Battle of the dopants: Challenges and opportunities for n-TOPCon vs Ga-PERC technologies

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N-type technologies are forecasted to make up to between 50% to 95% of manufactured modules by 2030 [1], [2]. Yet, for this to occur, there remains challenges for n-type to scale. Indeed, the yard stick is not boron doped wafers but now gallium doped wafers and cells which are showing much higher lifetimes and stability than their boron counterpart [2]. For n-type to continue competing, it needs to do so on a $/W basis, focusing on efficiency and costs [2]. There remain challenges for both efficiency and cost. Recent technoeconomic analysis show that for TOPCon to compete with PERC, it need to have an 0.4%-0.55% efficiency advantage [3]. In this paper, we will discuss the challenges and describe opportunities for n-type technologies.

Introduction

PERC is the safe evolutionary approach to reaching high-efficiency industrial cells. Ga-PERC benefits from all the improvements and ecosystem from PERC and previously AlBSF cells. It is with little surprise that n-PERT (providing little efficiency improvements over PERC but requiring new processes including boron diffusion) gained no significant marketshare over PERC in the last decade [2], [4], [5]. The story is different for more recent n-type technologies. In this paper we will focus on comparing the challenges and opportunities faced by p-type and n-type technologies.

The race for utility-scale modules is between PERC and TOPCon

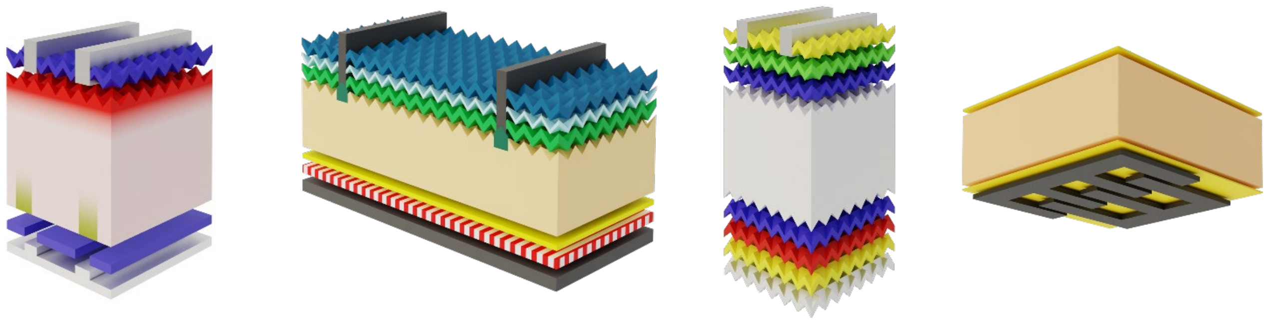

Figure 1: a) Ga-PERC and n-type technologies b) TOPCon c) HIT and d) IBC cells. PERC and HIT have partial rear contacts while TOPCon has full area rear contacts. All cells are represented here as monofacial cells but all also come with their bifacial counterpart.

The growth of n-type modules comes at the same time as a complete switch to gallium doping for p-type modules. TOPCon cells, heterojunction solar cells (HIT) or Interdigitated Back Contact (IBC) cells all provide significant efficiency improvements over baseline industrial PERC cells. At the moment it is challenging for HIT and IBC cells to compete with PERC (for utility scale modules); both involve markedly different cell processes to PERC and both involve more complicated/expensive metallisation and module design. TOPCon (PERT with polysilicon on oxide contact at the rear) on the other hand benefits from all learnings on n-PERT and from using similar tools to PERC in cell and module fabrication. TOPCon is the most direct competitor to PERC.

Conclusion

In this paper, we will present an updated perspective on the challenges faced by Ga-PERC and TOPCon. The results in this paper are informed by recent wide-ranging discussions with key industry stakeholders in China, the US and Europe. We will show how lower costs in ingot-growth, diffusion, wet-chemistry and silver for PERC are counterbalanced by its lower efficiency and bifaciality. In September 2022, this means the module costs of TOPCon and PERC overlaps (on a $/W) basis.

Resistivity drives part of the cost structure of Ga-PERC, lifetime that of TOPCon:

The typical ingot growth method used today is recharge-Czochralski growth (rCz). In this method at the end of ingot growth, the crucible is recharged with polysilicon allowing for the growth of another ingot [6], [7]. Typically, this allows to grow 4-6 ingots consecutively without having to change the crucible. This leads to an increase in throughput, a decrease in fixed-costs (such as the crucible) and a decrease in wasted polysilicon (one pot scrap remaining instead of six). To remain competitive at the ingot levels, both technologies must maximise the number of pulls performed via rCz without compromising on quality. The stronger requirement on wafer quality for n-type drives entirely different cost structures and approaches for n-type and p-type ingots. While the number of pulls is limited by low lifetimes for n-type ingots, the number of pulls is limited by out of specification resistivity for p-type ingots. From a cost perspective, n-type wafers remain 5%-10% more expensive than Ga-doped p-type wafers. N-type wafers make this up by having higher minority carrier lifetimes (>1ms for n-type vs >100µs for p-type). N-type technologies are also more forgiving for resistivity variations (0.3 Ω.cm - 2.2 Ω.cm for TOPCon vs 0.5 Ω.cm - 1.2 Ω.cm for PERC). A rule of thumb used to qualify materials is to have a lifetime over resistivity ratio of 100 for Ga-PERC and of 1000 for TOPCon. This means the requirement for purity are much higher for n-type technologies.

Diffusion and chemistry costs are higher for n-type technologies

TOPCon involves higher temperature processes (Boron diffusion) and polysilicon deposition. This leads to an increase of ≈20% in diffusion costs compared to PERC [3]. TOPCon also involves single side etching of polysilicon which also leads to an increase of ≈35% in wet chemistry costs [3].

Silver usage remains a problem for n-type

Another driver of cost is the higher reliance on silver for n-type technologies. Whilst Ga-PERC uses ≈90mg/cell, TOPCon uses ≈150mg/cell and HIT more than 200mg/cell in 2022 [2] There are evolutionary routes to reduce silver uses including numerous innovations in screen printing technologies. In the long-term, Cu platting technologies may prove a viable solution to permanently replace silver use in n-type technologies.

Compounding effect of efficiency and cost

The compound effect of efficiency and cost structure outline above and shown in Table I means that the cost of TOPCon and Ga-PERC modules overlaps as of September 2022 when I write this abstract [8]. As discussed above, HIT is less competitive than both at more than 2US cents per Watt above the cost of Ga-PERC modules and 1US cents per Watts above that of TOPCon modules.

Table I. Module costs, bifaciality

	PERC	TOPCON	HIT
Number of recharge ingots	8-10	5-6	5-6
Silver use	90mg/cell	150mg/cell	200mg/cell

Price	0.27-0.28$/W	0.28-0.31$/W	0.29-0.33$/W
Bifaciality	70%	75-80%	>80%

PERC has a lead on $/W but what about yield?

In September 2022, PERC modules have a slight lead on a $/W basis. But the focus of developers is now shifting to yield rather than $/W. So how does the yield of TOPCon and PERC compare? N-type technology show much higher bifacially than Ga-PERC (>80% for HIT and 75%-80% for TOPCon vs 70% for Ga-PERC) [9], [10]. The impact of yield is location dependent, but previous studies have noted a 5% increase in yield when using bifacial TOPCon instead of bifacial PERC of the same nameplate capacity [10]. Together with the impact of trackers, this compounds to significant gain in yield for n-type technologies. This is in turn visible as the expected TOPCon capacity by the end of 2022 is expected to exceed 50GW (as a comparison production capacity for large format PERC is 280 GW) [11].

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