



**HAL**  
open science

# USE OF AMORPHOUS HYDROGENATED SILICON CARBIDE AS A REAR-SIDE PASSIVATION LAYER FOR CRYSTALLINE SILICON SOLAR CELLS

Aurélien Gaufres, Frédéric Husser, Erwann Fourmond, Rémi Monna, M. Lemiti

► **To cite this version:**

Aurélien Gaufres, Frédéric Husser, Erwann Fourmond, Rémi Monna, M. Lemiti. USE OF AMORPHOUS HYDROGENATED SILICON CARBIDE AS A REAR-SIDE PASSIVATION LAYER FOR CRYSTALLINE SILICON SOLAR CELLS. 28th European Photovoltaic Solar Energy Conference, Sep 2013, Paris, France. hal-01890566

**HAL Id: hal-01890566**

**<https://hal.science/hal-01890566>**

Submitted on 8 Oct 2018

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# USE OF AMORPHOUS HYDROGENATED SILICON CARBIDE AS A REAR-SIDE PASSIVATION LAYER FOR CRYSTALLINE SILICON SOLAR CELLS

A.Gaufrès<sup>1</sup>, F. Husser<sup>1</sup>, E.Fourmond<sup>1</sup>, R.Monna<sup>2</sup>, M.Lemiti<sup>1</sup>

<sup>1</sup>Université de Lyon; Institut des Nanotechnologies de Lyon CNRS-UMR 5270  
INSA de Lyon, 7 Avenue Jean Capelle, 69621 Villeurbanne, France

<sup>2</sup>CEA-INES, 50 Avenue du Lac Léman, BP 332, 73310 Le Bourget du Lac, France

**ABSTRACT:** a-SiC<sub>x</sub>:H is a material which could be used as a passivating layer for a crystalline silicon solar cell with a minimum surface recombination velocity of 7.5 cm.s<sup>-1</sup>. The thermal stability should also be considered. As the Si-richest a-SiC<sub>x</sub>:H films are the less stable one, carbon-richer stoichiometry are preferred. From C(V) measurements, the interface between a-SiC<sub>x</sub>:H and c-Si seems to be in accumulation regime. In presence of local aluminium contacts, it means that a BSF on the whole rear side is established making the use of a-SiC<sub>x</sub>:H interesting for the rear-side passivation. For the PERC solar cells, two stoichiometries [C] = 0.15 and [C] = 0.24 are chosen because they are more thermally stable than Si-richest films and they ensure good surface passivation. An additional layer of SiN<sub>x</sub>:H at the rear side improves the internal reflection. We compare also results obtained with solar cells schemes with and without thin layer of oxide at the front-side.

**Keywords:** PERC, passivation, metallic contact, co-firing

## 1 INTRODUCTION

The reduction of the cost of fabrication of silicon solar cells is a challenging question for the competitiveness of solar energy because it involves the limitation of the quantity of raw materials. The thickness of the solar cell is reduced and the aspect ratio increases, which intensifies the impact of the surface properties over the volume ones. The importance of the surface passivation of the solar cell is thus enhanced. In this work, we investigate the use of amorphous hydrogenated silicon carbide (a-SiC<sub>x</sub>:H) as a passivating layer for the rear side of a PERC structure. Janz et al. [1] have deposited a Si-rich passivating layer of a-SiC<sub>x</sub>:H. Problems of hydrogen effusion which affect solar cell performances have been observed. Riegel et al. [2] enhanced the loss of quality of local contacts in a PERC structure between silicon and aluminum reducing the fill-factor. Despite this problem, better results than a standard configuration with Al-BSF have been obtained. Si-rich a-SiC<sub>x</sub>:H may be passivating, but its refractive index is close to the c-Si one. In order to optimize internal reflection, Glunz et al. [3] have added a C-rich layer with a lower refractive index with a gain of 2% efficiency. A stack of a-SiC<sub>x</sub>:H and oxide layers gives similar results [4].

Our work consists to investigate the passivating properties of a-SiC<sub>x</sub>:H depending on stoichiometry at the rear-side of PERC solar cell structures compared to a standard cell configuration.

## 2 PECVD DEPOSITION PROCESS

a-SiC<sub>x</sub>:H have been deposited using a semi-industrial low-frequency PECVD reactor (440 kHz) elaborated by Semco Engineering [5]. The plasma is pulsed. The experimental parameters are fixed to ensure good homogeneity of deposited layers throughout the 15 capacitive electrodes assembled in a vertical configuration. The deposition parameters are presented in table 1.

**Table I:** Experimental parameters of deposition

Temperature	370 °C
Pressure	1500 mTorr
Peak-power of plasma	0.3 W.cm <sup>-2</sup>
Effective power of plasma	0.052 W.cm <sup>-2</sup>

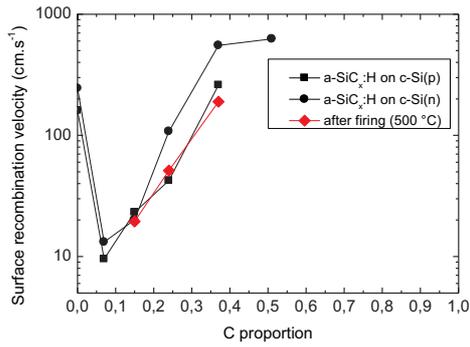
In the literature, most of the reactors use high-frequency, because of a better surface passivation properties, but low-frequency reactors are also of interest since the hydrogenation of the silicon substrate is more efficient [6]. Precursor gases are silane (SiH<sub>4</sub>) and methane (CH<sub>4</sub>) for a-SiC<sub>x</sub>:H and silane and ammoniac (NH<sub>3</sub>) for SiN<sub>x</sub>:H. The different layers are referred according to their carbon content [C] (at. %), defined as :

$$[C] = \frac{\text{at.\% C}}{\text{at.\% Si} + \text{at.\% C} + \text{at.\% H}} \quad (1)$$

## 3 PASSIVATING PROPERTIES OF a-SiC<sub>x</sub>:H LAYERS

a-SiC<sub>x</sub>:H layers are deposited on both n- and p-type c-Si wafers, Float-Zone quality, (100)-oriented with a resistivity comprised between 2 to 5 Ω.cm, and bulk lifetime close to 6ms. The samples were cleaned before deposition using CARO chemical cleaning followed by an HF dip.

The tested stoichiometries of a-SiC<sub>x</sub>:H in this study are [C] = 0.07, [C] = 0.15, [C] = 0.24, [C] = 0.37 and [C] = 0.51. At first, the influence of the stoichiometry on the passivation skills is investigated through lifetime measurements.



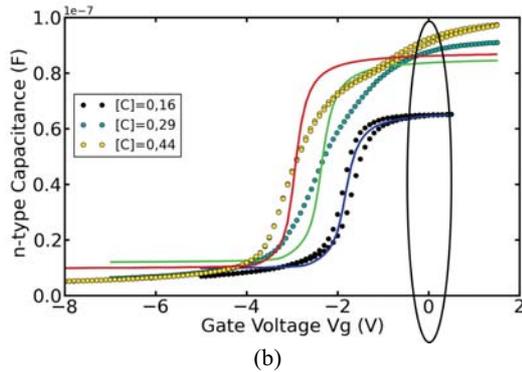
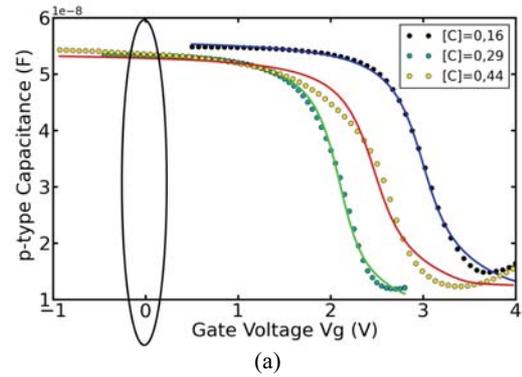
**Figure 1:** Surface recombination velocity before and after rapid thermal annealing at 500 °C for 3 stoichiometries

The surface recombination velocity of a-SiC<sub>x</sub>:H is extracted from the effective lifetime obtained by QSS-PCD method [7] at an injection level of  $1.10^{15} \text{ cm}^{-3}$ , with a Sinton Consulting WCT-100 apparatus [8]. The tendency of the experimental points is similar between both substrate doping types, which is not a determining parameter of the passivation. The Si-rich films are the more passivating ones with a minor surface recombination velocity of  $7.5 \text{ cm.s}^{-1}$  for p-type c-Si and  $11 \text{ cm.s}^{-1}$  for n-type c-Si.

The thermal stability of the films is tested with a Rapid Thermal Annealing (RTA). Two anneals at 500 °C and 800 °C are compared. All the samples annealed at 800 °C have lost their passivating properties. The Si-richest films are the most degraded because of the effusion of hydrogen atoms and then the increase of the concentration of dangling bonds at the interface between c-Si and a-SiC<sub>x</sub>:H. The annealing at 500 °C maintains the passivating properties of the layers, for  $[C] = 0.15$ ,  $[C] = 0.24$  and  $[C] = 0.37$ . For high-temperature step in the manufacturing process, a compromise should be done between the lifetime results and the thermal stability.

To have a low enough surface recombination velocity is an important condition for the use of a material as a passivating layer for not sufficient for the rear side. The most convincing example is the SiN<sub>x</sub>:H whose the positive fixed charge density induces “parasitic” shunt effect located at the aluminum contacts and reducing the short-circuit current [9]. The nature of the fixed charges is important to determine in case of a-SiC<sub>x</sub>:H in order to know if it matches with the rear-side passivation condition.

C(V) measurements have been realized on samples with the same quality of c-Si. A mercury-probe contact is used as metallic contact (metal/a-SiC<sub>x</sub>:H/c-Si structure). The experimental data are fitted with the Nicollian & Brews model described in [8] as we had difficulties to obtain complete C(V) curves because of the leaky nature of a-SiC<sub>x</sub>:H.



**Figure 2:** C(V) curves at 1 kHz obtained on p-type (a) and n-type (b) c-Si substrate for  $[C] = 0.15$ ,  $[C] = 0.24$  and  $[C] = 0.37$ .

Figure 2 displays the experimental C(V) fitted by the Nicollian & Brews model. The amphoteric nature of the fixed charge (explained in ref. [8]) is demonstrated by comparing the change of the sign of the flat-band voltage: negative in case of n-type c-Si substrate and positive in case of p-type c-Si substrate. Moreover, at a gate voltage of 0 mV or around 670 mV (ellipses on Figure 2) which is an usual open-circuit voltage of a PERC solar cell, the a-SiC<sub>x</sub>:H/c-Si interface is under accumulation regime. With local aluminum contacts, we would have an extended BSF to the whole rear face. This result is thus an argument for using a-SiC<sub>x</sub>:H as a rear-side passivation layer.

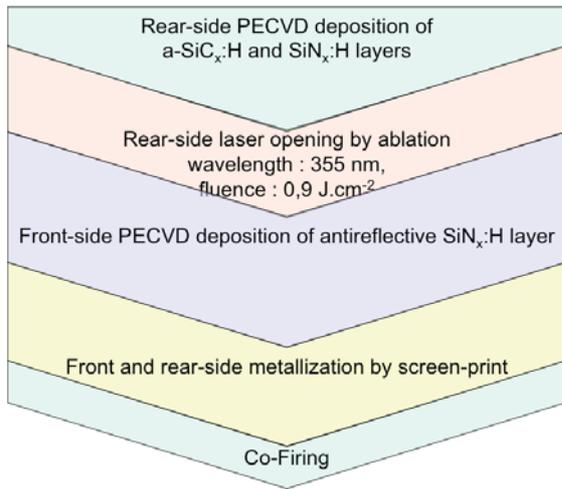
### 3 PERC SOLAR CELL EXPERIMENT

16 p-type Cz-Si  $156 \times 156 \text{ cm}^2$  wafers with a resistivity of 1-3  $\Omega \cdot \text{cm}$  are used for solar cells production. The emitter has a resistance of 70  $\Omega/\text{sq}$ . A thin layer of oxide is grown after emitter formation on front side. This improves the passivation of the emitter and the open-circuit voltage also increases slightly. The thickness of oxide is limited to about 10 nm and the thickness of SiN<sub>x</sub>:H is then adapted to limit the increase of reflectivity (0.5 % greater).

The manufacturing process of our PERC solar cells is described on Figure 3. The antireflective SiN<sub>x</sub>:H is deposited at CEA-INES in a reactor at 40 kHz. The rear-side a-SiC<sub>x</sub>:H and SiN<sub>x</sub>:H layers are deposited with the PECVD equipment at INL. As the more passivating a-SiC<sub>x</sub>:H films are Si-rich, the refractive index  $n$  has a value close to the c-Si one and then, an additional layer of low- $n$  SiN<sub>x</sub>:H is deposited in order to improve the internal reflection of photons inside the solar cell.

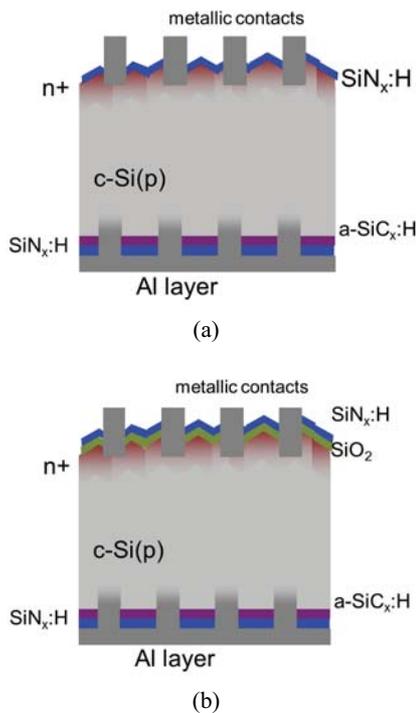
Two splits are done in the batch : 50 % of the wafers are

deoxidized by HF dip and two stoichiometries of a-Si<sub>x</sub>:H at [C] = 0.15 and [C] = 0.24 are chosen as they are more temperature-stable than the Si-richest stoichiometry. An oxidized wafer is processed as a standard solar cell and is the reference of the batch. The rear dielectric is then opened using UV pulsed laser beam, before complete metallization by Al-screen-printing.



**Figure 3:** Process flow followed for PERC solar cells

The final schemes of PERC solar cells are illustrated on Figure 4a for a solar cell without front oxide layer and on Figure 4b for a solar cell with front oxide layer.



**Figure 4:** Schema of solar cell schemes without (a) and with (b) front oxide layer

#### 4 SOLAR CELLS RESULTS

Solar cells results not available at the time of the

conference.

#### 5 DISCUSSION AND CONCLUSION

The unavailability of the solar cell results does not permit us to conclude neither about the gain obtained by a a-Si<sub>x</sub>:H/SiN<sub>x</sub>:H stack compared to a simple metallization layer nor about the confirmed tendency of the a-Si<sub>x</sub>:H passivation observed in Figure 1. Although we don't have any quantitative results, limitations are expected. Some problems could occur after the solar cell process which would make the obtained results not optimal. The low stability of a-Si<sub>x</sub>:H under high-thermal step as co-firing may cause some blistering of Si-H bonds increasing dangling bonds at the interface with c-Si and then some shunt effect at the electrical contacts. But the back-side SiN<sub>x</sub>:H could protect the a-Si<sub>x</sub>:H and limit its degradation. Lower-thermal process for metallization would then be required to save the passivating properties of a-Si<sub>x</sub>:H like aluminium sputtering or aluminium deposition by Physical Vapor Deposition for the rear side of the solar cell after a first firing for the front-side metallization.

The Al-Si interface at the opened-laser contacts is also something critical. The diffusion of Si in Al is more rapid than the diffusion of Al in Si during the firing leading the voids formation [10]. Aluminum paste used in the frame of the study could not be optimized for rear-side screen-printed as it can absorb the diffused silicon. The fill-factor could then be affected by a loss of conductivity at the localised contacts. In order to limit the formation of voids, we could apply a cooling-down of the temperature after the firing process facilitating the Al-Si alloy.

Acknowledgments :

I would like to acknowledge Nanolyon Platform team who took a certain part in this work. Funding is provided by a grant from Région Rhône-Alpes (France).

REFERENCES:

- [1] S. Janz, S. Reber, and S. W. Glunz, *21<sup>st</sup> European Photovoltaic Solar Energy Conference*, 2006, pp. 6–9.
- [2] S. Riegel, B. Raabe, R. Petres, S. Dixit, L. Zhou, and G. Hahn, *Proc. of 25th European PVSC*, 2009, pp. 2–5.
- [3] S. W. Glunz, A. Grohe, M. Hoffmann, S. Janz, O. Schultz, M. Vetter, I. Martin, R. Ferre, S. Bermejo, W. Wolke, W. Warta, R. Preu, and G. Willeke, *20<sup>th</sup> European Photovoltaic Solar Energy Conference*, 2005, p. 572.
- [4] D. Suwito, S. Janz, M. Hermle, and S. W. Glunz, *24<sup>th</sup> European Photovoltaic Solar Energy Conference*, 2009, pp. 2197–2201.
- [5] J. Dupuis, E. Fourmond, D. Ballutaud, N. Bererd, and M. Lemiti, *Thin Solid Films*, vol. 519, no. 4, pp. 1325–1333, 2010.
- [6] V. Yelundur, *19<sup>th</sup> European Photovoltaic Solar Energy Conference*, 2004, pp. 951–954.
- [7] R. A. Sinton, *Appl. Phys. Lett.*, vol. 69, no. 17, pp. 2510–2512, 1996.
- [8] A. Gaufres, F. Husser, E. Fourmond, and M. Lemiti, *Energy Procedia*, vol. 38, pp. 823–832, Jan. 2013.

- [9] S. Dauwe, L. Mittelstädt, A. Metz, and R. Hezel,  
*Prog. Photovoltaics Res. Appl.*, vol. 10, no. 4, pp.  
271–278, Jun. 2002.
- [10] E.O. Kirkendall, *Transaction AIME*, vol. 147, p. 104,  
1942