High-rate deposition of silicon nitride and silicon oxide films for surface passivation and (anti)reflection coating applications

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Abstract: In order to increase the cost-effectiveness of crystalline silicon solar cells, surface passivation and internal reflection at the back surface will become increasingly important. To keep processing times sufficiently short, it would be favorable if high-rate PECVD layers could satisfy both means. In this paper we will present that both high quality silicon nitride films and silicon oxide films can be deposited by means of the expanding thermal plasma technique which is employed in the commercially available DEPx system of OTB Solar. Consequently, both the front and back surface of a high-efficiency solar cell can be optimized while keeping processing times sufficiently low.

Key Words: Silicon nitride, silicon oxide, surface passivation, antireflection coating.

1 Introduction

One of the most promising approaches to increase the cost effectiveness of mono and multicrystalline silicon solar cells is to further reduce the wafer thickness. In this case surface passivation, both at the front and the back surface of the cell, is determinant for the solar cell performance. The standard material used for the front side of the solar cell is silicon nitride. Apart from the excellent antireflection coating behavior, silicon nitride also shows excellent surface passivation on *n*-type emitter structures [1].

Apart from the surface passivation, the internal reflection at the back will also become very important for increasing the performance of the solar cell. In the current high efficiency schemes generally thermally grown silicon oxide films are used for this purpose [2]. However, to achieve high internal reflection, thick (100-200 nm) silicon oxide films are necessary, requiring long processing times and high thermal budgets, thereby possibly degrading the bulk lifetime of the crystalline silicon wafer. Recently, it was shown that the thick thermal oxide can be replaced by a thermal silicon oxide/PECVD silicon oxide stack [3] thereby reducing both the processing time and the thermal budget during the process. Also it was shown that an additional silicon nitride film can dramatically improve the thermal stability of the thermal silicon oxide/PECVD silicon oxide stack.

In this paper we will show that both high quality silicon nitride (a-SiN_x:H) and silicon oxide (SiO_2 like) films can be deposited employing the expanding thermal plasma (ETP) technique.

2 Silicon nitride deposited by the ETP technique

The expanding thermal plasma (ETP) technique was developed at the Eindhoven University of Technology and is employed in the DEP*x* in line PECVD deposition tool as developed by OTB Solar (Fig. 1). The ETP technique is renowned for its high deposition rates of e.g. a-SiN_x:H [4, 5]. A plasma (e.g. argon) with a ionization degree up to ~10%, is created at sub-atmospheric pressures. This high pressure plasma expands into a low pressure deposition chamber, resulting in a high flow of reactive ions and/or neutrals. In this "plasma jet", large flows of deposition precursors can be injected and dissociated. For the deposition of a-SiN_x:H films silane and ammonia are used as precursor gasses.

Figure 1: The DEPx, the industrial PECVD tool developed by OTB-Solar employing the expanding thermal plasma technology. This reactor features a high throughput of 960 wafers/hour and a small footprint of 12 m^2. The reactor can be used for inline as well as for batch wise solar cell production [6].

In initial studies the anti-reflection coating behavior and bulk passivation of ETP deposited a-SiN_x:H films was already demonstrated [4, 5]. Though, the level of bulk passivation was lagging behind to other deposition techniques due to a low mass density of the a-SiN_x:H films. By our extensive process optimization, the mass density of the a-SiN_x:H films has significantly improved [7] and the level of bulk passivation was matched to state-of-the-art films used as a reference [8]. In our optimization process also the absorption of the a-SiN_x:H films was significantly reduced, thereby improving the short circuit current of the final solar cell [9]. Recently also the excellent surface passivation induced by ETP deposited a-SiN_x:H was demonstrated [10], as shown in Fig. 2. It should be noted that all results are obtained with deposition rates > 4 nm/s.

In conclusion, ETP deposited a-SiN_x:H can provide a solution for all requirements for a front surface layer of a solar cell, as it has a low reflection and absorption losses and a high level of both bulk and surface passivation.

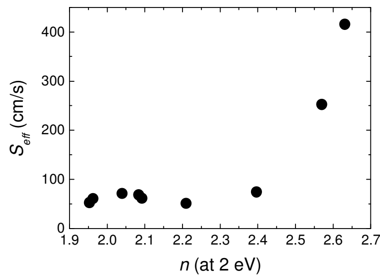

Figure 2: Surface recombination velocity on 8.4 Ω cm *p*-type c-Si wafer as a function of the refractive index of the a-SiN_x:H films deposited at 425 °C [10]. A good level of surface passivation is obtained for a broad refractive index range of 1.9-2.4.

3 Silicon oxide deposited by the ETP technique

As stated in the Introduction, also the internal reflection at the back of a solar cell will become important in maintaining high efficiencies when reducing the silicon wafer thickness. For this purpose we have investigated SiO_2 like films deposited by the ETP technique. For this reason oxygen and octamethyltetracyclosiloxane (D4) were used as the deposition precursors.

The deposited SiO_2 like films were analyzed by numerous techniques (e.g. spectroscopic ellipsometry, IR spectroscopy (FTIR) and Rutherford backscattering) and it was shown that good quality SiO_2 like films, with a refractive index close to that of thermally grown silicon oxide, can be deposited at deposition rates 5-15 nm/s. When increasing the D4 flow, some residual carbon and hydrogen is present in the film as shown in Fig. 3.

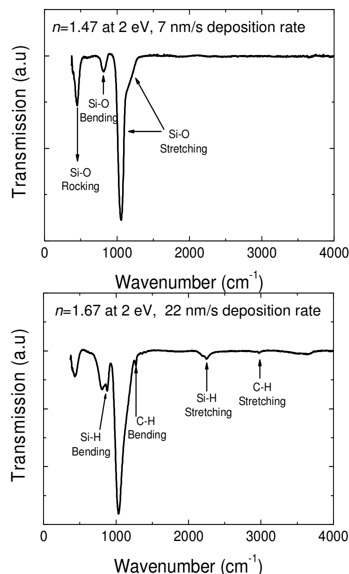

Figure 3: FTIR transmission spectra of SiO_2 like films deposited with low (top) and high (bottom) D4 flow. The refractive index and deposition rate of the SiO_2 like films are indicated in the figure. The presence of hydrogen and carbon is visible in the SiO_2 like film deposited with the high D4 flow but is absent in the SiO_2 like film deposited with a low D4 flow.

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