The Silicon Solar Cell Turns Fifty

John Perlin

The first advertisement for the Bell solar cell.
It appeared in the August 1954 issue of *National Geographic*.

The solar cell that has spawned today's booming photovoltaic industry had a most unexpected birth. But aren't many children surprises?

In 1953, the Bell telephone system had a problem. Traditional dry cell batteries that worked fine in mild climates degraded too rapidly in the tropics and ceased to work when needed. The company asked its famous research arm, Bell Laboratories, to explore other freestanding sources of electricity. It assigned the task to Daryl Chapin. Chapin tested wind machines, thermoelectric generators, and steam engines. He also suggested that the investigation include solar cells, and his supervisor approved the idea.

Chapin soon discovered that selenium solar cells, the only type on the market, produced too little power, a mere five watts per square meter, and converted less than 0.5 percent of the incoming sunlight into electricity. Word of Chapin's problems came to the attention of another Bell researcher, Gerald Pearson. This was not strange, since Pearson and Chapin had been friends for years. They had attended the same university, and Pearson had even spent time on Chapin's tulip farm.

At the time, Pearson was engaged in pioneering semiconductor research with Calvin Fuller. They took silicon solid-state devices from their experimental stage to commercialization. Fuller, a chemist, had discovered how to control the introduction of the impurities necessary to transform silicon from a poor to a superior conductor of electricity.

Gerald Pearson, Daryl Chapin, and Calvin Fuller (left to right), the principal developers of the silicon solar cell, measuring current from one of the first solar-electric cells.

P-N Junction

Fuller provided Pearson with a piece of silicon containing a small amount of gallium. The introduction of gallium made it positively charged. Pearson then dipped the gallium-rich silicon into a hot lithium bath, according to Fuller's instructions. Where the lithium penetrated, an area of poorly bound electrons was created, and it became negatively charged. A permanent electrical force developed where the positive and negative silicon meet. This is the P-N junction, the core of any semiconductor device.

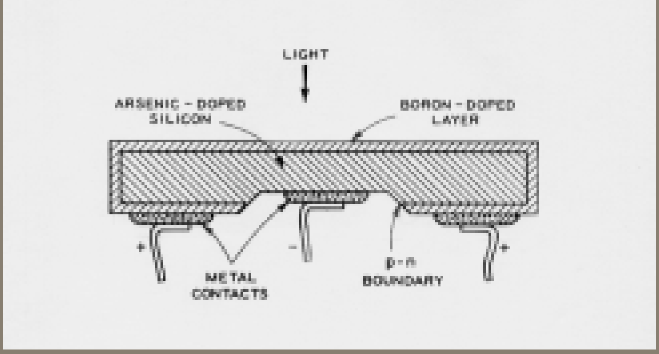
The P-N junction is like a dry riverbed, which has an incline that provides the means for flow, should it fill with water. The P-N junction will push electrons in an orderly fashion, commonly called electrical current, when some type of energy hits those loosely bound electrons nearby with enough power to tear them away from their atomic glue. Shining lamplight onto the lithium-gallium doped silicon provided the necessary energy, and Pearson's ammeter recorded a significant electron flow. To Pearson's surprise, he had made a solar cell superior to any other available at the time.

Calvin Fuller placing arsenic-laced silicon into a quartz-tube furnace where he introduced a controlled amount of boron to the material. This resulted in the first solar cell that could generate significant amounts of electricity.

Silicon Is the Answer

Hearing of his colleague's poor results with selenium, Pearson went directly to Chapin's office to advise him not to waste another moment on selenium, and to start working on silicon. Chapin's tests on the new material proved Pearson right. Exposing Pearson's silicon solar cell to strong sunlight, Chapin found that it performed significantly better than the selenium—it was five times more efficient.

An original cross-section diagram from Bell Laboratories of the first Bell power cell doped with boron and arsenic.



Theoretical calculations brought even more encouraging news. An ideal silicon solar cell, Chapin figured, could use 23 percent of the incoming solar energy to produce electricity. But building a silicon solar cell that would convert around 6 percent of sunlight into electricity would satisfy Chapin and rank as a viable energy source. His colleagues concurred and all his work focused on this goal.

Try as he might, though, Chapin could not improve on what Pearson had accomplished. "The biggest problem," Chapin reported, "appears to be making electrical contact to the silicon." Not being able to solder the leads right to the cell forced Chapin to electroplate a portion of the negative and positive silicon layers to tap into the electricity generated by the cell. Unfortunately, no metal plate would adhere well, presenting a seemingly insurmountable obstacle to grabbing more of the electricity generated.

Moving the Junction

Chapin also had to cope with the inherent instability of the lithium-bathed silicon, which moved deep into the cell at room temperatures. This caused the location of the P-N junction, the core of any photovoltaic device, to leave its original location at the surface, making it more difficult for light to penetrate the junction, where all photovoltaic activity occurs.

Then, an inspired guess changed Chapin's tack. He correctly hypothesized, "It appears necessary to make our P-N junction very next to the surface so that nearly all the photons are effective." He turned to Calvin Fuller for advice on creating a solar cell that would permanently fix the P-N junction at the top of the cell.

Coincidentally, Fuller had done just that two years earlier while trying to make a transistor. He then replicated his prior work to satisfy his colleague's need. Instead of doping the cell with lithium, the chemist vaporized a small amount of phosphorous onto the otherwise positive silicon. The new concoction almost doubled previous performance records.

Solar Cell vs. Atomic Battery

Still, the lingering failure to obtain good contacts frustrated Chapin from reaching the 6 percent efficiency goal he was aiming for. While Chapin's work reached an impasse, arch rival RCA announced that its scientists had come up with a nuclear-powered silicon cell, dubbed the atomic battery. Its development coincided with the U.S. Atoms for Peace program, which promoted the use of nuclear energy throughout the world.

Instead of photons supplied by the sun, the atomic battery ran on those emitted from Strontium 90, one of the deadliest nuclear residues. To showcase the new invention, RCA decided to put on a dramatic presentation in New York City. David Sarnoff, founder and president of RCA, who had initially gained fame as the telegraph operator who tapped out the announcement to the world that the Titanic had sunk, hit the keys of an old-fashioned telegraph powered by the atomic battery to send the message, "Atoms for Peace." The atomic battery, according to RCA, would one day power homes, cars, and locomotives with radioactive waste—Strontium 90—produced by nuclear reactors.

What its public relations people failed to mention, however, was why the Venetian blinds had to be closed during Sarnoff's demonstration. Years later, one of the lead scientists involved in the project came clean: If the silicon device had been exposed to the sun's rays, solar energy would have overpowered the contribution of the Strontium 90. Had the nuclear element been turned off, the battery would have continued to work on the solar energy streaming through the window.

The director of RCA Laboratories did not mince words when he ordered his scientific staff to go along with the deception, telling them, "Who cares about solar energy? Look, what we have is this radioactive waste converter. That's the big thing that's going to catch the attention of the public, the press, the scientific community."

The director had gauged the media well. *The New York Times*, for example, called Sarnoff's demonstration "prophetic." It predicted that electricity from the atomic battery would allow "hearing aids and wrist watches [to] run continuously for the whole of a man's useful life."

Cells with a Future

RCA's success stirred management at Bell Laboratories to pressure the solar investigators to hurry up and produce something newsworthy as well. Luckily for them, Fuller had busied himself in his lab to discover an entirely new way to make more efficient solar cells. He began with silicon cut into long, narrow strips modeled after Chapin's best performing cells. That's where the similarity ended.

Instead of adding gallium to the pure silicon and producing positive silicon, Fuller introduced a minute amount of arsenic to make the starting material negative. Then he placed the arsenic-doped silicon into a furnace to coat it with a layer of boron. The controlled

The success of the boron-doped silicon solar cells that allowed the Bell scientists to achieve their goal is shown in this table. Bell produced the first true solar cells, and spawned today's PV industry.

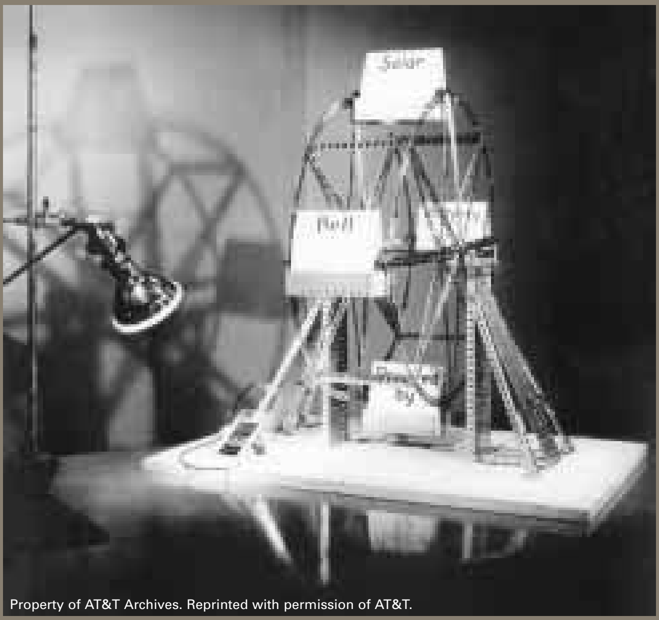
TABLE I

	Cell #88 Area = 4.85 cm^2		Cell #90 Area = 4.85 cm^2	
Total Resistance (including Meter)	Current	Power	Current	Power
0.11 ohms	114 mils		110.5 mils	
1.08	110	13.1 mw	109.0	12.8 mw
1.50	108.5	17.65	107.5	17.3
2.16	105.2	23.85	104.5	23.6
3.20	96.0	29.5	94.0	28.3
4.69	79.6	29.7	78.0	28.5
6.81	61.5	25.7	60.0	24.5
10.01	44.6	19.9	44.0	19.4
10,000	0.0552		0.0535	

Cell #88: Open circuit voltage = 0.552 v
Max. Power = 61 watts/m^2
= 5.65 watts/sq. ft.

Cell #90: Open circuit voltage = 0.535 v
Max. Power = 58.8 watts/m^2
= 5.47 watts/sq. ft.

Image credit to Lucent Technologies.



One of Bell's first silicon solar modules powers a Ferris wheel built from an Erector set at the first public demonstration on April 25, 1954.

introduction of an ultrathin layer of boron gave the cell a P-N junction extremely close to the surface. The Bell team had no trouble in making good electrical contacts to the boron-arsenic silicon cells, resolving the main obstacle in extracting electricity when exposing them to sunlight.

All cells built according to Fuller's new method did much better than previously. One, however, outperformed the rest, reaching the efficiency goal Chapin had set. The best-performing cell seemed to have the ideal width for peak performance. Bell scientists built cells to the same dimensions as that best-performing cell.

Chapin then confidently referred to these as "photocells intended to be primary power sources." Assured of success, the Bell solar team began putting together modules to publicly demonstrate this major breakthrough. On April 25, 1954, proud Bell executives held a press conference where they impressed the media with Bell solar cells powering a radio transmitter, broadcasting voice and music.

One journalist thought it important for the public to know that "linked together electrically, the Bell solar cells deliver power from the sun at the rate of fifty watts per square yard while the atomic cell announced recently by the RCA Corporation merely delivers a millionth of a watt" over the same area. *U.S. News & World Report* believed one day such silicon strips "may provide more power than all the world's coal, oil, and uranium."

Harnessing the Sun

The New York Times probably best summed up what Chapin, Fuller, and Pearson had accomplished. On page one of its April 26, 1954 issue, it stated that the construction of the first PV module to generate useful amounts of electricity marks "the beginning of a new era, leading eventually to the realization of one of mankind's most cherished dreams—the harnessing of the almost limitless energy of the sun for the uses of civilization."

Just think: fifty years ago the world had less than a watt of solar cells capable of running electrical equipment. Today, fifty years later, a billion watts of solar-electric modules are in use around the world.

They run satellites; ensure the safe passage of ships and trains; bring water, electricity, and telephone service to many who had done without; and supply clean energy to those already connected to the grid. We hope that the next fifty years will see solar cells on rooftops throughout the world, fulfilling the expectation triggered by the pioneering work of Chapin, Fuller, and Pearson.

Access

John Perlin, 102 North Hope Ave., #80, Santa Barbara, CA 93110 • solarperlin@aol.com • This article is an adaptation from material in John's book, *From Space to Earth: The Story of Solar Electricity*, reviewed in *HP75*.

The author thanks the National Renewable Energy Laboratory and the National Center for Photovoltaics for funding his work, which formed an exhibit as a highlight of the 3rd World Conference on Photovoltaics Energy Conversion, May 11-16, 2003, Osaka, Japan, and has become a permanent exhibit at the National Renewable Energy Laboratory.

From Space to Earth: The Story of Solar Electricity, John Perlin, 2002, ISBN 0-674-01013-2, 240 pages, paper, US$22.95 from Harvard University Press, 79 Garden St., Cambridge, MA 02138 • 800-405-1619 or 401-531-2800 • Fax: 800-406-9145 or 401-531-2801 • customer.care@triliteral.org • www.hup.harvard.edu/catalog/PERFRX.html