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Characterization of Amorphous Silicon Passivation Layer Deposited by Facing Target Sputtering Using Temperature-Dependent Minority Carrier Lifetime Measurement

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Abstract

We investigated the temperature dependence of the effective minority carrier lifetime (τ_{eff}) of crystalline silicon (c-Si) passivated by intrinsic amorphous silicon (i-a-Si:H) deposited by facing target sputtering method. The i-a-Si:H shows good passivation quality at room temperature and a small surface recombination velocity of 7.48 cm/s has been achieved. We found that temperature dependence of τ_{eff} is influenced by deposition condition. The i-a-Si:H with smaller bandgap shows reduction of τ_{eff} at high temperatures. This reduction is due to the valence band offset at the i-a-Si:H/c-Si interface.

1. Introduction

Silicon heterojunction (SHJ) solar cell is known as a high efficiency solar cell [1]. Intrinsic hydrogenated amorphous silicon (i-a-Si:H) is used for the passivation material of the SHJ solar cells and is typically deposited by plasma enhanced chemical vapor deposition (PECVD). Although high quality i-a-Si:H passivation layer can be deposited by PECVD, this technique uses explosive SiH_4 gas. The use of SiH_4 gas requires expensive safety system and gas scrubber. If we can develop a SiH_4-free deposition method for high quality i-a-Si:H passivation layer, cost for the safety system and gas scrubber can be reduced. One of the promising SiH_4-free deposition technique is facing target sputtering (FTS) [2,3]. In this technique, Ar plasma is confined between two Si targets and the Si substrate is not exposed to the Ar plasma as shown in Fig.1. Therefore, low-damage sputtering is expected. We have investigated i-a-Si:H deposition using FTS [4, 5, 6], however, its properties are not clearly understood yet.

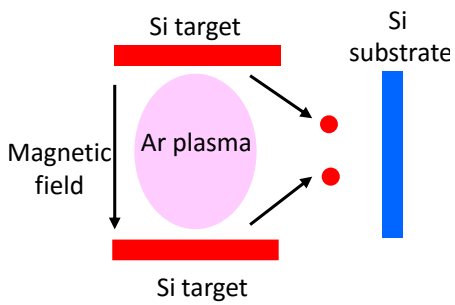

Fig. 1 Principle of facing target sputtering

To apply i-a-Si:H deposited by FTS for the passivation layer of SHJ solar cells, surface recombination velocity estimated from effective minority carrier lifetime (τ_{eff}) is the most important parameter. Room temperature τ_{eff} measurements are commonly used to evaluate the surface recombination velocity. Injection dependent τ_{eff} measurement using quasi steady-state photoconductance (QSSPC) is one of the standard evaluation methods. Recently, Inaba et al. reported the temperature-dependent τ_{eff} measurements for hydrogenated amorphous silicon based passivation layer deposited by PECVD [7]. They reported that the temperature dependence of τ_{eff} is strongly influenced by the properties of the passivation layer, especially by its bandgap. They concluded that the difference of the temperature dependence is mainly influenced by the valance band offset between passivation layer and c-Si. This indicates that the temperature-dependent τ_{eff} measurement is an useful toll to investigate the properties of the passivation layer/c-Si interface.

In this study, we investigated the interface properties of i-a-Si:H deposited by FTS by using temperature-dependent τ_{eff} measurement.

2. Experiment

The i-a-Si:H passivation layer was deposited on float-zone double-polished n-type c-Si wafer. The thickness and resistivity of the c-Si wafer were 280 μm and 1-5 Ω・cm, respectively. The bulk lifetime of the c-Si wafer was larger than 10 ms. Prior to the deposition of the i-a-Si:H passivation layer, the wafers were dipped in 1% HF to remove the native oxide. The wafers were then immediately dipped in 4 wt.% H_2O_2 for 30 sec at room temperature to form a thin SiO_x layer to prevent epitaxial growth [8]. Subsequently, i-a-Si:H was deposited on the c-Si wafer by using a FTS system. A mixture of Ar and H_2 was used for the deposition of i-a-Si:H. The ratio of H_2 to Ar was varied from 0.02 to 0.05 to control its optical bandgap. The pressure was fixed at 0.14 Pa. The plasma was generated by a combination of RF and DC power supply. The RF power was 200 W and the superimposed DC power was 40 W. The area of each Si target was 194.7 cm^2. The substrate heater temperature was 250 °C. The thickness of the i-a-Si:H layer was about 20 nm. Identical i-a-Si:H was deposited on both sides of the c-Si wafer. Annealing was carried out at an optimal temperature for 1 min in forming gas atmosphere (3% H_2 in N_2) to improve passivation quality of i-a-Si:H.

Temperature dependence of the τ_{eff} was measured by using a QSSPC system (Sinton Consulting WCT-120) equipped with a substrate heater. The temperature was varied from 60

°C to 180 °C. Optical bandgap and thickness of the i-a-Si:H layers were measured by spectroscopic ellipsometry.

3. Results and discussions

Figure 2 shows the temperature dependence of the τ_{eff} of two different samples. The main difference between these samples is the optical bandgap of the i-a-Si:H layer. Both samples showed very similar τ_{eff} at room temperature. The sample with wide optical bandgap showed τ_{eff} of 1.67 ms. A similar τ_{eff} of 1.53 ms was obtained from the sample with narrower optical bandgap. These τ_{eff} correspond to a surface recombination velocity lower than 8.5 cm/s. These results indicate that high quality i-a-Si:H passivation layer can be deposited by FTS and that it is a promising SiH_4-free deposition process.

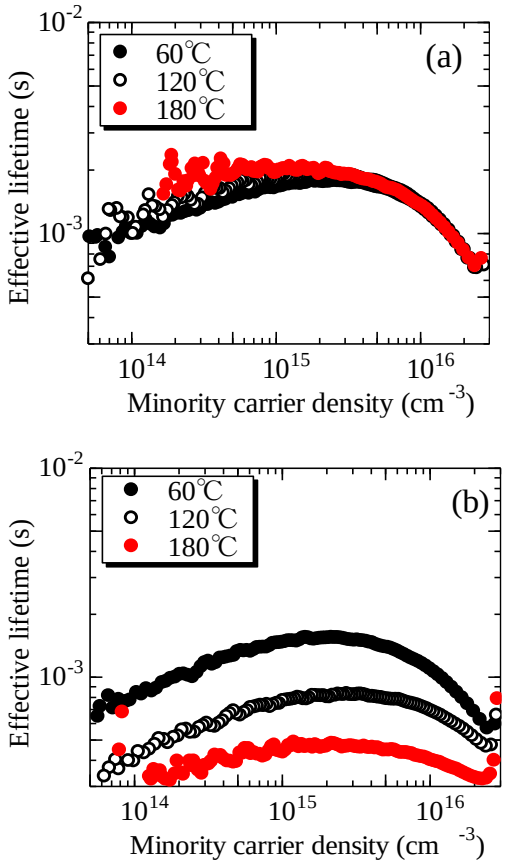

Fig. 2 Injection dependence of τ_{eff} at different measurement temperatures for different samples. (a) The bandgap of i-a-Si:H is 1.84 eV. (b) The bandgap of i-a-Si:H is 1.65 eV.

Although room temperature τ_{eff} is almost the same for both samples, temperature dependence of τ_{eff} is completely different. In case of the sample with wide optical bandgap, the temperature dependence of τ_{eff} is relatively small as shown in Fig. 2(a). On the other hand, large temperature dependence was observed from the sample with small optical bandgap, whose τ_{eff} significantly decreased with increasing the measurement temperature. According to the previous report, the difference in the temperature-dependence of τ_{eff} for a-SiO_x:H was explained by the difference in valence band offset [7]. Therefore, it is expected that our samples also have different valence band offsets. It is well known that the temperature of solar cells is higher than 60 °C under the sunlight. In this case, τ_{eff} at high temperature determine the solar cell performance. Based on the obtained results, wide bandgap passivation layer deposited by FTS method is suitable for high temperature operation.

4. Conclusion

We measured τ_{eff} of c-Si wafer passivated using i-a-Si:H deposited by a FTS system. After annealing, the samples showed small surface recombination velocity of 7.48 cm/s. In addition, we also found differences in the temperature dependence of τ_{eff} for different i-a-Si:H deposition conditions. The sample passivated by i-a-Si:H with wider optical bandgap shows higher τ_{eff} at high temperature.

Acknowledgements

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