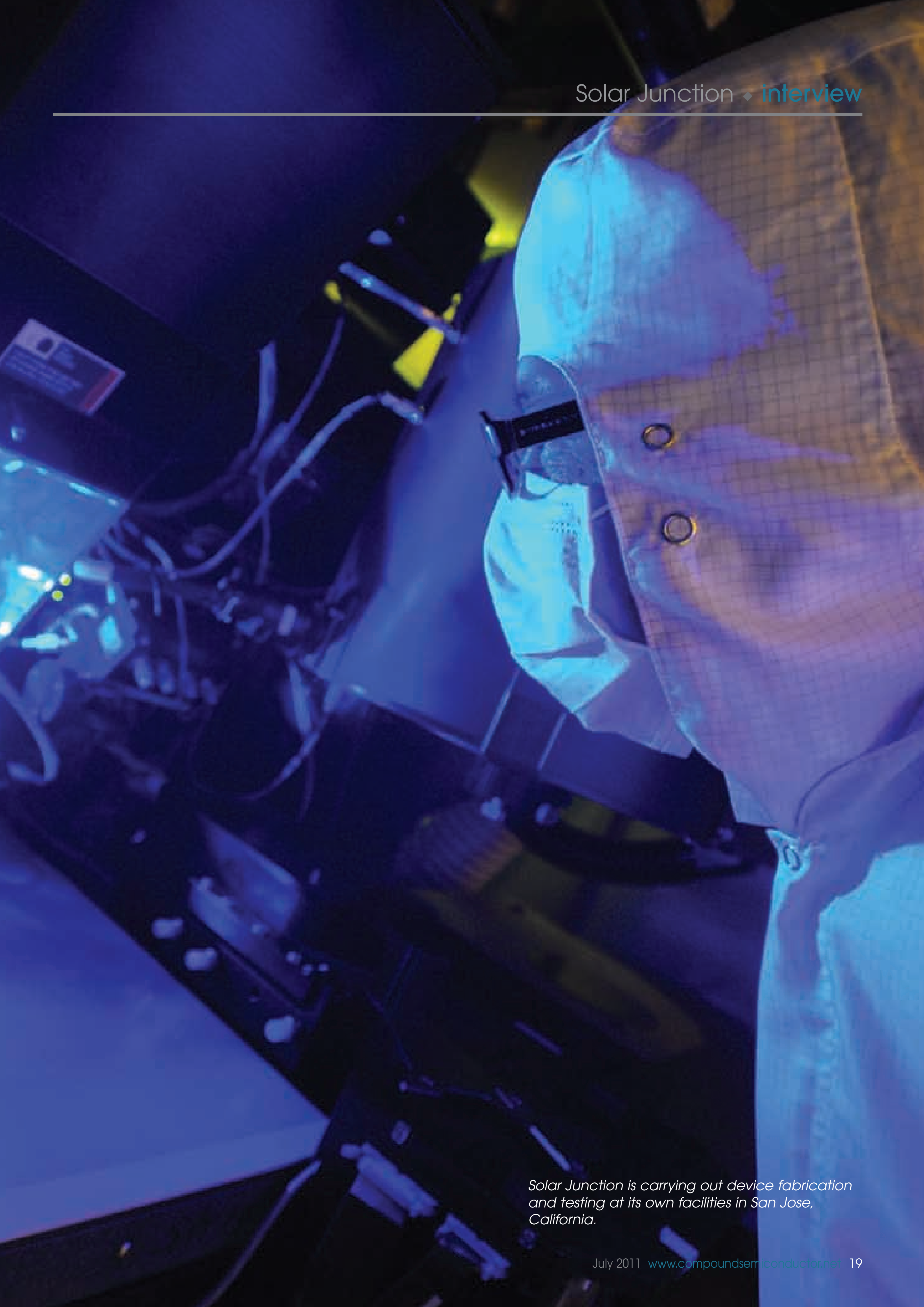
Dilute nitrides give Solar Junction a critical edge

Following years of quiet development, Solar Junction has recently shot to fame with record-breaking triple-junction cells incorporating dilute nitrides. The next phase for the company is to ramp its manufacturing capacity and help CPV to carve out its own segment in the PV market. **Richard Stevenson** catches up with the plans of the Stanford start-up.

Within the fraternity of multi-junction solar cells makers, bragging rights rest with those making the most efficient devices. Up until recently, the record for cells operating under high concentrations would regularly change hands between well-established manufacturers of triple-junction cells, such as Spectrolab and Emcore, and government-funded institutions, such as Fraunhofer ISE and the National Renewable Energy Laboratory (NREL). But recently, it has been a pair of smaller firms that have been driving solar cell efficiency to new levels. Late last year Spire Semiconductor unveiled a record-breaking cell efficiency of 42.3 percent, and this April Solar Junction trumped that effort with a 43.5 percent efficient device.

One incredibly impressive characteristic of the Solar Junction cell is its high level of performance at very high concentrations. Peak performance occurs at 400-600 suns, and efficiency in excess of 43 percent is recorded at 1000 suns. Increase concentration further to 2000 suns – an operating condition that is often unavailable in tests performed by independent labs to verify performance – and the cell's efficiency is believed to still be above 42 percent.



Solar Junction is carrying out device fabrication and testing at its own facilities in San Jose, California.

These groundbreaking efficiencies at very high concentration factors are a mouth-watering prospect for any concentrating photovoltaic system (CPV) manufacturer. If they could get their hands on large numbers of cells delivering this level of performance, they could cut production costs for systems with a given output power, thanks to the combination of fewer devices, fewer focusing elements and smaller tracking systems.What's more, Solar Junction promises to elevate solar cell performance to new levels over the next few years. The current design can potentially produce efficiencies of 44 percent of more, and future variants that do not require any major technical innovation could hit efficiencies approaching 50 percent.

From lasers to CPV

The trailblazing technology that lies at the heart of Solar Junction can be traced back to James Harris' group at Stanford University, CA. Research programmes run by Harris include the development of telecom lasers based around the dilute nitride InGaAsNSb. This material can be grown in a lattice-matched fashion on GaAs substrates, which are cheaper and less fragile than their InP cousins commonly used as a platform for making 1.3 μm and 1.55 μm lasers.

In the mid-noughties, many multi-junction cell developers were trying to fabricate efficient devices that incorporated a bottom junction made from dilute nitrides, which are strong absorbers in the infrared. The Stanford team had a brief stab at this problem, and unlike everyone else, they succeeded. They detailed their efforts in a joint paper with NREL.

Harris discussed these promising results at a conference in 2007, and they piqued the interest of Arno Penzias, a Nobel-prize winning physicist famous for his measurements of microwave background radiation. At that point in his career, Penzias was no longer a researcher – he had racked up ten years as a Venture Partner at New Energy Associates, a major investor in clean technology and a financial backer of the CPV system maker Sol Focus. Penzias was convinced that the Stanford team's dilute nitride technology could play a major role in accelerating the deployment of CPV technology, and it didn't take him long to convince NEA to fund a venture to try and make this happen.

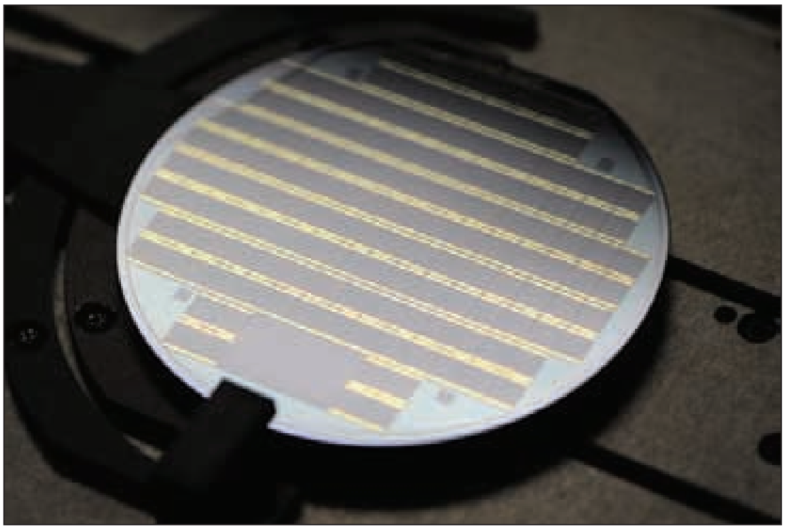
A handful of alumni from Harris' group were tremendously enthused by this opportunity to start a solar cell company. Stanford is renowned for fostering a culture of entrepreneurship, and back in early 2007 many of the founders of Solar Junction were working for local start-up Translucent, a developer of epitaxial materials for the electronics, photonics and solar industries.

On July 16, 2007 three former employees of Translucent and graduates of Stanford's dilute nitride group – Homan Yuen, Vijit Sabnis and Mike Wiemer – co-founded Solar Junction, in conjunction with Harris, Craig Stauffer and Jim Weldon. The latter is a former COO of Translucent, and has 29 years of experience in managing a technology company.

To begin with, the founders of Solar Junction based themselves in Cupertino, which is about a mile from Apple's headquarters. "We were basically just a bunch of guys cramped into one room, with a couple of laptops and some seed funding, working out what to do next," reminisces Sabnis, the company's Vice President of Technology.

As they sat together, they tried to figure out what their business model should be. And the key question that they chewed over was this: should they adopt an outsourcing model, following in the footsteps of Cyrium and Quantasol; or should they be an integrated device-making company? While the founders mulled over this question, they were able to continue developing their material technology by booking time at the public fabrication facility at Stanford University. In addition, they worked with epifoundries. "That wasn't surrounding our proprietary IP – we were basically getting our feet wet in multi-junction technology," explains Sabnis. In addition, the team learnt how to model multi-cell devices.

After the Stanford spin-off had been going for a few months, its founders started trying to secure investment. And by April 2008 they had won funding from three VCs: NEA, Advanced Technology Ventures and Draper Fisher Jurvetson. The team had also come to a conclusion about the company's future. "We decided that, at least at the early stage of our existence, we would do everything internally," says Sabnis. "We were not going to rely on outsourced vendors. The technology was too complicated to use an epifoundry, or even a wafer-processing foundry."



Taking that decision put the founders of Solar Junction in control of their destiny. They were well aware that they had to develop their technology fast to keep hitting the milestones agreed with investors, and felt that the only way to execute on this front was to have their own facility. The VCs supported this decision, even though it required a substantial amount of money to build a fab. In June 2008 the company moved to its current headquarters in San Jose, before bringing up an epi-reactor in a few months. The team hit a major technical milestone that December, upgraded the fabrication facility in early 2009, and made its first triple-junction cell that April. It had an efficiency of 10 percent. "We were surprised," says Yuen. " It was a shot in the dark – we thought we were going to get 0.02 percent!" From that day on cell efficiencies climbed fast, hitting 30 percent in August, and making further gains throughout 2010. This January the company reported an NREL-verified efficiency of 40.9 percent, and this February and April it announced efficiencies of 41.4 and 43.5 percent.

Simple structures

The device behind these record-breaking figures is anything but esoteric – Yuen, Solar Junction's Vice President of Research and Development, goes so far as to describe it as "boring". It's a justifiable description, because the cell is free from quantum wells, quantum dots and metamorphic layers. Instead, it is just a stack of bulk layers on a GaAs substrate – a dilute nitride for the base, and GaAs and GaInP for the middle and top cells, respectively. The dilute nitride can take the role of a tuneable infrared absorber, with a bandgap that can be adjusted from 0.8 eV to 1.4 eV by altering alloy composition.

Another great benefit of dilute nitrides is that they can be lattice-matched to GaAs or germanium substrates. This gives Solar Junction a significant edge over many of its rivals, including Spectrolab and Emcore. These incumbents have turned to metamorphic buffer layers to alter the lattice constant within the device, so that they can tune the bandgaps of the cells and ultimately reach higher efficiencies. "Those graded [buffer] layers introduce a lot of crystalline defects, such as dislocations, and managing those defects is a difficult thing," says Yuen. Yields can fall, and the increased thickness of the epilayers in an inverted metamorphic design adds to production costs. "It is also very difficult to ensure that those cells are going to remain reliable over a twenty-to-thirty year time frame," claims Yuen, who expects these issues to slow commercial introduction of inverted metamorphic triple-junction cells.

In his opinion, these delays are very damaging to the commercial prospects of CPV, which faces strong competition with thin-film and silicon technologies that are getting better and better, and cheaper and cheaper. "There's no time," argues Yuen. "You can't wait five years for a metamorphic structure to be available – you need it here and now." He argues that if CPV is to be successful, cells must deliver rapid, consistent and sustained improvements in efficiency, reliability and tuneability. "That's why Solar Junction's story resonates so well with our customers."

These customers can already receive limited quantities of cells with typically 41.5 percent efficiency, and Solar Junction plans to make this product widely available next year. "We have a roadmap that is going to take us up into the forties and even reach fifty percent, using a four or five junction cell that utilises a dilute nitride platform, in addition to using gallium arsenide, aluminium gallium arsenide and indium aluminium gallium phosphide," says Yuen. This roadmap should enable Solar Junction to deliver significant hikes in device efficiency on a biannual basis, thanks to the introduction of additional cells and evolutionary improvements that occur when devices are made in high volumes.

The high efficiency of Solar Junction's cell, along with its potential to get markedly better over the next few years, should help to enable CPV to grab a significant share of the PV market.

"The dream of CPV is for the PV market to see some real segmentation," says Yuen. He hopes that in locations with intense solar radiation, the financial case for installing CPV will be so strong that it will soon start to dominate this segment of the market.

Employing Solar Junction's devices in CPV systems operating in these environments can cut generating costs associated with the technology, because these cells are capable of operating efficiently at very high concentrations, such as 1000 suns. Magnification

There is a point at which if we sell our device at a certain price, (makers of 39.2 percent efficient cells) have to give it away, or pay for the customer to take it. At some point, cell efficiency trumps everything.

always leads to 'hot spots' – in this case local concentrations of 1500 or 2000 suns that produce very high current densities. "If your tunnel junction isn't very good, you kill cell performance," says Sabnis. He claims that tunnel junction performance typically falls off above 1000 suns. "Using our approach you can have tunnel junctions that approach 8000 [suns] without any failure, so system manufacturers don't have to worry about hot spots with our cells."

Makers of CPV systems also want cells with high levels of reliability. Solar Junction has carried out well-known reliability and ageing tests on its cells, which have revealed device lifetimes of many, many decades. The company currently carries out a 'flash test' on every cell produced, evaluating performance at the concentration that the cell is intended for. But in future Solar Junction is likely to use sample testing, an approach that the company says it can justify, thanks to the high yield of its production process. However, if customers prefer, each cell can be tested prior to shipment.

The costs associated with the production of the company's cells are similar to those of traditional triple-junction devices, according to Jeff Allen, Solar Junction's Director of Business Development. "And as the incumbents adopt a metamorphic cell, which requires thicker graded-buffer layers and lift-off, we become cost-advantageous." What's more, by employing a dilute nitride platform, the addition of a fourth and fifth junction does not lead to a significant change in overall device thickness. "So our advantage from a cost standpoint increases, because we get a substantial improvement in power output and efficiency while costs are very flat," adds Allen.

Today, Solar Junction is sampling cells to all the major CPV system manufacturers, plus many of their smaller rivals. And according to Yuen, feedback is excellent: "It is the most power output they have seen from all the cells they have." The Stanford start-up is now entering qualification with some of these companies, and also taking orders.

Solar Junction's highly efficient cells seem to be destined to have a profound impact on the CPV cell market. Modelling by the Stanford spin-off has compared the performance of CPV systems employing cells with 41 or 42 percent efficiency, and those delivering 39.2 percent, the value quoted for Spectrolab's devices that it is shipping today. "There is a point at which if we sell our device at a certain price, [makers of 39.2 percent efficient cells] have to give it away free, or pay for the customer to take it," claims Wiemer. "At some point, cell efficiency trumps everything."

Arguably, the only significant obstacle in the path of Solar Junction's future success is the raising of cash needed to expand manufacturing capacity from today's level, 7 MW, to 250 MW (capacities assume cell operation at 1000 suns). Urgency in this capacity build-out is critical, says Sabnis, because the likes of Soitec, Ammonix and Sol Focus are experiencing a tremendous ramp in orders for their CPV systems. "Our biggest focus right now is getting designed into their systems, going through the various qualification procedures necessary to do that, and developing a reliability data path on our cells."

If Solar Junction can raise the capital to expand its manufacturing capacity, it will surely have every opportunity to become one of the biggest makers of CPV cells in the world. And the company is giving itself a great chance of executing on this by not getting distracted by thoughts of becoming a vertically-integrated supplier of CPV modules and systems, and not diluting its resources by also battling to break into the market for solar cells for powering satellites. Any by focusing on what it does best – making really efficient cells – it to be promises to become a major force in helping CPV to establish its own space within the CPV market.

Dies and integrated assemblies

Customers can choose to either buy bare die from Solar Junction, or integrated solar assemblies. The San Jose start-up never intended to offer the latter on a commercial basis – it planned to just use the assemblies for testing. However, the company received several requests for this product from customers, who explained that known good-die shipped by the big solar cell manufacturers were failing after contract manufacturers had inserted them in solar assemblies. "[Our customers] were basically pleading with us: 'We just wish the cell manufacturers would do this for us to prevent this problem'," says Jeff Allen, Solar Junction's Director of Business Development. The company was well placed to address this issue, because it had hired engineers with tremendous expertise in packaging and reliability.