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On the quality of hydrogenated amorphous silicon deposited by sputtering

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ABSTRACT

Amorphous hydrogenated silicon (a-Si:H) is well-known material in the global semiconductor industry. The quality of the a-Si:H films is generally decided by silicon and hydrogen bonding configuration ($Si–H_x$, $x=1,2$) and hydrogen concentration (C_H). These quality aspects are correlated with the plasma parameters like ion density (N_i) and electron temperature (T_e) of DC, Pulsed DC (PDC) and RF plasmas during the sputter-deposition of a-Si:H thin films. It was found that the N_i and T_e play a major role in deciding $Si–H_x$ bonding configuration and the C_H value in a-Si:H films. We observed a trend in the variation of Si–H and $Si–H_2$ bonding configurations, and C_H in the films deposited by DC, Pulsed DC and RF reactive sputtering techniques. Ion density and electron energy are higher in RF plasma followed by PDC and DC plasma. Electrons with two different energies were observed in all the plasmas. At a particular hydrogen partial pressure, RF deposited films have higher C_H followed by PDC and then DC deposited films. The maximum energy that can be acquired by the ions was found to be higher in RF plasma. Floating potential (V_f) is more negative in DC plasma, whereas, plasma potential (V_p) is found to be more positive in RF plasma.

1. Introduction

Hydrogenated amorphous silicon is a well established material in the field of photovoltaics and thin film transistors (TFT). Various techniques were employed for the growth of a-Si:H thin films such as plasma enhanced chemical vapor deposition (PECVD) [1,2], Hot-wire chemical vapor deposition (HWCVD) [3], sputtering [4], etc. Among these, sputtering is popular for high directional deposition, and low process temperature. The high kinetic energy of the sputtered species makes the films dense with good adhesion. Various groups have worked towards the growth of a-Si:H using RF, PDC and DC sputtering techniques [5–7]. These three sputtering modes result in films with different micro structures. So it is very crucial to have an understanding about the influence of the type of plasma on the micro structure of the films so that, it helps in choosing the sputtering power mode to have required film properties that are suitable for a particular application. As a-Si:H is a material of interest in the semiconductor industry for microelectronics, photovoltaics and TFT etc, understanding its growth and correlating it with the plasma properties is pertinent.

In the present work we attempt to explain and correlate the micro structure properties of a-Si:H thin films deposited using DC, PDC and RF sputtering processes. Hydrogen incorporation into the films and micro structure factor (R^*) of the films have been correlated with the plasma parameters such as ion density (N_i), electron temperature (T_e) and plasma potential (V_p). Langmuir probe is used for plasma diagnostics. Our group has earlier reported the plasma diagnostics in sputtering [8,9] and

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electron cyclotron resonance chemical vapor deposition [10].

2. Experimental details

Sputtering chamber used for the deposition of a-Si:H films can be pumped to a base pressure of 2.0×10^{-6} mbar, with the combination of Turbomolecular pump and Rotary pump. Silicon target (99.99 purity) of 10 cm diameter was sputtered in argon (Ar) and hydrogen (H) ambient at a pressure of 2.0×10^{-3} mbar. Silicon substrates (p-type, ⟨1 0 0⟩ oriented with resistivity of 1–10 Ω-cm) were used in the present study. Substrates were cleaned by standard RCA procedure before loading into the chamber. The substrates are held at ground potential during measurements. Target to substrate distance was maintained at 9 cm. Pre-sputtering was carried-out for 15 min to remove any native-oxide or adsorbed contamination from the Si target prior to the deposition. DC, Pulsed DC (HUTTINGER Electronics, GmBH) at 100 kHz and RF (Advanced Energy with 13.56 MHz) powers were applied to the Si target depending on the requirement. FTIR spectroscopy (Bruker Tensor 27) was used for identifying the fundamental vibration modes, C_H and hydrogen bonding configuration. Raman spectroscopy (Lab-RAM HR from HORIBA) with 532 nm laser was used to identify the nature of the films. DC, PDC and RF plasmas were analyzed with Langmuir probe made of thin tungsten wire with a tip length of 4 mm and a diameter of 300 μm. Probe is kept 5 mm away from the substrate position during measurements. The current voltage characteristics of the probe have been studied in the voltage range of −80–+90 V with respect to ground. DC, PDC and RF plasmas were analyzed with optical emission spectroscopy (OES: Princeton Applied Research) within 200–1200 nm range. The schematic of the overall arrangement of the system is as shown in Fig. 1.

3. Results and discussion

a-Si:H can have three hetero-nuclear characteristic Si–H_x vibration modes, one wagging mode at 640 cm^{-1}, a bending mode at 840–890 cm^{-1} and two stretching modes at 1980–2030 cm^{-1} and 2060–2160 cm^{-1}. The 1980–2030 cm^{-1} mode is generally referred as the low stretching mode (LSM), whereas, the 2060–2160 cm^{-1} mode is referred as the high stretching mode (HSM). Generally The LSM is assigned to monohydrides (Si–H) and HSM is assigned to dihydrides (Si–H_2) [11–13]. The intensity of LSM and HSM decides the quality of the a-Si:H film. The film quality is often denoted as R^*, representing the compactness or quality of the film and is defined as

$$R^* = \frac{I_{HSM}}{I_{LSM}+I_{HSM}} \quad (1)$$

where I_{LSM} and I_{HSM} correspond the integrated absorption strength of the LSM and HSM, respectively. Generally a device quality a-Si:H material should have $R^*<0.1$ [14].

From the above discussion it is inferred that a good quality a-Si:H film is governed by a dominant LSM absorption. We have used three power modes: RF, PDC and DC for the deposition of a-Si:H films to identify the power mode that gives a dominant LSM absorption. All the films were deposited with the same deposition rate of 20 nm/min which is within the range (8–75 nm/min) for commercial solar cell manufacturing [15]. The optimized sputtering powers for RF, PDC and DC to get the deposition rate of 20 nm/min are 176 W, 310 mA and 205 mA, respectively. Three sets of films (i.e. with RF, PDC and DC) were deposited having same thickness of 500 nm, each at four different hydrogen partial pressures $P_H1=1.0\times10^{-5}$ mbar, $P_H2=4.0\times10^{-5}$ mbar, $P_H3=7.0\times10^{-5}$ mbar and $P_H4=1.0\times10^{-4}$ mbar. The substrate temperature was maintained at 523 K.

Fig. 2 shows the typical raman spectrum of a-Si:H film deposited by PDC sputtering with P_H3 partial pressure, indicating (i) transverse optical (TO) with a peak at 475 ± 10 cm^{-1} (ii) longitudinal optical (LO) with a peak at 380 ± 20 cm^{-1} (iii) longitudina1 acoustic (LA) with a peak at 300 ± 10 cm^{-1} and transverse acoustic (TA) with a peak at 140 ± 25 cm^{-1}. The TO peak centered at around 475 cm^{-1} corresponding to amorphous nature of a-Si:H. We did not observe any nano-crystalline or microcrystalline phases in our films, for which the absorption peaks appear at > 514 cm^{-1}. Since the films are shown to be amorphous by raman spectroscopy, the detailed understanding of amorphous phase microstructure has been carried out by FTIR spectroscopy. Fig. 3 shows the typical FTIR spectrum

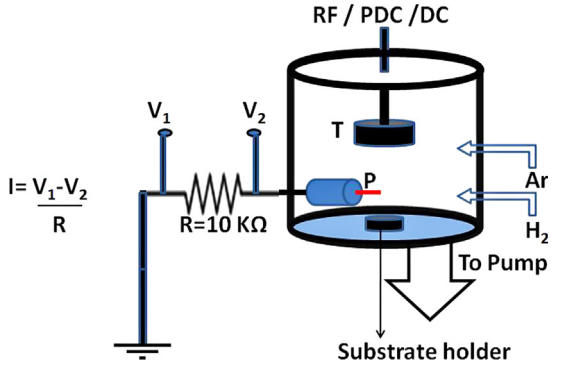

Fig. 1. Schematic of the sputtering chamber with Langmuir probe arrangement. Here *P* is Langmuir probe and *T* is target.

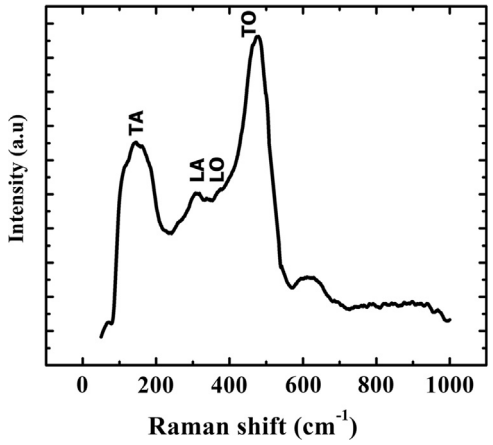

Fig. 2. Typical Raman spectrum of a-Si:H film.