SILICON CELLS

Catching rays

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Sphelar solar-cell technology uses an array of tiny spheres of silicon within a transparent matrix to generate power, promising new opportunities for the use of solar cells in power-generating windows and portable, foldable power supplies.

Conventional solar cells are flat; they have only a single surface for capturing sunlight, and in most cases that surface must be aligned perpendicularly to the incident radiation to achieve maximum power efficiency.

In an effort to improve the power-generation capability of solar cells, Kyosemi has developed Sphelar, a spherical solar-cell technology that captures sunlight in three dimensions. The technology is based on an array of single-crystalline silicon spheres, each measuring 1–2 mm across, embedded in a transparent medium. Each sphere functions as an individual, miniature solar cell (Fig. 1).

This design helps to maximize the effective use of silicon in the solar-cell manufacturing process — an important issue in the silicon solar cell industry, in which almost half of the silicon is lost during slicing because of 'kerf' (cut width) losses.

Several techniques for making spheres from molten silicon are currently under development. One of these, the approach adopted by Kyosemi, takes place under space-like conditions of microgravity. Molten silicon is dripped into a drop tube, with the silicon droplets becoming rounded by surface tension during free-fall. A small segment of one side of the sphere is removed by mechanical grinding. This is followed by an oxidation process, after which all of the outer oxide layer — excluding that covering the small segment — is removed. Phosphorus is then selectively diffused onto the surface, which forms a thin n-type outer layer and thus creates a spherical p–n junction between the inner and outer parts of the sphere (Fig. 2). The p–n junction covers almost the entire outer surface. Small electrodes on the top and bottom are then applied to link the n-doped shell and the p-doped core. This patented electrode arrangement makes the cell non-directive, gives an even distribution of generated current and facilitates serial or parallel connections between cells.

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Figure 1 | Thousands of silicon spheres produced through a molten silicon manufacturing process.

Placing a reflective material underneath the module significantly enhances the power output of the cell, as it gives any light bouncing off the reflector a second chance to be captured.

As shown in Fig. 3, the spherical cells are interconnected with a grid of thin filaments and are encased in either clear glass or a clear flexible membrane. Because each cell is discrete and any combination of serial and/or parallel connections is possible, the system has an inherent tolerance to individual cell faults such as short circuits and shadows.

This design also allows the cells to be used in transparent, flexible and irregularly shaped modules. In particular, the realization of highly transparent solar modules offers an aesthetic solution for power-producing facades, windows and semi-transparent roofs. Such modules have the distinctive features of optional transparency and a bifacial response to incident light, which cannot be achieved using conventional flat-cell technology. For example, Fig. 3 shows a 1.8 m × 0.5 m prototype transparent window photovoltaic module featuring 46,200 spherical cells. A double-glazing configuration with low-emissivity coatings is used to control heat transfer through the window module, which has a potential electrical power output of 13 W.

Spherical solar cell technology has several other advantages over conventional flat-cell technology. First, the power output of a module based on spherical solar cells is less dependent on the angle of incidence of the sunlight than a flat photovoltaic module. Spherical solar cell modules work efficiently at low angles of direct light during a sunny day, and also collect diffuse radiation more effectively than flat photovoltaic cells on a cloudy day.

Second, because spherical solar cell array modules are transparent, the light

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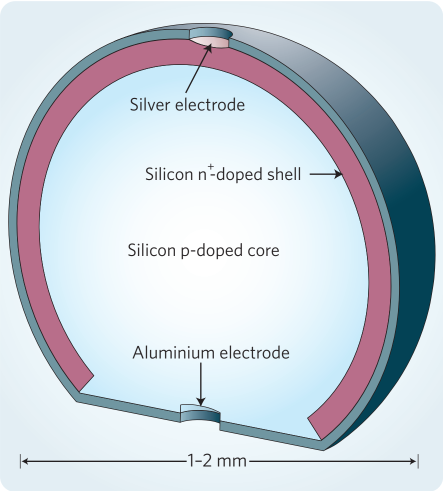

Figure 2 | Each sphere functions as its own silicon p–n junction solar cell. A spherical surface can capture sunlight in three dimensions, thus improving power generation over standard two-dimensional solar cells.

transmitted through them can be used for the natural lighting of a room. When no room lighting is necessary, however, it is possible to use a white curtain or reflective surface to bounce light back onto the module for power generation. Spherical solar cells therefore allow the utilization of sunlight that is normally wasted.

Third, spherical cell modules are less sensitive to partial shadows than traditional photovoltaic modules because of their ability to connect to other cells in either a serial or parallel arrangement. The efficiency and peak power obtained under standard test conditions (irradiance of 1 kW m^{-2}, spectrum of 1.5 air mass and cell temperature of 25 °C) are still frequently used to rate traditional photovoltaic modules. Such standards are inappropriate for testing spherical cells because they do not simulate real outdoor conditions. Instead, because global solar radiation has direct, reflected and diffused components, all of which can be used to generate electricity using Sphelar technology, it is preferable to use the value of the accumulated energy generated by the photovoltaic module. Furthermore, environmental factors such as the daily fluctuating levels of sunshine, solar spectrum and other meteorological parameters will affect the module's behaviour.

To compare spherical cell technology with conventional silicon photovoltaic technology, Kyosemi measured the energy accumulated by several different photovoltaic modules over a 1.5-month period. The investigation was performed on a rooftop in Hokkaido, Japan, in the autumn of 2009. Two spherical cell modules and two flat commercial photovoltaic modules were mounted vertically, with one of each pair facing south and the other facing west. The two spherical cell modules were found to accumulate more energy than the commercial flat modules. The energy generated by the west-facing spherical module was particularly high at 153 W h per 1 Wp, compared with that of the west-facing flat module, which accumulated only 55.9 W h per 1 Wp. The Wp (watt peak power) rating indicates the maximum supply of a module under optimum conditions, and thus allows photovoltaic modules with different parameters to be compared. The relative performance factor of 2.7 between the two modules is attributable to the bifacial response of the spherical cell module.

Kyosemi is currently applying Sphelar technology to low-power, high-value-added products, and many applications are possible. Sphelar technology could be integrated into bags, backpacks or even clothing. It could also be integrated into concentrator modules to increase their power output. Kyosemi has recently developed a compact module that incorporates an array of 12 spherical solar cells together with an array of lenses; irradiated light is concentrated by a factor of four by the lens effect, which greatly increases the power output of the system. Each cell has an output of 2.5 mA or 0.6 V and can be combined in various serial and/or parallel configurations by using different shapes of metal frames. The modules cover a wide range of voltages, from 0.6 V to 7.2 V.

Kyosemi has already shown in two separate demonstrations that Sphelar modules can be used to drive electrical components without any peripheral circuits. In the first, a 52-mm-long module was commercially used in Aimulet LA, an infrared light-activated handheld audio communication device designed by Japan's National Institute of Advanced Industrial Science and Technology. The device receives pulse-width-modulated infrared light via the Sphelar module and translates it into audio messages when the user stands over special infrared LEDs in the ground. The unit is therefore wireless and requires no battery, with its outer shell made from moulded bamboo sheet for environmental considerations. The device was adopted in the Walk Project installation for the World EXPO 2005 in Aichi, Japan, at which visitors used the device to receive audio messages as they wandered around the site.

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Figure 3 | Tiny spherical silicon solar cells can be incorporated into a variety of transparent materials. Left: A prototype glass window panel incorporating 46,200 spherical solar cells, with an estimated power output of around 13 W. Right: A flexible ribbon of transparent plastic containing Sphelar technology allows portable power generation for low-power devices.

In a second demonstration, Sphelar technology was incorporated in U-B-SAFE 1 — a personal UVB (medium-wave ultraviolet) radiation alarm dose meter from Australian company Healthtronics Sunsafe. It informs the user when their skin has absorbed the maximum safe daily amount of UV radiation for their skin type. It can be pinned to a hat to ensure that it is always in direct sunlight and is not inadvertently shaded. This product will be commercially available soon.

An exciting future application area is the integration of Sphelar technology in buildings. Architects from around the world have recognized that spherical solar cells could bring many benefits to their buildings, and prototype modules are already being evaluated by several designers. Such applications will require a high level of product certification, but unfortunately spherical solar cells are still at the development stage. It will therefore be several years before this potential application is fully realized.

Kyosemi is currently investing in ramping up production capacity. When the systems for mass-producing spherical solar cells are in place, the ultimate application of this technology will be for large power plants in sunny locations, where they can be used to generate significant amount of electrical energy. That's where the potential cost benefits of spherical solar cells will be fully realized. ❐

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