Vacuum 89 (2013) 43–46

Contents lists available at SciVerse ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Rapid communication

Hydrogenated amorphous silicon germanium alloy with enhanced photosensitivity prepared by plasma enhanced chemical vapor deposition at high temperature

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ARTICLE INFO

Article history:
Received 6 June 2012
Received in revised form
3 September 2012
Accepted 4 September 2012

Keywords:
a-SiGe:H
Deposition temperature
PECVD
Bandgap
Photosensitivity

ABSTRACT

Hydrogenated amorphous silicon germanium (a-SiGe:H) alloys were prepared by plasma enhanced chemical vapor deposition (PECVD) at different deposition temperatures. The optical, optoelectronic properties and the microstructure of the prepared a-SiGe:H alloys were investigated systematically by transmission, photo/dark conductivity, Raman, and Fourier transform infrared (FTIR) spectroscopy measurements. The Ge atom content was further determined by energy dispersive spectroscopy (EDS) and the surface roughness was checked by atomic force microscopy (AFM). It was found that the narrow bandgap (E_g) a-SiGe:H alloy with the enhanced photosensitivity (Ratio of photo conductivity to dark conductivity) and the rapid growth rate could be prepared when the deposition temperature was relatively high. The underlying mechanism was analyzed carefully. The results indicated that high temperature deposition might be an effective way to prepare a-SiGe:H alloys for solar cell application.

Hydrogenated amorphous silicon germanium (a-SiGe:H) alloy is attracting more and more attention in the solar cell fabrication due to its excellent properties compared to hydrogenated amorphous silicon thin film, such as narrow and tunable bandgap (E_g), large absorption coefficient in the near-infrared region and so on. These advantages make the a-SiGe:H alloy very applicative for the low bandgap cell in the multi-junction solar cell structures [1–5]. As well known, narrow E_g can be obtained by increasing the Ge atom content in the a-SiGe:H alloy. However, the increase of Ge content usually results in a decrease of photosensitivity (Ratio of photo conductivity to dark conductivity) [6–8]. For a-SiGe:H alloy deposited by plasma enhanced chemical vapor deposition (PECVD), the Ge content increase can make the photosensitivity be reduced from 10^5 to 10^2 [6,7]. Such photosensitivity deterioration is considered to be due to the high density of Ge dangling bonds ($>10^{17}$ cm^{-3}) induced by the increased Ge content [7,8]. Many researchers have been devoting to prepare the narrow E_g a-SiGe:H alloy with high photosensitivity. Zeman et al. found that hydrogen (H_2) dilution could improve the optoelectronic properties [9]. Zhang et al. fabricated highly photosensitive and narrow E_g a-SiGe:H film with a high H_2 dilution and a relatively high radio-frequency (RF) power. The photosensitivity of 2.01×10^5 was obtained for the alloy with E_g of 1.47 eV [10]. Xu et al. prepared narrow E_g a-SiGe:H alloys by alternately repeating thin film deposition and sequent exposure to hydrogen plasma. Such hydrogen plasma annealing improved the film quality and the photosensitivity higher than 10^4 was obtained [11]. However, both hydrogen dilution and hydrogen plasma annealing limited the film growth rate. Hazra et al. proposed to fabricate highly photosensitive a-SiGe:H using helium dilution by PECVD [12]. Jadkar et al. fabricated narrow E_g (1.39–1.53 eV) a-SiGe:H films with the photosensitivity up to 10^4–10^5 by hot wire chemical vapor deposition (HWCVD) [13]. Pulsed plasma CVD was also proposed [14]. Currently, PECVD is still the commonly used deposition method for the experimental and the industrial a-SiGe:H fabrication. Here, we studied the effect of the deposition temperature on the performance of a-SiGe:H alloy prepared by PECVD. The results presented that narrow E_g a-SiGe:H with the photosensitivity higher than 10^4 could be prepared at a relatively high deposition temperature with a low H_2 dilution by the conventional PECVD. Such high temperature deposition also brought about the expected high growth rate. We further analyzed the underlying mechanism carefully.

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http://dx.doi.org/10.1016/j.vacuum.2012.09.004

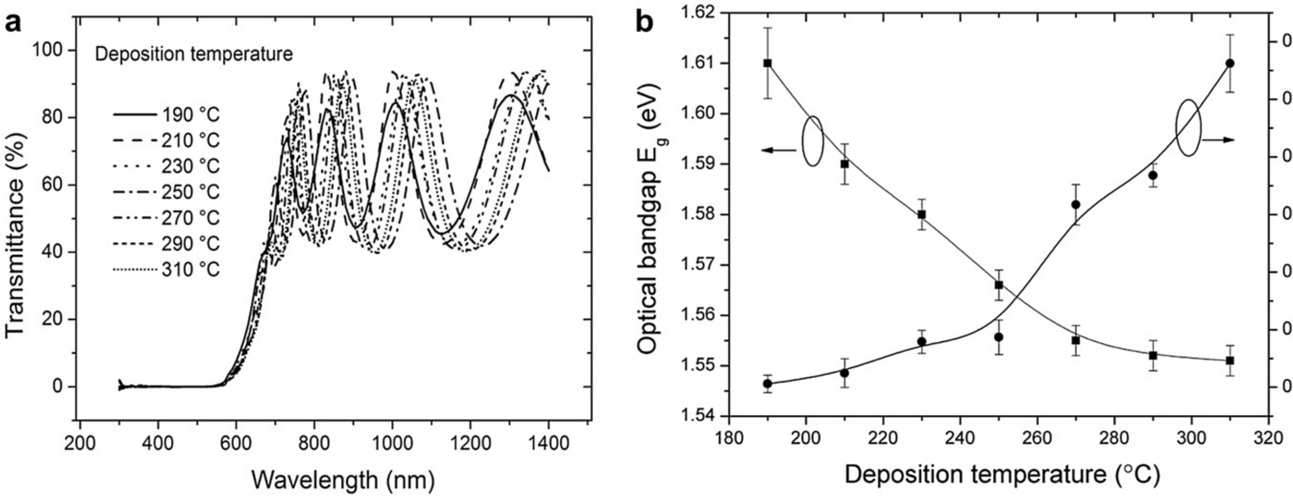

Fig. 1. (a) Transmission spectra of the a-SiGe:H alloys deposited at different temperatures. (b) The calculated optical bandgap E_g and the growth rate of the a-SiGe:H alloys deposited at different temperatures. The solid lines are guides to the eye.

The a-SiGe:H alloys were deposited in a multi-chamber RF PECVD reactor. Different substrates were used, including quartz substrates for transmission, Raman and photo/dark conductivity measurements, and crystalline silicon (c-Si) substrates for taking Fourier transform infrared spectroscopy (FTIR) measurement. The deposition parameters were as follows: the flow rates of SiH_4, H_2 and 20% GeH_4 diluted in H_2 were 8 sccm, 160 sccm and 2 sccm, respectively, the plasma power was 40 W, and the chamber pressure was 270 Pa. The deposition time was adjusted for the samples to get the similar thickness. And the deposition temperature was varied from 190 °C to 310 °C. The thicknesses of the deposited alloys were measured by a Dektak 150 surface profiler. To realize this, a mask was used to make a height step during the deposition. Transmission spectra of the samples on quartz substrates were measured at room temperature in the wavelength range from 300 nm to 1400 nm via a Spectral response/QE/IPCE system from PV measurements, Inc. Then E_g was calculated from the obtained transmission spectra via Tauc's plot. Raman and FTIR spectroscopies were utilized to reveal the microstructure of the deposited alloys. Raman measurement was carried out on a LabRAM HR system from HORIBA Scientific, operating at a wavelength of 488 nm with the laser power as 10 mW. FTIR measurement was carried out on a Varian 3100 Excalibur system. For the samples deposited on quartz substrates, the Ge atom content was further determined by energy dispersive spectroscopy (EDS) measurement via EDAX TEAM-EDS integrated on the scanning electron microscope (Zeiss SIGMA), and the surface roughness was checked by atomic force microscopy (AFM) (Bruker Model Icon). Then, the photo conductivity and the dark conductivity were measured in vacuum to investigate the photosensitivity by the coplanar electrode method. Two coplanar Al electrodes were thermally evaporated on the a-SiGe:H films. A bias voltage was supplied via the two electrodes, and the loop current was measured by a Keithley 6517B system. The conductivity (σ) was obtained by the following formula [15,16]:

$$\sigma = \frac{I \cdot W}{L \cdot d \cdot V} \tag{1}$$

where, I is the loop current, W is the electrodes width, L is the electrodes length, d is the film thickness and V is the bias voltage. For photoconductivity measurement, an AM1.5 solar simulator with the irradiation intensity of 100 mW/cm^2 was utilized to illuminate the samples.

Transmission spectra of the deposited a-SiGe:H alloys are presented in Fig. 1(a). And the corresponding E_g obtained by Tauc's plot is given in Fig. 1(b). Tauc's plot is an effective method to determine the energy bandgap in amorphous thin film materials [17–19]. It can be seen that with the increase of the deposition temperature, E_g of the a-SiGe:H alloy decreases monotonously from 1.61 eV to 1.55 eV. The thin film growth rate is also shown in Fig. 1(b). As the deposition temperature increases from 190 °C to 310 °C, the growth rate increases from 0.18 nm/s to 0.29 nm/s. Fig. 2 shows the optoelectronic properties of the a-SiGe:H alloy as functions of the deposition temperature. The results show that the dark conductivity (σ_{Dark}) of the prepared alloy decreases slowly and tends to be saturated as the deposition temperature increases. And the photosensitivity is improved gradually and almost saturates at 10^4 when the deposition temperature is above 250 °C. Low dark conductivity and high photosensitivity illustrate that the material quality of the SiGe:H alloy is well modified. As well known, the thin film properties are principally related to the inner microstructure.

It has been thought that there are three ways to increase the thin film growth rate [6]: the first is to increase the flux of active radicals, the second is to create more sites for growth, and the third is to increase the probability for the active radical to occupy the growth sites. Here, we attribute the temperature induced increase of the

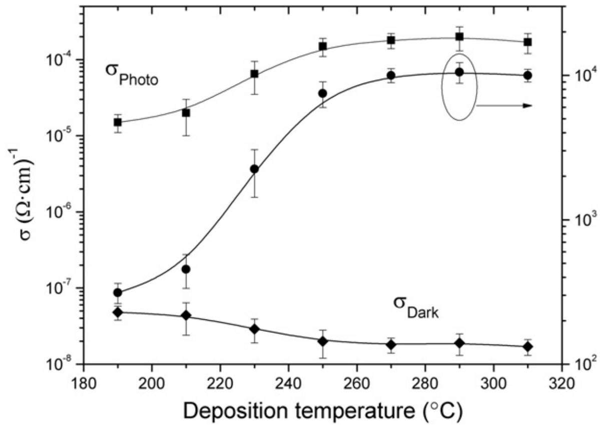

Fig. 2. Photo conductivity, dark conductivity and the corresponding photosensitivity of the a-SiGe:H alloy as functions of the deposition temperature. The solid lines are guides to the eye.