Crystalline silicon solar cells: Better than ever

Pierre-Jean Ribeyron

CRYSTALLINE SILICON SOLAR CELLS

Better than ever

Silicon-based photovoltaics dominate the market. A study now sets a new record efficiency for large-area crystalline silicon solar cells, placing the theoretical efficiency limits within reach.

Pierre-Jean Ribeyron

Crystalline silicon photovoltaics (PV) are dominating the solar-cell market, with up to 93% market share and about 75 GW installed in 2016 in total[1]. Silicon has evident assets such as abundancy, non-toxicity and a large theoretical efficiency limit up to 29% (ref. 2). Nevertheless, eighteen years have passed without a significant breakthrough since the historical efficiency record obtained in 1999 at the University of New South Wales, Australia. These solar cells were contacted on both their front and back surfaces and used the so-called passivated emitter rear localized (PERL) technology, leading to an efficiency of 25% on a 4 cm^2 device[3]. Since then, experts have considered that 25% was just about the practical limit for monocrystalline silicon solar cells[4–6]. Now, writing in *Nature Energy*, Kunta Yoshikawa and colleagues from the Kaneka R&D group in Japan have demonstrated a new record efficiency of 26.3% monocrystalline silicon solar cells over a large area (>180 cm^2; ref. 7).

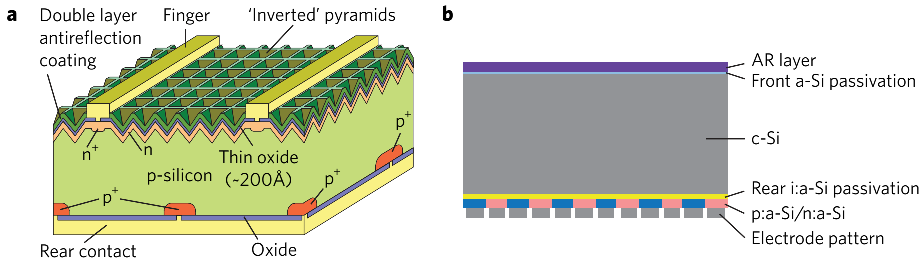

Figure 1 | Configurations of monocrystalline silicon solar cells. **a**, The configuration used for the preceding record from the University of New South Wales in 1999 reaching 25% on 4 cm^2. Silicon oxide passivates both the selective emitter (front side n$^+$ and n-doped) and rear side (p$^+$ and p-doped). Collecting contacts are both at the front and at the back of the cell: the front contact is a metallic finger contacting n$^+$ zones (and induces shadow losses), and the back electrode is covering the whole surface and locally contacting p$^+$ doped zones. A double layer antireflection coating and inverted pyramid microstructures reduce optical losses. **b**, The configuration used for the new 26.3% record efficiency from the Kaneka R&D team. Intrinsic amorphous silicon layers passivate the n-type c-Si absorber on both sides. Hole and electron contacts are both at the rear side of the cell, in an interdigitated pattern composed of a layer of doped amorphous silicon (either p-doped or n-doped) and of patterned rear electrode. An antireflection coating at the front reduces optical losses. Panel **a** is adapted with permission from ref. 3, Wiley; panel **b** is adapted with permission from ref. 7, Macmillan Publishers Ltd.

The design of the Kaneka solar cell is significantly different from that of the previous record, which employed solar cells contacted on their front and back surfaces to collect electrons and holes, respectively (Fig. 1a). In the Kaneka design, shadowing losses due to the front grid metallization are completely suppressed by using interdigitated back contact (IBC) solar cells. Both the anode and the cathode contacts are localized at the back of the solar cell, in an interdigitated design, as shown in the schematic in Fig. 1b. The back contacts are thus intrinsically better suited to optimize light absorption and short-circuit current compared to cells contacted on both sides.

However, this design is more demanding with respect to the electronic quality of the bulk and surfaces of the Si wafer. Indeed, electron–hole pairs are generated by photon absorption within the silicon bulk and in particular in the front part of the cell, but the carriers need to go through the full silicon thickness to reach the contacts now located at the back of the solar cell. In addition, since both electron and hole collections occur at the back side, the minority carriers (holes for the n-type silicon used by Yoshikawa and colleagues) located behind the electron contact need to move laterally to reach the hole contact. This means that carrier diffusion lengths should be much longer in IBC solar cells than in cells contacted from both sides. Increasing carrier diffusion in the Si bulk was not an easy task at the end of the past century, as silicon quality was not optimized for PV. Indeed, most of the advanced process steps and materials were coming from the microelectronic industry and few laboratories were dedicated to PV research and development. Today, thanks to continuous improvements focusing specifically on PV, silicon is meeting these high requirements and combines high bulk material quality with low cost.

The surface properties also need to be optimized for high-efficiency devices and heterojunction technology using hydrogenated amorphous silicon is well adapted because it helps to dramatically reduce recombination at the surface[4]. Yoshikawa and colleagues exploit the silicon heterojunction design to completely de-correlate the passivation and the collection of carriers. Carrier collection is maximized at the back of the solar cells using interdigitated back contacts[5] which are composed of adequately doped amorphous silicon layers and back contact electrodes. The passivation of all surfaces and the back contact design leads to the success of the IBC solar cells, providing a defi itive advantage in terms of efficiency.

Of course, the following question arises immediately: will the record be broken again? In my opinion, it will happen, and soon. Yoshikawa and colleagues present a convincing and detailed loss analysis, pointing to a number of optimizations that remain to be implemented on their record solar cell, such as wafer quality, surface passivation, lower series resistance and optical confi ement. These optimizations could allow efficiencies up to 27.1%. Not only are these endeavours exciting scientifically, but they are also bound to have important impacts at the industrial level, as the combination of low cost and high efficiency makes Si PV ever more competitive. The new monocrystalline silicon solar cell record is yet another sign that the energy transition is happening not only because of climate change issues and thanks to political support, but also simply because renewable electricity, and especially PV, is becoming cheaper than existing electricity sources from fossil fuel. ❒

Pierre-Jean Ribeyron is at Commissariat à l'énergie atomique et aux énergies alternatives, Institut National de l'Energie Solaire, 50 avenue du Lac Léman, 73375 Le Bourget-du-Lac, France.
e-mail: pierre-jean.ribeyron@cea.fr

References

1. *International Technology Roadmap for Photovoltaic: 2016 Results* 5th edn (ITRPV, 2017).
2. Richter, A., Hermle, M. & Glunz, S. W. *IEEE J. Photovolt.* **3,** 1184–1191 (2013).
3. Zhao, J., Wang, A. & Green M. A. *Prog. Photovolt.* **7,** 471–474 (1999).
4. Taguchi, M. *et al. IEEE J. Photovolt.* **4,** 96–99 (2014).
5. Masuko, K. *et al. IEEE J. Photovolt.* **4,** 1433–1435 (2014).
6. Glunz, S. W. *et al.* The irresistible charm of a simple current flow pattern — 25% with a solar cell featuring a full-area back contact. In *Proc. 31st Eur. Photovolt. Solar Energy Conf. Exhibition* 259–263 (2015).
7. Yoshikawa, K. *et al. Nat. Energy* **2,** 17032 (2017).
8. Lammert, M. D. & Schwartz, R. J. *IEEE Trans. Electron Devices* **24,** 337–342 (1977).