Solar cell

Contributed by: K. W. Mitchell, Margorie L. Tatro

Publication year: 2017

Key Concepts

- Solar cells, also known as photovoltaic (PV) cells, are devices that convert light energy directly to electrical energy.
- A solar cell consists of a semiconductor material (such as silicon), an electrical junction, and electrical terminals to conduct electric current.
- Energy conversion in a solar cell involves three major processes: light absorption in the semiconductor material; generation and separation of charges to create a voltage; and transfer of these charges through terminals to the outside application.
- When light is absorbed in the semiconductor, a negatively charged electron and positively charged hole are created. The electrical junction separates these electrons and holes from one another.
- Connecting solar cells in series increases the voltage; connecting them in parallel increases the current.

A device that converts light energy directly to electrical energy; also known as a photovoltaic (PV) cell. PV cells are made of various semiconductor materials, such as silicon and gallium arsenide. Solar cells may be used individually to power small applications, such as calculators, or connected in series and parallel as modules or panels to obtain the required values of current and voltage for electric power generation (**Fig. 1**). Connecting them in series increases the voltage; connecting them in parallel increases the current. Modules may be grouped in parallel or strung in series to form PV arrays. *See also:* SOLAR ENERGY.

Photovoltaic effect

The conversion of sunlight into electrical energy, or the photovoltaic effect, involves three major processes: absorption of the sunlight in the semiconductor material; generation and separation of free positive and negative charges to different regions of the solar cell, creating a voltage in the solar cell; and transfer of these separated charges through electrical terminals to the outside application in the form of electric current.

In the first step the absorption of sunlight by a PV cell depends on the intensity and quality of the sunlight, the amount of light reflected from the front surface of the solar cell, the semiconductor band-gap energy which is the minimum light (photon) energy the material absorbs, and the layer thickness. Some materials such as silicon

Fig. 1 **Photovoltaic panels for renewable electric production, Zaragoza province, Aragon, Spain. (Credit: Shutterstock/pedrosala)**

require tens of micrometers' thickness to absorb most of the sunlight, while others such as gallium arsenide, cadmium telluride, and copper sulfide require only a few micrometers.

When light is absorbed in the semiconductor, a negatively charged electron and positively charged hole are created. The heart of the solar cell is the electrical junction which separates these electrons and holes from one another after they are created by the light. An electrical junction may be formed by the contact of: a metal to a

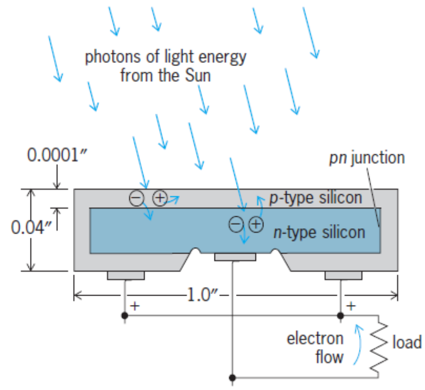

Fig. 2 **Cross-sectional view of a silicon *pn* junction solar cell, illustrating the creation of electron pairs by photons of light energy from the Sun. 0.0001″ = 2.5 μm; 0.04″ = 1 mm; 1.0″ = 25 mm.**

semiconductor (this junction is called a Schottky barrier); a liquid to a semiconductor to form a photoelectrochemical cell; or two semiconductor regions (called a *pn* junction).

The fundamental principles of the electrical junction can be illustrated with the silicon *pn* junction. Pure silicon to which a trace amount of a fifth-column element such as phosphorus has been added is an *n*-type semiconductor, where electric current is carried by free electrons. Each phosphorus atom contributes one free electron, leaving behind the phosphorus atom bound to the crystal structure with a unit positive charge. Similarly, pure silicon to which a trace amount of a column-three element such as boron has been added is a *p*-type semiconductor, where the electric current is carried by free holes. Each boron atom contributes one hole, leaving behind the boron atom with a unit negative charge. The interface between the *p*- and *n*-type silicon is called the *pn* junction. The fixed charges at the interface due to the bound boron and phosphorus atoms create a permanent dipole charge layer with a high electric field. When photons of light energy from the Sun produce electron-hole pairs near the junction, the built-in electric field forces the holes to the *p* side and the electrons to the *n* side (**Fig. 2**). This displacement of free charges results in a voltage difference between the two regions of the crystal, the *p* region being plus and the *n* region minus. When a load is connected at the terminals, electron current flows in the direction of the arrow, and electrical power is available at the load. *See also:* PHOTOVOLTAIC CELL; PHOTOVOLTAIC EFFECT; SEMICONDUCTOR; SEMICONDUCTOR DIODE.

Applications

Although the photovoltaic effect was discovered by A. C. Becquerel in 1839, practical solar cells made of silicon crystals were not developed until 1955. Beginning with *Vanguard 1*, launched in 1958, silicon solar cell arrays have become the almost exclusive power source for satellites. *See also:* SPACE POWER SYSTEMS.

Solar cell arrays have been used primarily to power small remote electrical loads that would otherwise be impractical or uneconomical to power by conventional means such as storage batteries or motor-generator sets.

Fig. 3 **Rooftop solar panel installation. (Credit: Elenathewise/Getty Images)**

However, as the costs of solar cells have fallen and their efficiencies have improved, demand has materialized for large arrays that can power larger facilities or feed into a utility grid (**Fig. 1**). For residential solar energy systems, PV modules and arrays can be mounted on a structural surface, such as a rooftop and faced toward the Sun (**Fig. 3**). When powering loads that require ac voltage, a power inverter is used to convert the dc voltage from the solar cell array into usable ac power.

K. W. Mitchell, Margorie L. Tatro

Keywords

solar cell; photovoltaic cell; photovoltaic; PV effect; PV cell; solar energy; solar panels; light energy conversion

Test Your Understanding

1. Describe the energy conversion that takes place inside a solar cell.
2. What is a *pn* junction?
3. Critical Thinking: Suppose you observe that the semiconductor material in a faulty solar cell has an excess of positive holes. However, no current is being generated. What part of the solar cell is likely to be defective?
4. Critical Thinking: A solar panel array provides an off-grid homeowner with 100 amp current at 120 volts. How can the homeowner power a clothes dryer that requires 220 volts?
5. Critical Thinking: Compare the energy output of a solar panel on a satellite to the same type of panel on farmland in the midwestern U.S. What factor affects output?

Additional Readings

I. Åberg et al., A GaAs nanowire array solar cell With 15.3% efficiency at 1 sun, *IEEE J. Photovoltaics*, 6(1):185–190, 2016 DOI: http://doi.org/10.1109/JPHOTOV.2015.2484967

C. Brabec et al., (eds.), *Organic Photovoltaics: Materials, Device Physics, and Manufacturing Technologies*, 2d ed., Wiley-VHC, 2014

D. M. DeLongchamp, Organic photovoltaics, *Springer Ser. Mater. Sci.*, 218:169–196, 2016 DOI: http://doi.org/10.1007/978-3-319-20331-7_6

P. Fulay and Jung-Kun Lee, *Electronic, Magnetic, and Optical Materials*, 2d ed., CRC Press, 2016

M. A. Green, A. Ho-Baillie, and H. J. Snaith, The emergence of perovskite solar cells, *Nat. Photon.*, 8(7):506–514, 2014 DOI: http://doi.org/10.1038/nphoton.2014.134

M. A. Green et al., Solar cell efficiency tables (version 49), *Prog. Photovolt: Res. Appl.*, 25:3–13, 2016 DOI: http://doi.org/10.1002/pip.2855

O. Isabella et al., *Solar Energy: The Physics and Engineering of Photovoltaic Conversion, Technologies and Systems*, UIT Cambridge Ltd., 2016

P. V. Kamat, Semiconductor surface chemistry as holy grail in photocatalysis and photovoltaics, *Acc. Chem. Res.*, 50:527–531, 2017 DOI: http://doi.org/10.1021/acs.accounts.6b00528

M. Lira-Cantu et al. (ed.), *The Future of Semiconductor Oxides in Next-Generation Solar Cells*, Elsevier, 2017

C. Liu et al., Low bandgap semiconducting polymers for polymeric photovoltaics, *Chem. Soc. Rev.*, 45:4825–4846, 2016 DOI: http://doi.org/10.1039/C6CS90071B

M. Parans Paranthaman, W. Wong-Ng, and R. N. Bhattacharya (eds.), *Semiconductor Materials for Solar Photovoltaic Cells*, Springer, 2016

F. Priolo et al., Silicon nanostructures for photonics and photovoltaics, *Nat. Nanotechnol.*, 9:19–32, 2014 DOI: http://doi.org/10.1038/nnano.2013.271

A. Reinders et al., *Photovoltaic Solar Energy: From Fundamentals to Applications*, Wiley, 2017

J. Ye et al., High-temperature shaping perovskite film crystallization for solar cell fast preparation, *Sol. Energy Mater. Sol. Cells*, 160:60–66, 2017 DOI: http://doi.org/10.1016/j.solmat.2016.10.022

Florida Solar Energy Center: Solar Electricity Basics

National Aeronautics and Space Administration: How Do Photovoltaics Work?

U.S. Department of Energy: Solar Photovoltaic Cell Basics