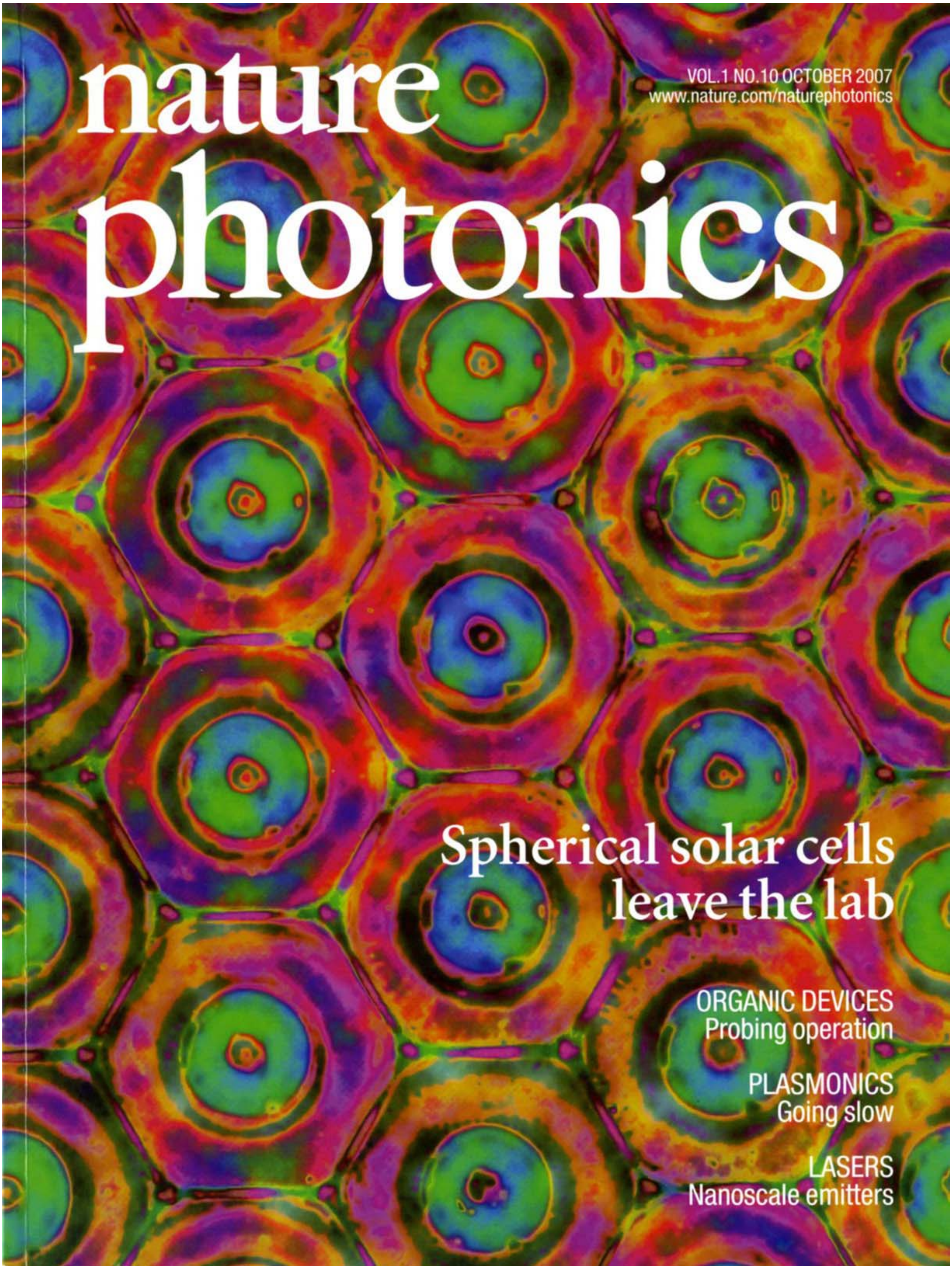

nature photonics

VOL.1 NO.10 OCTOBER 2007
www.nature.com/naturephotonics

Spherical solar cells leave the lab

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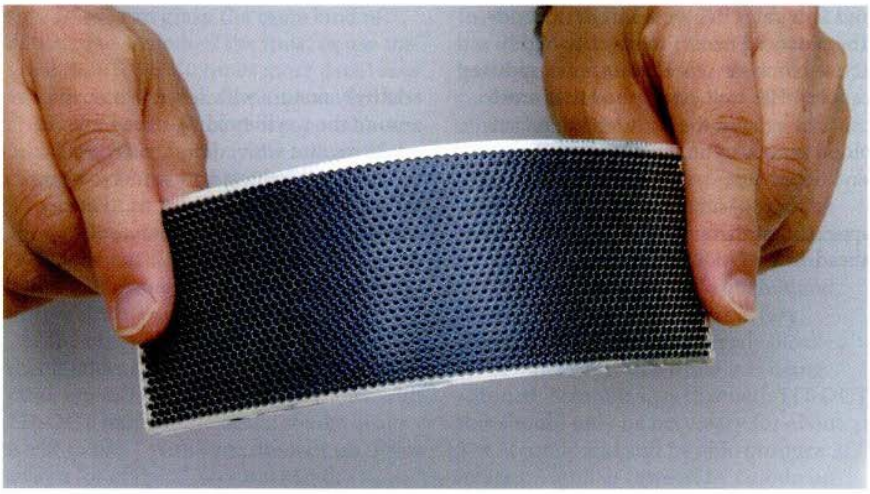
An innovative approach to making silicon solar cells more cost-effective and robust has now entered mass production. *Nature Photonics* took a trip to Kyoto, Japan, to find out more.

A type of photovoltaic that is based on an array of tiny silicon spheres mounted on a carefully shaped foil substrate could soon be dramatically improving the price-to-performance ratio of silicon solar cells. Although conventional crystalline silicon photovoltaics have steadily grown in popularity and efficiency over the years, mass deployment has ultimately been limited by material and production costs and the fragile nature of the cells. This could now be about to change thanks to the efforts of a small Japanese company, which has now successfully commercialized a rugged alternative that requires much less silicon per cell and is also flexible.

"The big attraction of our approach is that we use one-fifth of the amount of silicon in one of our cells compared with a wafer-based cell," explained Mikio Murozono, president of Clean Venture 21 (CV21), a start-up based in Kyoto that was founded in 2001 and has now started mass production of its spherical-cell technology. "This means that we need just 3–4 g of silicon to generate 1 W of electricity, whereas a crystalline wafer cell requires 12–14 g."

The idea is beautifully simple. Instead of a continuous silicon wafer, CV21 uses an array of 1-mm-diameter silicon spheres, which are carefully treated, aligned and bonded into a series of 2.2-mm-sized hexagonal reflector cups stamped into aluminium foil. Sunlight incident on the cell is either directly absorbed by a sphere or bounced onto one by the internal surfaces of the hexagonal reflector. The result is a collection efficiency that is comparable to a conventional solar cell, but requires much less silicon.



Robust: CV21's foil-based cells are laminated with plastic and can be bent without damage.

The spheres are processed so that each forms a miniature p–n junction, required for energy generation (the outer surface of each sphere is treated so that it becomes n-type while the inner central region remains p-type). Clever production technology is then used to apply electrodes and electrically connect each sphere in parallel to create a giant p–n array solar cell (Box 1). Any spheres that are defective or out of position are left unconnected. The top surface of the cell is laminated with a clear plastic film to protect the spheres.

The end product is a solar-cell module measuring 15 × 5 cm that is flexible, weighs just 8.5 g and contains 1,794 individual silicon spheres. So just how good are these cells in terms of performance? Well, according to datasheets from CV21 its best cells in the lab have an efficiency of 11.7% and each module is able to generate a power output of just over 0.8 W with an output voltage and current of 0.4 V and 2.1 A. The voltage and power output can be scaled up by simply connecting together several cells to create a large solar panel.

"Our cells in production right now have an efficiency of around 10%. Within a year or so that will reach 13%," commented Murozono. "In the future it's likely that we may move towards 0.8-mm-sized spheres instead to reach an efficiency of 15–16%, equivalent to 2 g of silicon per watt."

After having spent the past six years solving a series of tough engineering and technical challenges, CV21 has now started mass production and is now manufacturing cells on a daily basis.

The success is not due to the efforts of CV21 alone, however, as the company has worked closely with several partners in Japan to turn the idea into a commercial reality. The University of Tokyo studied the fundamentals of how to manufacture the spheres, the company Fujipream addressed module fabrication, Ritsumeikan University performed theoretical analysis of cell efficiency and scientists from the National Institute of Advanced Industrial Science Technology (AIST) also helped.

"Texas Instruments came up with the idea of using silicon spheres about 30 years ago, but the engineering challenges involved meant that they never succeeded in commercializing it," Murozono told *Nature Photonics*. "We're now producing 12,000 cells per day at our facilities in Kyoto and by the end of the year this will be expanded to 48,000 cells. By the end of 2007 we want to be beating the cost-to-performance ratio of conventional crystalline silicon cells."

CV21 says that to hit financial breakeven it needs to produce 60,000 cells per day. Plans are underway to add

Box 1 Cell fabrication and design

Manufacturing the spherical cells in a manner that is both cost-effective and provides high throughput is certainly not an easy task. However, CV21 claims to have solved these challenges and says that it has an operational production line that can make 12,000 cells per day, each containing 1,794 spheres. So what exactly are the stages of cell manufacture? First, the silicon spheres need to be made. CV21 does this by a freefall method that is similar to that used to manufacture lead shot. Silicon (p-type) is melted on a crucible placed at the top of a 12-m-tall tower and then drops are released that freefall to the bottom. During the freefall, surface tension pulls the silicon drops into a spherical shape and they cool and crystallize. According to Murozono, thousands of silicon spheres can be made per minute. Next the spheres pass through a grinding machine to improve their surface quality and the surface is treated to become n-type silicon. An antireflection coating of tin dioxide is then applied to each sphere to optimize their ability to absorb light. Meanwhile the foil substrate is stamped to form miniature hexagonal reflectors, with a 0.7-mm-diameter hole at the base of each reflector cup, and coated in silver. A precision alignment machine then deposits 1,794 spheres into the hexagonal reflectors on the foil substrate and they are bonded into place using a silver paste. The lower surface of each sphere, which is accessible through the hole in the reflector, is then etched for attachment of the p-electrode to the inner p-type region of the sphere by laser sintering of a metal paste. Finally the top surface is coated with a plastic laminate and the rear surface attached to a sheet of aluminium to become a common p-electrode. (Final product shown in Fig. B1). Interestingly, the company says that it has come up with an ingenious additional step that ensures that any defective spheres do not short-circuit a cell and can simply be deactivated, but it did not reveal details of how it achieves this. Murozono stated that the entire manufacturing process from start to finish takes around 2 days and has a yield of 98–99%.

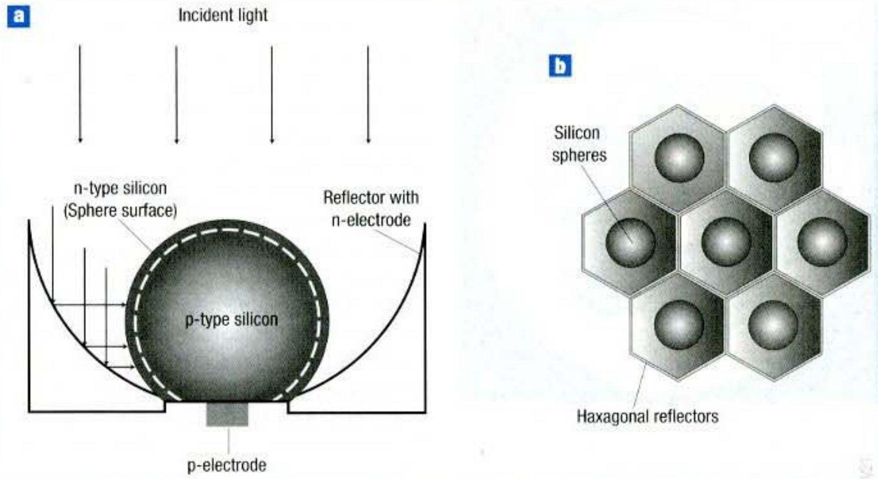
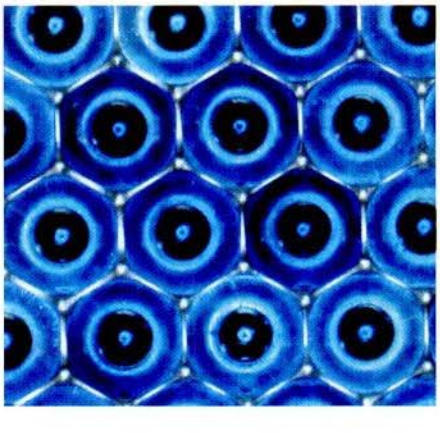


Figure B1 A Schematic of the spherical-cell technology. Each cell is positioned in its own hexagonal reflector to increase the exposure to light and connected to electrodes. **a**, Side view. **b**, Top view.

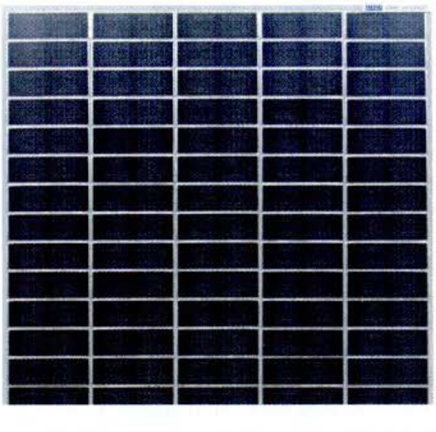
a second factory next year and ramp production to 100,000 cells per day.

As for potential applications for the spherical-cell technology, Murozono believes that hybrid cars are one promising opportunity. The idea is that the cells could be applied to parts of vehicles to help charge the internal battery and help increase the range of such cars.

As with most good ideas, CV21 is not the only firm developing the technology and one of its closest competitors is right on its doorstep. Kyosemi, also based in Kyoto, is developing its own spherical-solar-cell technology, which it calls Sphelar and is based on a similar concept with silicon spheres 1–2 mm in diameter. Unlike CV21, Kyosemi is considering the use of a transparent matrix material between the spheres rather than an opaque foil to help realize applications, such as power-generating windows. The density of the spheres controls the trade-off between the window's transparency and its generation efficiency. The firm has made prototype windows by sandwiching a sheet of its sphelar modules between float glass and says that electrical powers of several tens of watts per square metre are possible. Kyosemi says that it is now in the final stages of commercializing its technology.



Intricate: A close up showing the detailed structure of the cells reveals the individual hexagonal reflectors and silicon spheres.



Scalable: By connecting together an array of cells 15 ×5 cm^2 in size, a large solar panel with higher-power output can be made.