Spherical Cells Promise To Expand Applications for Solar Power

By harnessing more sunlight, spherical silicon micro solar cells developed by Kyoto Semiconductor Corp. offer a new direction for solar power generation.

Because it is a clean and renewable, solar power is an attractive source of energy. However, for solar cells to proliferate, two challenges need to be addressed. First, the cost of solar cells must be further reduced. Second, applications for solar cells must be expanded.

In Japan, the New Energy Development Organization (NEDO) leads efforts in this area. Through NEDO's efforts and collaboration among Japan's industrial, academic and government sectors, Japan has grown into the leading producer of solar cells in the world.

Current residential solar power generation systems generate power at a cost of ¥70 to ¥100 per kilowatt-hour. This is roughly three times the cost of conventional residential electrical power and six times that of commercial electric power. This high cost is an important factor in holding back the large-scale proliferation of these systems.

In addition, solar power generation systems are being used only in residential applications as supplemental power to existing power supplies.

With conventional energy sources becoming scarce and with the looming problem of global warming, solar power should be more widely applied.

One way to make better use of solar power is to develop it into a primary power source. To make this practical, power generation costs must be reduced. Also new power generation systems must be developed that would, for example, electrolyze water using surplus electrical power generated during the day to produce hydrogen and oxygen gas. That hydrogen and oxygen would be stored to be later supplied to fuel cells and gas turbines when required to generate electrical power.

Kyoto Semiconductor Corp. has developed spherical silicon micro solar cells designed to play a central role in these solar power generation systems. They also offer the promise of reducing the cost of solar power generation equipment and making such equipment easier to use.

Greater Efficiency

Conventional solar cells employ a flat light-receiving surface regardless of the kind of semiconductor, the shape of the bulk crystals or the structure of the amorphous crystals employed in the cells. Modules consisting of rows of these cells also are typically flat.

Solar cells vary in weight depending on the installation site of the module. Sunlight enters each cell from all directions in the form of direct radiation, reflection and scattering. However, in conventional modules with flat light-receiving surfaces on one side, the light that enters the solar cells is limited to the two-dimensional size of the light-receiving surface. This means that very little of the light shining onto the sides and back of the cells can make any contribution to power generation.

To make sure the modules capture as much sunlight as possible, installers of conventional solar cell modules select the best possible azimuth and angle of inclination for the light-receiving surface. However, when the incident angle changes with the movement of the sun, reflection on the light-receiving surface increases, decreasing power output.

To be more effective, a solar cell must make use of sunlight entering from all directions. This increases optical input, which in turn increases output.

Spherical micro solar cells are such cells. They have a light-receiving surface covering the entire sphere, enabling more light to enter the cells for greater electrical power generation.

Spherical Silicon Crystals

The production of spherical silicon cells differs significantly from the production of conventional solar cells. Bulk solar cells now in use are made from recycled scraps and other remnants of high-purity silicon for semiconductor devices. This silicon is re-melted, formed into ingots and then cut into wafers. They are then formed into square cells measuring 15cm on a side with a thickness of about 0.3mm.

The wafers could be made thinner, which would reduce waste and costs. However, thinner wafers are more likely to break during handling. Thus they are thicker than otherwise necessary only to maintain strength, adding to material costs.

One way to address this problem is through the use of amorphous and microcrystalline structures formed when a silicon thin film is generated from a vapor phase. However, solar cells made in this way have a lower photoelectric conversion efficiency than bulk varieties. Also, they deteriorate more readily than other models, require expensive vapor deposition equipment and need costly high-purity glass as a substrate.

Better Solution

Spherical silicon solar cells offer a better solution. First, the light-receiving surface receives light from all directions. It is made up of silicon formed into spheres with p-n junctions over most surfaces.

Second, spherical cells, formed as microspheres, have a diameter of about 1mm which raises the ratio of surface area to volume. This means a small amount of silicon forms a large light-receiving surface, saving on the cost of materials.

Third, single crystals are produced by melting granular silicon polycrystals and then allowing them to solidify into spheres using surface tension in a microgravity environment. This eliminates the processing loss associated with conventional wafer production, ensuring a high photoelectric conversion efficiency and reducing problems related to deterioration.

The production process begins when granular silicon is fed into the upper melting unit where it melts and then falls (Fig. 1). During the course of falling about 14m in 1.5 seconds, the silicon solidifies into spheres to produce single crystals. During melting, the volume of the silicon shrinks and impurities evaporate from the molten liquid surface. After the silicon solidifies, the purity is further increased by subsequent etching processes to remove impurities on surfaces.

With this method, less silicon is required for producing a cell and processing costs are low. Additionally, this method produces strong, high-quality spherical crystals while conserving resources, saving energy and saving time.

Texas Instruments Inc. (TI) has conducted research on similar methods for producing solar cells using spherical silicon. TI researchers propose spherical solar cells made by affixing silicon spheres that form a p-n junction so as to allow direct contact by two isolated aluminum foil layers on a flat substrate and each p and n surface. Instead of each cell having an independent set of electrodes, the cells are all connected in a row in contact with the aluminum foil while sharing electrodes. Consequently, the positive and negative electrodes of the cells are biasly formed on a common substrate, and the substrate blocks out light on the back side, restricting the capture of surrounding light. In addition, the cells can only be connected in parallel.

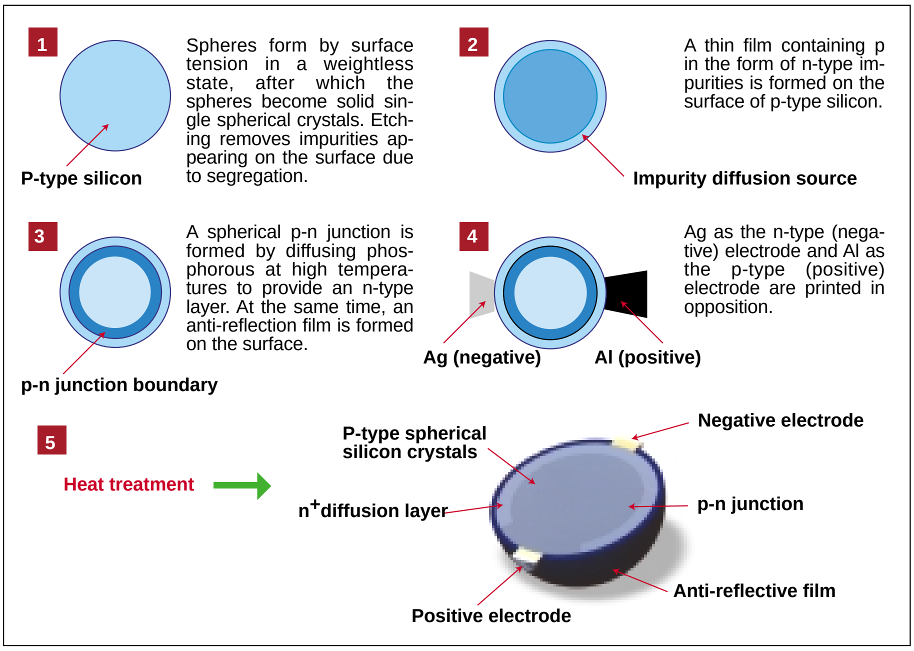


Fig. 2: Structure and production process of spherical micro solar cells with anti-reflection film

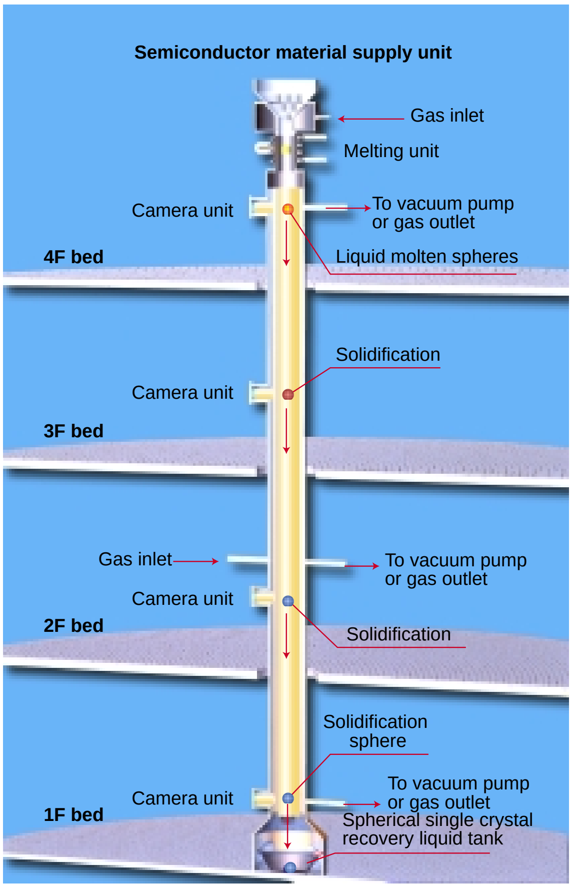


Fig. 1: Method and production equipment for producing spherical single-crystal silicon

In contrast, spherical micro solar cells each have their own independent electrodes, and the cells themselves can each be used alone as minute solar cells. Because the electrodes are provided in opposition at symmetrical locations relative to the center of the sphere, the electrodes of adjacent cells can be directly coupled in series using an adhesive. Because this allows the effective use of light in all directions in addition to the axial direction when the cells are integrated into a module, output is improved and separation results in its non-directivity (Fig. 2).

Compared to conventional processes for making solar cells, the process for making spherical micro solar cells is simple. According to measurements using the light of a solar simulator from a single direction (Fig. 3), output increases by a factor of 1.5 when a reflecting plate is placed in back of the cell. Furthermore, when laterally scattered light is incorporated, output nearly doubles. Therefore, through the effective use of surrounding light, output is significantly higher than that produced by flat solar cells.

Solar Cell Modules

In a conventional residential solar cell module using bulk crystals, a filler sheet and square solar cells measuring 10 to 15cm on a side are arranged on front protective transparent glass. The cells are then connected in series with an inner lead. A laminated sheet is affixed to protect the back of the cells and the entire structure is contained in an aluminum frame. However, because of the size of the wafers, the cells are especially fragile. Also, the modules are troublesome to produce because of all the work of arranging and connecting the cells.

Modules using spherical micro solar cells are much easier to manufacture. These can be produced first by coupling the required number of cells in series and in parallel, and then molding the entire structure, excluding the external terminals, into a single unit with transparent resin, thereby forming a package.

Through the use of curved surfaces, light convergence and reflection are prevented. Also, the package has a coating of anti-reflective film. These features serve to increase the amount of external light reaching the module.

Moreover, the structure uses an optical design that guides as much light as possible to the cell surface inside the resin. That is, the structure is nearly free of components that block light. Light is only blocked in the axial direction, the direction in which the cells are coupled.

A basic module using spherical micro solar cells would typically have a white reflector added to the back side (Fig. 4). Each cell string would have a spherical reverse current preventing diode. The cells would be molded together with transparent resin. The reflector would reflect light that passes between each cell string back onto the backs of the cells, thus increasing the amount of light reaching each cell.

The simplicity of this structure makes it suitable for mass production. Through the use of standard sizes and other means, makers can reduce costs and facilitate efficient coupling.

Solar cell panels using spherical micro solar cells can be made in various sizes, curvatures and colors to match diverse needs (Fig. 5). The modules can also be replaced easily.

These panels can be installed on the sides of buildings and vehicles to take advantage of their low-directivity characteristics. Other uses also will tap the enhanced design.

While solar power has many obvious benefits, many problems still remain. For example, solar power generators cannot be counted on during darkness, and their output fluctuates a great deal. Furthermore, solar power generators take up considerable amount of space and are costly. How these problems are addressed will determine the role solar power generation will play in this century.

Spherical micro solar cells may provide some of the answers. Such cells are more efficient than conventional cells at converting light to power. They also should reduce material and production process costs. In addition, due to the low level of directivity, they allow space to be used three-dimensionally, enabling panels to be installed vertically, thereby saving space.

Because spherical micro solar cells can also be protected with transparent glass, they are suited to methods for generating hydrogen and oxygen. They can, for example, be immersed in an electrolysis tank. In such a tank, the cells could capture sunlight entering the tank and provide energy for hydrolysis. The hydrogen and oxygen generated in this way can be stored, thereby enabling unused electrical energy to be accumulated in the form of chemical energy. This gas can be used for power generation by fuel cells. A power generation system combining solar cells and fuel cells would be able to generate electricity even in the absence of sunlight. Many have high hopes for such systems to stimulate demand for solar cells while at the same time providing a more benign alternative to the use of fossil fuels.

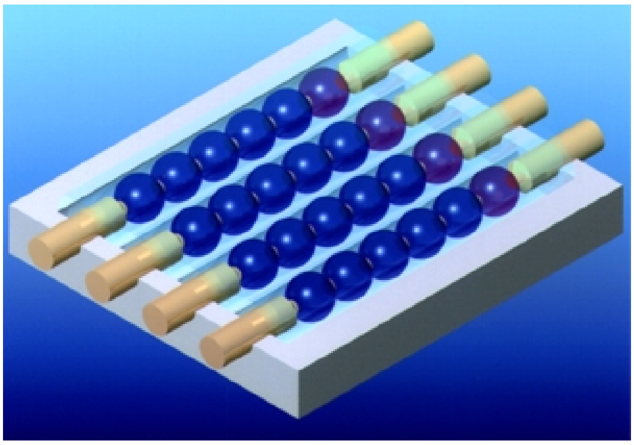


Fig. 4: Basic module using spherical micro solar cells

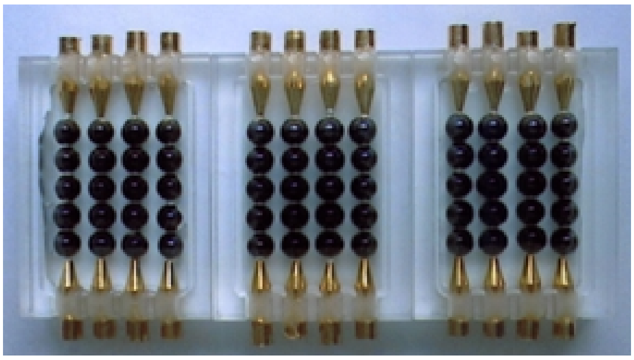
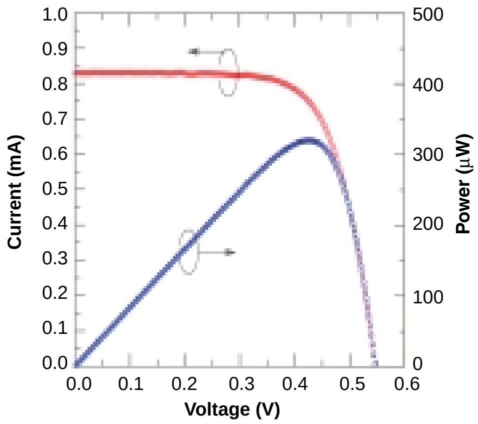
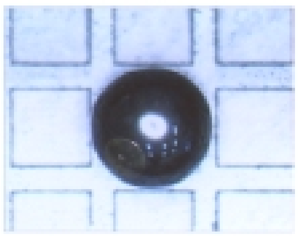


Fig. 5: Prototype of spherical micro solar cell module



Characteristics of spherical micro solar cells (diameter: 1.8mm)

- Output increases roughly 1.5 times when a reflective plate is provided on the back side. When laterally scattered light is incorporated, output nearly doubles.



Ambient temperature : 24¡C
Open circuit voltage Voc = 0.546V
Short circuit Isc = 0.83mA
Current density Jsc = 33.2 mA/cm^2
Optimum operating voltage Vpm = 0.42 V
Optimum operating current Ipm = 0.76 mA
Output power P = 0.319mW
Curve factor FF = 0.7
Conversion efficiency η = 12.7%
(AM 1.5, 100mW/cm^2, no anti-reflective film, irradiated on one side)

Fig. 3: Basic characteristics of spherical micro solar cells

Reference

J.D. Leine, G.B. Hotchkizz and M.D. Hammer-Bacher: Proc. 15th IEEE Photovoltaic Specialist Conference, Las Vegas, IEEE, 141, 1991.

About This Article

The author, Josuke Nakata, is President and Chief Executive Officer of Kyoto Semiconductor Corp.