Journal of Alloys and Compounds 658 (2016) 543–547

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Fabrication of amorphous silicon–germanium thin film solar cell toward broadening long wavelength response

G.H. Wang [a, *], C.Y. Shi [b], L. Zhao [a], H.W. Diao [a], W.J. Wang [a]

[a] Key Laboratory of Solar Thermal Energy and Photovoltaic System of Chinese Academy of Sciences, Institute of Electrical Engineering, The Chinese Academy of Sciences, Beijing, 100190, China
[b] China Telecommunication Technology Labs, China Academy of Information and Communication Technology, Beijing, 100015, China

ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form
21 October 2015
Accepted 25 October 2015
Available online 30 October 2015

Keywords:
Plasma enhanced chemical vapor deposition
Amorphous silicon germanium solar cell
Long wavelength response
Optical emission spectroscopy

ABSTRACT

The morphous silicon germanium (a-SiGe) thin films are fabricated in a radio frequency plasma enhanced chemical vapor deposition system. This paper summarizes our recent works on how to make a suitable a-SiGe solar cell to enhance the light absorption in the long wavelength region. Up to now, a single junction p-i-n a-SiGe solar cell with an initial efficiency of 9.06% is obtained. The long wavelength response in QE is broadened to 950 nm. The QE reaches about 26.63% at 800 nm wavelength.

1. Introduction

Amorphous silicon germanium (a-SiGe) alloys have widely been used as the absorption layer of the middle or/and bottom cells in multi-junction thin film solar cells. Their optical band gap (E_g) shifts to lower energies with increasing germanium content, which aims to make a suitable and narrow band gap a-SiGe material of the solar cells to enhance the light absorption in the long wavelength region [1–4]. However, the increase of Ge content usually results in the deteriorating of the performance of a-SiGe thin films and thus leads to a low solar cell conversion efficiency [5].

Many groups investigated the a-SiGe materials and solar cells on the optimization of materials performance and solar cell band gap structure [6–9]. The spectral response at long wavelength of a-SiGe solar cells is improved by exponential band gap design of intrinsic layers (i-layers). The quantum efficiency (QE) of cell prepared by Liu is broadened to 900 nm. The QE reaches about 20% at 800 nm wavelength [3]. The advantage of i-layer band gap shape was analyzed by space charged defect density and the electric field [10,11].

In the work, we also have been investigating the possibility of obtaining higher cell efficiency which has higher long wavelength response. The optimum performance of the device is obtained by controlling deposition parameters and using a multiple-profiled band gap in the intrinsic layer. The radical density in plasma is monitored by optical emission spectroscopy (OES).

2. Experiments and measurements

The a-SiGe thin films are fabricated in a capacitively coupled radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) system with a base vacuum of 10^{-5} Pa. The substrate temperature is fixed at 270 °C. The reactive gases for the deposition of thin films include silane (SiH_4), germane (GeH_4), hydrogen (H_2), trimethylboron (TMB) and phosphine (PH_3). The flow rate is shown in standard cubic centimeters per minute (sccm). The pressure and gas flow are independently controlled by a downstream throttle valve controller and upstream mass flow controllers, respectively. The solar cells are fabricated with the structure of glass/textured SnO_2:F/p-i-n a-SiGe/ITO/Ag. The area is 0.30 cm^2. The ITO films are deposited by intermediate frequency magnetron sputtering from a sintered ceramic SnO_2-doped In_2O_3 (10 wt.%) in an argon atmosphere. The Ag films are obtained by direct current magnetron sputtering from pure Ag target, respectively.

The a-SiGe thin films are deposited on the glass substrate. The thickness of the films is measured by Veeco Dektak 150 surface

* Corresponding author.
E-mail address: wangguanghong@mail.iee.ac.cn (G.H. Wang).

http://dx.doi.org/10.1016/j.jallcom.2015.10.235
0925-8388/

profiler. The optical reflection and transmission of thin films is measured by Varian Excalibur HE 3100 UV-VIS-NIR Spectrophotometer and the band gap of thin films has been estimated from these data. The Raman or Fourier Transform infrared spectroscopy (FTIR) spectroscopy is utilized for the layers deposited on quartz or c-Si substrates to reveal their microstructure. FTIR measurement is taken on a Varian 3100 Excalibur system. Raman measurement is carried out on a LabRAM HR system from HORIBA Scientific, operating at a wavelength of 532 nm.

The photo current–density versus voltage (J–V) characteristics of the fabricated solar cells is measured at 25 °C under 1-sun (AM1.5, 100 mW/cm^2) solar simulator radition on Ivtest Station system from Crowntech Inc. The QE measurement is performed to evaluate the spectral response of the fabricated solar cells. In situ OES diagnostics of the plasma during a-SiGe thin films deposition process are performed by AvaSpec-2048-USB2-RM Fiber Optic Spectrometer. The technique has already been reported in published paper [12].

3. Results and discussion

3.1. The effect of GeH_4 source gas

Fig. 1 shows Raman spectra of the prepared thin films. Three broad peaks near 480, 390, and 280 cm^{-1} are assigned to Si–Si, Si–Ge, and Ge–Ge transverse optical vibrations, respectively [13]. The intensity of Si–Ge and Ge–Ge modes intensifies with GeH_4 flow from 2 to 10 sccm, which also corresponds to the increase of Ge content in the a-SiGe thin films.

The optical reflection and transmission of thin films is measured. The absorption coefficient is estimated by the following formula:

$$\alpha = \frac{\ln\left(\frac{(1-R)^2}{T}\right)}{d} \quad (1)$$

where α is the absorption coefficient, d is the thickness of thin film, R and T is the optical reflection and transmission of thin film, respectively.

The E_g is deduced from a linear fit of the absorption data according to the well-known relation proposed by Tauc [14].

$$(\alpha h\nu)^{1/2} = B(h\nu - E_g) \quad (2)$$

where hν is the photon energy, B is a constant, so that E_g is obtained by extrapolation of the linear fit to $\alpha = 0$. Fig. 2 shows E_g of a-SiGe thin films at different GeH_4 flow. The E_g decrease shows the increase of Ge content with GeH_4 flow [15]. This is consistent with the result measured in Raman spectra of thin films. The E_g determines what portion of the solar spectrum a photovoltaic cell absorbs. Its small band-gap allows the absorption of a large portion of the photons available from the solar spectrum [16].

The standard i-layers are incorporated into solar cells at 2 and 4 sccm GeH_4 flow, namely the E_g of total i-layer keeps constant. The QE curves of solar cells are shown in Fig. 3. Clearly, the QE is higher in the long wavelength at 4 sccm GeH_4 flow because of the increase of Ge content in the intrinsic layer.

3.2. The effect of SiH_4 source gas

The radical density in plasma is monitored by optical emission intensity. Fig. 4 shows intensity of SiH*, and GeH* with different SiH_4 gas flow in a pressure of 2 Torr, power of 80 w and hydrogen gas flow of 200 sccm. The SiH* emission intensity is higher than GeH* one because of a preferential attachment of H to Si over Ge [17]. The SiH* emission intensity increases greatly as a function of SiH_4 flow. The reaction source gases in plasma are depleted when the above deposition parameters are used in our RF-PECVD system [12].

The residence time, t_{res}, of gas particles in the plasma space can be estimated using the following formula [18]:

$$t_{res} = \frac{Adp}{fp_0} \quad (3)$$

Here d is the electrode distance, A is the substrate area, p_0 is the standard pressure (1013 hPa), p is the deposition pressure and f is the total gas flow (combined flow of SiH_4, GeH_4 and H_2). The increase of SiH_4 gas flow from 2 to 10 sccm has little effect on the total gas flow because hydrogen flow is much higher than SiH_4 and GeH_4 flow. So the t_{res} is almost constant. The emission intensity increases as a function of SiH_4 gas flow when the reaction source gases in plasma are depleted.

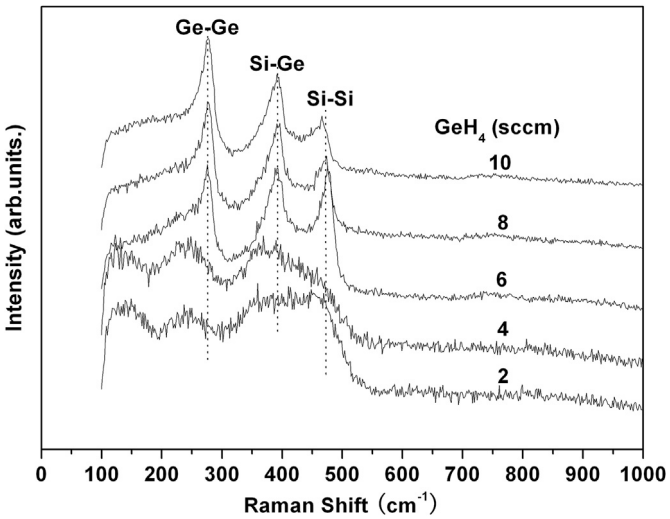

Fig. 1. Raman spectra of a-SiGe thin films at different GeH_4 flow. The curves have been shifted vertically for clarity.

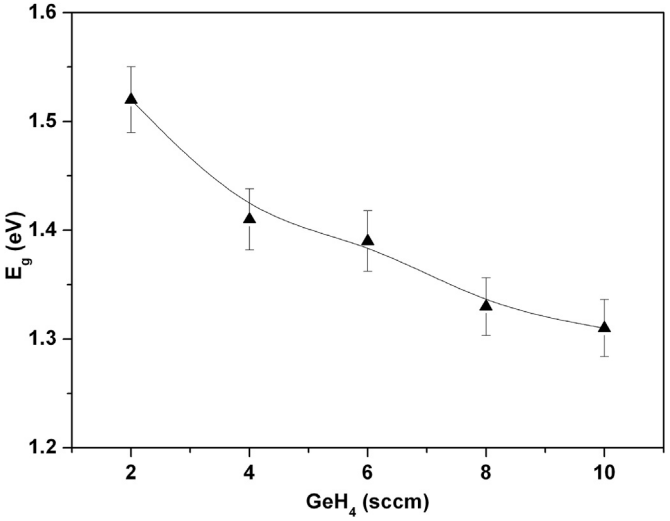

Fig. 2. E_g of a-SiGe thin films at different GeH_4 flow. Lines are drawn as guides for the eyes.