IMPACT OF THE SIN$_X$ THICKNESS ON PASSIVATION QUALITY AND CONTACT RESISTIVITY OF SILICON SOLAR CELL

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Abstract: In this work the influence of thickness of Silicon Nitride (SiN$_X$) layer deposited by Plasma Enhanced Chemical Vapour Deposition (PECVD) on passivation quality and contact resistivity (ρ_C) of *n*-type Passivated Emitter Rear Totally-diffused (*n*-PERT) cell was investigated. The solar cell structure comprises front boron emitter and a phosphorous back surface field (BSF) with SiN$_X$ layers on both sides for surface passivation. Contacts are made by screen printed and fired through metallization using commercial silver (Ag) paste.

Keywords: silicon solar cell, *n*-type, *n*-PERT, SiN$_X$, passivation, contact resistivity.

1. INTRODUCTION

The solar cell based on *n*-type silicon, as one of the promising alternatives to conventional solar cells, has attracted extensive research attention due to its several advantages. The *n*-type material has relative tolerance to higher minority carrier diffusion lengths compared to *p*-type monocrystalline silicon (mono-Si) substrates with a similar impurity concentration [1]. The minority carrier life time does not suffer from light induced degradation (LID) due to the boron-oxygen related defects which is frequently found in *p*-type material [2]. With conversion efficiencies above 23 %, the potential of *n*-type silicon has been demonstrated at the device level in recent years [3-5].

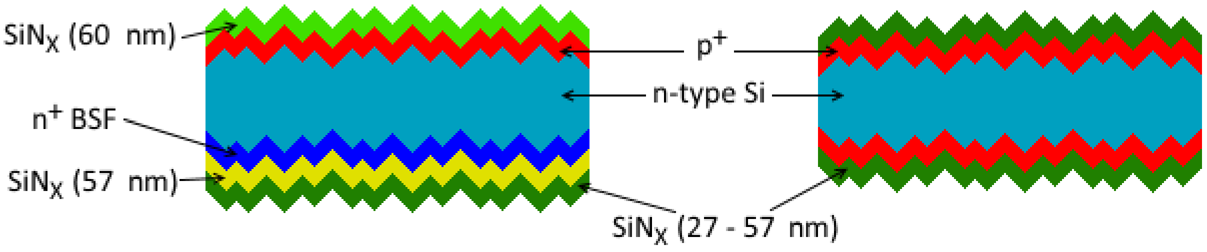
The solar cell efficiency is directly related to short-circuit current and contact resistivity, which in turn strongly depends on thickness of antireflection (ARC) and passivation layer [5, 6]. It was proved, that SiN$_X$ layer deposited by PECVD provide excellent surface and bulk passivation and their deposition processes can be executed with a high throughput as required by the industry [7].

2. EXPERIMENTAL

2.1. SAMPLES PREPARATION

For this experiment the 6’’ monocrystalline phosphorous-doped *n*-type mono-Si wafers with average base resistivity ρ_{base} = 2,3 Ωcm were used as a base material. All samples were processed using standard industrially available techniques for mass production such wet chemical alkaline texturization, cleaning by HCl and HF solutions, diffusion in quartz tube furnace containing $POCl_3$ (n^+ BSF, resulting sheet resistance 60 – 65 Ω/sq) or BBr_3 (p^+ emitter, resulting sheet resistance 70 – 80 Ω/sq). The p^+ and n^+ regions were subsequently passivated by SiN$_X$ layer deposited by PECVD for the each side separately.

A schematic cross-section of solar cell precursor (solar cell without metallization) is presented in the Fig. 1 a). The deposition of passivating layer on the rear side of solar cell consisted of two steps. Firstly, the layer with thickness 57 nm was deposited; the SiN$_X$ layer with various thicknesses was deposited subsequently. During the second deposition samples used for measurement of SiN_X thickness (see Fig. 1 b) were also prepared. The annealing at peak temperature υ_{peak} = 815 °C followed after deposition of all SiN_X layers.



a) b)

Figure 1: a) the structure of cell precursor (solar cell without metallization) and b) sample used for measurement of SiN_X thickness.

In a next step the silver finger grid at the front side and rear side were screen printed. The cell process was finished by co-firing of the metal contacts in a belt furnace in air ambient. The temperature profiles differed from each other in the maximum temperature (υ_{firing}), which was set to the 780 °C, 795 °C, and 815°C.

3. RESULTS AND DISCUSSION

3.1. THICKNESS OF SiN_X LAYER

Method based on measurement of a reflectance spectrum of a wafer was used for the determination of thickness of SiN_X layer (d_{SiNX}) deposited on textured surface. The detector was inclined by 8° perpendicular to the sample. The dependence of reflection on wavelength of incident light for samples A, B, and C is shown in the Fig. 2.

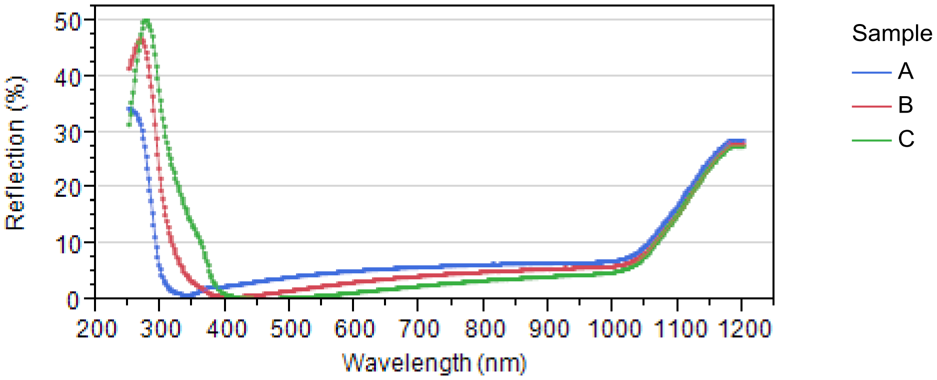


Figure 2: The reflectance of samples A, B, and C with different SiN_X thickness.

The thickness was calculated from the wavelength λ_{min} at the minimum of the reflectance curve according to:

$$d_{SiN_X} = \frac{\lambda_{min}}{4n_1}\sqrt{1+\frac{{n_0}^2}{{n_1}^2}[\sin(90-\ \theta)]^2} \qquad (1)$$

where n_0 was the refractive index of air ($n_0 = 1$), n_1 was the refractive index of SiN_X ($n_1 = 2{,}03$), and θ was the angle of incident beam ($\theta = 8°$) [6]. The resulting values of SiN_X thickness are given in the Table 1. In case of samples X and Y the SiN_X thickness was evaluated by extrapolation based on deposition time (see Fig. 3).

Table 1: Calculated of SiN_X thickness for samples.

Sample	$t_{deposition}$ [s]	λ_{min} [nm]	d_{SiNX} [nm]
X	280	_	27,2
Y	380	_	34,8
A	480	341	42,1
B	580	406	50,1
C	680	462	57,0

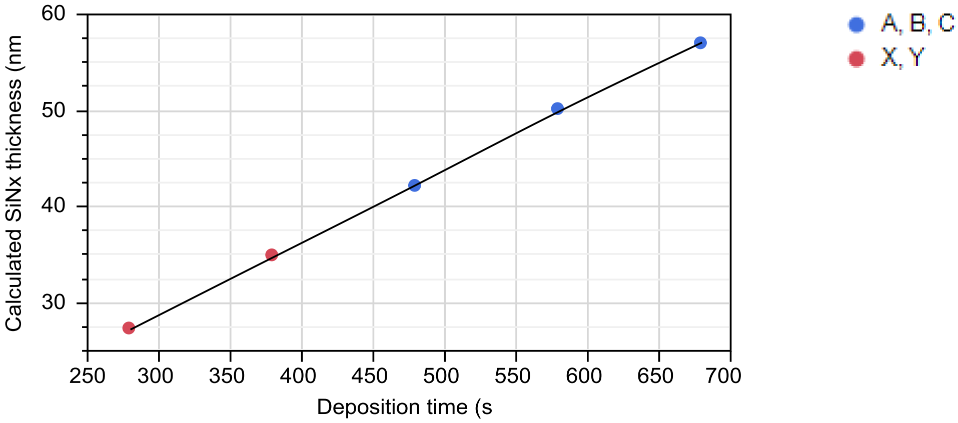


Figure 3: The dependence of SiN_X thickness on deposition time.

3.2. IMPLIED V_{OC} AND J_0

The passivation quality could be determined by the values of implied open-circuit voltage at one sun (iV_{OC}; the V_{OC} value determined from the carrier concentration) and dark saturation current density (J_0), measured by the Quasi-Steady-State Photoconductance technique (QSSPC) [8]. The iV_{OC} and J_0 values were measured after annealing, but before printing the metallization grid. The measurements were done on front side of each sample in five points. In the Fig. 4 there is shown dependence of implied V_{OC} and J_0 on the total thickness of the SiN_X layer on the rear side.

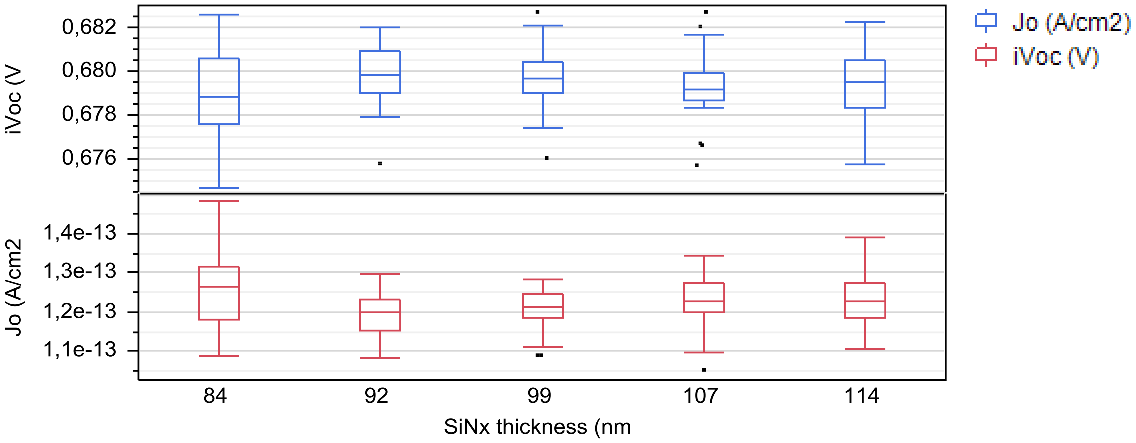


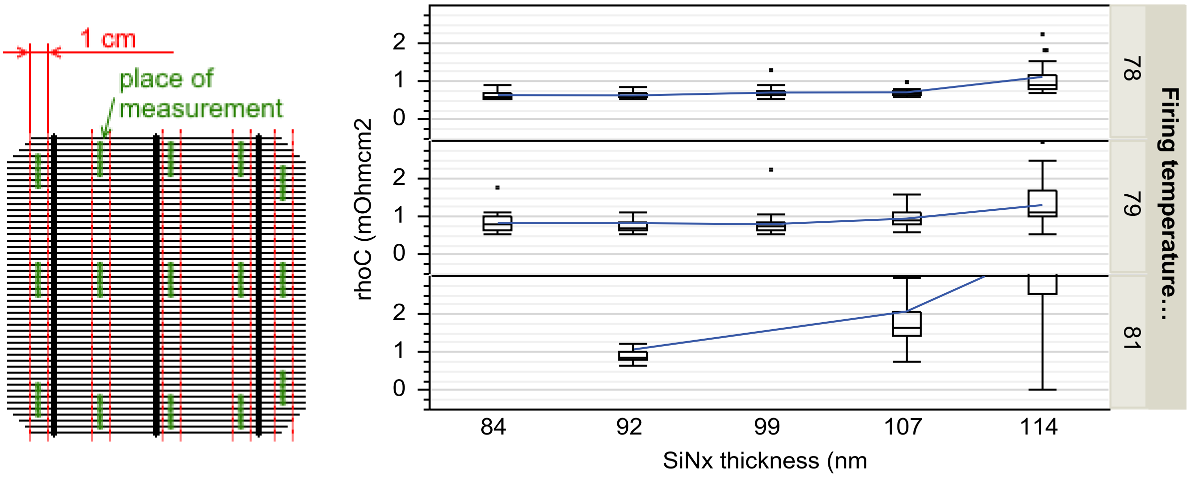
Figure 4: iV_{OC} at 1 sun and J_0 of the cell precursors (before metallization). The J_0 was extracted at an injection level of $\Delta n = 2 \times 10^{15}$ cm^{-3}.

It is obvious that the best passivation quality (high iV_{OC} and low J_0) gives the SiN_X layer with average thickness 92 nm and 99 nm. The mean values of iV_{OC} and J_0 were 679,8 mV and 11,98 fA/cm^2 in case of SiN_X thickness 92 nm, or rather 679,7 mV and 12,10 fA/cm^2 for samples with SiN_X thickness 99 nm.

3.3. CONTACT RESISTIVITY

The contact resistivity (ρ_C; also called specific contact resistance) characterizes the electrical quality of an ohmic contact formed between a metallization grid and an underlying semiconductor. The low value of ρ_C for the metal contacts indicates very good firing-through process, which leads to lower ohmic power loss.

After printing and firing step the dependence of contact resistivity on SiN_X thickness and firing temperature was detected by the Transmission Line Model (TLM) method. Five stripes 1 cm wide were laser-cut out of samples, perpendicularly to fingers (see Fig. 5 a). The contact resistivity of rear side metallization was measured on 3 different positions per stripe; each position includes 6 contact fingers.



a) b)

Figure 5: The influence of SiN_X thickness and firing temperature on resulting contact resistivity.

The dependence of contact resistivity on total SiN_X thickness on rear side of solar cell and on peak firing temperature is shown in the Fig. 5 b). In spite of the fact that the thicker SiN_X layer leads to slightly higher value of ρ_C, the temperature υ_{firing} has a major effect on the resulting contact resistivity. The lower values of ρ_C indicate that the larger Ag crystallites were formed during the firing process. The big variation of ρ_C of overfired cells, i.e. υ_{firing} = 815 °C and cells with d_{SiNx} = 107 nm and 114 nm, can be caused by the high inhomogeneity of junction depth and depletion width.

The lowest contact resistivity (below 1 mΩcm^2) was achieved for combination of low peak firing temperature (780 °C and 795 °C) and SiN_X thickness in the range of 84 nm and 99 nm (or 107 nm for υ_{firing} = 780 °C). The lowest contact resistivity (ρ_C = 0,65 mΩcm^2) was reached for combination of the thickness 84 nm and temperature υ_{firing} = 780 °C.

4. CONCLUSION

The QSSPC measurements for different thickness of SiNX layer showed, that the best passivation quality (high iV_{OC}, and low J_0) gives the SiN_X layer with average thickness 92 nm (679,8 mV; 11,98 fA/cm^2) and 99 µm (679,7 mV; 12,10 fA/cm^2).

The value of contact resistivity depends mainly on the firing profile (in this case υ_{firing}) and much less on the SiN_X thickness. The lowest contact resistivity ($\rho_C = 0{,}65\ \mathrm{m\Omega cm^2}$) was achieved for combination of low firing temperature (υ_{firing} = 780 °C) and total SiN_X thickness 84 nm.

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