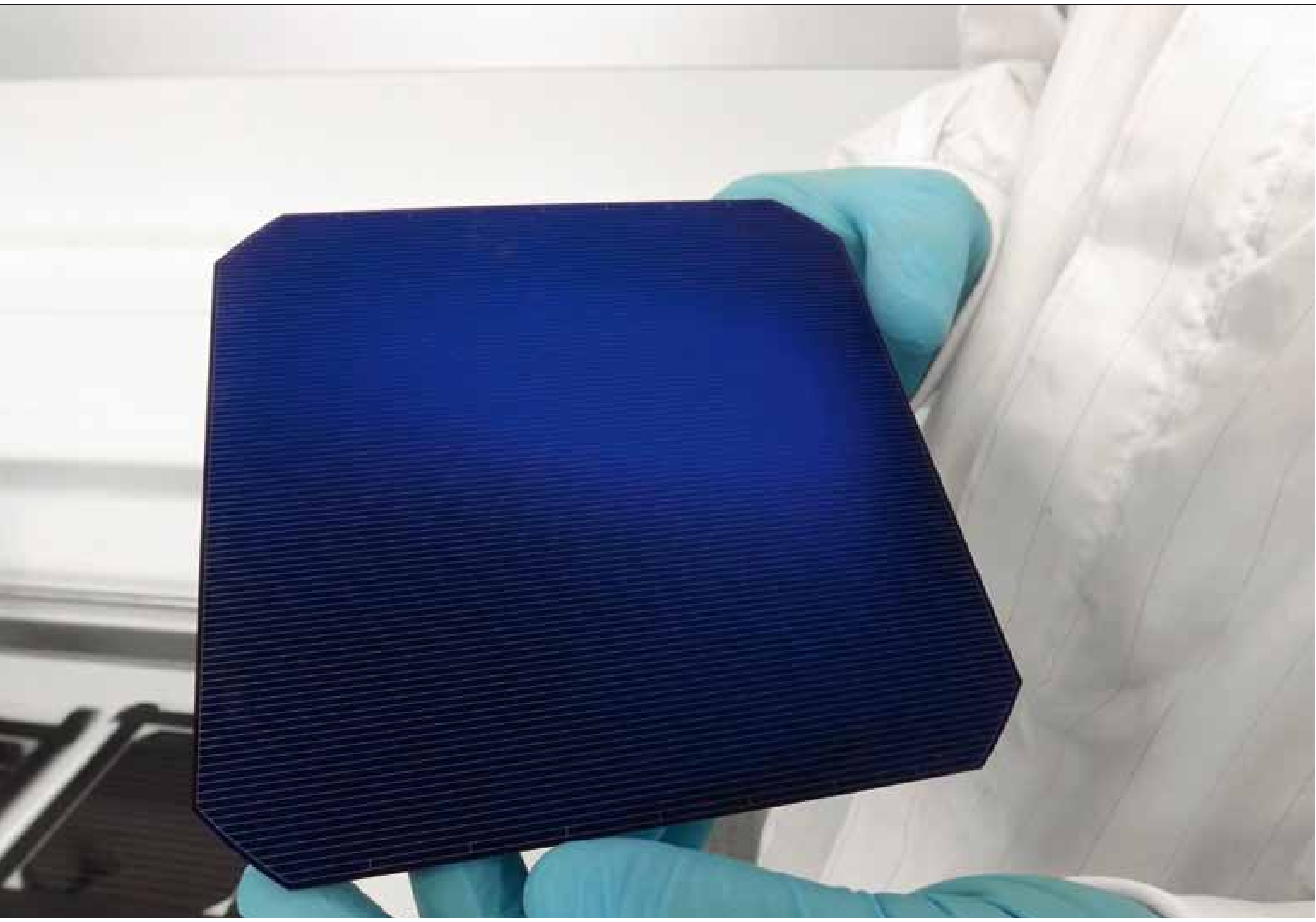


Photo: pv magazine/Jonathan Gifford

The production of heterojunction cells requires specialized tools and know-how.

The uncertain future of silicon heterojunction solar

PV cells: Heterojunction PV cells can deliver impressive efficiency results, but they are neither easy nor cheap to produce.

On the edge of a river in de-industrialized South Buffalo, New York, a massive factory is rising. The 110,000 square meter facility on the site of a former steel mill is expected to employ 5,000 workers and will be the largest solar PV module factory in the Western Hemisphere when complete, with the capacity to produce 1 GW of PV modules annually.

Unlike other massive PV module production facilities in China, this factory will not be focused on making multicrystalline silicon at the lowest cost feasible. Instead, SolarCity's "gigafactory" in Buffalo will produce PV cells and modules that incorporate multiple thin layers on a monocrystalline silicon substrate. "Triex" technology is a highly proprietary, high efficiency architecture that SolarCity acquired with its purchase of startup Silevo in 2014.

In August 2013, another PV factory began full-scale production in a technology park in the state of Kedah, Malaysia. Japanese electronic giant Panasonic's factory is by no means small, and has the capacity to produce 300 MW of PV modules annually. Panasonic Energy Malaysia likewise produces PV cells and modules based on a design that incorporates a layer of monocrystalline silicon sandwiched between layers of amorphous silicon.

Panasonic's heterojunction with intrinsic thin layer (HIT) technology is produced at two other factories in Japan. Together these three factories represent around 1 GW of annual production, much more than any other heterojunction producer has online at present.

HIT is more than decade older than Triex, and has a different structure.

Despite these differences, these two technologies, and the factories that produce them, tell much of the story of silicon heterojunction solar.

War of efficiencies

On October 2, SolarCity announced that it had produced a 22.04% efficient PV module using Silevo's Triex technology, which it claimed was the most efficient solar panel available for the rooftop market. This claim was immediately disputed by SunPower, which is producing modules based on its back-contact technology at greater than 22% efficiency (see pp. 54-55).

Four days later, Panasonic announced that it had produced a 22.5% efficient HIT PV module on mass-production equipment. The company currently offers its 330 watt, 1.7 square meter modules, which offer 19.7% efficiency.

Record efficiencies are often achieved using "champion" modules, and competing claims can leave a lot of grey area in terms of which manufacturer is actually mass-producing the most efficient PV modules for the rooftop market. But what was clear is that SolarCity had sparked a public competition for who could boast the product with the greatest efficiency and the highest output, and that two of the three modules in the race – SolarCity/Silevo's Triex and Panasonic's HIT – were heterojunction designs.

What is heterojunction?

Solar photovoltaic cells absorb only a portion of the spectrum of available light, which is determined by the material used. For more than 40 years, researchers have been working on bonding several semiconductor layers to create heterojunction devices, for a variety of applications including solar PV.

Dual-junction PV cells have been produced with efficiencies higher than 20% since the late 1980s, and in the last decade efficiencies above 40% were achieved with three and four-junction PV cells. These efficiencies were achieved under conditions of concentrated sunlight, and the concentrated photovoltaic (CPV) modules which were deployed by Soitec and other companies were based on multi-junction cells.

Despite promises of lower levelized cost of electricity and a number of plants, CPV never reached significant scale. Industry leader Soitec abandoned CPV technology in January 2015.

Meanwhile, heterojunction technology has survived without the concentration. The efficiencies are far lower than CPV, however Panasonic has demonstrated that such modules can be produced for the rooftop market.

While other semiconductors such as various gallium compounds were typically utilized in three, four and five-junction PV cells created for concentrator applications, rooftop heterojunction designs are largely based on crystalline silicon (c-Si) and amorphous silicon (a-Si) layers, and are termed "silicon heterojunction."

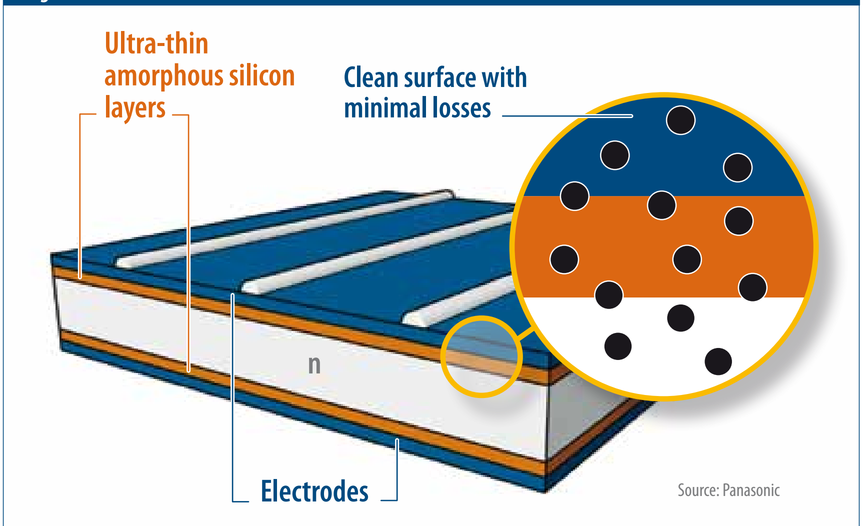
These cells and modules offer a number of technical advantages over conventional crystalline silicon. The use of multiple layers allows for higher efficiencies, both through the ability to absorb more of the available spectrum of sunlight and reduced recombination losses. Additionally, the use of amorphous silicon allows for a lower temperature coefficient, meaning that these modules perform better in hot climates.

However they are not easy, or cheap, to make.

AT A GLANCE

- SolarCity is deploying HJT technology at gigawatt-scale in Buffalo, New York State.
- The inherent conservatism within the PV cell production market has seen PERC deployed at far greater volumes.
- While some industry experts remain firmly skeptical as to HJT technology's deployment, advocates argue it is the logical extension to the PV efficiency journey.

Diagram of Panasonic HIT cell



Panasonic's HIT incorporates both thin intrinsic a-Si layers and doped a-Si layers on both sides of a monocrystalline wafer

Graphic: pv magazine/Harald Schütt

The big three

While a number of PV makers, equipment makers and research institutes are working on silicon heterojunction technology, there are three large players who either have achieved scale or are approaching it.

Panasonic's work with silicon heterojunction PV began in its work with amorphous silicon, which the company commercialized for use in portable electronic devices in 1980. After pushing up a-Si efficiencies, the company began exploring heterojunction designs in 1990.

This line of research proved fruitful. In 1994 Panasonic produced a 20% efficient, one square centimeter silicon heterojunction cell, and in 1997 started mass production of HIT. Since 1997 Panasonic has scaled HIT to 1 GW of annual production, however global solar demand has grown more than 100-fold, so even at this scale it remains a niche product.

As a pioneer in commercializing silicon heterojunction, Panasonic has held valuable intellectual property in this field. However, core heterojunction patents expired in 2010.

For development of heterojunction technology, you need not only a manufacturer, but equipment makers who can supply the specialized tools to make these products. Swiss equipment maker Meyer Burger's work with heterojunction PV dates back to 2008, when Germany's Roth & Rau, which it acquired in 2011, began collaborating with the University of Neuchâtel on heterojunction technology.

As Meyer Burger, the company began making its industrial-scale plasma-enhanced chemical vapor deposition (PECVD) tools for heterojunction applications. In the fall of 2014 Meyer Burger unveiled a full-scale test heterojunction line in collaboration with the Swiss Center for Electronics and Microtechnology (CSEM). Since that time Meyer Burger has begun offering a turnkey solution for production of heterojunction PV cells, and has provided tools to three different PV makers.

Silevo arrived at heterojunction via a different route, and its technology is based on Metal Insulation Semiconductor PV technology developed in the 1970s. In 2009 the company's two founders developed the Triex PV cell architecture, and began mass production in 2011. And while the scale of this production has been limited, SolarCity's acquisition of Silevo in June 2014 has promised to change that.

Photo: Silevo Solar

Silevo's HJT technology is being deployed by SolarCity at its new fab.

Silicon heterojunction designs

Panasonic, Meyer Burger and Silevo all use n-type monocrystalline silicon wafers, which provide both good performance and are not affected by light-induced degradation (LID), with doped a-Si layers in a bifacial cell design. However there are significant differences.

Panasonic and Meyer Burger have a similar approach to silicon heterojunction technology, incorporating both thin intrinsic a-Si layers and doped a-Si layers on both sides of the monocrystalline wafer.

Silevo has a different approach, depositing semiconductor oxide layers and doped a-Si layers on the mono wafers. Silevo's "tunneling" oxide layer has its origin in the semiconductor industry, and the company says that the combination of the n-type mono, passivated a-Si and oxide layers provides "unique benefits."

The a-Si layers in silicon heterojunction cells would be damaged by the high temperatures of standard techniques for firing of screen-printed silver contacts, therefore Panasonic and Meyer Burger both utilize low-temperature silver paste. Silevo uses electroplated copper, which it says helps to reduce cost.

In addition to these two variations, the Energy Research Centre of the Netherlands (ECN) had developed a heterojunction cell design which incorporates Metal Wrap Through (MWT) back-contact technology. In collaboration with Japan's Choshu Industry, ECN has achieved a 21.5% cell efficiency with this architecture.

Technical challenges

Meyer Burger notes that heterojunction cell production has fewer process steps than either competing high efficiency designs such as passivated emitter rear contact (PERC) or even standard crystalline silicon cell manufacturing, due to the low temperature process.

And while the device physics of heterojunction cells are well known in the PV industry, this does not mean the process is easy. Heterojunction cells begin with wet chemical baths for preparing

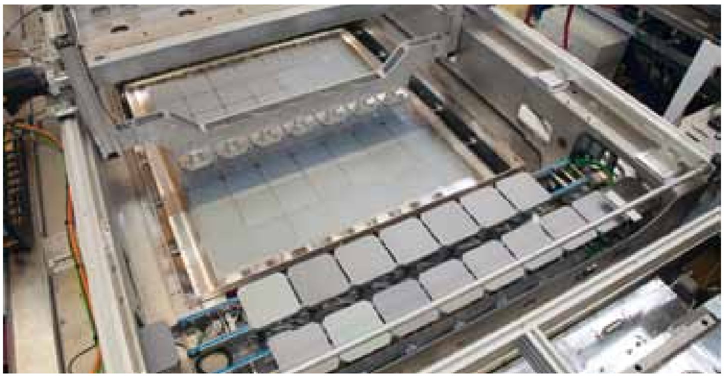
Photo: Meyer Burger

Specialized carriers have been designed by production equipment suppliers, including Meyer Burger, for heterojucntion cell production.

Photo: John Hickey/Buffalo News

SolarCity's vast 110,000 square meter facility in South Buffalo, New York, will represent a significant bet on heterojunction technology.

Photo: Meyer Burger



Highly automated heterojunction production processes may allow for cost reductions.

the wafer, and ECN's Director of Solar Research Paul Wyers says getting this part right is "technically challenging."

"You need a perfect interface for silicon heterojunction cells, and therefore wet chemistry, and the position technology are very important," Wyers told **pv magazine**.

Meyer Burger says that the passivation of the surface of the c-Si wafer and the proper deposition of the a-Si layer is the most challenging part. "If the amorphous silicon is the right crystalline structure, you can avoid losses," notes Meyer Burger Business Development Manager Andre Richter.

Silevo agrees it is a challenge to maintain uniform film properties across the surface of the wafer as well as wafer-to-wafer when producing large volumes.

Panasonic says that the challenges of the technology ultimately boil down to cost, and the difficulty moving from R&D to mass production. "The biggest challenge is the mass production of the cells," says Panasonic Eco Solutions Solar Division Group Manager Mukesh Sethi. "Everybody is not able to achieve that kind of mass production, and keeping the costs low at the time."

Commercialization issues

Beyond these specific technical issues, there are larger challenges to the spread of silicon heterojunction technology. "The established producer, Panasonic, does not exchange any information with the rest of the world from their technology," notes ECN's Wyers. "It is still in a way, and for everybody except Panasonic, a new technology."

Wyers says that while a supply chain exists in principle, scaling up to volume production is a challenge, as it is for all new technologies. "Of course you have this chicken and egg situation," states Wyers. "You need volume before investments can be made in capacity to produce these materials and equipment."

Another barrier that is not unique to heterojunction technologies is the inherent conservatism of PV manufacturers. This has been exacerbated in the past four years, as many cell and module makers have avoided making investments in new equipment due to overcapacity, low selling prices and crushed margins.

During this time the few investments made by cell makers tended to be in low cost processes that could be added to existing lines, instead of the entirely new equipment that would be needed for a technology like silicon heterojunction.

"It is easier to upgrade for PERC, than to invest in a new technology and a new line," notes Meyer Burger's Andre Richter. "You just add two or three devices, and you can keep producing cells."

Heterojunction on the market

Meyer Burger says that it can offer a lower levelized cost of electricity for PV systems using its heterojunction (HJT) technology than standard crystalline silicon solar cells. The basis of this and the argument for high efficiency PV in general is that module costs are falling much faster than balance of system costs, meaning that higher output tends to offset a relative difference in module costs. This is more the case at smaller scales, and Panasonic is primarily selling its HIT modules into the residential market.

High efficiency module types still command a price premium well above standard c-Si. Solar market analyst Paula Mints puts Panasonic's HIT at an average price of around $0.95 per watt. This is competitive with other very high efficiency designs, but the limiting factor preventing any given silicon heterojunction PV maker from scaling may not be competition with other heterojunction designs. Instead, it may be the limited market for high efficiency, high cost PV modules.

Panasonic estimates that it is selling 80% of its HIT product into Japan, and Paula Mints estimates that HIT and other heterojunction solutions supply around 10% of the nation's market. This makes Japan the only nation that has a significant market for heterojunction PV to date, however HIT sales have suffered from slowness in the nation's PV market and Panasonic is looking to expand its sales globally.

SolarCity says that it expects to complete its "gigafactory" in Buffalo in 2017, and when that factory comes online this will bring a large volume of heterojunction PV to the U.S. rooftop market. The company is already operating Silevo's pilot plant with an annual capacity of 100 MW in Fremont, California. SolarCity has a natural advantage in that it has an internal sales channel for Silevo modules. However, if it cannot offload enough of these to its customers, Silevo modules may end up on the retail market. This makes the giant building in Buffalo a tremendous gamble for the largest residential installer in the U.S.

Market analysts have not been bullish about the prospects for big increases in the market share of HJT modules. When **pv magazine** asked Paula Mints about this possibility, her answer was one word: "no." But researchers are more optimistic. "It's a new technology, there is little experience of mass manufacturing, only one company with long experience, and technical challenges," notes ECN's Wyers. "But I am sure that these will be overcome." ◆

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