The Silicon Solar Cell Turns 50

by John Perlin

Daryl Chapin, Calvin Fuller, and Gerald Pearson likely never imagined inventing a solar cell that would revolutionize the photovoltaics industry. There wasn't even a photovoltaics industry to revolutionize in 1952.

The three scientists were simply trying to solve problems within the Bell telephone system. Traditional dry cell batteries, which worked fine in mild climates, degraded too rapidly in the tropics and ceased to work when needed. The company therefore asked its famous research arm—Bell Laboratories—to explore alternative sources of freestanding power. Daryl Chapin got the assignment. At that time, his job was to test wind machines, thermoelectric gensets, and steam engines. Being a solar energy enthusiast, he suggested that the investigation include solar cells. His supervisor approved the idea.

The inventors of the Bell Solar Battery, from left, Gerald Pearson, Daryl Chapin, and Calvin Fuller, check devices for the amount of solar electricity derived from sunlight, here simulated by a lamp.

Chapin began work in February 1952, but his initial research with selenium was unsuccessful. Selenium solar cells, the only type on the market, produced too little power—a mere 5 watts per square meter—converting less than 0.5% of the incoming sunlight into electricity. Word of Chapin's problems came to the attention of another Bell researcher, Gerald Pearson. The two scientists had been friends for years. They had attended the same university, and Pearson had even spent time on the Chapins' tulip farm.

At the time, March 1953, 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. Fuller provided Pearson with a piece of silicon containing a small concentration 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. The spot where the lithium penetrated created an area of poorly bound electrons and became negatively charged.

Then came the test. Pearson shined light from a lamp onto the lithium-gallium silicon. One can only guess whether or not he crossed his fingers. An ammeter connected to the silicon recorded a significant electrical flow. Much to his surprise, Pearson had made a solar cell superior to any other available at the time.

Switching to Silicon

Pearson went directly to Chapin's office and advised him to switch to silicon, rather than wasting another moment on selenium. Chapin's tests on this new material proved Pearson right. Exposing Pearson's silicon solar cell to strong sunlight, Chapin found that it performed significantly better—five times more efficiently, in fact—than selenium. Theoretical calculations brought even more encouraging news. An ideal silicon solar cell, Chapin figured, could convert 23% of sunlight into electricity. Developing a silicon solar cell with 6% conversion efficiency, though, would satisfy Chapin and rank as a viable power source. His colleagues concurred, and all his work focused on this goal.

However, try as he might, Chapin could not improve on Pearson's accomplishment. "The biggest problem appears to be making electrical contact to the silicon," Chapin reported. Not being able to solder the leads directly to the cell forced Chapin to electroplate a portion of the negative and positive silicon layers in order to tap into the electricity generated by the cell. Unfortunately, no metal plate would adhere very well, thus presenting a seemingly insurmountable obstacle to collecting more of the electricity generated. Chapin also had to cope with the inherent instability of the lithium-bathed silicon, because the lithium migrated through the cell at room temperature. This caused the location of the p-n junction, the core of any photovoltaic device, to shift from its original location near the surface, making it more difficult for light to penetrate the junction where all electrical activity occurs.

Then an inspired guess changed Chapin's tack. He correctly hypothesized that "it appears necessary to make our p-n junction very near 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 very close to the top of the cell. Coincidentally, Fuller had done that very thing two years earlier while trying to make a transistor. He therefore replicated his prior work to satisfy his colleague's need. Instead of doping the cell with lithium, Fuller vaporized a small amount of phosphorous onto the otherwise positive silicon. The new concoction almost doubled previous performance records. Still, the lingering failure to obtain good contacts frustrated Chapin from reaching the 6% efficiency goal.

"The biggest problem appears to be making electrical contact to the silicon," Chapin reported. The problem was solved when Fuller incorporated an ultra-thin layer of boron, which gave the cell a p-n junction that was extremely close to the surface.

The Competition Heats Up

While Chapin's work reached an impasse, Bell's competitor, RCA, announced that its scientists had come up with a nuclear-powered silicon cell dubbed the Atomic Battery. Its development coincided with America's Atom's for Peace program, which promoted the use of nuclear power throughout the world. Instead of photons supplied by the sun, the Atomic Battery ran on photons from strontium-90 (which is now classified as one of the more hazardous constituents of nuclear waste). 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."

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

The Atomic Battery, according to RCA, would some 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 room's blinds had to be closed during Sarnoff's demonstration. Years later, one of the lead scientists involved in the project told the rest of the story: 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 component been removed, the battery would have continued to work on sunlight if allowed to stream into the building. "Who cares about solar energy?" said the director of RCA Laboratories. "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," and predicted that power from the Atomic Battery would allow "hearing aids and wrist watches [to] run continuously for the whole of a man's useful life."

Proof of Concept

RCA's success stirred management at Bell Laboratories to pressure the solar investigators to hurry up and produce something newsworthy. Luckily for them, Fuller had busied himself in his lab and discovered 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. But 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 introduction of an ultra-thin layer of boron gave the cell a p-n junction that was extremely close to the surface. The Bell team had no trouble making good 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. Chapin now confidently referred to the silicon solar cells the lab now produced as "power photocells intended to be primary power sources." Assured of success, the Bell solar team began putting together modules for a public demonstration of this exciting breakthrough.

A Bell technician measures the characteristics of a completed solar battery. According to a Bell Labs press release, the 6% efficiency "compares favorably with the efficiency of steam and gasoline engines, in contrast with other photoelectric devices which have never been rated higher than 1%."

Telling the World

On April 25, 1954, proud Bell executives held a press conference where they impressed the media with the Bell Solar Battery powering a radio transmitter that was 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 50 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. An article in *U.S. News & World Report* speculated that one day such silicon strips "may provide more power than all the world's coal, oil, and uranium." *The New York Times* probably best summed up what Chapin, Fuller, and Pearson had accomplished. On page one of its April 26, 1954, issue, the *Times* stated that the construction of the first solar module to generate useful amounts of power 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."

In 1954, the world had less than a watt of solar cells capable of running electrical equipment. Fast-forward through 50 years of continued discovery and development of silicon and other PV materials and this is what you'll see. Today, a billion watts of electricity generated by solar cells help to power the satellites so necessary for modern life, ensure the safe passage of ships and trains, bring abundant water, lighting, and telephone service to many who had done without, and supply clean power to those already connected to the grid.

The worldwide market for solar electric energy has grown by 20%–25% per year over the past 10 years. According to *Solarbuzz*, the international solar electric industry now generates around \$3–\$4 billion (U.S.) in revenues each year.

With each passing year, the expectation triggered by the pioneering work of Chapin, Fuller, and Pearson—the harnessing of almost limitless energy from the sun—comes closer to being fulfilled. But the revolution is not yet won. The hope for the next 50 years is to see solar cells providing power throughout the world and being used in ways we can't even imagine today.

Advertisement photos, such as this one that appeared in the 1956 issue of Look Magazine, show off the "Bell Solar Battery" to the American public.

About the Author: John Perlin served as a consultant for the exhibit developed by the National Renewable Energy Laboratory and the National Center for Photovoltaics. First shown at the 3rd World Conference on PV Energy Conversion, Osaka, Japan, May 11–16, 2003, the exhibit celebrates the 50th anniversary of the development of the silicon solar cell. The article is an adaptation from material in Mr. Perlin's book, *From Space to Earth: The Story of Solar Electricity*, 2002, Harvard University Press. For further information, contact Mr. Perlin at 805-569-2740 or solarperlin@aol.com

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