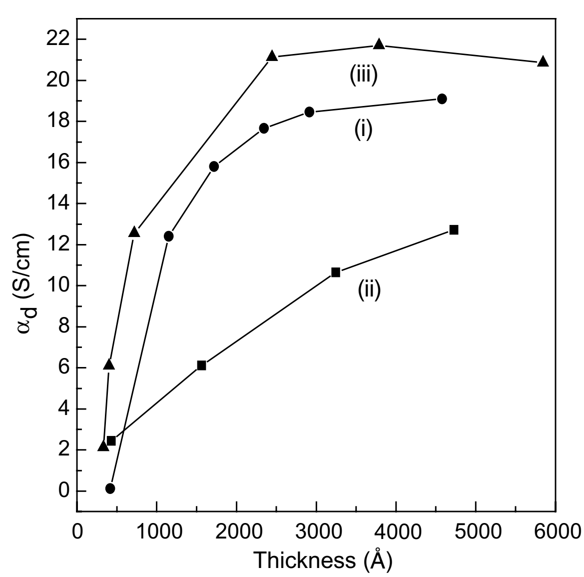

Fig. 1. Variation of the dark conductivity σ_d with the film thickness for p-type Si:H films deposited at (i) 10 W–1.4 Torr, (ii) 25 W–3 Torr and (iii) 40 W–4 Torr power–pressure.