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SiN_x deposited by in-line PECVD for multi-crystalline silicon solar cells

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Abstract

SiN_x:H anti-reflective coating (ARC) layers were successfully grown by an in-line plasma enhanced chemical vapor deposition (PECVD) system with an extremely high throughput. Film thickness and refractive index of the as-grown samples were evaluated as functions of growth parameters, such as growth pressure, total gas flow rate, radio frequency (RF) power and SiH_4 to NH_3 gas ratio. It was found that we could achieve high quality films with proper growth conditions and proper post-deposition annealing.

Keywords: In-line PECVD; SiN_x:H; Anti-reflection coating; Throughput

1. Introduction

Non-stoichiometric silicon nitride with portion hydrogen content (SiN_x:H) deposited by plasma enhanced chemical vapor deposition (PECVD) appears to be the best solution as the anti-reflective coating (ARC) of commercial crystalline solar cells. It has been demonstrated that one could grow high quality SiN_x:H layers with a near optimum anti-reflective properties (Leguijt et al., 1996; Ruby et al., 1994; Schuurmans, 1996). The production cost of SiN_x:H layers is also lower than that of thermal oxide layers (Leguijt et al., 1996). Thus, the use of PECVD SiN_x:H films as the ARC layers in commercial solar cells has become very popular in recent years. However, the process speed and throughput of the PECVD process is low in general. As a result, the PECVD process itself often becomes the bottleneck process in the whole solar cell production line. To solve this problem, we could use the in-line PECVD system, which could provide us a much larger throughput, as compared to *conventional batch-type PECVD process*. With this technique, we cannot only raise the throughput of PECVD significantly but also have the ability to fabricate large area solar cells by using the plate-form carriers. Although such a technique is potentially useful, we could only find very few reports regarding to the in-line PECVD system in the literature.

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In this paper, we report the growth of SiN_x:H layers on commercial 12.5 cm multi-crystalline Si wafers. A detailed study on the physical properties of the as-grown SiN_x:H layers as functions of growth parameters will be reported. The effects of post-deposition annealing will also be discussed.

2. Experiments

The SiN_x:H ARC layers used in this study were all grown on 5'' multi-crystalline Si wafers by a large area multi-chamber in-line PECVD system. As shown in Fig. 1, the in-line PECVD system consists a pre-heating chamber, a process chamber and a cooling chamber. To achieve a high throughput, we loaded two palettes, each accommodates 18 12.5 cm × 12.5 cm multi-crystalline Si wafers, into the pre-heating chamber of the in-line PECVD system in each batch. The 36 Si wafers were then pre-heated by infrared lamps rapidly for 205 s. The rack and pinion assembly then automatically transferred these Si wafers into the process chamber. At the same time, another 36 12.5 cm × 12.5 cm Si wafers were loaded into the pre-heating chamber as the second batch. We then introduce SiH_4 and NH_3 into the process chamber to grow the SiN_x:H ARC layers on top of the Si wafers of the first batch. During deposition, four 13.56 MHz radio frequency (RF) generators with automatic matching networks were used as the plasma sources and where the *gap spacing between electrodes is only 7 cm*. The maximum power of each RF generator is 300 W. During the growth of SiN_x:H ARC layers, various growth conditions were used. However, we did keep the growth temperature and the growth time at 350 °C and 205 s, respectively, throughout this study (Nybergh, 1997). After SiN_x:H deposition, the 36 Si wafers of the first batch were transferred into the cooling chamber. The cooling chamber is water cooled, using a closed loop water chiller. With back filling of the chamber with nitrogen gas, the samples can be cooled via heat exchange. With such a cooling chamber, we should be able to prevent trap generation due to the mismatch of thermal expansion coefficients between silicon substrates and the SiN_x:H ARC layers. It should be noted that two pneumatically actuated gate slit valves are used to separate the process chamber from the pre-heating chamber and the cooling chamber. By using such a large area multi-chamber in-line PECVD system, we could achieve 475 wafers per hour throughput of 12.5 cm × 12.5 cm Si wafers.

3. Results and discussion

Fig. 2 shows measured film thickness and refractive index of the as deposited samples as functions of process pressure. It can be seen clearly that the film thickness increases monotonically as the process pressure increases (Kahn et al., 2000). Such an increase suggests that the limiting factor for growth rate is the amount of SiH_4 and NH_3 molecules available to provide excited Si and N atoms. At higher process pressure, the number of excited Si and N atoms will increase so as to result in a larger SiN_x:H film thickness. On the other hand, no obvious changes in refractive index could be observed from samples prepared at different process pressures (Kahn et al., 2000). Fig. 3 shows measured thickness and refractive index uniformities for samples grown at

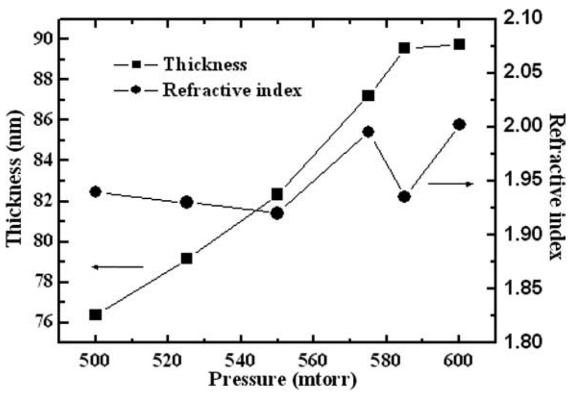

Fig. 2. Measured film thickness and refractive index of the as-deposited samples as functions of process pressure.

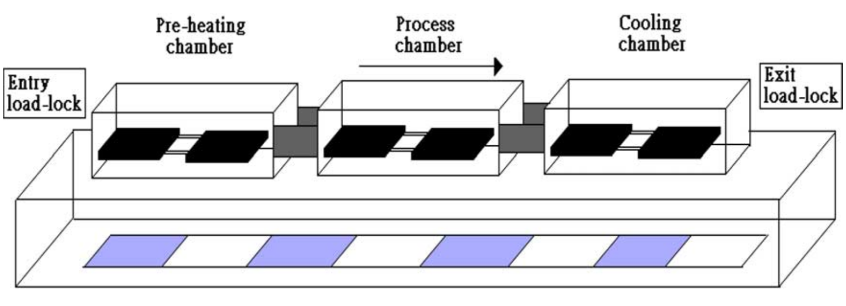

Fig. 1. Schematic diagram of the in-line PECVD system used in this study.