Competing for solar energy records and applications

Until recently compound semiconductor photovoltaic energy conversion has been restricted by cost to space vehicles, where the higher efficiencies lead to lighter panels. Mike Cooke reports on new developments that may lead to terrestrial applications.

Although compound semiconductors have since the 1980s produced the most efficient photovoltaic (PV) conversion of solar energy, their application has tended to be restricted to space applications due to their high production cost, which can be up to 100 times that of alternatives.

In the single-junction cell, gallium arsenide (GaAs) PV cells and modules offer the highest conversion rates with the minimum weight and area/size penalties. These devices also operate over a wider range of temperatures, allowing deployment in extreme conditions.

Further performance improvement can be made by adding multi-junction layers sensitive to different wavelength ranges that match the device more closely to the relevant solar spectrum. Multi-junction cells have been deployed in space for about two decades.

However, companies and researchers would like to find ways to make compound semiconductor PV more attractive in terrestrial applications.

One method that has come to the fore is for compound semiconductor PV cells to be put under the magnifying glass with the development of concentrator photovoltaic (CPV) systems. By focusing and tracking sunlight on small compound semiconductor PV cells, systems are being developed that, it is hoped, will be competitive with lower cost silicon-based modules.

Another way forward is to package compound semiconductor PV in thin and light-weight formats that allow deployment into a wider variety of applications.

At the same time, researchers and companies are keen to develop PV cells and modules with the very highest performance that will enable these hopes to come to fruition. Here we look at some of the leaders in these technical developments and their vision of how these technologies can be used.

To aid us in our search for the current leadership, we consulted the rather helpful 'Research Cell Efficiency Records' chart on the US National Renewable Energy Lab (NREL) National Center for Photovoltaics (NCPV) website (www.nrel.gov/ncpv/).

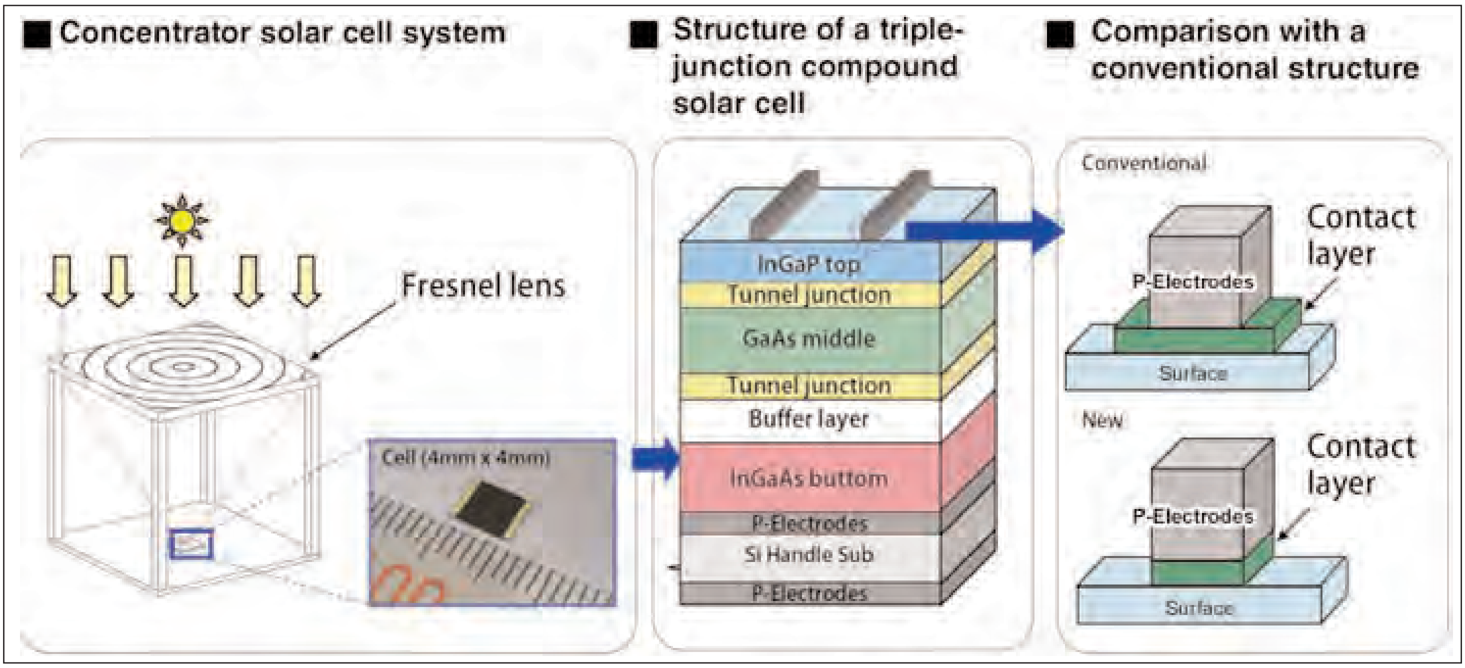

Figure 1. Structure of Sharp concentrator system and compound semiconductor solar cell, compared with conventional structure.

Power of concentration

As of writing, the leading cell technology is from Sharp. The Japanese company announced in June 2013 the achievement of 44.4% conversion efficiency for a concentrator triple-junction compound semiconductor solar cell (Figure 1). The research leading to this achievement was part of the 'R&D on Innovative Solar Cells' project promoted by Japan's New Energy and Industrial Technology Development Organization (NEDO).

The efficiency figure was validated by Germany's Fraunhofer Institute for Solar Energy Systems (ISE) in April under 302-suns concentration and with a cell surface area of $0.165cm^2$. Sharp and Fraunhofer are also part of an EU-Japanese project 'New Generation CPV' (www.ngcpv.org/) set up in June 2011 that is due to last 42 months up to the end of 2014. NGCPV has "the objective of approaching the 50% efficiency goal at cell level and 35% at module level".

Sharp's cell uses three photo-absorption layers: indium gallium arsenide (InGaAs), gallium arsenide (GaAs), and indium gallium phosphide (InGaP) in an inverted metamorphic multi-junction (IMM) configuration. In the research, Sharp worked to expand the effective concentrator cell surface area and on improving the interface between concentrator cell and electrodes. The plan (Figures 1 and 2) is to use such cells in modules that combine many cells with Fresnel lens concentrators in fields of modules.

Sharp began its development of solar cells for space applications in 1967, using single crystal silicon. The development of triple-junction compound semiconductor devices for the same purpose but with improved efficiency and durability, and reduced weight, began in 2000. Application of these cells began in 2005 with the small Riemei scientific satellite. The company has also developed triple-junction compound solar cells with 37.9% conversion efficiency under 1-sun illumination for use in space, particularly in its work with the JAXA Japanese space agency.

Preparing for high volume

Solar Junction is a US company that is developing cells for CPV and has held the record cell efficiency until recently. In October 2012, the company beat its own April 2011 record of 43.5% conversion efficiency (418 suns) with a 44% NREL-validated measurement under 947 suns.

This has apparently been edged up to 44.1%, according to an August 2013 announcement from Solar Junction's epitaxial wafer supplier and strategic partner IQE. The wafers were produced on IQE's high-volume molecular beam epitaxy (MBE) equipment. IQE claims that "the standard three-junction solar cells are believed to set a new world record for production-scale CPV wafer technology." The cell uses a lattice-matched

Figure 2. Sharp's vision of solar power generation using concentrator triple-junction solar cells in fields of modules.

InGaP/GaAs/GaInNAs(Sb) structure on GaAs substrate [for further details: Mike Cooke, Semiconductor Today, p72, March 2013].

Vijit Sabnis, CEO at Solar Junction, comments: "Breaking a world record is a major achievement, but improving on our most recent record using high-volume production equipment produced in conjunction with our manufacturing partner IQE, and Solar Junction's fabrication line in Sunnyvale, CA, is dramatically more significant."

Amonix, a CPV module manufacturer that uses Solar Junction cells, announced an NREL-validated record module efficiency rating of 35.9% in August. The test was carried out under the recently adopted IEC Concentrator Standard Test Condition (CSTC) of $1000W/m^2$ at 25ºC cell temperature, rather than the older Concentrator Standard Operating Condition (CSOC) of $900W/m^2$ at 20ºC ambient. The data for the rating were generated in an outdoor test at NREL from late February to April 2013.

Junction pile-up

SOITEC in Europe is another firm with multi-junction cells. The NREL chart gives SOITEC the record for 4-junction devices, at 43.6% conversion efficiency under 319 suns. At the time of writing, SOITEC's device is the only one listed on the chart under the "four junction or more (concentrator)" category, suggesting that the technology has plenty of room to improve.

For more traditional three-junction devices based on GaInP/GaInAs/Ge technology, SOITEC has achieved efficiencies of more than 41%.

SOITEC's CPV solar module work is marketed under the trade-name Concentrix, after acquiring the

Figure 3. Schematic diagram of SOITEC's concentrated photovoltaic module.

Figure 4. Installation of SOITEC CPV technology at Wadi El Natrun, Egypt.

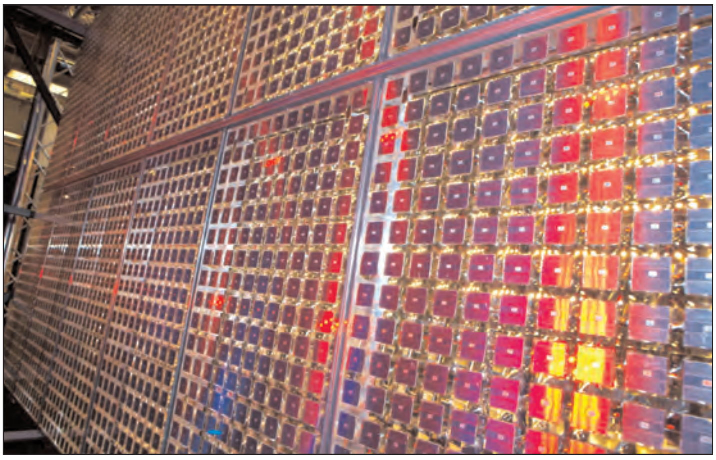

Figure 5. Picture from grand opening of SOITEC's San Diego facility.

Fraunhofer spin-off Concentrix Solar in 2009. The base technology was developed for more than a decade at Fraunhofer's ISE solar energy laboratory. SOITEC uses its Smart Cut and Smart Stacking layer transfer and wafer bonding techniques to produce high-quality semiconductor materials for solar cells.

SOITEC works also with France's CEA-Leti organization, along with Fraunhofer ISE. The research collaboration hopes to use these technologies to create high-quality III-V compounds materials to deliver significantly higher efficiency than conventional multi-junction cells grown by epitaxy.

Like Sharp, SOITEC's modules use Fresnel lenses to concentrate the sunlight (Figure 3). The module efficiency has reached 30%. SOITEC has developed an automated production process and, from its first demonstration systems in 2005, now has an installed module base of more than 10MWp in 14 countries. SOITEC's production capability is 70MWp (Figure 4). The company also inaugurated a US manufacturing facility in December 2012 (Figure 5).

Boeing's Spectrolab subsidiary was another solar cell record holder, achieving 37.8% efficiency for a "new class of high-efficiency multi-junction solar cell, created from two or more materials" without concentration. The device is labeled on the NREL chart as '5-J', presumably meaning that it involves five junctions (Figure 6). The Boeing announcement on 9 April was pipped on 24 April by Sharp with its 37.9%-efficient 1-sun 3-J IMM device described above.

Spectrolab is part of Boeing's Defense, Space & Security unit. The Boeing corporation describes Spectrolab as "the world's leading merchant supplier of high-efficiency

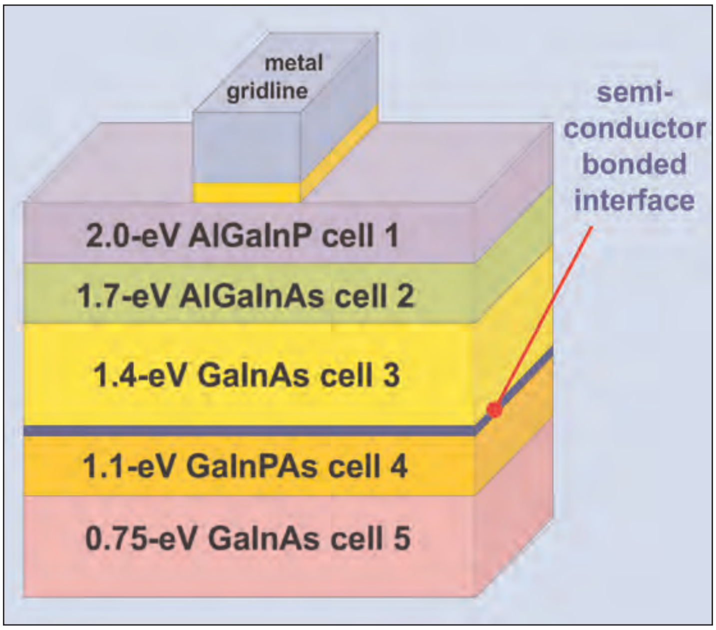

Figure 6. Schematic diagram of Boeing Spectrolab's five-junction cell.

multi-junction solar cells and panels for concentrated photovoltaic and spacecraft power systems”.

The cells and panels are based on GaInP/GaAs/Ge multi-junctions. “The greatest share of Spectrolab’s product deliveries are fully assembled space solar panels” the company says on its website. The firm provides arrays of panels for commercial, science, and military space program solar power. Spectrolab also works on cells and assemblies for CPV systems.

Widening the application net

Alta Devices of Santa Clara, CA, USA develops thin-film single-junction GaAs and two-junction non-concentrator cells. The single-junction devices hold that class’s record for efficiency at 28.8%. Alta also announced in March that its dual-junction GaAs/InGaP cells broke the record for two-junction devices at 30.8% efficiency. Since then, NREL announced in June that one of its own two-junction (GaAs/GaInP) IMM devices had achieved 31.1% efficiency. Alta has an efficiency target of 38% for its two-junction device. Alta modules containing single-junction cells have reached 24.1% efficiency,

In collaboration with NREL, Alta has also shown that its solar technology runs at temperatures up to 10°C lower than silicon under full solar illumination. The Alta module was five times less sensitive to increased temperature. In fact, rather than performance being degraded, the Alta module showed higher efficiency at high temperature due to the different spectral profile of the sun on hot days.

Alta’s application strategy is somewhat different from the companies above in that its devices are designed for single-sun illumination. The aim is to extend battery life in unmanned, consumer device, remote power, and automotive systems. In particular, the company wants to apply the technology to mobile, portable or wearable objects. In some cases, Alta hopes that its power delivery systems will eliminate the need to plug into the grid.

One recent achievement enabled by Alta’s solar power was a 9 hour flight by AeroVironment’s Puma AE small unmanned aircraft that is being developed for military, public safety and commercial applications (Figure 7). Alta also sees uses for solar-powered unmanned aerial vehicles (UAVs) in agriculture, wild-fire mapping, search and rescue, law enforcement, and industry. The solar panels are integrated into the wings of the UAVs.

Figure 7. Launch of AeroVironment’s Puma AE small unmanned aircraft that has achieved 9 hours flight using Alta solar power.

Alta has developed an efficient growth process to deliver thin films of active material that consume small amounts of raw material, while maintaining high conversion efficiency, reducing costs and manufacturing time. The company has also developed ways to package the cells in lightweight, robust, and flexible form factors, allowing integration into curved surfaces such as the wings of UAVs or the roofs of cars. Alta Devices claims that its technology produces between 2x and 4x more electricity per unit area and per unit weight than all competing technologies. ■

The author Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.