

# Realization of point contact for stacks $\text{Al}_2\text{O}_3/\text{SiN}_x$ rear surface passivated solar cells

S J Wang<sup>1,2</sup>, G J Jin<sup>1</sup>, L L Wang<sup>1</sup>, Z Zuo<sup>3</sup>, Y L Meng<sup>1\*</sup>,

Y Zhao<sup>4</sup> and S Z Jin<sup>1</sup>

<sup>1</sup>College of Optics and Electronic Technology, Chia Jiliang University, Hangzhou, China

<sup>2</sup>Laboratoire de Nanotechnologie et d'Instrumentation Optique (LNIO), University of Technology of Troyes, Troyes, France

<sup>3</sup>Department of Physics, University of Toronto, Toronto, Ontario, M5S1A7, Canada

<sup>4</sup>State Key Laboratory on Integrated Optoelectronics, Jilin University, Changchun, China

\*Corresponding author: myl@cjlu.edu.cn

**Abstract.** A simple locally-sintered process for realizing rear point contacts of the Passivated emitter and rear cells, of which rear surface is passivated by  $\text{Al}_2\text{O}_3/\text{SiN}_x$  double layers, is demonstrated in this paper. As compared to conventional cells passivated by aluminium back surface field, the cells show higher open circuit voltage and short circuit current. The sintering effect on the final passivation quality of stacks  $\text{Al}_2\text{O}_3/\text{SiN}_x$  during the sintering process is investigated and discussed in detail.

## 1. Introduction

Since it has been proven that  $\text{Al}_2\text{O}_3$  is capable of passivating the surface of silicon, its application becomes more and more attractive for high-efficiency industrial crystalline silicon solar cells, especially for passivated emitter and rear cells (PERC) [1-3]. It is well known that the full area passivation can provide a higher effective lifetime than conventional structure of industrial silicon solar cells with aluminum back surface field (Al-BSF) [4]. Meanwhile, the stack films of  $\text{Al}_2\text{O}_3/\text{SiN}_x/\text{Al}$  on the rear side of cell also provide an excellent reflector for near-bandgap photons, which can improve the light trapping properties and the short-circuit current of the cell [5].

As the development of equipment for deposition of  $\text{Al}_2\text{O}_3$  [6,7], the application of  $\text{Al}_2\text{O}_3$  in high-efficiency PERC cells is generalized rapidly, which also drives the development of other techniques for improving the fabrication processes of PERC cells. Point contacts on rear side of PERC cells play a very important role for the performance of PERC cells, because the status of their contact with the silicon base area directly affects the series resistance and fill factors.

Hence, the process for realizing rear point contacts is a key factor to obtain PERC cells with high efficiency successfully. Up to now, many techniques are introduced to realize point contacts, such as laser ablation [8], wet chemical etch [5], etc. But most of these techniques are not suitable to mass production because of expensive cost and complicated processes. In order to comply with the processes utilized now in solar cells factories, screen-printing point contact is explored in this study. The influence of locally-sintered point contact on the passivation quality of  $\text{Al}_2\text{O}_3$  is also studied.

## 2. Experimental

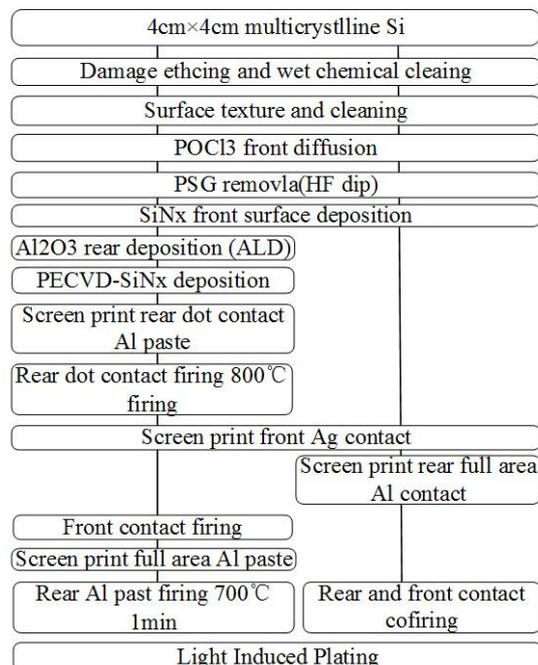
### 2.1. Fabrication of locally-sintered processing point contacts



Locally-sintered point contacts were fabricated by two steps in which different types of aluminum paste were used to realize different functional layers. The aluminum paste with glass frit was screen printed onto rear side of PERC cells firstly for the purpose of forming point electrodes. Then the locally-sintered point contact was obtained via a high temperature sintering processing. After the formation of point contacts, another screen printing processing or Al evaporation onto those point contacts was carried out to form rear electrode. In order to gain the optimized sinter temperature and time for the formation of locally-sintered point contacts, the full area Al was deposited onto surface of a Cz monocrystalline silicon wafer. Before Al paste with glass frit was printed on the other side, stacked 20nm-thick  $\text{Al}_2\text{O}_3$  and 50nm-thick  $\text{SiN}_x$  layers were grown on the silicon as passivation layers sequentially. The  $\text{Al}_2\text{O}_3$  film was deposited in commercial atomic layer deposition reactor Beneq TFS200. The source of reaction used in ALD was traditional metal-organic compound tri-methyl-aluminum [ $\text{Al}(\text{CH}_3)_3$ ].  $\text{SiN}_x$  was grown in Plasma-Therm 790+. A reference sample with Al/p-Si/Al structure was also fabricated. The reference sample was fired firstly at  $600^\circ\text{C}$  for 5min to form ohm contact between Al and Si.

## 2.2. Solar cells fabrication

Figure 1 shows the whole fabrication processes flow of PERC solar cells based on p-type multicrystalline silicon. The size of multicrystalline silicon was  $40\text{ mm}\times 40\text{ mm}$ . The thickness was  $200\text{ }\mu\text{m}$ , and the resistivity was  $1.5\sim 3\text{ }\Omega\cdot\text{cm}$ . After etching the surface damage, an acid-etched texturing was made on both sides. Subsequently, wet chemical cleaning and phosphorus diffusion were performed. The single-step phosphorus emitter was diffused from a  $\text{POCl}_3$  source, resulting in an  $\text{n}^+$ -emitter with a sheet resistance of  $60\text{ Ohm/square}$ .



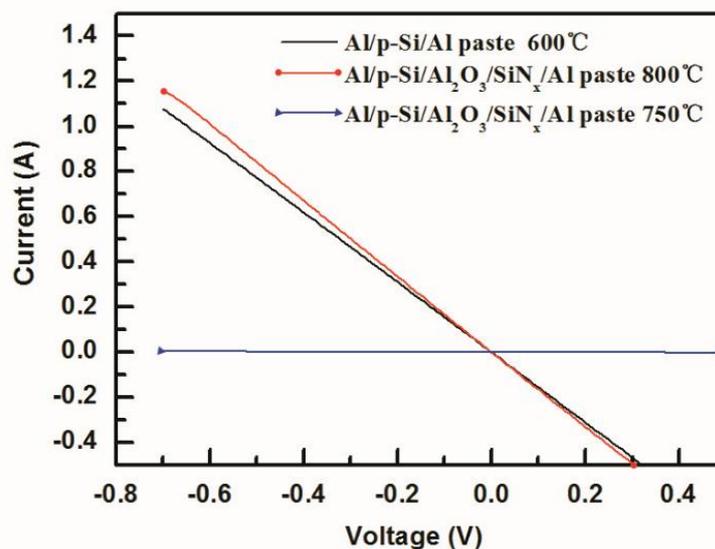
**Figure 1.** Processing flowchart for the PERC-type solar cells and conventional cells fabricated in this study

The phosphorus glass was removed by a short HF dip before deposition of front  $\text{SiN}_x$ . Then 80-nm-thick  $\text{SiN}_x$  was deposited on samples, after that the cells were divided into two groups. Each group had four samples. The rear surfaces of the two groups cells were passivated in different ways. One group were passivated by Al-BSF, while the other group were passivated by stack layers which consist of a 20nm  $\text{Al}_2\text{O}_3$  and 50nm  $\text{SiN}_x$ . Afterwards, Ag front grid and a full area Al electrode were screen

printed on front sides of the cells in the first group. The cofiring was performed after front contact and Al-BSF generation. As to the second group, the point contacts were screen printed on rears of the cells after the  $\text{Al}_2\text{O}_3/\text{SiN}_x$  stacks layers were deposited. The contact size was  $500\ \mu\text{m} \times 500\ \mu\text{m}$ . The contact pitch was 2mm. Before Ag grid on the front surfaces was screen printed,  $800\ ^\circ\text{C}$  sintering was performed to form the point contact. After front Ag contact firing, rears full area Al paste was screen printed too. 1 minute firing at  $750\ ^\circ\text{C}$  was performed to ensure the contact between full area Al paste and point contact screen printed. At last, light induced 10 minutes plating was adopted to increase the thickness of front Ag grid. All cells were measured under standard testing conditions ( $25\ ^\circ\text{C}$ ,  $100\text{mW}/\text{cm}^2$ , AM1.5G).

### 3. Results and discussion

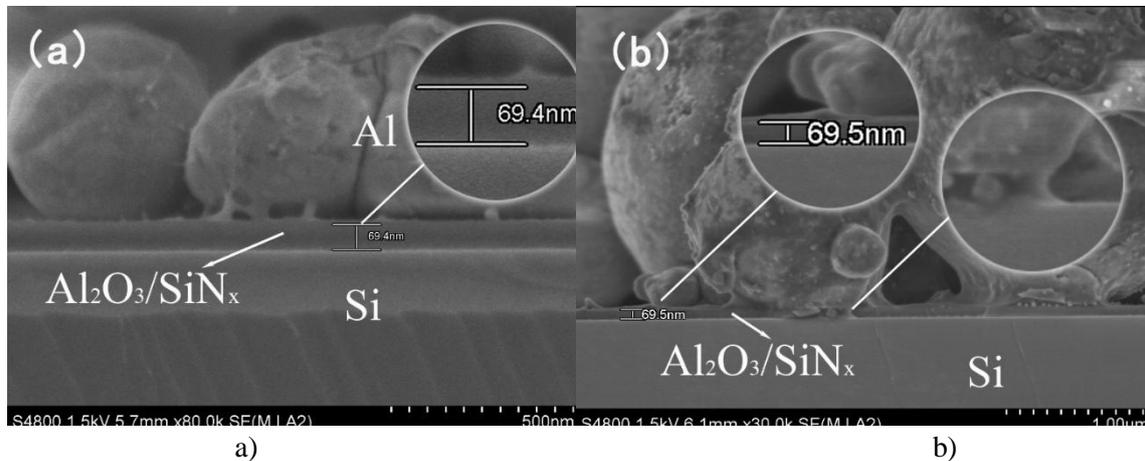
Figure 2 shows the I-V characteristics of samples with different contacts which were realized via various sinter conditions. In order to verify the formation of good contact between Al paste and p-Si under different conditions, we made three samples with different structures and sinter temperature. All sintering time is 1 minute. As displayed in figure 2, the Ohm contact between Al paste and p-Si can be observed even at  $600\ ^\circ\text{C}$ . The current changes linearly as bias changes from  $-0.7\ \text{V}$  to  $0.3\ \text{V}$ . It indicates that there is no rectifying effect between p-Si and the two electrodes. However, there is no current in the sample with structure Al/p-Si/ $\text{Al}_2\text{O}_3/\text{SiN}_x$ /Al paste even the sinter temperature reaches  $750\ ^\circ\text{C}$ . Hence, we assume that the  $\text{Al}_2\text{O}_3/\text{SiN}_x$  double films cannot be fired through by such paste at this temperature. It results in the failure of forming contact between Al paste and p-Si layers. When the temperature is increased up to  $800\ ^\circ\text{C}$ , the sample with structure Al/p-Si/ $\text{Al}_2\text{O}_3/\text{SiN}_x$ /Al paste shows a current comparable to that without  $\text{Al}_2\text{O}_3/\text{SiN}_x$  double films. The result indicates that the  $\text{Al}_2\text{O}_3/\text{SiN}_x$  stacks layers have been fired through, with generation of the alloy junction between p-Si and Al paste.



**Figure 2.** Comparison of I-V characteristics of samples with different firing conditions.

The SEM images show the cross-sections of samples after sintering at different temperatures. Figure 3(a) shows the cross-section of sample sintered at  $750\ ^\circ\text{C}$ . It is obvious that there still is a clear boundary between Al and  $\text{Al}_2\text{O}_3/\text{SiN}_x$  layers. Since both  $\text{Al}_2\text{O}_3$  and  $\text{SiN}_x$  are dielectric materials, it is hard to distinguish the boundary of  $\text{Al}_2\text{O}_3$  and  $\text{SiN}_x$  in SEM image. The SEM image in figure 3(a) reveals that the pasted Al does not penetrate into  $\text{Al}_2\text{O}_3/\text{SiN}_x$  double layers and form an alloy junction with p-Si as well. Figure 3(b) shows the cross-section of the sample sintered at  $800\ ^\circ\text{C}$ , in which the boundary between Al particles and  $\text{Al}_2\text{O}_3/\text{SiN}_x$  vanishes. Additionally, the Al particles ablate with p-Si

at some position as shown in the enlarged images of figure 3(b). These images also support the deduction obtained from the I-V comparison. According to the experimental results, the rear point contacts of PERC cells can be realized via sintering.



**Figure 3.** SEM micrograph of a cross-section: for a full area screen-printed Al paste after 1 minute firing at 750 °C (a) and point contact Al paste after 1 minute firing at 800 °C (b).

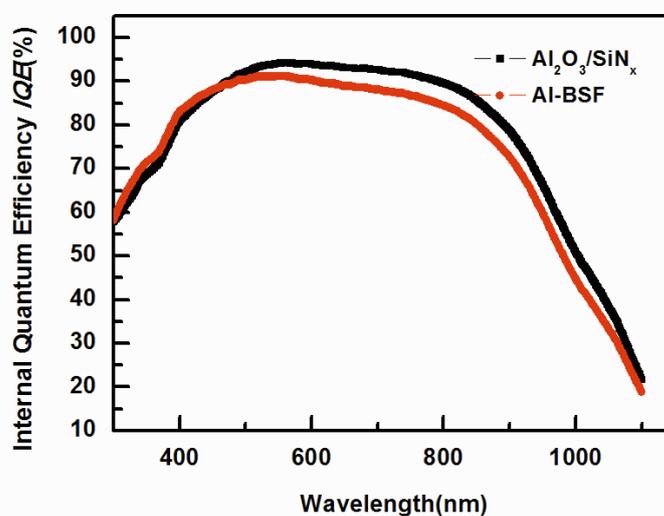
One-sun parameters of cells in different groups are summarized in table 1. The average open-circuit voltage of cells in the second group with  $\text{Al}_2\text{O}_3$  rear surface passivation is slight higher than that of cells passivated by Al-BSF. The higher  $V_{oc}$  is attributing to the better passivation ability of  $\text{Al}_2\text{O}_3$  for rear surface [5]. On the other hand, the small point contacts area results a higher contact resistance which is one of parts of series resistance of cells, and that leads to a low fill factor. Though  $\text{Al}_2\text{O}_3/\text{SiN}_x$  passivated cells have enhanced  $V_{oc}$  and  $I_{sc}$ , the average conversion efficiency of 9.20% is slightly lower than that of cells keeping Al-BSF. The lower fill factor also affects the efficiency, which results in an efficiency of 9.20%.

**Table 1.** Average One-sun parameters measured under standard testing conditions of two batches with different (Al-BSF and  $\text{Al}_2\text{O}_3/\text{SiN}_x$ ) rear surface passivations

Rear side	$V_{oc}$ (mV)	$J_{sc}$ ( $\text{mA}/\text{cm}^2$ )	FF (%)	Eff (%)	$R_s$ ( $\Omega$ )
Al-BSF	577.1	27.7	58.2	9.25	0.30
$\text{Al}_2\text{O}_3/\text{SiN}_x$	582.9	28.3	55.6	9.20	0.32

Note: All cells were fabricated on 1.5~3 $\Omega\text{cm}$  multicrystalline p-Si. The aperture cell area is 16 $\text{cm}^2$ .

In order to confirm the good passivation performance of  $\text{Al}_2\text{O}_3/\text{SiN}_x$  on rear surface after firing at 800°C, the internal quantum efficiency (IQE) of the best cell in each group is compared in Figure 4. It is obvious that IQE value of cell with  $\text{Al}_2\text{O}_3/\text{SiN}_x$  passivation is higher than that of cell with Al-BSF in the long-wavelength range. The higher IQE value in long-wavelength range due to excellent rear surface passivation of  $\text{Al}_2\text{O}_3/\text{SiN}_x$  stacks layers. The results also indicate that the passivating quality of  $\text{Al}_2\text{O}_3$  is still good even though firing at 800°C. Combined with the results shown in table 1, the comparison of IQE proves that the point contacts formed via screen printing and different firing processes is feasible. Our research also provides a new cost-effective way to fabricate PERC cells.



**Figure 4.** Measured internal quantum efficiency as a function of wavelength for p-type solar cells with different (Al-BSF and Al<sub>2</sub>O<sub>3</sub>/SiN<sub>x</sub>) rear passivating procedures

#### 4. Conclusions

In this study, a co-firing is proven to be a feasible way to form point contacts on rear side of PERC cells of which emitter and rear are passivated by Al<sub>2</sub>O<sub>3</sub>. Though three steps of firing were utilized in this study to form different contacts, cells with point contacts also exhibit a better  $V_{oc}$  and  $I_{sc}$  than that of cells with Al-BSF. It is also expected that the printed aluminum paste screen printed can be substituted by fritless Al paste to realize front and rear contact co-firing. The fabrication process to form point contacts on rear side of PERC cells proposed in this study may simplify the whole fabrication process of current industrial solar cells based on bulk silicon.

#### Acknowledgments

This work was supported by the Open Fund of the State Key Laboratory on Integrated Optoelectronics (No.IOSKL2015KF28), the fund of Zhejiang Provincial Natural Science Foundation (No.LQ15F040004 and No.LQ15F050004), and the National Natural Science Foundation of China (No.61505192).

#### References

- [1] Dingemans G 2010 *Proceedings of the 25th EU PVSEC*. Spain.
- [2] Saint-Cast P, Benick J, Kania D, Weiss L, Hofmann M, Rentsch J, Preu R, and Glunz Stefan W 2010 *IEEE Electron Device Letters* 31 695.
- [3] Li T T, A C, Tan J, Samundsett C, Saynova D and Geerligs B 2010 *Proceedings of the Conference on Optoelectronic and Microelectronic Materials and Devices*. Australia.
- [4] Lauermaun T, T L, Scholz S, Raabe B, Hahn G and Terheiden B 2010 *Proceedings of the 35th IEEE Photovoltaic Specialists Conference*. Honolulu.
- [5] Schmidt J, Merkle A, Hoex B, van de Sanden M C, Kessels W.M.M and Brende R 2008 *Proceedings of the 33rd IEEE Photovoltaic Specialists Conference*.
- [6] Schmidt J, Bock R, Altermatt P P and Cuevas A 2008 *Proceedings of the 23rd EU PVSEC*.
- [7] Sperlich H P, Saint-Cast P, Erben E and Peters L 201 *Proceedings of the 25th EU PVSEC*.
- [8] Schneiderlochner E, Preu R, Ludemann R, and Glunz S W 2002 *Progress in photovoltaics: Research and Applications* 10 2.