Hydrogenated amorphous silicon deposited by ECR-CVD for hybrid a-Si:H-p$^+$/c-Si-n^{++} solar cells

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1. Abstract:

Hydrogenated amorphous silicon (a-Si:H) thin films has been deposited by an Electron Cyclotron Ressonance Chemical Vapor Deposition (ECR-CVD) system using a radio frequency power (RF) on the sample holder (chuck samples) of 1W, 3W and 5W. These deposited films were used to fabricate the amorphous/silicon (a-Si:H/C-Si) heterojunction (SHJ) photovoltaic (PV) cells. After a rapid thermal annealing process (RTA), for the activation of dopants implanted boron ions, the crystallinity of the films changed from totally amorphous to partially crystalline with the largest grain size for the 5W film and a small grain size for the 3W film. In the electrical measurements, the 5W of RF film, had the highest values of FF, VOC and an efficiency (~1%).

2. Introduction

The amorphous/silicon (a-Si:H/C-Si) heterojunction (SHJ) solar cells [1], such as HIT (heterojunction with intrinsic thin-layer) cell had achieved a high efficiency with records of 24.7% [2].For this, one concentration of H of about 7% into the a-Si:H is an important parameter to get the excellent passivation and high efficiency of up to 22.25% [3]. Thus, in this work, the electrical parameters of the obtained solar cells, such as efficiency, are related to the effects of RF chuck power in the incorporation of H into the a-Si:H films for different RF powers of 1, 3 and 5W. Our solar cells are SHJ devices without intrinsic layer between p$^+$-a-Si:H and n^{++}-c-Si regions.

3. Experimental Proceeding

The a-Si:H films were deposited in n^{++}c-Si substrates to study the effects of RF chuck power in the incorporation of H into the films using a high density plasma ECR-CVD system with RF power of 1W, 3W and 5W on the chuck. TheECR systems are downstream plasma reactors that allow a separate control of ion energy and flux. A 2.45 GHz ECR microwave power generates the plasma and a 13.56 MHz of RF chuck power controls the ion bombardment and silane dissociation. The 98% SiH_4 gas diluted in argon (Ar) allows low silane concentration in the ECR plasma that, with high degree of dissociation, can reduce the Si-H bond incorporation in the films deposited. Moreover, to optimize the composition and the microstructure of the deposited a-Si:H films, the hydrogen (H) incorporation should be kept at less than 20%, depending on RF power source bias under the chuck Furthermore, this bias controls the ion bombardment on substrate. The films with thickness of ~200nm were deposited with: 1W, 3W and 5W of RF powers biases, a ECR power of 500 W, pressure of 4 mTorr, substrate temperature of 20 °C, gas flows of 200 sccm of SiH_4, 20 sccm of Ar for 20 minutes. Then, the samples were implanted with boron ion (B^+) with energy of 20 KeV and dose of 5x10^{15} cm³ and annealed for the activation and creation of a p$^+$ layer of the dopant at 1000 °C, during 60s in a RTA process. For the electrical measurements, back and front contacts of 500 nm aluminum were deposited by sputtering. A thin layer of silicon oxide for passivation and an antireflective coating of silicon nitrite (SiN_x) was deposited in the ECR-CVD for PV Cells efficiency measurements.

4. Results and discussions

To obtain the hydrogen concentration ([H]) into the films, the FTIR absorbance spectra (A(ω)) was obtained in the regions between 600 - 700 cm^{-1} (figure 1). The quantity of silicon-hydrogen bonds (n_H) was estimated from the Si-H rocking/waging mode at 640 cm^{-1} using expression (1) [[4], [5]] and the hydrogen concentration from expression (2).

$$n_H = A_{640} \int \frac{\alpha'(\omega)}{\omega} d\omega \ (1); \qquad [H] = \frac{n_H}{n_H + 5\,x 10^{22}} \ (2).$$

where:
n_H = the quantity of silicon-hydrogen bonds; A_{640} = the oscillator strength at ω (wavenumber) = 640 cm^{-1}; [H] = the hydrogen concentration ([H]) into the films.

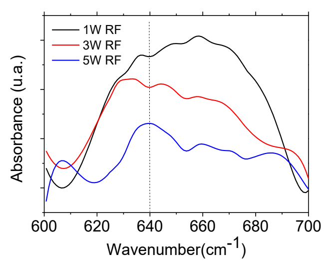

Fig. 1: FTIR spectra of the films in the 600-700 cm^{-1} range.

The oscillator strength A_{640} equals 1.6 x 10^{19} cm^{-2} [6] and the silicon density is 5 x 10^{22} cm^{-3}. From that, the calculated [H] for the films was: 30.0%, 9.12% and 6.05% for the films deposited with 1W, 3W and 5W of RF power.

The crystallinity of the films was determined by analyzing the Raman spectra of the films. The as-deposited films are totally amorphous (figure 2 left), due to the absence of a crystalline peak at 520 cm^{-1}. This peak can be observed at the post RTA/ B^+ I/I film spectra (figure 2 right). Deconvoluting these curves, the crystalline factor was (F_C) and the grain diameter (d_{Raman}) were calculated, using the expressions (3) and (4), respectively [7]. Where Ic is the area under the crystalline peak at 520 cm^{-1} and Ia the area under the amorphous peak at 480 cm^{-1}, $\gamma = 0.8$ a correction factor, $\Delta\omega$ the displacement of the crystalline peak from 520 cm^{-1} and $B = 0.2\ nm^2 cm^{-1}$.

$$F_c = \frac{I_c}{I_c + \gamma I_a} \quad (3); \quad d_{Raman} = 2\pi\sqrt{\frac{B}{\Delta\omega}} \quad (4)$$

Fc is equal to 65% for all the three films and the d_{Raman} is equal to 9±44 nm, 7±6 nm and 14 ±4 nm for the 1W, 3W and 5W films.

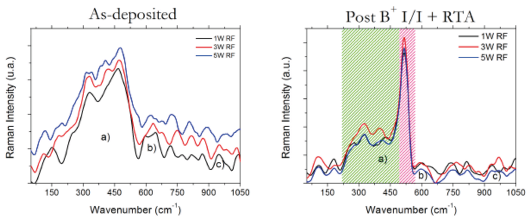

Fig. 2: Raman spectra of the films as-deposited left and post B+ I/I/ RTA in the right. The areas under the spectra shows: a) Si-Si vibration modes, b) and c) Si-H vibration mode at 620 cm^{-1} and 950 cm^{-1}, respectively.

During the RTA process, the Si-H bonds can dissociate due to the high temperatures. Thus, hydrogen atoms are released from their bonds and start to out diffuses through the film. This out diffusion is indicated by the absence of Si-H vibration modes at 620 cm^{-1} and 950 cm^{-1} peaks in the spectra after the B^+ I/I/ RTA.

The rms surface roughness of the films was measured by AFM (figure 3). The rms roughness values are 1.24 nm, 0.99 nm and 6.41 nm for the deposited films using RF powers of 1W, 3W and 5W, respectively. From figure 3, heavily, medium and low granulated surfaces occurred for the films of 5W, 1W and 3W, respectively, which agree with the calculated grain diameters from Raman results.

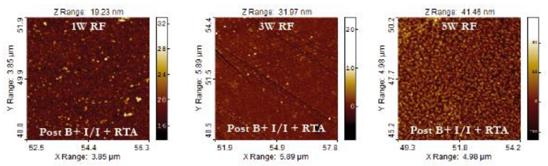

Fig. 3: AFM Images of the film surfaces after B^+ I/I/RTA.

The amorphous/silicon (a-Si:H/C-Si) heterojunction (SHJ) solar cells were fabricated and IV curves, in figure 4, in dark and illuminated (with AM 1.5) conditions were measured. The solar cells, with films of 5W and 3W, presented the highest efficiencies of about 1%. Furthermore, the solar cell fabricated with the 5W films presented the maximum values of V_{oc}=462 mV and FF=31%. However, the value of J_{cc} = 6.7mA/cm^2 was not maximum. The maximum value of J_{cc}=21.12 mA/cm² was for the 1W solar cells with the 1W films. However, these cells had the lowest values of η=0.47%, Voc=92 mV and FF = 24.8%.

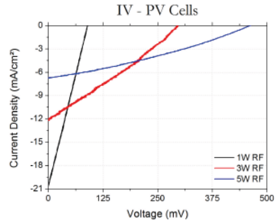

Fig. 4: IV curves of the amorphous/silicon (a-Si:H/C-Si) heterojunction (SHJ) solar cells illuminated (with AM 1.5) conditions.

5. Conclusion:

In this work the morphologies of a-Si:H deposited by ECR-CVD with RF power of 1W, 3W and 5W were studied, before and after the B^+ I/I and RTA annealing. The films presented the [H] values of 30%, 9.12% and 6.05%, respectively, extracted by FTIR spectra. After the RTA, the film crystallinity, extracted by Raman spectra, was changed, from totally amorphous to partially crystalline, with the largest grain size for the 5W film. This result agrees with the highest surface roughness, which was obtained for this film. From the electrical measurements, the 5W film had the highest values of FF, VOC and an efficiency (~1%). Thus, it can be concluding that the best film for PV cells was for the 5W RF power.

Referencies

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