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# Progress in the development of industrial nPERT cells

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**Abstract**

This article addresses several issues and challenges that have been faced, when developing an industrially feasible n-type solar cell (n-PERT) process employing homogeneous gas-phase diffusions of front and back side. As a result of the presented developments and optimizations solar cell front side efficiencies close to 21% could be obtained.
The first issue that has been investigated is the impact of rear side treatments, i.e. etching and diffusion, on the rear side contact formation. We have seen process instabilities in the rear side contacting step when moving to a back surface field with high sheet resistance, especially with current diamond sawed wafers becoming increasingly flat. The second challenge was to develop an edge isolation process that is superior to conventional laser edge isolation. Wet chemical edge isolation is used for the first time to obtain well defined reverse bias behavior. Less than -1.5 A were recorded at -12 V reverse bias. Furthermore, a major increase in efficiency was achieved by using Al-free Ag-paste for front- and back-side metallization. A significantly improved $V_{oc}$ demonstrates a reduced recombination current $J_{0met}$. Finally we present the determination bifacial characteristics according to the Equivalent Irradiance method showing an effective efficiency $\eta_{effective\_BiFi20}$ of 24.6 % in applications with 20 % rear side illumination.



*Keywords:* nPERT; bifacial; n-type; industrial; metallization; edge isolation.

## 1. Introduction

PERT (Passivated emitter rear totally diffused) solar cells on n-type wafers are an interesting alternative to p-type cells, as they do not suffer from light induced degradation and feature high bifacial properties due to their symmetric

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structure [1]. ISC Konstanz has recently shown that its BiSoN (bifacial industrial solar cell on n-type substrate) is well suited for industrial production [2]. High throughput low pressure diffusion furnace technology has been shown to further lower production costs [3], resulting in very low levelized costs of energy (LCOEs), especially when taking bifaciality into account [3, 4]. Further potential for this technology, as has been pointed out recently, lies in its suitability for including poly-Si based passivated contacts in combination with screen printing of standard Ag-pastes [5]. The BiSoN structure features a boron-diffused, textured front side and a phosphorus-diffused, polished rear side. The $p^+$ emitter is passivated by silicate glass obtained during the boron diffusion process, saving costs associated with aluminum oxide deposition which is used in similar cell concepts.

One drawback of the polished $n^+$ diffused rear side is that screen printed silver containing pastes (similar pastes as used on textured front sides on standard p-type solar cells) have problems contacting flat surfaces as the formation of silver crystallite is propagated by rugged surfaces [6]. Another impact factor on the quality of the contact formation is the doping profile [7]. In the following we show how rear surface roughness as governed by the material and the rear side polishing and the phosphorus doping interrelate.

A further obstacle of the PERT cell structure is that the doped regions on the front and rear side along the wafer edge are difficult to separate from each other. PERT cells without edge isolation generally perform well in light forward conditions; however, under reverse bias conditions high currents are recorded [8]. Laser scribing around the edges provides sufficient edge isolation (LEI) but goes along with losses of short-circuit current and fill factor, a fact that is being rarely reported. Therefore, we have developed a wet chemical edge isolation step (WEI) dedicated for the BiSoN solar cell technology that, based on widely used equipment, hardly alters the cell performance.

One of the key factors for the large discrepancy of implied open circuit voltage measurements to finished cells open circuit voltages (*Voc*) values in screen printed nPERT cells is the recombination under the metal contacts [9]. The largest losses are caused by contacting of the boron emitter by aluminum-containing silver pastes, exhibiting high recombination currents $J_{0met}$. Although it has been shown that in principle also aluminum-free silver-pastes can establish electrical contact with sufficiently low resistivity, these findings could not yet be translated into an increase of cell efficiency [10, 11]. We present data which proves that silver-only metallization can be used to further improve solar cell efficiencies toward 21 % front side efficiency. As bifaciality significantly adds to the harvested electricity and needs to be taken into account when calculating LCOE numbers, a reliable and standardized determination of the power gain is required. We relate to current discussions on standardization of measurement of bifacial cells of the IEC project team and report IV results, based on the Equivalent Irradiance method, in which can be performed in standard industrial IV flasher systems.

## 2. Experiment

Bifacial n-type solar cells on M2 (156.75x156.75 $mm^2$ with a diameter of 210 mm) diamond wire sawed n-type wafers obtained by several different manufacturers were fabricated using the ISC Konstanz pilot line, all based on standard industrial manufacturing equipment such as RENA batch and inline wet benches, Centrotherm diffusion furnaces (atmospheric pressure boron and phosphorus diffusion) and PECVD tools, Baccini screen printers, a Centrotherm firing furnace and a Baccini edge isolation laser. IV-characteristics of solar cells were recorded using an H.A.L.M. flasher system with hysteresis measurement.

The surface roughness of the rear side of cell precursors (solar cells without metallization) was measured using scanning laser confocal microscopy (Olympus LEXT OLS4000) and the 3D image was assessed according to EUR 15178N by MountainsMap software. The *Sdr* value was used, which describes the developed surface area in percent. 25 spots per wafer were measured for every condition.