Photovoltaic Materials

During the worldwide energy crisis in the 1970s, researchers focused enormous effort toward developing new energy sources, including "clean and inexhaustible" solar power. Unlike electric generators, solar cells have no moving parts, thus eliminating one common wear mechanism. And unlike batteries or fuel cells, solar cells produce no pollution from using chemical reactions to produce power.

Small solar cells placed into arrays can be used to generate power in remote locations, such as for water pumps in the deep desert, navigational beacon buoys at sea, and satellites in space. Thousands of cells can work together as central electric power stations, or smaller arrays can power hand calculators and portable telephones. They can operate almost indefinitely if protected from damage.

The concepts and crude prototypes for solar power have been around for about a century and a half. The theory behind solar cells was first touched on in 1839 by the physicist Becquerel in France. Becquerel experimented with a solid electrode immersed in an electrolyte solution, observing that a voltage developed when light fell upon the electrode. This is called the photovoltaic effect.

In 1887 Heinrich Rudolf Hertz, a physicist in Germany, discovered the photoelectric effect. Hertz observed that ultraviolet light could facilitate a spark across an air gap between metallic electrodes. It wasn't until 1899 that Joseph J. Thomson (discoverer of the electron) and Philipp Edward Anton Lenard determined that light was causing the emission of electrons from the surface of a material. By 1902, Lenard had also shown that the number of electrons emitted per second from a photoelectric material was proportional to the intensity of the incident light, but that the energy of those electrons depended on the wavelength of the incident light. This result was puzzling and incomprehensible to the classical physics community at the time, and was not resolved until 1905, when Albert Einstein proposed a quantum theory on the dual nature of light. It was primarily for this work that Einstein won the Nobel Prize in 1921.

Working from the 50-year-old theories of Becquerel, Charles Fritts constructed the first actual solar cell in 1889 by coating the semiconductor selenium with an extremely thin layer of gold. Though Fritts' prototype cells succeeded in converting only 1% of the incident sunlight into electricity, they fostered visions of clean and inexhaustible power (which must have seemed very desirable in the dirty, early days of the industrial revolution). Two years after Fritts created his first cell, R. Appleyard wrote excitedly of "the blessed vision of the Sun, no longer pouring his energies unrequited into space, but by means of photoelectric cells...gathered into electrical storehouses to the total extinction of steam engines and the utter repression of smoke."

Also in 1889, Julius Elster and Hans Gertel published the first of a long series of papers on photoelectricity. They showed that when certain metals (including potassium, sodium, zinc, and aluminum) were amalgamated with mercury, they became photoelectrically sensitive not only to the ultraviolet light Hertz had used, but also to visible light—which meant the effect was caused by simple sunlight. A plate of zinc in air at atmospheric pressure could acquire a potential difference of up to 2.5 volts. Elster and Gertel also showed that other metals—tin, copper, and iron—remained inactive.

The following year they designed the forerunner of a modern photoelectric cell, an evacuated glass bulb containing alkali metals or their alloys or amalgams. With an external battery to provide a positive potential, this cell produced an electric current when illuminated by visible light. In 1892, they used a device operating on the same principle as the first photoelectric photometer, measuring ultraviolet radiation from the sun.

By 1927 a metal-semiconductor-junction solar cell had been made of copper and copper oxide. In 1930 and 1931, B. Lange and L. Bergman, respectively, discovered the photoelectric effect in selenium barrier-layer cells. Actually, this work had already been done in 1876 by W.G. Adams and R.E. Day, but went unnoticed. In the decade of the 1930s, Lange as well as L.O. Grendahl in the United States and Walter Schottky in Switzerland conducted detailed studies of selenium and cuprous oxide photovoltaic cells. Both types of cells were used in light-sensitive devices, although their conversion efficiencies still rarely exceeded 1%.

A breakthrough finally occurred in 1941, when Russell Ohl proposed using silicon for a photovoltaic cell. Not until 13 years later, however, did an engineer—Paul Rappaport in America—conceive of using silicon photovoltaic cells as relatively efficient power sources. Later in 1954, Daryl M. Chapin, G.L. Pearson, and Calvin Fuller demonstrated a functioning silicon solar cell capable of 6% energy conversion efficiency when used in direct sunlight.

Silicon is now the most commonly used semiconductor material for photovoltaic cells. This material is useful at wavelengths less than 1,100 nm, which is the visible and near-infrared region of the spectrum. While selenium and copper-oxide photovoltaic cells use a semitransparent metallic film of gold or platinum deposited on the semiconductor surface to create the necessary potential barrier, silicon solar cells use the p-n junctions within two adjacent layers of silicon; the layers of silicon are doped with impurities of arsenic or boron to create electrons and holes that generate a potential difference.

Such semiconductor cells can be extremely thin, about a millimeter or less. However, the power generated depends on the total surface area illuminated by sunlight. Current manufacturing techniques make silicon solar cells about 1 cm wide by 2 cm long, but power arrays can contain as many as 20,000 individual cells. Until the early 1960s, silicon solar cells such as the Bell battery functioned at up to 12% efficiency and could produce a current of about 40 mA/cm^2. Bell solar batteries were put to use as power sources on satellites.

In the 1970s, a great many semiconducting materials were used in effective photovoltaic cells, including gallium arsenide, indium phosphide, copper indium selenide, cadmium sulfide, and cadmium telluride. Efficiencies with some of these materials reached 20% when used in direct sunlight. In 1989 a "concentrator solar cell," which uses lenses to concentrate sunlight onto the cell surface, reached an efficiency of 37%.

Solar cells are now frequently used in specialized applications such as toys, calculators, portable phones, and radios, where power needs are usually less than a kilowatt. Widespread application of solar cells has been hindered by their cost—solar electricity still costs about 100 to 1,000 times as much as conventionally generated electricity. And because their peak efficiencies are possible only during days of total sunlight, solar cells are impractical in cloudy climates. New materials, improved fabrication techniques, and more efficient solar cell designs, however, are bringing the cost down and making solar cells more feasible.

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