

N-type emitters passivation through antireflective phosphorus doped a-SiC_xN_y:H(n) stacks

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Abstract— This paper studies the passivation of industrially textured deep silicon emitters using amorphous silicon carbonitride layers in stack configuration, deposited by plasma enhanced chemical vapor deposition. With this technique, emitter saturation current density can be decreased to values around 250 fA·cm⁻². As a consequence, open circuit voltages can be increased 25 mV achieving values around 640 mV.

I. INTRODUCTION

During the last decade, we have been investigating the surface passivation achieved by different hydrogenated amorphous silicon carbide alloys, deposited by plasma enhanced chemical vapour deposition (PECVD) [1],[2]. This technique is suitable for industrial applications due to its low process temperature (< 400 °C) and fast deposition rate (50 Å/s). One of our last results was the possibility of passivating p-type and n-type float zone (FZ) planar c-Si substrates, using hydrogenated and n-type phosphorus-doped amorphous silicon carbonitride films (a-SiC_xN_y:H(n)). We found that by using a stack of two layers with different composition, excellent surface passivation and antireflective (AR) properties can be achieved at the same time. The first layer (labelled PAS) is a thin silicon rich passivation film, and the second one (labelled ARC) is a hydrogenated nitrogen rich layer acting as antireflective coating [3]. We measured for these bilayers values of effective surface recombination velocities at the interface between the deposited layer and silicon substrate (S_{eff}), lower than 12 cm·s⁻¹ for p-type substrates, and 7 cm s⁻¹ for n-type substrates, at 1 sun illumination. The corresponding effective refractive index [4] of the bilayer is 2.57. It can be concluded that this approach offers a good solution for the trade-off between AR and surface passivation properties. Finally, we explored the stability of these films under high-temperature processes similar to the typical ones needed for the creation of screen-printed contacts. We used a conventional belt furnace with a maximum temperature of 720 °C for 35 s. The stacks lost some passivation properties whereas S_{eff} remained below 200 cm·s⁻¹.

In this work we analyze the use of these stacks for the passivation of industrially textured Czochralski (CZ) p-type silicon substrates and phosphorus diffused (n+) emitters with

emitter sheet resistances (R_{sq}) compatible with screen printed metallization.

II. FABRICATION

We used <100> oriented CZ, p-type, textured silicon wafers with resistivity of 1 Ω·cm and 238 μm thick. The wafers were cleaned in a RCA standard cleaning that was composed of: i) pre-etching with buffered HF; ii) immersion in RCA1 cleaning (5:1:1vol NH₄OH (29%) + H₂O₂ (30%) + DI H₂O) 10 min after reaching the boiling point (70-80 °C); iii) dipping in 2% HF solution for 10 seconds, till obtaining a hydrophobic surface through removing the impurity-containing oxidized film; iv) immersion in RCA2 cleaning (6:1:1vol HCl (37%) + H₂O₂ (30%) + DI H₂O) 10 min after reaching the boiling point (75-80 °C). Immediately afterwards, the samples were dipped into a HF solution (2%) in order to remove any grown oxide, and introduced into a PECVD reactor (13,56 MHz RF commercial Plasmalab DP-80 system from Oxford Instruments in a direct configuration). Then, a-SiC_xN_y:H(n) stack formed by PAS+ARC films were deposited on both sides of the wafers. Substrate temperature (400 °C), process pressure (300 mTorr) and RF power (0.043 W·cm⁻²) were kept as constant technological parameters. Table I shows the gas flow ratios and thickness for the two different layers.

The effective minority carrier lifetime (τ_{eff}) obtained for this structure is assumed to be a minimum limit for the bulk lifetime. The same stack was used to passivate samples with double side n+ diffused emitters with $R_{\text{sq}} = 30 \Omega/\text{sq}$ PAS layer thickness was optimized in order to find the most favourable passivation.

TABLE I
A-SiC_xN_y:H(N) STACK DEPOSITION PARAMETERS

Layer	SiH ₄ (5% PH ₃) flow (sccm)	CH ₄ flow (sccm)	N ₂ flow (sccm)	Thickness (nm)
PAS	30	20	15	30
ARC	3	2	25	80

III. RESULTS

The quality of the passivation was determined by measuring the τ_{eff} dependence on the injection level (Δn), with the quasi-steady-state photo conductance (QSS-PC) technique [5]. From these measurements, the S_{eff} was extracted assuming identical surfaces and considering Auger and radiative recombination processes within the silicon bulk [6]. The effective lifetime measurement and the corresponding S_{eff} for textured 1 Ω -cm p-type CZ substrates is shown in fig.1. The obtained S_{eff} values are an upper limit to the real ones because no Shockley-Read-Hall bulk recombination is taken into account. S_{eff} values as low as 220 $cm^{-2}s^{-1}$ were achieved at 1 sun illumination. These values are however one order of magnitude higher than those obtained in our previous studies for FZ flat materials.

In order to analyze the effect of the PAS layer thickness on the passivation properties, we passivated the phosphorus diffused 30 Ω /sq emitter varying the thickness of the PAS layer, and the τ_{eff} (Δn) was measured again by the QSS-PC technique. Fig.2 compares the effective lifetime for the emitter not passivated and passivated using stack layers with two different thicknesses. In addition the effective lifetime for non-passivated samples with and without phosphorus glass created during emitter diffusion are also showed.

Fig.3 shows the extracted measured lifetime values and implicit open circuit voltages at 1 sun illumination. The passivating properties saturates around the last value of 25 nm where the implicit open circuit voltage is around 639 mV. This value represents an increase of 25 mV with respect to the emitter without the PAS layer and without phosphorus glass.

We extracted then, the emitter saturation current density (J_{oe}) for each sample using a model including all the recombination mechanisms in order to get an accurate estimation of this parameter [7]. Fig.4 shows an example of lifetime measurement and a simulation (fitting) corresponding to a PAS thickness of 25 nm. Good agreement between

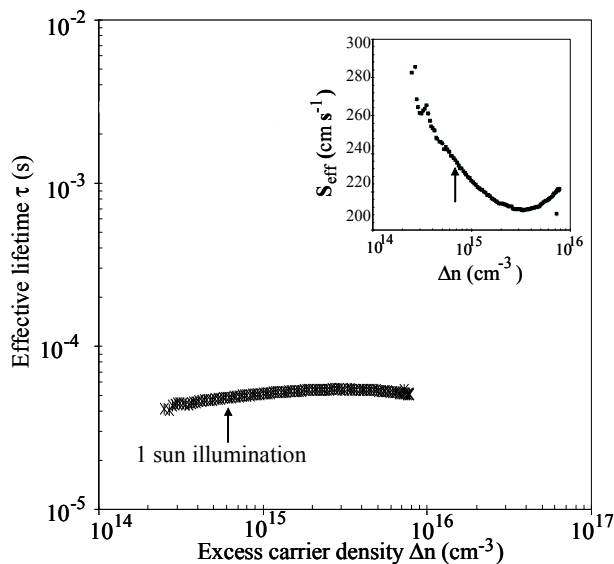


Fig.1. Effective lifetime curve passivated by a-SiC_xN_y:H(n) stack. The arrows indicate 1 sun illumination. The inset shows the corresponding S_{eff} values.

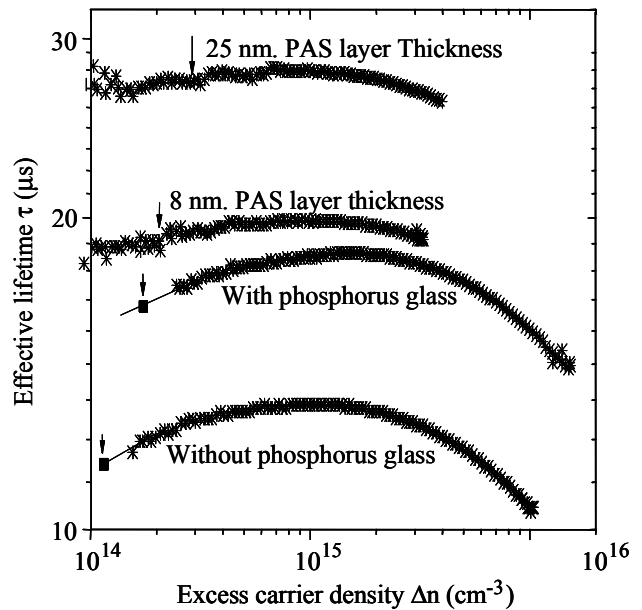


Fig.2. Effective lifetime curves for two different PAS layer thickness. The effective lifetime curves without passivation, with and without phosphorus glass, are also plotted for comparison. The arrows indicate 1 sun illumination.

measured and theoretical curves over the whole injection level range can be observed. For this deep emitter, suitable for metal contact by screen printing process (30 Ω /sq), we achieved a J_{oe} value around 250 $fA \cdot cm^{-2}$ after passivation

Fig.5 shows this result together with results reported in a previous work where the emitter was diffused by annealing phosphorus doped amorphous silicon carbide layers (a-SiC:H(n)) also deposited by PECVD but on high quality 0.8 Ω -cm p-type FZ silicon substrates [8]. It can be observed that the J_{oe} value has been reduced (labelled this work) in spite of using textured 1 Ω -cm p-type CZ silicon substrates. This fact indicates the good quality passivation achieved by the a-

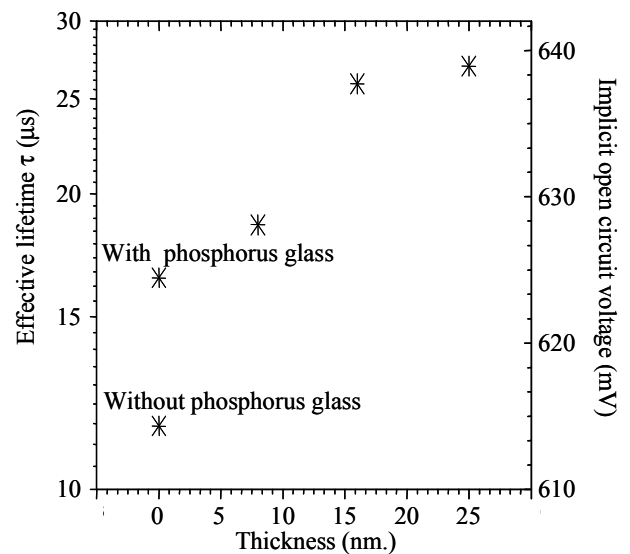


Fig.3. Effective lifetime and implicit open circuit voltage at 1 sun illumination for three values of PAS layer thickness. The results without passivation, with and without phosphorus glass, are also plotted for comparison.

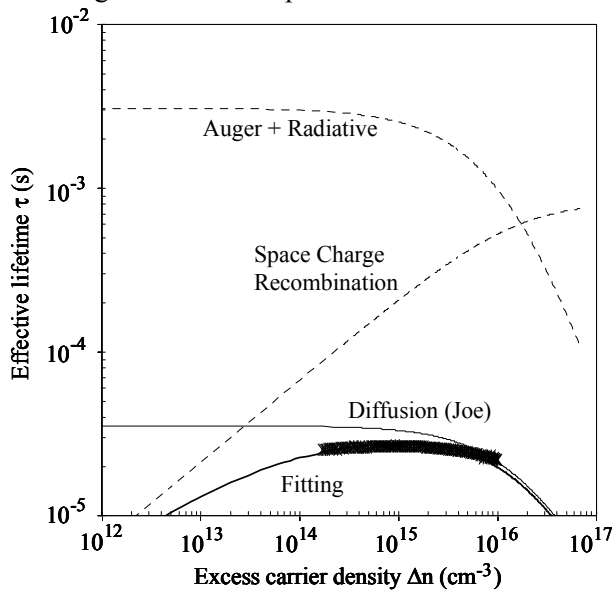


Fig.4. Example of extraction of J_{oe} from $\tau(\Delta n)$ measured curve (symbols). The model for the fitting includes the diffusion diode ($J_{oe} = 250 \text{ fA}\cdot\text{cm}^{-2}$), the recombination diode ($J_{rec} = 20 \text{ nA}\cdot\text{cm}^{-2}$, $n_{rec}=2$) and Auger+Radiative lifetime.

$\text{SiC}_x\text{N}_y\text{:H(n)}$ stack used in this work. Finally, from the J_{oe} value, a $S_{\text{eff}} = 2\cdot 10^4 \text{ cm/s}$ can be extracted through PC1D program [9] simulation, that is more than two orders of magnitude lower than for the metal-contacted not passivated conventional diffused emitters.

IV. CONCLUSIONS

We conclude that $\text{a-SiC}_x\text{N}_y\text{:H(n)}$ stack can be used in industrial solar cell fabrication. Three different objectives can be accomplished simultaneously: i) Passivation of $1 \Omega\cdot\text{cm}$ p-type CZ silicon back surface solar cell with values of $S_{\text{eff}} = 220 \text{ cm}\cdot\text{s}^{-1}$ at 1 sun illumination, ii) Realization of an AR coating at the front solar cell, and iii) Passivation of $30 \Omega/\text{sq}$ diffused emitters obtaining $J_{oe} = 250 \text{ fA}\cdot\text{cm}^{-2}$.

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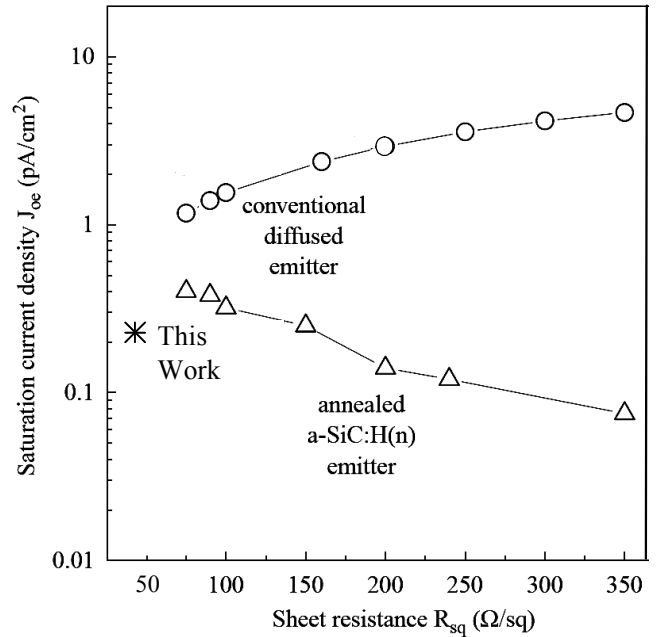


Fig.5. Saturation current density (J_{oe} as a function of sheet resistance (R_{sq}) for emitters diffused annealing $\text{a-SiC}_x\text{N}_y\text{:H(n)}$ (triangle symbols) and for conventionally diffused textured emitter passivated by $\text{a-SiC}_x\text{N}_y\text{:H(n)}$ (this work). Circle symbols correspond to saturation current densities calculated with PC1D program for metallized conventional diffused emitters without passivation.

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