RESEARCH ARTICLE | AUGUST 24 2022

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AIP Conf. Proc. 2487, 110003 (2022)
https://doi.org/10.1063/5.0096661

Rear Side Optimization for Mass Production PERC Solar Cell with Efficiency above 23%

Shude Zhang[1, 2], Baoxing Zhao[2], Weifei Lian[2], Yawei Kuang[1], Yushen Liu[1] and Zhichun Ni[2, 3, a)]

[1]*Changshu Institute of Technology, Changshu, Jiangsu, 215500, P. R. China.*
[2]*Suzhou Talesun Solar Technologies Co., Ltd., Changshu, 215542, China.*
[3]*Nanjing University of Aeronautics & Astronautics, Nanjing, Jiangsu, 210016, P. R. China.*

[a)]Corresponding author: paul@talesun.com

Abstract. When LDSE (Laser Doped Selective Emitter) is applied to the front side of PERC solar cell, the low sheet resistance requirement for metal contact can be realized by laser doping. Therefore, at present the front sheet resistance has increased from 85 Ω to 140±10 Ω. The emitter saturation current density reduces from 100 fA/cm^2 to less than 50 fA/cm^2. Therefore, the rear surface optimization of PERC solar cell becomes more and more important. In this paper, three aspects about the rear surface are studied. Firstly, the effects of alkali polishing and acid polishing on the performance of LDSE PERC solar cell are compared for the improvement of rear surface polishing. Then, bilayer SiN_x:H capping film is adoped on the Al_2O_3 layer instead of monolayer SiN_x:H. The bottom layer of bilayer structure is made up of high refractive index SiN_x:H, which can improve the hydrogen passivation effect. The top layer of bilayer structure is made up of low refractive index SiN_x:H, which can improve the resistance to aluminum paste erosion. Finally, the influence of different kinds of laser ablation patterns on the cell performance is investigated, aiming to optimize the metal contact recombination. Benefiting from the three methods above, an average efficiency of 23.1% and a champion efficiency of 23.3% are achieved.

INTRODUCTION

In 2019, PERC solar cell had become the mainstream product of photovoltaic market[1]. The cost performance of PERC solar cell is higher than the HJT, IBC and TOPCon solar cells. In recent years, with the selective emitter (SE) technology, the efficiency of PERC solar cell has been improved by 0.3%[2]. In a selective emitter, the lightly doped region contains a low surface concentration of phosphorous atom for a low recombination velocity, and the heavily doped region provides a low metal contact resistance. Along with the sheet resistance increase of lightly doped emitter from 85 Ω to 130-150 Ω, $J_{0,emitter}$ reduces from 100 fA/cm^2 to 22-50 fA/cm^2 [3,4]. Therefore, the rear surface optimization of PERC solar cell becomes more and more important for the further efficiency improvement[5]. Therefore, this paper is devoted to the optimization research of the rear surface of PERC solar cell.

EXPERIMENTS

In Table 1, the process flow of PERC solar cell is listed.

Lifetime samples with symmetrical structure were fabricated. After the texturization and phosphorous diffusion, the samples were polished symmetrically on both sides. Afterwards, Al_2O_3 and SiN_x:H were deposited by PECVD on both sides. Finally, sintering was applied to activate the hydrogen passivation of SiN_x:H.

SiliconPV 2021, the 11th International Conference on Crystalline Silicon Photovoltaics
AIP Conf. Proc. 2487, 110003-1–110003-5; https://doi.org/10.1063/5.0096661
Published by AIP Publishing. 978-0-7354-4362-4/$30.00

TABLE 1. Process flow of solar cell.

Boron-doped Cz silicon wafer (M2 size)
Texturization
Phosphorous Diffusion
Laser Selective Doping
Rear Alkali Polishing or Rear Acid Polishing
Thermal Oxidation
Rear Al_2O_3 and SiN_x:H by PECVD (Monolayer SiN_x:H or Bilayer SiN_x:H)
Front SiN_x:H ARC by PECVD
Rear Laser Ablation
Screen Printing & Sintering

RESULTS AND DISCUSSION

The rear surface recombination depends on the surface morphology and passivation quality. Rear polishing can remove the rear junction and achieve edge isolation. Besides, rear polishing can reduce the specific surface area and improve passivation quality. In this paper, alkali polishing is employed to compare with the traditional acid polishing. Due to the laser doping process, the PSG on heavily doped emitter region will be destroyed. In order to protect the heavily doped emitter during alkali polishing, an additional thermal oxidation process was applied to grow silicon oxide on heavily doped emitter before alkali polishing.

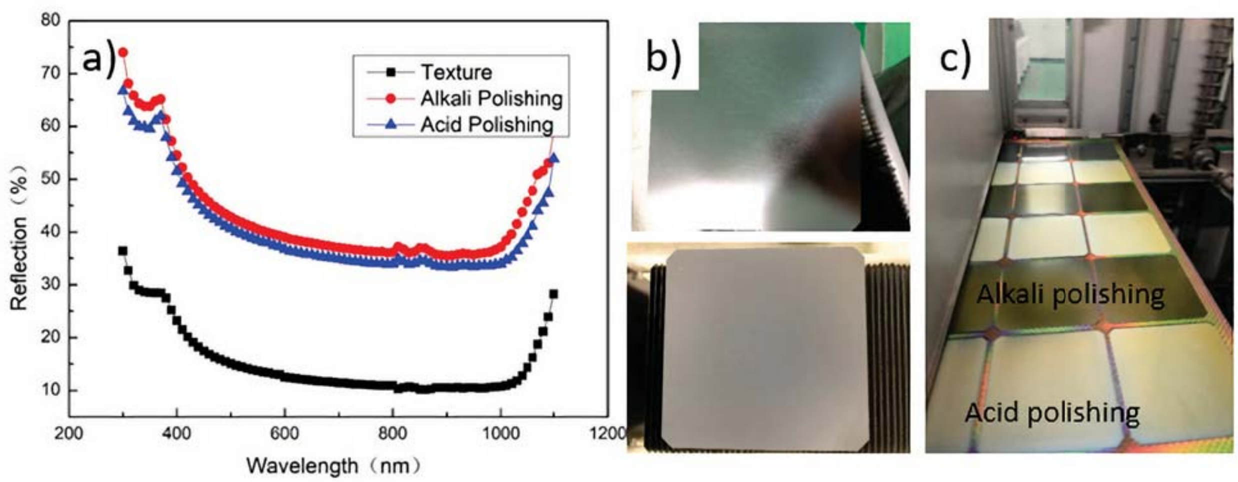

FIGURE 1. The reflection curves (a) and optical images (b) of rear surface polished by alkali and acid respectively. (c) The appearance after the coating of passivation stack.

According to Fig. 1a, the silicon surface reflectivity greatly increases after polishing. In particular, the alkali polishing provides a higher reflectivity than acid polishing. The weighted average reflectance after alkali polishing is 38.6%, while the acid polishing lower than 30%. From Fig. 1b & 1c, the appearance of samples polished by alkali is significantly different from the ones polished by acid.

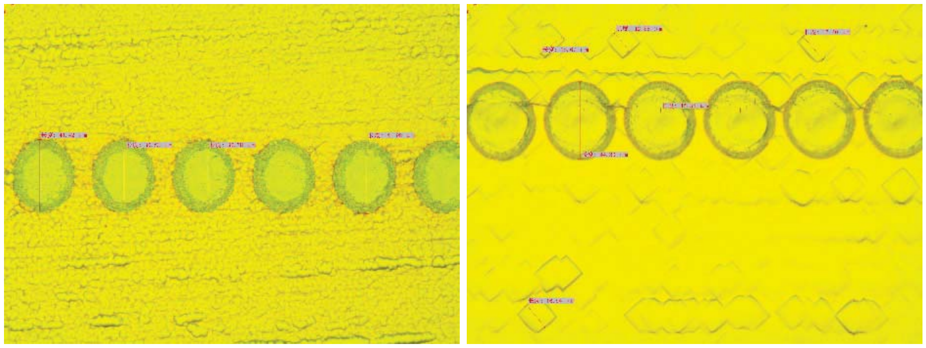

FIGURE 2. The optical microscope images of rear surface after the passivation stack coating and laser ablation. The left image is acid polishing, and the right is alkali polishing.

TABLE 2. Photovoltaic parameters of PERC solar cells with different polishing methods. Each group contained about 100 samples, and average different values were extracted.

	Voc/V	Isc/A	FF/%	Eff/%
Alkali polishing	0.0044	0.01	0.113	0.19
Acid polishing	-	-	-	-

The optical microscope images of rear surface after the passivation stack coating and laser ablation are shown in Fig. 2. It is obvious that the surface roughness after alkali polishing is much lower than acid polishing. Due to the lower roughness, the laser spot on alkali polished surface is more uniform than acid polished surface. The photovoltaic parameter differences of PERC solar cells with different polishing methods are listed in Table 2. It can be seen that, mainly due to the open voltage increase of 4.4 mV, an efficiency gain of 0.19% is achieved. It is deduced that the smoother surface with alkali polishing contributes to the suppression of rear surface recombination, which is beneficial for the open voltage improvement. Besides, we think that the additional thermal oxidation before the alkali polishing may contribute to the suppression of front surface recombination, which is also beneficial for the open voltage improvement.

The rear passivation stack of PERC solar cell is composed of alumina layer with fixed negative charge and silicon nitride capping film with hydrogen atoms, which can be released to the silicon surface and bulk during sintering process to passivate the defects. The hydrogen content in silicon nitride increases with the refractive index, while the atom density of silicon nitride decreases with the refractive index. On the one hand, the atom density needs to be high to improve the resistance to aluminum paste corrosion during sintering. On the other hand, the hydrogen content needs to be high to improve the hydrogen passivation effect. Therefore, a bilayer SiN_x:H capping film was constructed with a higher refractive index bottom layer and a lower refractive index top layer.

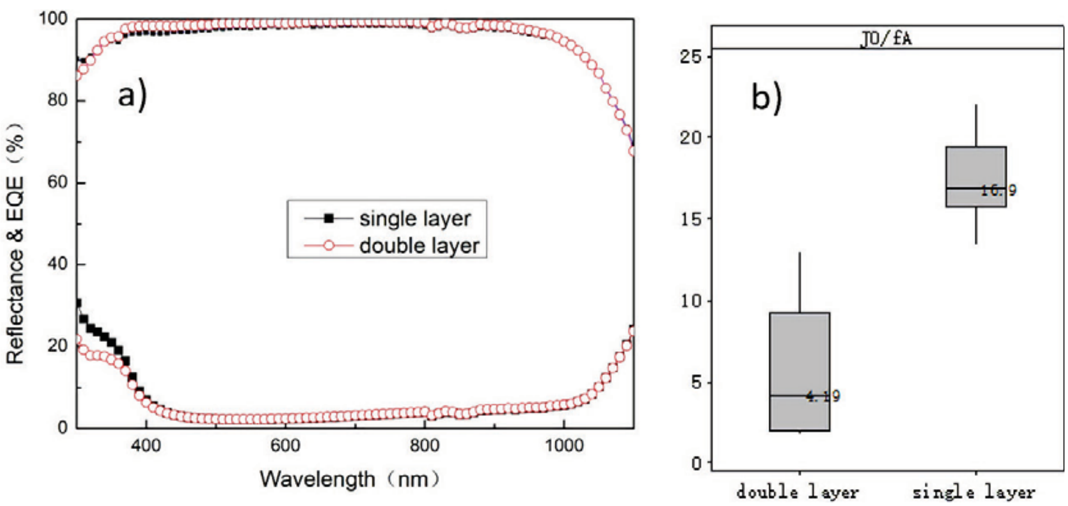

FIGURE 3. a) Reflectance and external quantum efficiency curves of solar cells with monolayer or bilayer SiN_x:H capping film on Al_2O_3. b) $J_{0,surface}$ values extracted from the lifetime samples with symmetrical structure and different capping films. Median values are listed.

Although the internal reflectance provided by the bilayer SiN_x:H capping film should be higher than the monolayer SiN_x:H, the reflectance and external quantum efficiency curves of two different solar cells at long wavelengths are almost the same as shown in Fig. 3a, which means that the present bilayer capping film structure can be further optimized to improve the internal reflectance. Nevertheless, according to the $J_{0,surface}$ results of lifetime samples with symmetrical structure, the bilayer capping layer can offer better surface passivation quality, which can be ascribed to the hydrogen-rich bottom SiN_x:H layer. From Table 3, on account of the open voltage increase of 1.4 mV, an efficiency gain of about 0.05% is achieved.

TABLE 3. Photovoltaic parameters of PERC solar cells with different capping films. Each group contained about 100 samples, and average different values were extracted.

	Voc/V	**Isc/A**	**FF/%**	**Eff/%**
Bilayer SiN_x:H capping film	0.0014	0.0026	0.01	0.05
Monolayer SiN_x:H capping film	-	-	-	-

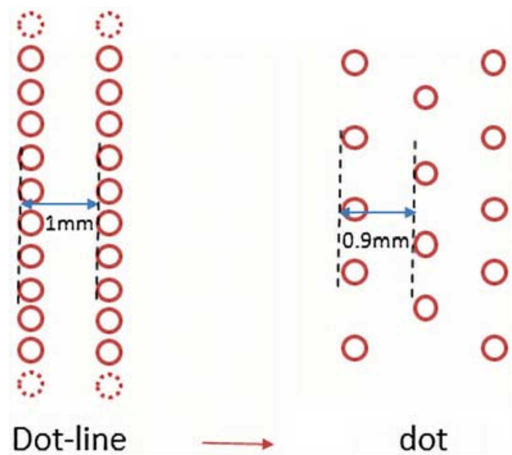

FIGURE 4. Two different laser ablation patterns.

TABLE 4. Ablation ratio, $J_{0,rear}$ reduction calculated and V_{oc} gain expected of PERC solar cells with two different laser ablation patterns. $J_{0,local\text{-}BSF}$ = 600 fA/cm^2, and $J_{0,passivation}$ = 10 fA/cm^2.

Laser ablation pattern	Dot-line	Dot
Ablation ratio	3.1%	＜1%
$J_{0,rear}$ reduction calculated (fA/cm^2)	-	＞12.76
V_{oc} gain expected (mV)	-	＞3

As we all know, the recombination velocity of the metal contact region is much higher than the passivation region. Therefore, reducing the size of metal contact region, i.e. laser ablation ratio, can effectively improve the entire rear recombination. However, the carrier lateral transport in silicon bulk needs to be optimized to minimize the negative influence on solar cell series resistance and fill factor. In this paper, the distance between adjacent laser spots in a line was significantly extended, and the distance between adjacent lines was shortened, which resulted in a dot pattern as shown in Fig. 4. According to the ablation ratios listed in Table 4, the total $J_{0,rear}$ calculated of dot pattern reduces by more than 12.76 fA/cm^2, which means that an open voltage gain of more than 3 mV can be expected for solar cell.

TABLE 5. Photovoltaic parameters of PERC solar cells with different laser ablation patterns. Each group contained about 100 samples, and average different values were extracted. In A×B, A represents the distance between adjacent laser spots in a line, and B represents the distance between adjacent lines.

	Voc/V	Isc/A	FF/%	Eff/%
Dot-line	-	-	-	-
Dot 450×450	0.0030	0.006	-0.120	0.099
Dot 450×600	0.0045	0.009	-0.201	0.111
Dot 450×800	0.0057	0.017	-0.485	0.088
Dot 450×900	0.0062	0.015	-0.625	0.056

The difference values of photovoltaic parameters of PERC solar cells with different laser ablation patterns are listed in Table 5. Among the four dot pattern designs, when the distance between adjacent lines increases, the V_{oc} and I_{sc} increases, but the FF decreases. As a result, the 450×600 design achieves the best efficiency. Compared with the dot-line pattern, the open voltage increases by 4.5 mV due to the lower total $J_{0,rear}$, but the fill factor decreases by 0.2% due to the reduced ablation ratio. Finally, an efficiency gain of about 0.1% is achieved with the dot pattern.

TABLE 6. Photovoltaic parameters of PERC solar cells with the rear surface optimization.

	Qty.	Voc/V	Isc/A	FF/%	Eff/%
Average	~400	0.6854	10.10	81.56	23.1
Champion	1	0.6871	10.12	81.70	23.3

The three methods discussed above for the rear surface optimization of PERC solar cell were combined with the other methods for the front surface optimization, which are not shown in this paper. Ultimately, as illustrated in Table 6, the average efficiency of PERC solar cells reaches 23.1%, and the champion efficiency reaches 23.3%.

CONCLUSIONS

In this paper, the rear surface of PERC solar cell is optimized with three methods, i.e. alkali polishing, bilayer SiN_x:H capping film on Al_2O_3 and dot pattern of laser ablation. Each of the methods can restrain the rear surface recombination and improve the solar cell efficiency. Ultimately, an average efficiency of 23.1% and a champion efficiency of 23.3% are achieved.

ACKNOWLEDGMENTS

This work was supported by the R&D team of Talesun Solar.

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