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# 19% Efficient Inline-diffused Large-area Screen-printed Al-LBSF Silicon Wafer Solar Cells

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## Abstract

Presently, large-area high-efficiency (> 19%) screen printed p-type silicon solar cells are dominated by the aluminium local back surface field (Al-LBSF) technology. However, all those cells were fabricated with tube diffused emitters. Inline diffusion, using phosphoric acid as the dopant source, offers potentially low-cost emitter formation for p-type silicon wafer solar cells. To achieve higher efficiencies for these solar cells, the authors have applied a new Si etch solution to remove the dead layer of the inline diffused emitter. Efficiencies up to 18.3% were obtained for standard Al back surface field (Al-BSF) solar cells. In this work, the same etch-back process was applied to Al-LBSF devices. We report a maximum efficiency of 19.0%, an average batch efficiency of 18.9% (± 0.1% StDev), and a maximum open-circuit voltage of 640 mV for the cells, using industry-grade p-type 6 inch wide pseudosquare Cz mono-Si wafers. These results indicate that inline-diffused emitters can be used in high-efficiency silicon wafer solar cells.

*Keywords:* Singlecrystalline silicon wafer; Inline emitter diffusion; SERIS etch; Al-LBSF; PECVD $SiN_x$ front and $AlO_x$-$SiN_x$ rear passivation; Laser opening

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## 1. Introduction

Aluminium local back surface field (Al-LBSF) is a well-known device structure for decades [1] for high-efficiency crystalline silicon solar cells. Presently a well passivated emitter coupled with passivated rear surface for low back surface recombination velocity yielded 19.4% cell efficiency for 5 inch pseudo-square monocrystalline Si (c-Si) screen printed solar cell using "print-on-print" metallisation as reported in the scientific literature [2]. A recent press release from the same group announced an independently confirmed result of 20.1% efficiency [3] also using "print-on-print" metallisation. The $n^+$ emitter layer for *p*-type silicon wafer solar cells is normally formed using tube diffusion with phosphorus oxychloride ($POCl_3$) as the dopant source. An alternative low-cost approach for $n^+$ emitter fabrication is inline belt furnace diffusion using spray-on phosphoric acid ($H_3PO_4$) as the dopant source, which yields significantly higher throughput with the potential for significant cost reduction. However, inline diffused solar cells typically have a lower efficiency compared to tube-diffused solar cells. The main reason for this is the short duration of the diffusion process, which leads to a surface dead layer (due to a high dopant concentration at the surface and process contaminants) and a very shallow junction [4]. Rounsaville *et al.* [5] reported a solar cell efficiency of 18.2% for inline diffused solar cells with light-induced plated front contacts. The diffusion was performed on both sides of the wafers, which generates two benefits: (i) prevention of back surface contamination from the metallic conveyor belt [6] and enhanced gettering [7]. Other researchers have introduced the use of emitter etch-back methods to remove the surface dead layer to enhance the solar cell efficiency [3, 4, 8] Recently, the present authors have developed a new Si etching process [9] to enable the fabrication of high-quality inline-diffused $n^+$ emitters that achieve up to 18.3% efficiency for standard Al back surface field (Al-BSF) cells on industry-grade *p*-type six inch wide pseudo-square Cz mono-Si wafers [10].

In this work, we report on screen-printed inline-diffused Cz c-Si Al-LBSF solar cells with an efficiency up to 19.0%. The main progress reported here is the inclusion of the "SERIS etch" [9] to realise a high-quality, homogenous, 70 Ω/square $n^+$ emitter by improved removal of surface contamination and reduction of the surface dead layer.

## 2. Experimental details

The complete cell fabrication process flow is shown in Fig. 1. We used industrial-grade six inch pseudosquare, boron doped, p-type, <100> orientation, 0.5-3 Ωcm resistivity, and 150-170 μm thick Cz mono-Si wafers. After saw damage etching of nearly 10 μm of silicon from each side, 100 nm of $SiN_x$ was deposited by plasma-enhanced chemical vapour deposition (PECVD). This layer served as a sacrificial mask layer during the subsequent texturing and diffusion. After texturing in an alkaline solution at 80ºC [11] the emitter diffusion was performed in an industrial inline diffusion furnace (Despatch, DCF-3615) at a temperature of 890°C with a belt speed of 790 mm/minute with an spray-on $H_3PO_4$: $C_2H_5OH$ dopant source. After simultaneous front phosphorus glass and back $SiN_x$ protective mask removal by hot 10% HF solution, the SERIS etch process step was applied to remove any surface contamination left on the wafer by the diffusion process and also to remove the surface dead layer. Then a 70 nm thick PECVD $SiN_x$ antireflection coating (ARC) with a refractive index (RI) of 2.05 (at 633 nm) was deposited on the emitter surface at 450ºC in an inline plasma reactor (Roth & Rau, SiNA-XS). A PECVD aluminium oxide ($AlO_x$, thickness = 40 nm, RI = 1.6)/$SiN_x$ (thickness = 100 nm, RI = 2.05) stack was deposited at the rear surface for rear surface passivation. Line openings with a width of 100 μm and pitch of 1 mm were formed at the rear side by picosecond laser ablation (frequency doubled Lumera, SuperRAPID, 532 nm). The laser process was optimised in order to minimize the generation of silicon damage during the ablation. After forming gas annealing (FGA) at 400ºC for 30 min a standard industrial screen printing process was applied using silver paste for the front contact (DuPont, PV159A) and Al paste for the rear contact (DUPONT PV 382) on standard screen print line (DEK, PVP1200). Finally the samples were co-fired in an industrial inline fast firing furnace (Despatch, UltraFlex). The complete cell fabrication process flow is shown in Fig. 1. The resulting solar cell samples were studied in detail by scanning electron microscopy (SEM), photoluminescence (PL) imaging, series resistance ($R_s$) imaging and one-sun *I-V* measurements under standard testing conditions (Aescusoft, SolSim-210).

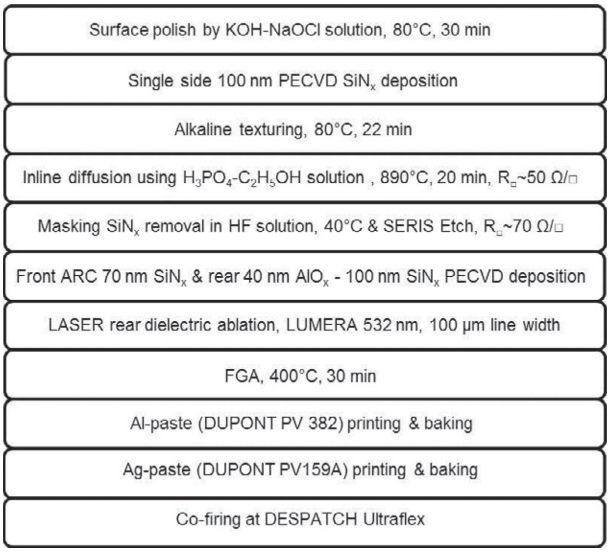

Fig. 1. Process flow for the Al-LBSF solar cells fabricated in this study

## 3. Results and discussion

After inline diffusion and phosphorus glass removal, still a noticeable amount of foreign material was observed on the pyramid surfaces. This is quite clear in the SEM micrographs shown in Fig. 2(a). This unwanted foreign material is commonly associated with the inline diffusion process and is suspected to degrade the open-circuit voltage ($V_{oc}$) of the solar cells. We have developed a special etching process ("SERIS etch") to eliminate this foreign material. The SEM micrograph in Fig. 2(b) shows the same inline-diffused pyramid-textured Si surface after the SERIS etch at the same magnification. As can be seen, the SERIS etch has removed the foreign material and at the same time created small holes (nanopores) on the pyramid surfaces. If was found that these nanopores were not affecting the final solar cell efficiency. The morphology of the textured surface was otherwise unchanged and thus the front surface reflectance was not affected. Importantly, the SERIS etch also results in an increase in the sheet resistance ($R_\square$) value of the emitter, which is due to the conformal removal of a certain Si thickness and thus a thinning of the surface dead layer. We have controlled the process in such a way that a uniform $R_\square$ value of 70 Ω/□ can reproducibly be achieved, which is essential for a good solar cell performance.

An average efficiency of 18.9% ± 0.1% (StDev) was achieved, with best cell efficiencies of 19.0% and open-circuit voltages of up to 640 mV (see Fig. 3). The PL intensity and $R_s$ image of the best solar cell is shown in Fig. 4. These images indicate that the inline diffusion and Al-LBSF process is relatively uniform, however, some non-uniformities can be seen in the form of stripes in both images. These non-uniformities can be related to clustered void formation at the Al-LBSF rear, which partly explains the relatively modest FFs obtained in this work. To the best of our knowledge, this is the highest efficiency reported for a homogenous-emitter inline-diffused p-type Cz solar cell with screen printed metallisation. This clearly demonstrates the high efficiency potential of the optimised inline diffusion process.

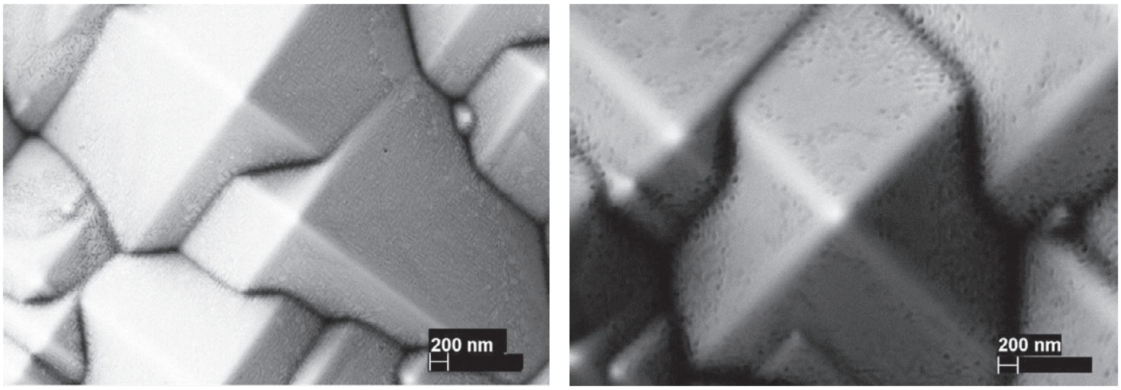

Fig. 2. SEM micrograph of an inline diffused Si wafer after phosphorus glass removal. (a) before and (b) after the SERIS etch

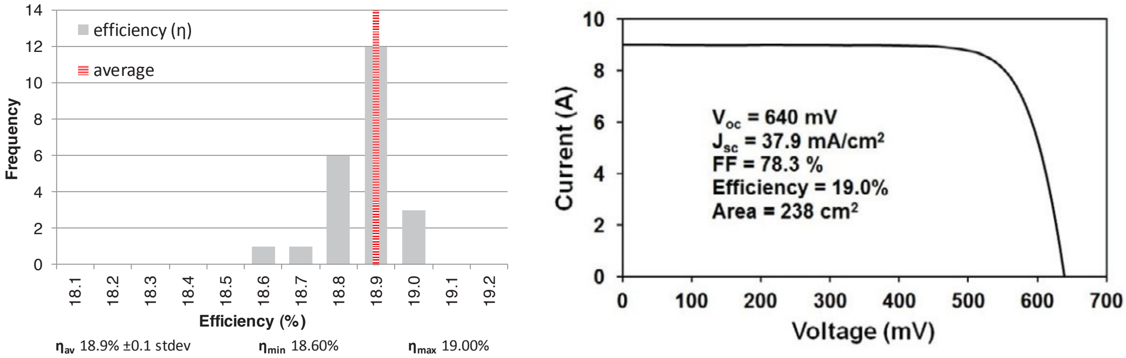

Fig. 3. (a) Distribution of the one-sun solar cell efficiencies of the 25 wafer batch. (b) The one-sun *I-V* characteristics of the best solar cell

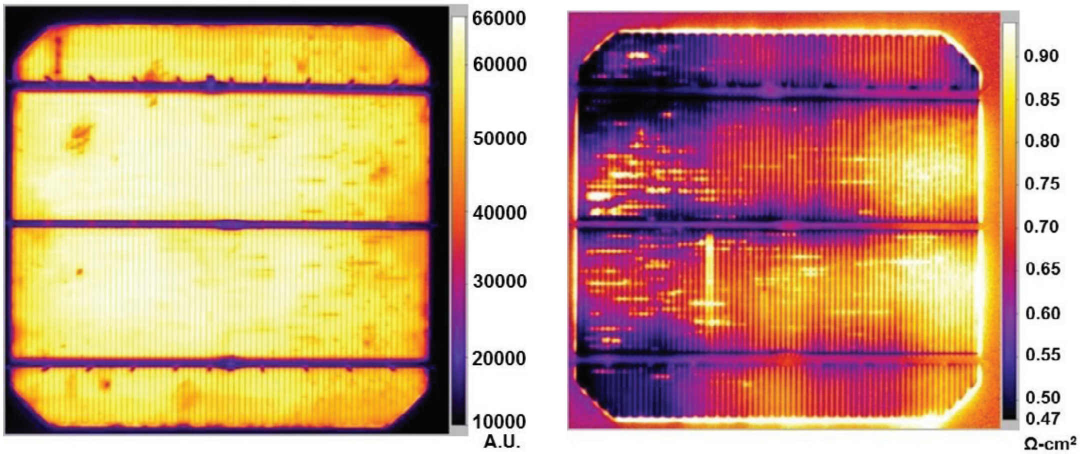

Fig. 4. (a). PL intensity and (b) $R_s$ image of the best solar cell produced in this study

## 4. Conclusion

In this work we have demonstrated that silicon wafer solar cell efficiencies of 19.0% are achievable while using inline diffusion for the $n^+$ emitter formation. These high efficiencies are enabled by a novel conformal etch-back process developed by the authors that allows a significantly wider range compared to conventional etch-back technologies. In this work the authors have applied an etch-back of 20 Ω/sq without sacrificing the uniformity of the front surface texture. This etch-back effectively removes the dead layer of the inline diffused emitter thereby enabling a better blue response and higher $V_{oc}$ values for the solar cells.

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## References

[1] Aberle A, Warta W, Knobloch J and Voss B. Surface passivation of high efficiency silicon solar cells. *Proc. 21st IEEE Photovoltaic Specialists Conference (21st IEEE PVSC)*; 1990: 233-8.

[2] Gatz S, Hannebauer H, Hesse R, Werner F, Schmidt A, Dullweber T, Schmidt J, Bothe K and Brendel R. 19.4% efficient large-area fully screen printed silicon solar cells. *Physics Status Solidi RRL*; 2011: 5: 147-9.

[3] Institut für Solarenergieforschung Hameln, 20.1%-efficient screen printed silicon solar cell with novel rear passivation layer. Press release: 2 Mar 2012.

[4] Ebong A, Cooper IB, Rounsaville B, Tate K, Rohatgi A, Bunkenburg B, SCathey J, Kim S and Ruf D. High efficiency inline diffused emitter (ILDE) solar cells, on mono-crystalline CZ silicon. *Prog. in Photovoltaics*; 2010; 18: 590-5.

[5] Rounsaville B, Ebong A, Kim D, Cooper I and Rohatgi A, Tailoring the inline diffused emitter (ILDE) profiles for high efficiency screen-printed silicon solar cells. *Proc. 25th European Photovoltaic Solar Energy Conference and Exhibition (25th EU PVSEC),* 2010: 2408-11.

[6] Richter P, Bottari F, and Wong D, Industrial process and materials for in-line boron diffusion in n-type silicon. *Proc. 35th IEEE Photovoltaic Specialists Conference,* 2010: 3593-6.

[7] Hoornstra J, Van Strien W, Lamers M, Tool K and Weeber A, High throughput in-line diffusion: emitter and cell results. *Proc. 22nd European Photovoltaic Solar Energy Conference and Exhibition (22nd EU PVSEC),* 2007: 1586-9.

[8] Stassen A, Koppes M, Komatsu Y, Weeber A, Hoogboom J, Oosterholt J, Ritmeijer S and Groenewoud L, Further improvements in surface modification of MC silicon solar cells: comparison of different post-PSG cleans suitable for inline emitters. *Proc. 22nd European Photovoltaic Solar Energy Conference and Exhibition (24th EU PVSEC),* 2009: 1657-59.

[9] Basu PK, Boreland MB, Vinodh S and Sarangi D, Non-acidic isotropic etch-back method for silicon wafer solar cells. *US Provisional Application No.: 61/644730*, 2012.

[10] Basu PK, Boreland MB, Shetty KD, Sarangi D and Aberle AG. 18.3% efficient inline diffused emitter silicon wafer solar cells. *Technical Digest of the 21st International Photovoltaic Science and Engineering Conference (PVSEC-21)*; 2011: paper 4D-1P-12.

[11] Basu PK, Chaturvedi P, Shetty KD, Boreland MB and Aberle AG. Improved texturisation process for fabricating 18.3% efficiency inline-diffused industrial monocrystalline silicon solar cells. *Technical Digest of 16th International Workshop of Physics of Semiconductor Devices (IWPSD-XVI)*; 2011: PV O.02.