Passivating Antireflection Coating for Improving Optical Properties of Concentrated Photovoltaics Using PECVD

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***Abstract*—Concentrated photovoltaic (CPV) is a rapidly developing technology in the field of solar energy. CPV solar cells are coated with an antireflection coating (ARC) with low reflectivity over the entire wavelength absorbing range of the triple-junction structure (3JSC). Most of ARCs in industry are made from metal oxides (e.g. Al_2O_3, TiO_2) deposited by sputtering. Metal oxides are known to offer low insulation quality against environment factors (moisture, contaminants) compared to other dielectric materials, especially silicon nitride (SiN_x) widely used in microelectronic for encapsulation. SiN_x is used for ARC on Si solar cells, but has not been used for 3JSC since it absorbs light at short wavelengths in the top-cell absorbing range. As part of this research, low-absorption SiN_x will be developed by optimizing the parameters of the plasma-enhanced chemical vapor deposition (PECVD).**

***Index Terms*—Antireflection coating (ARC), concentrated photovoltaic (CPV), passivation, plasma-enhanced chemical vapor deposition (PECVD), silicon nitride**

I. Introduction

Concentrated photovoltaics use multi-junction solar cells made from series-connected sub-cells with different bandgaps. This design limits the overall device photocurrent by the limiting sub-cell, but benefits from a wide absorption spectrum (300-1800 nm). Figure 1 shows a schematic of a standard triple-junction III-V semiconductor solar cell (3JSC).

The front face of solar cells is coated with an antireflection coating (ARC), which is essential to maximize its efficiency while acting as a durable barrier against moisture and other contaminants. It has been shown by simulations that a dual-layer ARC made of silicon dioxyde over silicon nitride (SiN_x) can provide excellent optical transmission properties over the entire spectral domain of the triple-junction [1]. Good conditions are met with low-frequency (380 kHz) PECVD deposited silicon nitride (LFSiN) [2].

LFSiN has also demonstrated its ability to passivate the surface of III-V semiconductor junctions, including GaAs [3] and AlGaAs [4]. The high level of hydrogen bombardment of the substrate may explain the passivation potential of the low-frequency plasma.

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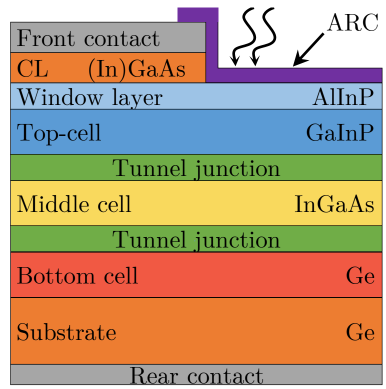


Fig. 1. Triple-junction solar cell schematic. CL stands for contact layer.

We propose here to use LFSiN as part of a dual-layer ARC (2L-ARC) using its good transmission and passivation properties and to verify experimentally the performance of .

II. Modeling

In order to determine the best properties for our SiN_x layers, we performed some simulations. The transfer matrix method at normal incidence was then used to calculate the reflection, absorption and transmission at each layer of the stack according to the method proposed by [1].

We used the solar-weighted reflectance R_W to quantify the performance of the ARC we developed:

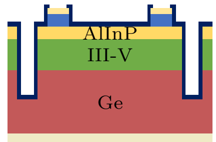
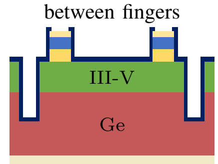
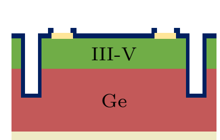
$$R_W = 1 - \frac{J_{\mathrm{sc}}}{J_{\mathrm{sc},T=1}} \tag{1}$$

where J_{sc} is the short-circuit current and $J_{\mathrm{sc},T=1}$ is the short-circuit current with no optical loss and is calculated by integrating the quantum solar irradiance weighted by the internal quantum efficiency of the cell (IQE). R_W represents the fraction of incident light lost by reflection and absorption weighted by the IQE.

III. Experimental methodology

In order to determine experimentally if LFSiN can be used to produce high-perfromance 2L-ARC for 3JSC, we made

TABLE I
SOLAR CELL SAMPLES FABRICATED FOR THIS STUDY WITH THE CORRESPONDING PAIR OF THICKNESSES FOR EACH LAYER OF THE DEVELOPED ARC MINIMIZING R_W.

	Structure		
	CT-etch	CT-etch + window-etch between fingers	CT-etch + window-etch over whole surface
			
ARC	**Thicknesses of optimal ARC layers (SiO [nm] / SiN [nm])**		
HFSiO/LFSiN	81/59	64/70	64/70
HFSiO/HFSiN	65/67	41/82	41/82
No ARC (ref)	N/A	N/A	N/A

solar cells with 9 different configurations corresponding to the combinations of the 3 structures and the 3 ARC summarized in table I.

HFSiN and HFSiO are standard PECVD recipes while the LFSiN used for this study has been developed to minimize the theoretical solar-weighted reflectance R_W.

The solar cells from which we etched the AlInP window layer were made to push the study one step further. By adjusting the deposition conditions of SiN_x, we expect to be able to increase the density of fixed charges to an adequate value and provide field-effect passivation with the silicon nitride layer. If this study demonstrates that LFSiN can indeed replace the AlInP window layer field-effect passivation, we could therefore remove the AlInP window layer which absorbs light in the top cell. This may improve overall cell performances, more importantly in the case of top-limited triple-junction solar cells (TL-3JSC).

The quality of the developed coating is assessed according to three axes: the optical performance of the ARC, the ability to provide good surface passivation and the mechanical durability of the coating.

The characterization of the optical performance is done with the reflectance spectrum across the whole wavelength absorption range.

In order to characterize the surface passivation, dark I-V curves, C-V curves and external quantum efficiency (EQE) will be performed. These curves will give a global picture of the magnitude of recombination processes in a solar cell. By comparing them for identical solar cells for which only the surface coating differs, we will be able to determine which configuration gives the best passivation.

An additional aspect to be taken into account in the development of thin layers is the stress (either tensile or compressive) induced in the deposited layer. If the stresses cross a threshold value, the layer will relax by fracture propagation or even delamination, rendering the layer unusable. Therefore, care must be taken to optimize the mechanical properties of the layer to prevent the apparition of the failure modes. Mechanical integrity must be preserved over 20 to 30 years of outdoor operation.

The intrinsic stress will be calculated by radius of curvature measurements. Micro-scratch testing will be used to evaluate with greater precision the critical stress associated with most of the failure modes and the adhesion strength of the films [5].

IV. CONCLUSION

The goal of this research is to demonstrate the added value of an antireflection coating for triple-junction solar cells using low absorption PECVD silicon nitride. Numerical modeling of different ARC designs have been performed in order to determine the optimal parameters enabling very low solar weighted reflectance. From there, solar cells have been built with different configurations to characterize the passivation properties and the optical performance of the coating. Optimization of optical transmission, passivation and mechanical strength of the anti-reflection coating must be considered simultaneously to achieve the best device performance. This study will also investigate the field-effect passivating properties of SiN_x. The long-term goal is to improve the optical properties of multi-junction solar cells by replacing the window layer and ARC by a unique layer that is both passivating and anti-reflective.

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