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# Investigation of hydrogenated amorphous silicon as passivation layer by high density plasma

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ABSTRACT

In this study, we use an electron cyclotron resonance chemical vapor deposition to deposit hydrogenated amorphous Silicon (a-Si:H) by different process parameters. We investigated the structure and passivation quality of a-Si:H by tuning the hydrogen dilution ratio and thermal annealing. The properties of films were measured by spectroscopic ellipsometry, optical emission spectroscopy, Fourier transform infrared spectrometer, and quasi-steady-state photoconductance methods. The best passivation quality results from films are consistent with a low microstructure parameter, abundant hydrogen content, and high photosensitivity. The maximum value of $\tau_{eff}$ at about 1182 μs at an injection level of $10^{-15}$ $cm^{-3}$ was obtained on single-side polished p-type Cz (100) substrates after thermal annealing around 270 °C. The high passivation quality can be obtained at the onset of the amorphous–crystalline transition, while the thin film remains in the amorphous phase.



## 1. Introduction

Recently, in crystalline silicon (c-Si) solar cell fabrication technology, great effort is being put forward to reduce the thermal budget as well as the initial wafer thickness in order to decrease the total cost. The most often used passivation scheme for the silicon surfaces is the high temperature above 800 °C thermal oxidation [1] for conventional diffusion solar cell. In contrast, thin film silicon solar cells using hydrogenated amorphous silicon (a-Si:H) film and hydrogenated microcrystalline silicon (μc-Si:H) film do not need a high temperature. The low thermal budget for processing reduced not only energy payback time but also the cost [2–4]. Moreover, the fabrication process of heterojunction silicon solar cells with low temperature below 250 °C can be applied to wafers as thin as 100 μm without introducing significant wafer bowing [5]. Therefore, for the reduction of surface recombination ($S_r$) and obtaining a high performance solar cell, the structure inserting a-Si:H film as intrinsic layer between emitter thin film and base c-Si called a heterojunction with intrinsic thin layer solar cell has been proposed by the Sanyo group [6].

One of the state-of-the-art main techniques for depositing a-Si:H films is radio frequency (RF) plasma-enhanced chemical vapor deposition (PECVD), in which an RF bias is applied directly between anode and cathode. However, this method may have inherent drawback such as damages on depositing film caused by high energy ion particles. For this reason, many methods for avoiding the damage caused by plasma have been demonstrated such as very high frequency CVD (VHF-PECVD), hot-wire CVD and electron cyclotron resonance CVD (ECRCVD) [7–9]. Among these, ECRCVD has certain advantages for deposition at low temperatures due to its high plasma density of ~$10^{12}$ $cm^{-3}$, no electrode contamination, and low ion bombardment. In particular, the ECR plasma zone is far away from the substrate, thus the ion bombardment damage will be reduced significantly. Therefore, in this study, films were deposited by ECRCVD with 2.45 GHz microwave plasma source. The passivation effects of a-Si:H films on p-type c-Si wafer with varying $H_2/SiH_4$ ratio and annealing temperature were investigated.

## 2. Experimental

The undoped a-Si:H films were prepared using ECRCVD with a 2.45 GHz microwave to generate high-density plasma. The ECRCVD has a main magnetic coil around plasma chamber and a dual magnetic coil under the substrate stage as shown in Fig. 1. The $H_2$ gas is injected into the reaction chamber from upstream as well as the $SiH_4$, Ar are injected into the reaction chamber from downstream. The intrinsic a-Si:H films with a thickness of 20 nm were deposited on Corning 7059 glass (2 × 2 $cm^2$) and on both sides of the crystalline silicon (c-Si) (2 × 2 $cm^2$). The single-side polished p-type 1–100 Ω cm Cz (100) substrates with a thickness of 625 μm were used.

We investigated the properties of a-Si:H by varying the hydrogen dilution ratio ($R = H_2/SiH_4$) in the range of 0–5 as well as the deposition

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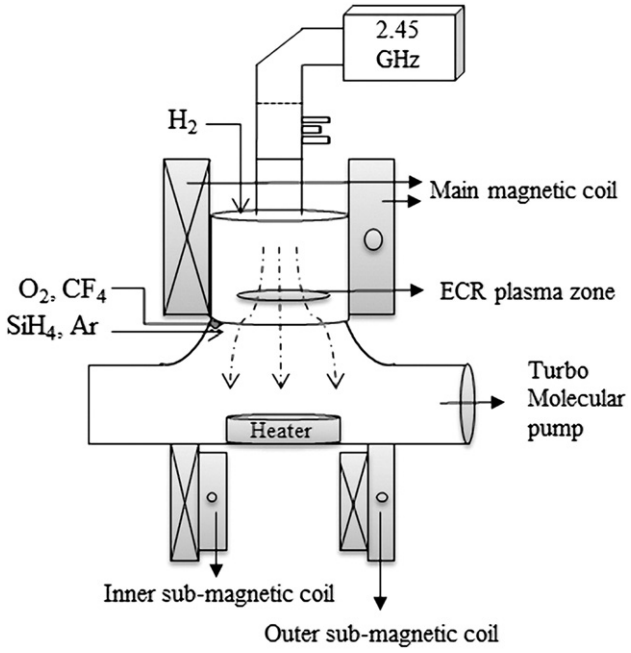


**Fig. 1.** Schematic diagram of the ECRCVD equipment.

time from 15 to 39 s. In addition, the microwave power, working pressure, and substrate temperature were maintained at 500 W, $3.75 \times 10^{-5}$ Pa, and 160 °C, respectively. Prior to deposition, the wafer oxidation in $H_2O_2$:$H_2SO_4$ (1:2) solution is performed, followed by a 2% HF dip for 1 min to remove oxides, rinsed in deionized water, and dried in $N_2$ atmosphere. After wafer cleaning, the wafers are immediately transferred into a vacuum chamber. Inside the chamber the wafers are allowed to warm up for 5 min for thermal equilibrium. The optical emission spectroscopy (OES) was employed during deposition to monitor the Si* (288 nm), SiH* (414 nm), and $H_\alpha$* (656 nm). The thickness and crystalline volume fraction of a-Si:H films were characterized using an ex-situ spectroscopic ellipsometry (SE) with Tauc–Lorentz model. The composition property of the a-Si:H films and hydrogen contents ($C_H$) are evaluated by Fourier transform infrared spectrometer (FTIR) that is associated with the peak intensity at 640 $cm^{-1}$. The quasi-steady-state photoconductance method was used to measure the effective lifetime ($\tau_{eff}$) at an injection level of $10^{-15}$ $cm^{-3}$ for the symmetric structure (a-Si:H/c-Si/a-Si:H) as shown in Fig. 2. For the electrical properties, the ratio of photo/dark conductivity under 100 mW/$cm^2$ exposure was measured using a coplanar gap type Al electrode on a-Si:H films. Moreover, the effect of post annealing by the rapid thermal annealing on the carrier lifetime was studied in a temperature range of 180–300 °C with a nitrogen atmosphere for 2 min.

## 3. Results and discussion

### 3.1. Spectroscopic ellipsometry

SE is a non-destructive method to determine the optical properties of thin films. Fig. 3 represents the spectrum of the imaginary part of

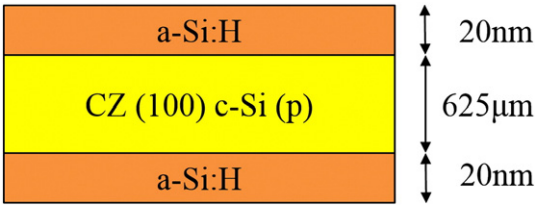


**Fig. 2.** The symmetric structure (a-Si:H/c-Si(p)/a-Si:H) for lifetime measurement.

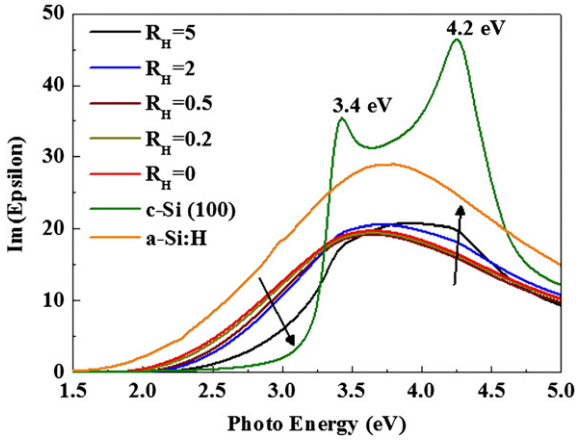


**Fig. 3.** The distribution in the imaginary part of pseudo-dielectric function ($\varepsilon_2$) for thin films prepared at various hydrogen dilution ratios ($H_2/SiH_4$).

pseudo-dielectric function ($\varepsilon_2$) extracted from SE data with various $H_2$ dilution ratio. In the low energy region below 3.0 eV is related to the property of film thickness, whereas the magnitude of $\varepsilon_2$ at high energies region has a correlation with the crystalline volume fraction. The crystalline silicon has two characteristic peaks at 3.4 eV and 4.2 eV representing the two prominent structures of optical absorption in the crystalline (green line) [10,11]. In contrast, the amorphous silicon structure exhibits a spectrum with a broadened absorption peak (orange line). The results show that the structure of the deposited film gradually changes from amorphous to microcrystalline when increasing the hydrogen dilution ratio from $R_H = 0$ to $R_H = 5$. The phase transition occurred as the dilution ratio is increased above $R_H = 2$, two distinct shoulders appear on the characteristic of $\varepsilon_2$. Furthermore, the measurement of Raman spectroscopy was also used to determine the crystalline volume fraction of films deposited on glass substrate. But there is no crystal signal at 520 $cm^{-1}$ due to the fact that the thin films were deposited on the glass substrate, in which the surface is amorphous. Such that we further verify the structure of the films deposited on Si substrate by X-ray diffraction measurement. Fig. 4 shows that the structure of the films is poly-crystalline when $R_H = 2$, and 5. The same phase transition phenomenon is obtained as the above result from SE measurement.

### 3.2. Optical emission spectroscopy

OES diagnosis with the advantage of in-situ as well as non-destructive was used to monitor plasma condition. The relationship

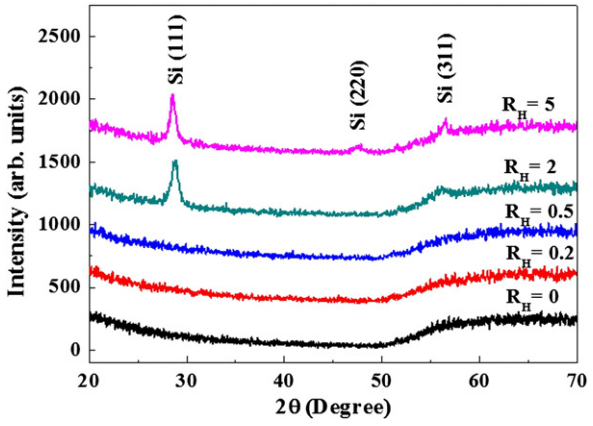


**Fig. 4.** Low angle X-ray diffraction spectra of thin films deposited on silicon substrates with various hydrogen dilution raties (R = $H_2/SiH_4$) in the range of 0–5.