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# monoPoly™ cells: Large-area crystalline silicon solar cells with fire-through screen printed contact to doped polysilicon surfaces

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ABSTRACT

Successful integration of carrier selective contacts (so-called passivated contacts) in *p*-type and *n*-type front-and-back contact (FAB) silicon solar cells could lift cell efficiencies to above 24% in mass production. In this work, we introduce one of SERIS' monoPoly FAB cell structures, which features the monofacial (single-sided) application of a polysilicon (poly-Si) layer. Using industrial tools, doped poly-Si on an ultrathin interface oxide is shown to provide extremely low recombination current density of 4 fA/cm$^2$ and implied open-circuit voltage of about 745 mV that are able to withstand the high-temperature firing process of screen-printed metal contacts. The interface oxide and the doping concentration of the poly-Si film are of great importance for the surface passivation quality and the transport of majority carriers, especially for fire-through screen-printed contacts as used in this work. Our initial pilot-line results show a very promising cell efficiency of 21.4% on large-area (244.3 cm$^2$) *n*-type monocrystalline wafers with screen-printed and fire-through metal contacts on both sides. A roadmap for *n*FAB monoPoly cells towards 24% efficiency is presented on the basis of an optimisation of the device architecture and various processing steps.

## 1. Introduction

Global photovoltaic (PV) production continues to be dominated by *p*-type crystalline silicon (*c*-Si) cell technologies [1]. Despite continual improvements in screen-printed passivated emitter and rear cells (PERC), it is apparent that the path towards even higher commercial device efficiencies (> 22%) must be through the use of more advanced processes, as evidenced by the monocrystalline silicon efficiency records achieved in recent years [2–6]. The use of *n*-type Czochralski (Cz) substrates seems advantageous as these wafers feature higher bulk lifetimes than *p*-type Cz wafers and could enable higher open-circuit voltages ($V_{OC}$) and thus provide a path towards higher efficiency. *n*-type devices are believed to have the additional advantage of being unaffected by the light-induced degradation problem caused by boron-oxygen complexes [7]. It is for these reasons that the ITRPV predicts that *n*-type *c*-Si devices will account for > 25% of global PV production by 2027 [1].

In SERIS, front-and-back contact (FAB) cells are referred to as *n*FAB or *p*FAB cells, depending on the polarity of the substrate (*n*-type or *p*-type). These structures can be monofacial or bifacial. Until mid-2017, the best fully screen-printed commercial *n*-type *c*-Si cells had efficiencies of about 21%, using H-patterned contacts on both sides and a homogenous emitter and phosphorus-doped back-surface field (BSF), the latter achieved either with thermal diffusion or with ion implantation. Progress towards higher efficiencies (> 24%) in mass production will likely come from suppression of recombination at the front and, particularly, the rear *c*-Si surfaces, including recombination losses at the metal-silicon contacts. Passivated contacts using doped poly-Si have recently gained considerable interest as a possible solution to this problem [5]. An interface oxide (iOx) layer separating the silicon absorber and the contact system appears to be the mandatory ingredient for ultra-high efficiency silicon solar cells, as used for many years in heterojunction cells [2,3] and, very likely, also in SunPower's interdigitated back contact cells [4], although none of these cells uses high-temperature fire-through contacts. The metal-insulator-semiconductor (MIS) solar cells [8,9] also used a thin insulator between the semiconductor and the metal in order to reduce recombination losses, while retaining charge carrier selectivity. The introduction of passivated contacts to high-volume screen-printed solar cell manufacture is, hence, very appealing and at the same time challenging. It requires the passivated contact to be thermally stable when metallized with an industrial screen-printing process that includes commercially available fire-through pastes. It also requires high-throughput and low-cost deposition schemes for the passivated contacts preferably with minimal additional process steps, for example with single-side deposition and multi-layer deposition within a single system.

Although there is a large variety of materials that can be implemented in a carrier-selective passivated contact (see the summary in Ref. [10]), one combination which has demonstrated successful results is an ultrathin (1–2 nm) silicon oxide ($SiO_x$) iOx layer capped by an *n*-

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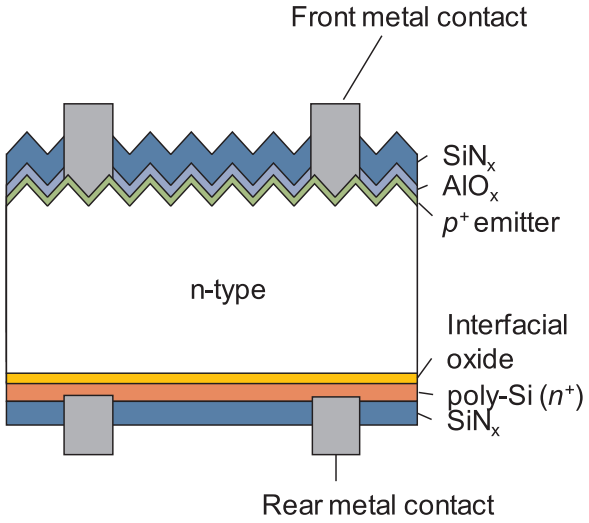


**Fig. 1.** Schematic of an *n*-type bifacial monoPoly silicon solar cell structure with an electron-selective passivated contact at the rear.

type (phosphorus-doped) polycrystalline silicon layer [hereafter referred to as poly-Si ($n^+$)] for large-area fire-through screen-printed contacts [11]. Interface oxide films can be grown using several methods, usually wet chemically [12–15], by thermal oxidation, or by ALD [16,17]. SERIS' monoPoly FAB cell structure features polysilicon (poly-Si) contacts at the front or at the rear side of the *c*-Si substrate that can be either electron or hole-selective. The emitter could be either at the front or at the rear side. The cell structure with bifacial polysilicon (poly-Si) contacts is referred to as biPoly FAB cell (not presented in this paper). The substrates can be either multicrystalline or monocrystalline wafers with either *n*-type or *p*-type polarity. An example for a monoPoly FAB cell with front boron emitter and rear-side poly-Si ($n^+$) contact, as investigated in this work, is shown in Fig. 1. In this paper, we report our initial results on $SiO_x$ iOx layers grown in-situ by a low-pressure chemical vapour deposition (LPCVD) process. monoPoly solar cell results achieved in SERIS' R&D pilot cell line are then presented, followed by a roadmap towards 24% monoPoly cell efficiency in mass production.

Fig. 2 shows examples of process flows used for the fabrication of classical nFAB cells and monoPoly FAB cells using *n*-type or *p*-type substrates and a poly-Si layer at the rear. Process flow A is a simple bifacial *n*FAB process with a homogeneous emitter and a homogeneous BSF – based on the so-called Passivated Emitter and Rear Totally Diffused (PERT) structure - with merely 8 steps. There are also ways to avoid the masking step, however, this is not part of the scope of this paper. This cost-effective *n*FAB cell with commercial material (wafer material, pastes) properties available today has an efficiency potential of about 21.5% with a homogeneous emitter and BSF, each having a screen-printed H-pattern electrode with 5 busbars. Recombination at the rear $n^+$-BSF (both passivated and metal-contacted regions) and within the $n^+$ layer is the main limiting factor that prevents this cell structure from reaching very high efficiencies (i.e. > 22%). Process flows B and C introduce iOx and hydrogenated poly-Si layers at the rear side that can significantly reduce overall recombination and at the same time maintain good majority carrier transport. The main difference between B and C is the method of deposition. B uses a tube-based LPCVD process, while C uses a single-sided PECVD process. Another difference is the need for a mask and an alkaline wet-chemical step to etch polysilicon wrap-around in process flow B, which is not needed in process flow C. The poly-Si layers can be in-situ doped or ex-situ doped (diffused or implanted), based on manufacturers' preferences.

## 2. Experimental details

SERIS' *c*-Si photovoltaic R&D focuses on large-area (6 in. - M0, M1, M2 and M4 sizes) *p*- and *n*-type Si wafers as used by solar cell manufacturers in high-volume production. In this work, we report our initial results using process flow B of Fig. 2. We limit the results to process B mainly due to page restrictions. *n*-type (170 µm, 2 Ω cm, < 100 >) Cz

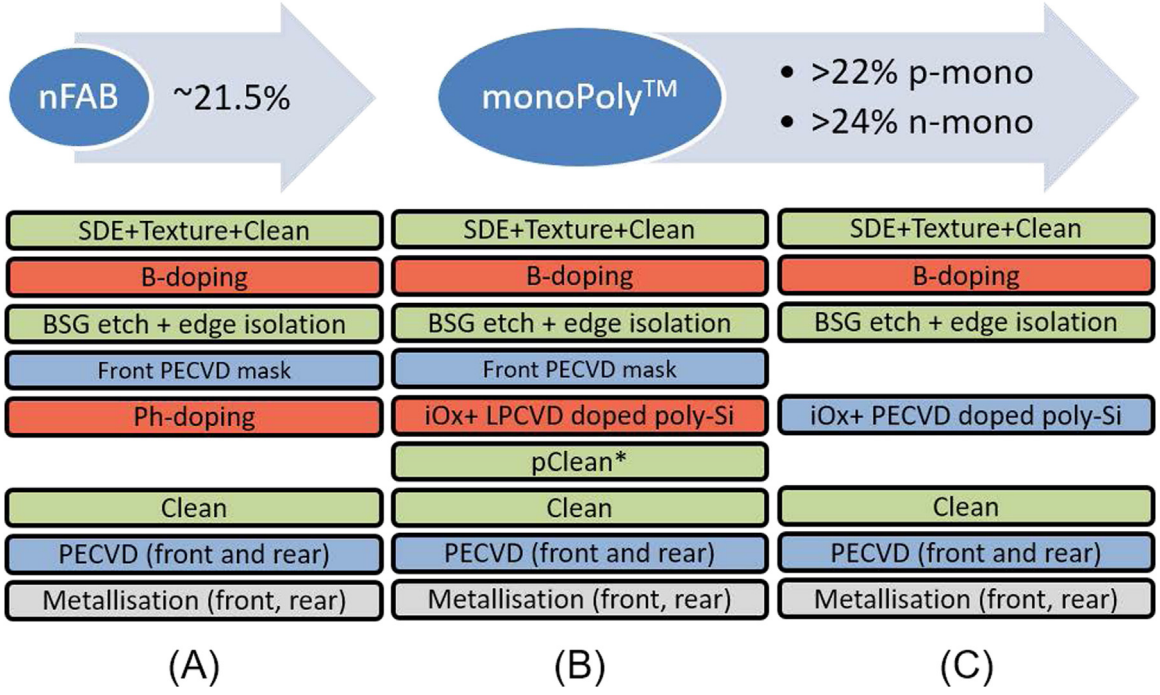


**Fig. 2.** (A) Simple process flow to fabricate SERIS' bifacial nFAB cells. Presently, such cells have about 21.5% efficiency potential in mass production, with a homogeneous emitter and a homogeneous BSF. (B) Preliminary process flow at SERIS to fabricate monoPoly FAB cells with a rear poly-Si layer deposited by a LPCVD process. (C) Preliminary process flow at SERIS to fabricate monoPoly FAB cells with a rear poly-Si layer deposited with a 'single-sided' PECVD process. Process flows B and C are estimated to have efficiency potentials of 24% in mass production.