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# СОЛНЕЧНЫЕ  БАТАРЕИ: АЛЬТЕРНАТИВНЫЕ ИСТОЧНИКИ ЭНЕРГИИ

# SOLAR CELLS : ALTERNATIVE ENERGY SOURCES

A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

Assemblies of cells used to make solar modules which are used to capture energy from sunlight, are known as solar panels. The energy generated from these solar modules, referred to as solar power.

Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight.

Cells are described as photovoltaic cells when the light source is not necessarily sunlight. These are used for detecting light or other electromagnetic radiation near the visible range, for example infrared detectors, or measurement of light intensity.

## History of solar cells

The term "photovoltaic" comes from the Greek word  meaning "light", and "voltaic", from the name of the Italian physicist Volta, after whom a unit of electro-motive force, the volt, is named. The term "photo-voltaic" has been in use in

English since 1849.

The photovoltaic effect was first recognized in 1839 by French physicist A. E. Becquerel. However, it was not until 1883 that the first photovoltaic cell was built, by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form the junctions. The device was only around 1% efficient. In 1888 Russian physicist Aleksandr Stoletov built the first photoelectric cell (based on the outer photoelectric effect discovered by Heinrich Hertz earlier in 1887). Albert Einstein explained the photoelectric effect in 1905 for which he received the Nobel prize in Physics in 1921. Russell Ohl patented the modern junction semiconductor solar cell in 1946, which was discovered while working on the series of advances that would lead to the transistor.

The modern photovoltaic cell was developed in 1954 at Bell Laboratories. The highly efficient solar cell was first developed by Daryl Chapin, Calvin Souther Fuller and Gerald Pearson in 1954 using a diffused silicon p-n junction. At first, cells were developed for toys and other minor uses, as the cost of the electricity they produced was very high; in relative terms, a cell that produced 1 watt of electrical power in bright sunlight cost about $250, comparing to $2 to $3 for a coal plant.

Solar cells were rescued from obscurity by the suggestion to add them to the Vanguard I satellite. There was some skepticism at first, but in practice the cells proved to be a huge success, and solar cells were quickly designed into many new satellites, notably Bell's own Telstar.

Improvements were slow over the next two decades, and the only widespread use was in space applications where their power-to-weight ratio was higher than any competing technology.

In the late 1960s, Elliot Berman was investigating a new method for producing the silicon feedstock in a ribbon process. However, he found little interest in the project and was unable to gain the funding needed to develop it. In a chance encounter, he was later introduced to a team at Exxon who were looking for projects 30 years in the future. The group had concluded that electrical power would be much more expensive by 2000, and felt that this increase in price would make new alternative energy sources more attractive, and solar was the most interesting among these. In 1969, Berman joined the Linden, New Jersey Exxon lab, Solar Power Corporation (SPC).

The first improvement was the realization that the existing cells were based on standard semiconductor manufacturing process, even though that was not ideal. This started with the boule, cutting it into disks called wafers, polishing the wafers, and then, for cell use, coating them with an anti-reflective layer. Berman noted that the rough-sawn wafers already had a perfectly suitable anti-reflective front surface, and by printing the electrodes directly on this surface, two major steps in the cell processing were eliminated. The team also explored ways to improve the mounting of the cells into arrays, eliminating the expensive materials and hand wiring used in space applications. Their solution was to use a printed circuit board on the back, acrylic plastic on the front, and silicone based glue between the two, potting the cells. But the largest improvement in price point was Berman's realization that existing silicon was effectively "too good" for solar cell use; the minor imperfections that would ruin a boule (or individual wafer) for electronics would have little effect in the solar application. Solar cells could be made using cast-off material from the electronics market.

Putting all of these changes into practice, the company started buying up "reject" silicon from existing manufacturers at very low cost. By using the largest wafers available, thereby reducing the amount of wiring for a given panel area, and packaging them into panels using their new methods, by 1973 SPC was producing panels at $10 per watt and selling them at $20 per watt, a fivefold decrease in prices in two years.

In the time since Berman's work, improvements have brought production costs down under $1 a watt, with wholesale costs on the order of $2.

As the semiconductor industry moved to ever-larger boules, older equipment became available at fire-sale prices. Cells have grown in size as older equipment became available on the surplus market. Another major change was the move to polycrystalline silicon. This material has less efficiency, but is less expensive to produce in bulk. The widespread introduction of flat screen televisions in the late 1990s and early 2000s led to the wide availability of large sheets of high-quality glass, used on the front of the panels.

Other technologies have tried to enter the market. First Solar was briefly the largest panel manufacturer in 2009, in terms of yearly power produced, using a thin-film cell sandwiched between two layers of glass.

## Applications

Solar cells are often electrically connected and encapsulated as a module. Photovoltaic modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain, hail, etc. Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current. Modules are then interconnected, in series or parallel, or both, to create an array with the desired peak DC voltage and current.

To make practical use of the solar-generated energy, the electricity is most often fed into the electricity grid using inverters (grid-connected photovoltaic systems); in stand-alone systems, batteries are used to store the energy that is not needed immediately. Solar panels can be used to power or recharge portable devices.

## Theory

The solar cell works in three steps:

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
2. Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
3. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

## Efficiency

The efficiency of a solar cell may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of each of these individual efficiencies.

Due to the difficulty in measuring these parameters directly, other parameters are measured instead: thermodynamic efficiency, quantum efficiency, integrated quantum efficiency, $V_{OC}$ ratio, and fill factor.

Crystalline silicon devices are now approaching the theoretical limiting efficiency of 29%.

**Materials**

The Shockley-Queisser limit for the theoretical maximum efficiency of a solar cell. Semiconductors with bandgap between 1 and 1.5eV have the greatest potential to form an efficient cell.

Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth surface. However, some solar cells are optimized for light absorption beyond Earth's atmosphere as well. Light absorbing materials can often be used in multiple physical configurations to take advantage of different light absorption and charge separation mechanisms.

Materials presently used for photovoltaic solar cells include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide.

Many currently available solar cells are made from bulk materials that are cut into wafers between 180 to 240 micrometers thick that are then processed like other semiconductors.

Other materials are made as thin-films layers, organic dyes, and organic polymers that are deposited on supporting substrates. A third group are made from nanocrystals and used as quantum dots (electron-confined nanoparticles). Silicon remains the only material that is well-researched in both bulk and thin-film forms.

- Crystalline silicon

By far, the most prevalent bulk material for solar cells is crystalline silicon (abbreviated as a group as c-Si), also known as "solar grade silicon". Bulk silicon is separated into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon, or wafer.

1. monocrystalline silicon (c-Si). Single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most c-Si panels have uncovered gaps at the four corners of the cells.

2. Poly- or multicrystalline silicon (poly-Si or mc-Si. Poly-Si cells are less expensive to produce than single crystal silicon cells, but are less efficient.

- <u>Cadmium telluride solar cell</u>

A cadmium telluride solar cell uses a cadmium telluride (CdTe) thin film, a semiconductor layer to absorb and convert sunlight into electricity.

The cadmium present in the cells would be toxic if released. However, release is impossible during normal operation of the cells and is unlikely during fires in residential roofs. A square meter of CdTe contains approximately the same amount of Cd as a single C cell Nickel-cadmium battery, in a more stable and less soluble form.

- <u>Copper indium galium selenide</u>

Copper indium gallium selenide (CIGS) is a direct-bandgap material. It has the highest efficiency (~20%) among thin film materials. Traditional methods of fabrication involve vacuum processes including co-evaporation and sputtering.

- <u>Light-absorbing dyes (DSSC)</u>

Dye-sensitized solar cells (DSSCs) are made of low-cost materials and do not need elaborate equipment to manufacture.

Typically a ruthenium metalorganic dye is used as a monolayer of light-absorbing material.

- <u>Organic/polymer solar cells</u>

Organic solar cells are a relatively novel technology, yet hold the promise of a substantial price reduction (over thin-film silicon) and a faster return on investment.

Organic solar cells and polymer solar cells are built from thin films (typically 100 nm) of organic semiconductors including polymers, such as polyphenylene vinylene and small-molecule compounds like copper phthalocyanine (a blue or green organic pigment) and carbon fullerenes and fullerene derivatives. Energy conversion efficiencies achieved to date using conductive polymers are low compared to inorganic materials.

These devices differ from inorganic semiconductor solar cells in that they do not rely on the large built-in electric field of a PN junction to separate the electrons and holes created when photons are absorbed. The active region of an organic device consists of two materials, one which acts as an electron donor and the other as an acceptor.

## Manufacture

Because solar cells are semiconductor devices, they share some of the same processing and manufacturing techniques as other semiconductor devices such as computer and memory chips. However, the stringent requirements for cleanliness and quality control of semiconductor fabrication are more relaxed for solar cells.

Poly-crystalline silicon wafers are made by wire-sawing block-cast silicon ingots into very thin (180 to 350 micrometer) slices or wafers.

## Lifespan

Most commercially available solar panels are capable of producing electricity for at least twenty years. The typical warranty given by panel manufacturers is over 90% of rated output for the first 10 years, and over 80% for the second 10 years. Panels are expected to function for a period of 30 – 35 years.

## Research topics

There are currently many research groups active in the field of photovoltaics in universities and research institutions around the world. This research can be divided into three areas: making current technology solar cells cheaper and/or more efficient to effectively compete with other energy sources; developing new technologies based on new solar cell architectural designs; and developing new materials to serve as light absorbers and charge carriers.

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