

## SILICON NITRIDE COATINGS FOR Si SOLAR CELLS: CONTROL OF OPTICAL REFLECTION AND SURFACE/BULK PASSIVATION

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Solar cell fabrication involves a number of major process steps, which include formation of an N/P junction, contact metallization, and antireflection coatings. Additional process steps are often necessary to accommodate other functions, such as surface passivation, impurity gettering, and bulk passivation of defects and impurities. However, because of the additional cost incurred for these process steps, the photovoltaic (PV) industry has sought processes that can accomplish multiple functions. For example, in a typical solar cell processing regime, impurity gettering is accomplished during junction and contact formation. Likewise, a thin layer of SiO<sub>2</sub> is used to produce surface passivation and is then made a part of the antireflection coating.

Because commercial silicon solar cells are fabricated on low-cost substrates that contain high concentrations of impurities and defects, an important process issue in Si solar cell fabrication is to be able to mitigate deleterious effects of impurities and defects. A typical solar cell processing regime must include impurity-gettering to remove the majority of the dissolved minority-carrier lifetime killing impurities (such as transition metals). Even after such gettering processes, the concentration of the residual impurities and defects can be unacceptably high. A standard solution is to use H to passivate the residual impurities and defects. Until recently, hydrogen passivation required an additional processing step, such as plasma processing, to introduce H deep into the cell. However, it is now possible to combine metallization firing, hydrogen passivation, and surface passivation as part of an antireflection coating. But integration of these multiple functions demands a detailed knowledge of various mechanisms that influence optical parameters, interface charge, and transport of H in Si.

In the past, the PV industry has used materials such as SiO<sub>2</sub> and TiO<sub>2</sub> for antireflection coatings. Recently, silicon nitride (SiN<sub>x</sub>:H) has found an exclusive niche in this application because it can accomplish multiple functions, eliminating several additional process steps in fabrication of high-efficiency solar cells. In a typical commercial solar cell processing sequence, a thin layer of silicon nitride is deposited on an N/P junction by a plasma-enhanced CVD (PECVD) process. A nitridation process also produces an accumulation of positive charge at the SiN<sub>x</sub>:H-Si interface that helps in surface passivation. Furthermore, it introduces H into Si, which resides within a thin plasma-damaged surface layer. Following the nitride deposition, a Ag-based contact metallization is then screen printed and fired through the nitride. In this step, the metal penetrates through the nitride to form a low-resistance ohmic contact, while the H diffuses into the bulk of the cell to passivate impurities and defects. The multipurpose role of nitride demands that it be a low-absorption AR coating, serve as a barrier layer for control in metallization, and promote favorable electronic processes that can passivate the surface, as well as the bulk, of the device. It is imperative that SiN<sub>x</sub>:H deposition and processing be designed carefully to optimize optical and electronic properties of the solar cell.

The optical properties of SiN<sub>x</sub>:H can be adjusted by controlling the composition of the film. A Si-rich, high-density, non-stoichiometric film has a high refractive index (~ 2.4) and higher absorption loss, whereas a low

Si content film can have refractive index as low as 1.9 with a low optical loss. Typically, a textured solar cell is deposited with 750 Å of SiN<sub>x</sub>:H. The reflectance spectrum (thick solid line) of a typical solar cell, 300 μm thick and has a back Al contact, is shown in Figure 1. This figure also shows the absorbance spectrum of the Si cell (thin solid line). These calculations use a refractive index of 1.95 to maximize the cell performance (measured in air). However, for a solar cell operating in a module, the refractive index must be close to 2.2. Figure 1 also shows the reflectance spectrum (thick dotted line) and absorbance spectrum (thin dotted line) of a solar cell encapsulated in a glass module. These calculations show excellent characteristics of the AR coating both for air and module operations. The photocurrent densities achievable by the optimized coatings are 40.97 mA/cm<sup>2</sup> and 39.74 mA/cm<sup>2</sup> for air and module operation, respectively.

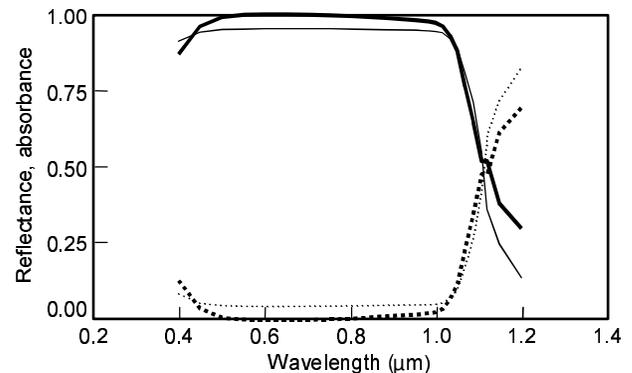


Figure 1. Calculated reflectance and absorbance spectra of a Si solar cell operating in air (solid lines), and in an encapsulated module (dotted lines).

An important issue in the use of PECVD nitride is its ability to passivate defects and impurities in the solar cell. It is believed that H is introduced in a surface layer, where it is “stored” in the surface damage produced by the plasma process during the nitride deposition, and diffuses deep into the cell during subsequent firing of the metal. Figure 2 is a SIMS plots of H in a Si solar cell before and after metallization firing. This figure clearly shows that the surface H is redistributed (limited by the detection sensitivity of H in the SIMS measurement). The redistribution of H deep inside the cell can lead to excellent passivation and high device performance.

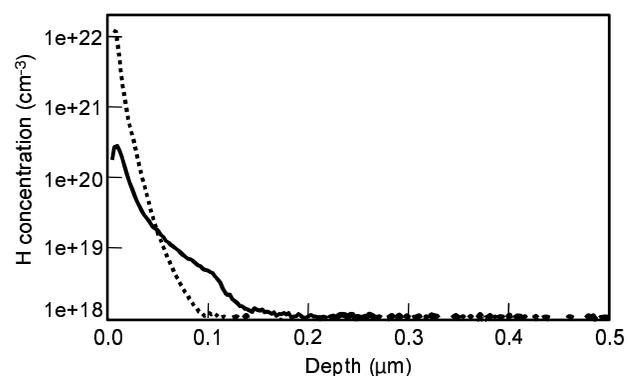


Figure 2. SIMS profiles of H in a solar cell introduced during a PECVD SiN<sub>x</sub>:H coating before (dotted line) and after contact firing (solid line).

Maximization of solar cell performance requires the selection of deposition conditions that provide low-loss coating with a suitable refractive index and the ability to “store” H during the deposition and to subsequently diffuse it into the bulk of the device (without release from the cell) in a way that H interacts preferentially with the harmful impurities. This paper will discuss physical mechanisms involved in the deposition and the processing of SiN<sub>x</sub>:H, and optimization of optical and electronic properties of a solar cell.