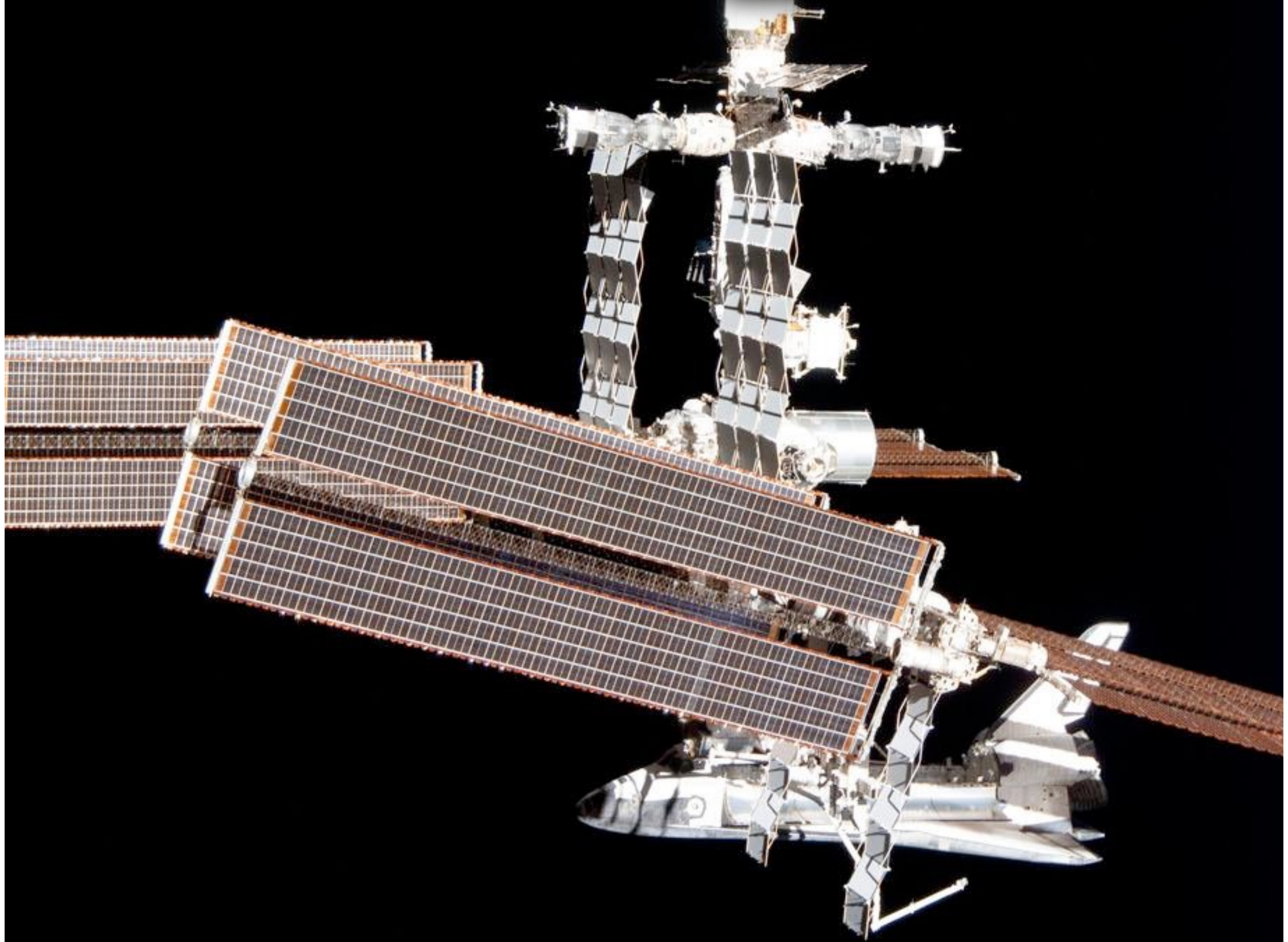
COMENIUS 2014 - 2015

ENERGY IN THE IIS



Italian team

CHAPTER 1

THE PRODUCTION OF THE ENERGY

Electrical Power System (EPS)

http://spacestationlive.nasa.gov/visitspacestation.html

Electrical power is one of the most important resources onboard the ISS. Electrical power is what keeps the space station and its crew alive. The ISS needs power for all functions onboard, such as command and control, communications, lighting, and life support. The ISS gets its power by converting sunlight to electricity using solar cells.

The Russian Orbital Segment (ROS) and United States On-Orbit Segment (USOS) are responsible for providing electrical power for their own segments and share power as needed. The SPARTAN console is responsible for the operation of the Electrical Power System (EPS) that generates and stores power for the USOS. The EPS then converts and distributes power to users (i.e. equipment). The SPARTAN console is also responsible for monitoring system performance and protecting both the system and users from electrical hazards.

The EPS is an example of a distributed power system. It functions much the same way municipal electric utilities work here on earth. Higher voltage power is generated in one location (the eight Solar Arrays). This power is then distributed over distance to user locations. Power is then stepped down to a lower voltage level by a transformer. This makes it safer to be used by the consumer (astronauts, in this case).

The EPS is made up of the following:

Solar Array Wings - convert sunlight (solar power) into DC (direct current) power (electrical energy).

Photovoltaic Thermal Control System (PVTCS) - circulates cooling fluid to remove heat and maintain EPS battery temperature.

Solar (Array) Alpha Rotary Joint - a joint which allows for rotation of either entire arm of solar array.

Beta Gimbals - objects used to rotate the individual solar arrays so they face the Sun to provide maximum power.

Main Bus Switching Units (MBSU) - route power to correct locations in the ISS.

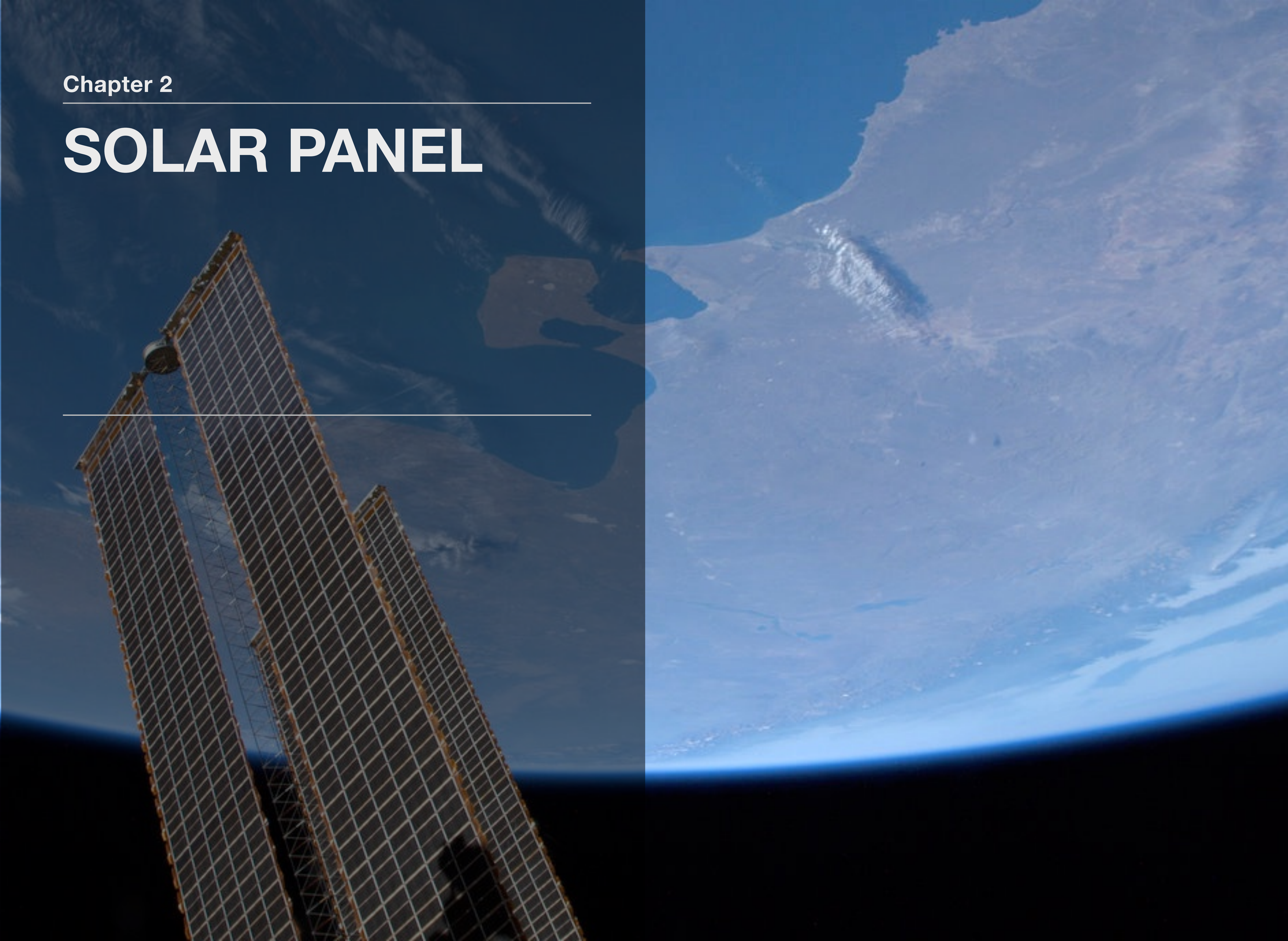
Direct Current Switching Unit (DCSU) - routes power from the solar arrays to the MBSUs.

Remote Power Controllers (RPCs) - individual switches which control the flow of electric power to users (such as how a light switch controls a light bulb).

Electronics Control Unit (ECU) - controls pointing of solar arrays

Chapter 2

SOLAR PANEL



The electrical system of the International Space Station

The electrical system of the International Space Station is a critical resource for the International Space Station (ISS) because it allows the crew to live comfortably, to safely operate the station, and to perform scientific experiments. The ISS electrical system uses solar cells to directly convert sunlight to electricity. Large numbers of cells are assembled in arrays to produce high power levels. This method of harnessing solar power is called photovoltaics.

An ensemble of soar cells make up a solar pannel, an a ensambe of solar panels make up a photovoltaic system

The process of collecting sunlight, converting it to electricity, and managing and distributing this electricity builds up excess heat that can damage spacecraft equipment. This heat must be eliminated for reliable operation of the space station in orbit. The ISS power system uses radiators to dissipate the heat away from the spacecraft. The radiators are shaded from sunlight and aligned toward the cold void of deep space.

Image 2.1 Solar array wing

Close-up view of folded solar array

Each ISS solar array wing (often abbreviated "SAW") consists of two retractable "blankets" of solar cells with a mast between them. Each wing uses nearly 33,000 solar cells and when fully extended is 35 metres (115 ft) in length and 12 metres (39 ft) wide. When retracted, each wing folds into a solar array blanket box just 51 centimetres (20 in) high and 4.57 metres (15.0 ft) in length.The ISS now has the full complement of eight solar array wings.

Batteries

Since the station is often not in direct sunlight, it relies on rechargeable nickel-hydrogen batteries to provide continuous power during the "eclipse" part of the orbit (35 minutes of every 90 minute orbit). The batteries ensure that the station is never without power to sustain life-support systems and experiments. During the sunlit part of the orbit, the batteries are recharged. The batteries have a design life of 6.5 years which means that they must be replaced multiple times during the expected 20-year life of the station.

How are made the solar panels?

Solar panel refers either to a photovoltaic module, a solar thermal energy panel, or to a set of solar photovoltaic (PV) modules electrically connected and mounted on a supporting structure. A PV module is a packaged, connected assembly of solar cells. Solar panels can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module given the same rated output - an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. There are a few solar panels available that are exceeding 19% efficiency. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, an inverter, and sometimes a battery and/or solar tracker and interconnection wiring.

Image 2.2 Solar panel

A solar photovoltaic module is composed of individual PV cells. This crystalline-silicon module comprises 4 solar cells and has an aluminum frame and glass on the front.

Theory and construction

Solar modules use light energy (photons) from the sun to generate electricity through the photovoltaic effect or photoelectric effectThe majority of modules use wafer-based crystallinesilicon cells or thin-film cells (is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal.)based on cadmium telluride or silicon. The structural (load carrying) member of a module can either be the top layer or the back layer. Cells must also be protected from mechanical damage and moisture. Most solar modules are rigid, but semi-flexible ones are available, based on thin-film cells. These early solar modules were first used in space in 1958.

Image 2.3 Solar modules on the International Space Station

A solar photovoltaic module is composed of individual PV cells. This crystalline-silicon module comprises 4 solar cells and has an aluminum frame and glass on the front.

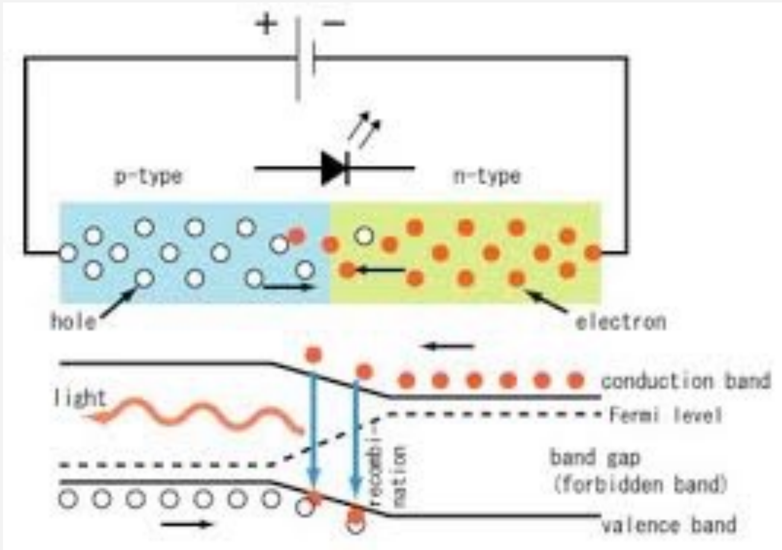
Electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability. The conducting wires that take the current off the modules may contain silver, copper or other non-magnetic conductive transition metals. The cells must be connected electrically to one another and to the rest of the system.
Bypass diodes may be incorporated or used externally, in case of partial module shading, to maximize the output of module sections still illuminated.
Some recent solar module designs include concentrators in which light is focused by lenses or mirrors onto an array of smaller cells. This enables the use of cells with a high cost per unit area (such as gallium arsenide) in a cost-effective way

zero) resistance to current in one direction, and high (ideally infinite) resistance in the other, the most common function of a diode is to allow an electric current to pass in one direction (called the diode's forward direction), while

What is a diode?

In electronics, a **diode** is a two-terminal electronic component with asymmetric conductance; it has low (ideally zero) resistance to current in one direction, and high (ideally infinite) resistance in the other, the most common function of a diode is to allow an electric current to pass in one direction (called the diode's *forward* direction), while blocking current in the opposite direction (the *reverse* direction).

Image 2.4 The function of diode junction



Efficiencies

Depending on construction, photovoltaic modules can produce electricity from a range of frequencies of light, but usually cannot cover the entire solar range (specifically, ultraviolet, infrared and low or diffused light). Hence much of the incident sunlight energy is wasted by solar modules, and they can give far higher efficiencies if illuminated with monochromatic light. Therefore, another design concept is to split the light into different wavelength ranges and direct the beams onto different cells tuned to those ranges.This has been projected to be capable of raising efficiency by 50%.

Currently the best achieved sunlight conversion rate (solar module efficiency) is around 21.5% in new commercial products typically lower than the efficiencies of their cells in isolation.

- Efficiencies of solar panel can be calculated by MPP(Maximum power point) value of solar panels
- Solar inverters convert the DC power to AC power by performing MPPT process: solar inverter samples the output Power(I-V curve) from the solar cell and applies the proper resistance (load) to solar cells to obtain maximum power.
- MPP(Maximum power point) of the solar panel consists of MPP voltage(V mpp) and MPP current(I mpp): it is a capacity of the solar panel and the higher value can make higher MPP.

Micro-inverted solar panels are wired in parallel which produces more output than normal panels which are wired in series with the output of the series determined by the lowest performing panel (this is known as the "Christmas light effect"). Micro-inverters work independently so each panel contributes its maximum possible output given the available sunlight.

Recycling

Most parts of a solar module can be recycled including up to 97% of certain semiconductor materials or the glass as well as large amounts of ferrous and non-ferrous metals.[11] Some private companies and non-profit organizations are currently engaged in take-back and recycling operations for end-of-life modules.

Recycling possibilities depend on the kind of technology used in the modules:

- Silicon based modules: aluminum frames and junction boxes are dismantled manually at the beginning of the process. The module is then crushed in a mill and the different fractions are separated - glass, plastics and metals. It is possible to recover more than 80% of the incoming weight. This process can be performed by flat glass recyclers since morphology and composition of a PV module is similar to those flat glasses used in the building and automotive industry. The recovered glass for example is readily accepted by the glass foam and glass insulation industry.
- Non-silicon based modules: they require specific recycling technologies such as the use of chemical baths in order to separate the different semiconductor materials.For cadmium telluride modules, the recycling process begins by crushing the module and subsequently separating the different fractions. This recycling process is designed to recover up to 90% of the glass and 95% of the semiconductor materials contained. Some commercial-scale recycling facilities have been created in recent years by private companies.

Since 2010, there is an annual European conference bringing together manufacturers, recyclers and researchers to look at the future of PV module recycling.

Chapter 3

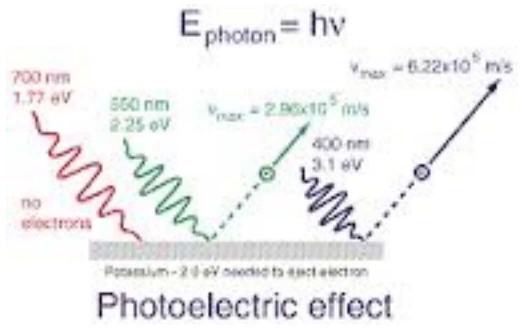
THE PHOTOELECTRIC EFFECT

THE PHOTOELECTRIC EFFECT

The photoelectric effect is the observation that many metals emit electrons when light shines upon them. Electrons emitted in this manner can be called photoelectrons

According to classical electromagnetic theory, this effect can be attributed to the transfer of energy from the light to an electron in the metal. From this perspective, an alteration in either the amplitude or wavelength of light would induce changes in the rate of emission of electrons from the metal. Furthermore, according to this theory, a sufficiently dim light would be expected to show a lag time between the initial shining of its light and the subsequent emission of an electron. However, the experimental results did not correlate with either of the two predictions made by this theory

Image 3.1 The Photoelectric effect



Instead, as it turns out, electrons are only dislodged by the photoelectric effect if light reaches or exceeds a threshold frequency, below which no electrons can be emitted from the metal regardless of the amplitude and temporal length of exposure of light. To make sense of the fact that light can eject electrons even if its intensity is low, Albert Einstein proposed that a beam of light is not a wave propagating through space, but rather a collection of discrete wave packets (photons), each with energy hf. This shed light on Max Planck's previous discovery of the Planck relation (E = hf) linking energy (E) and frequency (f) as arising from quantization of energy. The factor h is known as the Planck constant.

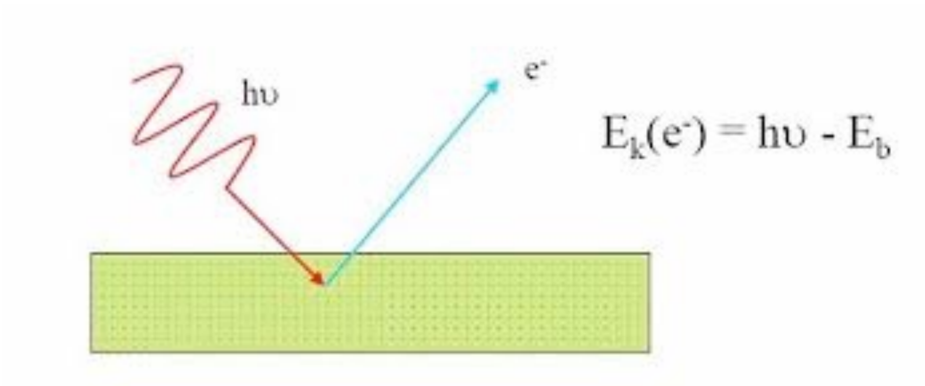
In 1887, Heinrich Hertz discovered that electrodes illuminated with ultraviolet light create electric sparks more easily. In 1905 Albert Einstein published a paper that explained experimental data from the photoelectric effect as being the result of light energy being carried in discrete quantized packets. This discovery led to the quantum revolution. Einstein was awarded the Nobel Prize in 1921 for "his discovery of the law of the photoelectric effect".

The photoelectric effect requires photons with energies from a few electronvolts to over 1 MeV in elements with a high atomic number. Study of the photoelectric effect led to important steps in understanding the quantum nature of light and electrons and influenced the formation of the concept of wave–particle duality.

Emission mechanism

The photons of a light beam have a characteristic energy proportional to the frequency of the light. In the photoemission process, if an electron within some material absorbs the energy of one photon and acquires more energy than the work function (the electron binding energy) of the material, it is ejected. If the photon energy is too low, the electron is unable to escape the material. Since an increase in the intensity of low-frequency light will only increase the number of low-energy photons sent over a given interval of time, this change in intensity will not create any single photon with enough energy to dislodge an electron. Thus, the energy of the emitted electrons does not depend on the intensity of the incoming light, but only on the energy (equivalently frequency) of the individual photons. It is an interaction between the incident photon and the outermost electrons.

Electrons can absorb energy from photons when irradiated, but they usually follow an "all or nothing" principle. All of the energy from one photon must be absorbed and used to liberate one electron from atomic binding, or else the energy is re-emitted. If the photon energy is absorbed, some of the energy liberates the electron from the atom, and the rest contributes to the electron's kinetic energy as a free particle.



Experimental observations of photoelectric emission

The theory of the photoelectric effect explains the experimental observations of the emission of electrons from an illuminated metal surface.

For a given metal, there is a certain minimum frequency of incident radiation below which no photoelectrons are emitted. This frequency is called the threshold frequency and it depends on"minimum threshold". In the electromagnetic radiation ,energy is not distributed evenly over the entire face of the wave, but concentrated in single quanta (discrete packets) energy : photons. Each photon interacts with a single electron, which gives up its energy. In order to occur it is necessary that the photon has enough energy to break the bond that holds electron tied at the atom. This "minimum threshold" energy of the photon is determined by the Einstein relation $E = h \cdot f = h \cdot (c / \lambda)$ (where h = 6,626 x 10-34Js is the Planck constant, "f" is the frequency,"λ" is the wavelength, and "c" the speed of light). In other words, the electron can leave the metal only if the photon energy is at least equal to " work function" or "extraction work" ($hf \geq W_e$).There exists, therefore, a "minimum threshold" (and so there is threshold frequency $f \geq W_e/h$) of extraction for each metal, which refers to the wavelength or to the frequency of the incident photon . The energy "hf" has to coincide with the "work of extracting "(W_e)

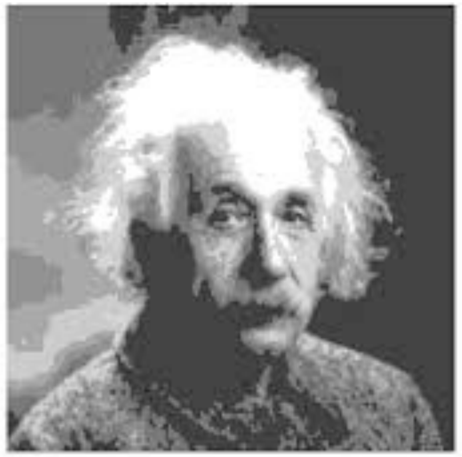


Figure 121-1 *Albert Einstein explained the photoelectric by claiming that light had a particle-like nature.*

The maximum kinetic energy of the emitted photoelectron depends on the frequency of the incident light, but it is independent from the intensity of the incident light.

For a given metal and frequency of incident radiation, the rate of photoelectrons which are ejected, is directly proportional to the intensity of the incident light. An increase in the intensity of the incident beam (keeping the frequency fixed) increases the magnitude of the photoelectric current, although the stopping voltage remains the same.

The time lag between the incidence of radiation and the emission of a photoelectron is very short, less than 10–9 second.

The direction of emitted electrons peaks in the direction of polarization (the direction of the electric field) of the incident light, if it is linearly polarized.

Mathematical description

Diagram of the maximum kinetic energy as a function of the frequency of light on zinc

The maximum kinetic energy Kmax of an ejected electron is given by

$Kmax = hf - W_e$

where h is the Planck's constant and f is the frequency of the incident photon. The term W_e is the work function , which gives the minimum energy required to remove a delocalised electron from the surface of the metal. The work function satisfies

$W_e = hf0$

where f0 is the threshold frequency for the metal. The maximum kinetic energy of an ejected electron is then

$Kmax = h(f - f0)$

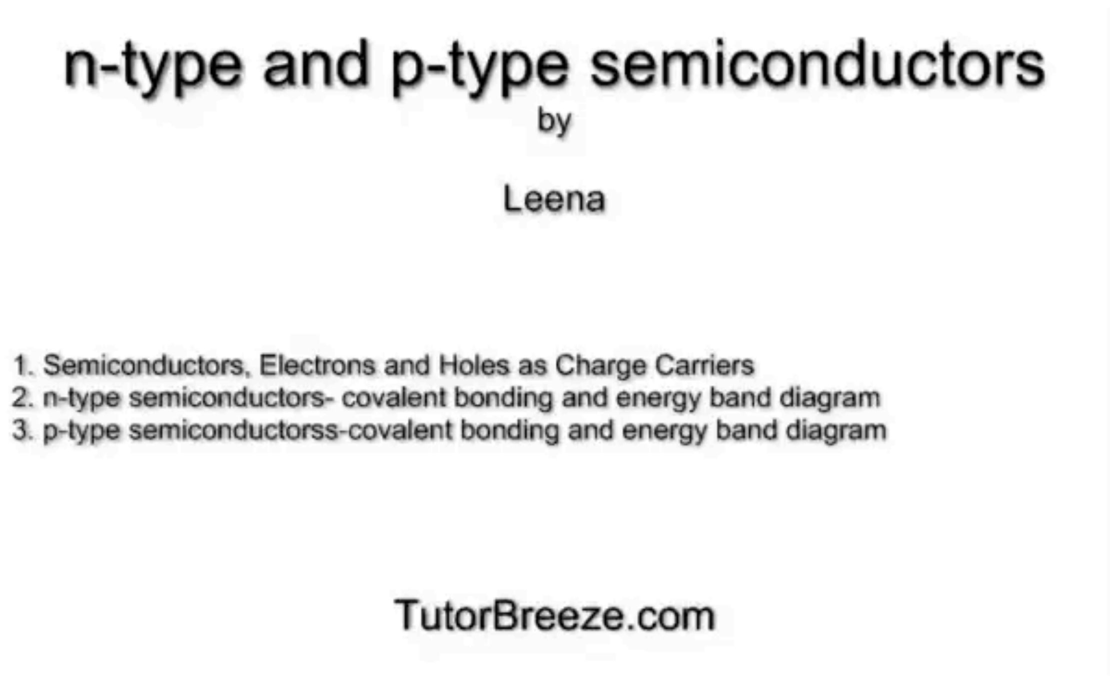
Kinetic energy is positive, so we must have f > f0 for the photoelectric effect to occur.

Chapitre 4

SEMICONDUCTOR

How Silicon Makes a Solar Cell

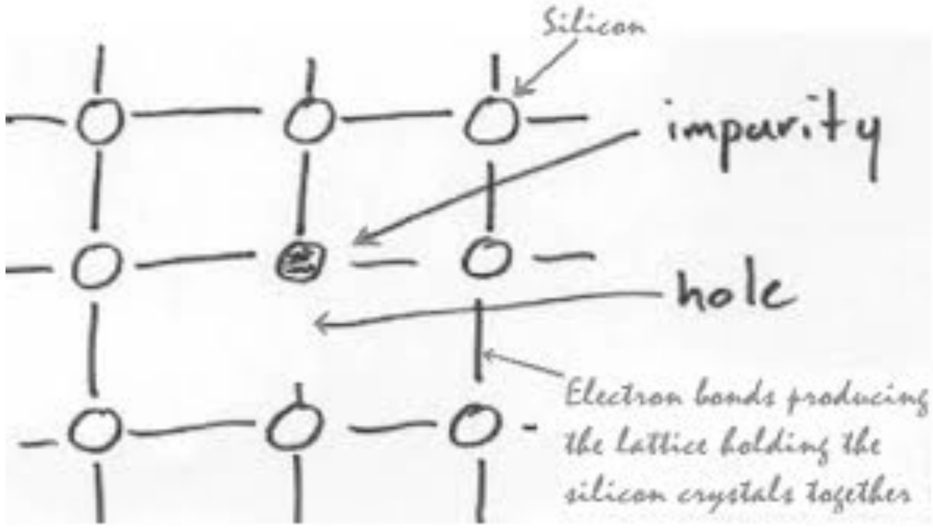
Silicon has some special chemical properties, especially in its crystalline form. An atom of sili con has 14 electrons, arranged in three different shells. The first two shells -- which hold two and eight electrons respectively -- are completely full. The outer shell, however, is only half full with just four electrons. A silicon atom will always look for ways to fill up its last shell, and to do this, it will share electrons with four nearby atoms. It's like each atom holds hands with its neighbors, except that in this case, each atom has four hands joined to four neighbors. That's what forms the crystalline structure, and that structure turns out to be important for PV cell.

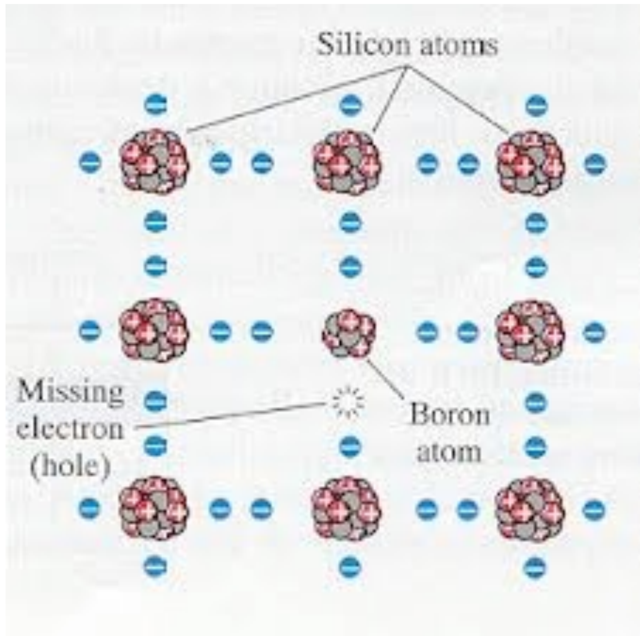


The only problem is that pure crystalline silicon is a poor conductor of electricity because none of its electrons are free to move about, unlike the electrons of conductors like copper. The silicon in a solar cell has impurities -- other atoms purposefully mixed in with the silicon atoms -- which changes a bit the way things work . We usually think of impurities as something undesirable, but in this case, our cell wouldn't work without them. Consider silicon with an atom of phosphorous here and there, maybe one for every million silicon atoms.

Phosphorous has five electrons in its outer shell, not four. It still bonds with its silicon neighbor atoms, but in a sense, the phosphorous has one electron that doesn't have anyone to hold hands with. It doesn't form part of a bond, but there is a positive proton in the phosphorous nucleus holding it in place.

When energy is added to pure silicon, in the form of heat for example, it can cause a few electrons to break free of their bonds and leave their atoms. A hole is left behind in each case. These electrons, called free carriers, then wander randomly around the crystalline lattice looking for another hole to fall into and carrying an electrical current. However, there are so few of them in pure silicon, that they aren't very useful.





As a result, most of these electrons do break free, and we have a lot more free carriers than we would have in pure silicon. The process of adding impurities on purpose is called doping, and when doped with phosphorous, the resulting silicon is called N-type ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon.

The other part of a typical solar cell is doped with the element boron, which has only three electrons in its outer shell instead of four, to become P-type silicon. Instead of having free electrons, P-type ("p" for positive) has free openings and carries the opposite (positive) charge.

Anatomy of a Solar Cell

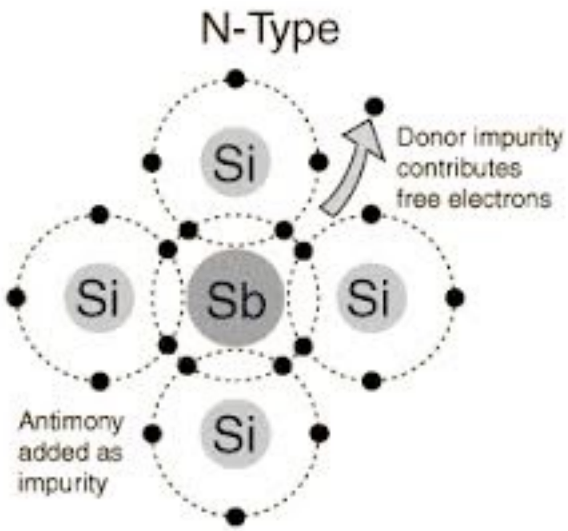
Before now, our two separate pieces of silicon were electrically neutral; the interesting part begins when you put them together. That's because without an electric field, the cell wouldn't work; the field forms when the N-type and P-type silicon come into contact. Suddenly, the free electrons on the N side see all the openings on the P side, and there's a mad rush to fill them. Do all the free electrons fill all the free holes? No. If they did, then the whole arrangement wouldn't be very useful. However, right at the junction, they mix and form something of a barrier, making it harder and harder for electrons on the N side to cross over to the P side. Eventually, equilibrium is reached, and we have an electric field separating the two sides.

This electric field acts as a diode, allowing (and even pushing) electrons to flow from the P side to the N side, but not the other way around. It's like a hill -- electrons can easily go down the hill (to the N side), but can't climb it (to the P side).

When light, in the form of photons, hits our solar cell, its energy breaks apart electron-hole pairs.

Each photon with enough energy will normally free exactly one electron, resulting in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This causes further disruption of electrical neutrality, and if we provide an external current path, electrons will flow through the path to the P side to unite with holes that the electric field sent there, doing work for us alo ng the way. The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, we have power, which is the product of the two.

PV modules are generally made by connecting several individual cells together to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with positive and negative terminals.



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Chapter 5

EXERCISES

Interactive 5.1 TEST