The change of state of matter

Vocabulary:

Substances; to condense; to freeze; liquid; gas

If water is cold sufficiently it changes to ice; which is water in its solid state. If water is heated, it vaporizes. Water vapour is water in gas state. If water vapour is cold, it returns to water, if ice is heated, it returns to water.

Most substances have tree states: solid, liquid, and gas. When a solid liquefies, it is said to melt. When a liquid is converted to gas, it is said to vaporize. When a gas liquefies on cooling, it is said to condense. A liquid returning to the solid state, it is said to freeze or to solidify.

At constant pressures these changes are stated invariably take place at fixed temperatures. ie: ice invariably melts and water invariably freezes at 0°C; therefore 0°C is known as **freezing point of water**. Water in normal conditions boils at 100°C, therefore is known as **boiling point of water**

Heat transfer:

(1) Radiation

Vocabulary:

dull shiny wave

Heat is derived from the sun in a way which is not fully understood, but it is thought to be with invisible electro-magnetic waves, which are able to pass through a vacuum. Although they themselves are not hot, when the rays of the sun touch an abject, they make it warm. This is known because space remains quite cold, although the rays are travelling through it.

However, on reaching the earth, they warm the air, the ground, and all other objects they touch. The rays are partly reflected and partly absorbed by the objects they fall. A polished surface reflects more heat than a dull surface, which absorbs more heat than a polished surface.

The sun is said to radiate heat, and this method of heating is known as heat transfer by radiation. Radiation is only one of the three methods by heat is transferred.

(2) Conduction

Vocabulary:

Asbestos fibre-glass material silver cork handle molecule wool to dip

If a silver and a wooden spoon are dipped simultaneously into boiling water, the handle of the silver spoon rapidly becomes hot, while that of the wooden one remains cool. Why is this?

The reason is that the heat at one end of the silver spoon is transferred rapidly from one molecule of silver to the next. However, this is not the case with wood.

The transfer of heat from one molecule to the next is known as conduction. When the heat is transferred in this way, it is said to be conducted.

Materials in which this occurs readily are said to be good conductors of heat, and all metals are good heat conductors. In materials such as wood, rubber and air, heat is not transferred readily from one molecule to the next. By this is meant that these materials are poor conductors of heat.

Poor conductors of heat are frequently known as insulators. They prevent heat from escaping because their molecules do not transfer heat readily from one to the next. Still air is one of the poorest conductors; consequently it is one of the best insulators. Any material which encloses plenty of air is a good insulator: e.g. wool, cork, asbestos and fibre-glass.

(3) Convection

Vocabulary:

Crystal mainly permanganate of potash vessel current movement

Text B:

If a glass vessel is filled with water and a few crystals of potassium permanganate - chemical formula: $KMnO_4$ – are dropped into it, the water near the crystals is seen to turn pink. If the water is heated, the way in which the pink water moves can be seen. First it rises, then it moves across the surface, and then it sinks down the side of the vessel.

Movement of water is known as current. As the water moves, the heat is carried with it, and the heat is said to travel by convection. These movements are known as convection currents. Heat does not travel by convection in a solid, because the solid does not move as does a liquid.

Convection currents are found only in fluids.

To summarize: the three methods of heat transfer are (i) radiation, by which heat travels in space or in gases, (ii) conduction, by which heat travels in solids and (iii) convection, by which heat travels in fluids.

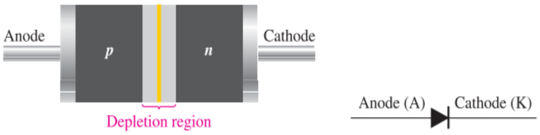
Heat is radiated by the sun, and this is known as heat transfer by radiation. Heat is conducted in solids, and this is knows as heat transfer by conduction. Heat is convected in fluids, and this is known as heat transfer by convection.

The diode

A diode is a two-terminal semiconductor device formed by two doped regions of silicon separated by a p-n junction. In this part, the most common category of diode is covered. Other names, such as rectifier diode or signal diode, depend on the particular type of application for which the diode was designed. You will learn how to use a voltage to cause the diode to conduct current in one direction and block it in the other direction. This process is called biasing.

The Diode

As mentioned, a diode is made from a small piece of semiconductor material, usually silicon, in which half is doped as a p region and half is doped as an n region with a p-n junction and depletion region in between. The p region is called the anode and is connected to a conductive terminal. The n region is called the cathode and is connected to a second conductive terminal. The basic diode structure and schematic symbol are shown in Figure 1.

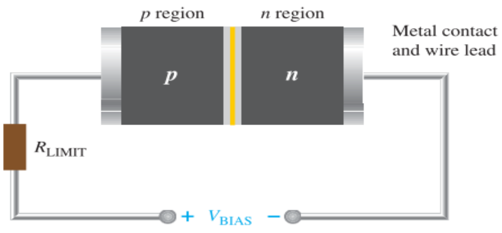


(a) Basic structure

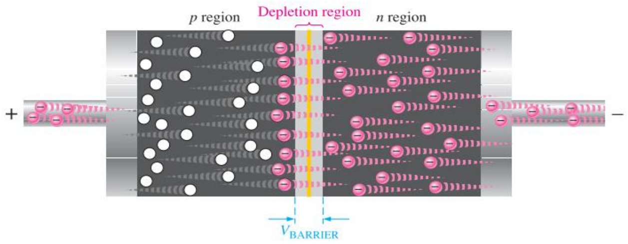
(b) Symbol

Forward Bias

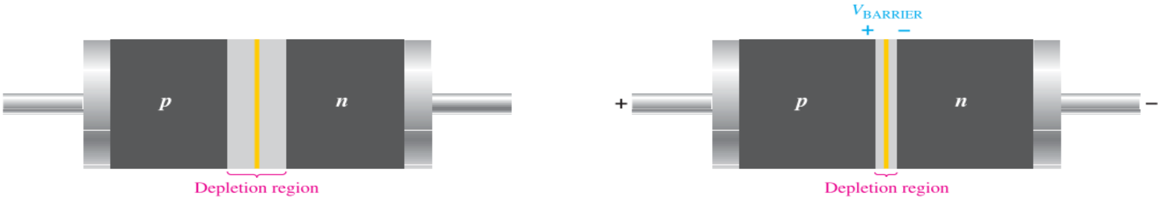
To bias a diode, you apply a dc voltage across it. Forward bias is the condition that allows current through the p-n junction. Figure 2 shows a dc voltage source connected by conductive material (contacts and wire) across a diode in the direction to produce forward bias. This external bias voltage is designated as V_{BIAS}. The resistor limits the forward current to a value that will not damage the diode. Notice that the negative side of V_{BIAS} is connected to the n region of the diode and the positive side is connected to the p region. This is one requirement for forward bias. A second requirement is that the bias voltage, V_{BIAS}, must be greater than the barrier potential.



A fundamental picture of what happens when a diode is forward-biased is shown in Figure 3. Because like charges repel, the negative side of the bias-voltage source “pushes” the free electrons, which are the majority carriers in the n region, toward the p-n junction. This flow of free electrons is called electron current. The negative side of the source also provides a continuous flow of electrons through the external connection (conductor) and into the n region as shown. The bias-voltage source imparts sufficient energy to the free electrons for them to overcome the barrier potential of the depletion region and move on through into the p region. Once in the p region, these conduction electrons have lost enough energy to immediately combine with holes in the valence band.



Now, the electrons are in the valence band in the p region, simply because they have lost too much energy overcoming the barrier potential to remain in the conduction band. Since unlike charges attract, the positive side of the bias-voltage source attracts the valence electrons toward the left end of the p region. The holes in the p region provide the medium or "pathway" for these valence electrons to move through the p region. The valence electrons move from one hole to the next toward the left. The holes, which are the majority carriers in the p region, effectively (not actually) move to the right toward the junction, as you can see in Figure 3. This effective flow of holes is the hole current. You can also view the hole current as being created by the flow of valence electrons through the p region, with the holes providing the only means for these electrons to flow. As the electrons flow out of the p region through the external connection (conductor) and to the positive side of the bias-voltage source, they leave holes behind in the p region; at the same time, these electrons become conduction electrons in the metal conductor. Recall that the conduction band in a conductor overlaps the valence band so that it takes much less energy for an electron to be a free electron in a conductor than in a semiconductor and that metallic conductors do not have holes in their structure. There is a continuous availability of holes effectively moving toward the p-n junction to combine with the continuous stream of electrons as they come across the junction into the p region. The Effect of Forward Bias on the Depletion Region As more electrons flow into the depletion region, the number of positive ions is reduced. As more holes effectively flow into the depletion region on the other side of the p-n junction, the number of negative ions is reduced. This reduction in positive and negative ions during forward bias causes the depletion region to narrow, as indicated in Figure 4.



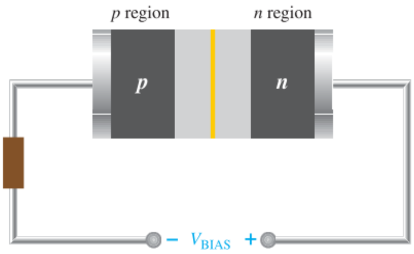
(a) At equilibrium (no bias)

(b) Forward bias narrows the depletion region and produces a voltage drop across the *pn* junction equal to the barrier potential.

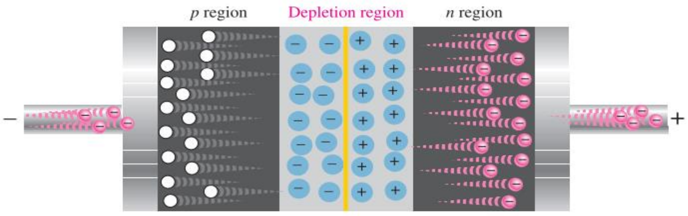
The Effect of the Barrier Potential during Forward Bias Recall that the electric field between the positive and negative ions in the depletion region on either side of the junction creates an "energy hill" that prevents free electrons from diffusing across the junction at equilibrium. This is known as the barrier potential. When forward bias is applied, the free electrons are provided with enough energy from the bias-voltage source to overcome the barrier potential and effectively "climb the energy hill" and cross the depletion region. The energy that the electrons require in order to pass through the depletion region is equal to the barrier potential. In other words, the electrons give up an amount of energy equivalent to the barrier potential when they cross the depletion region. This energy loss results in a voltage drop across the p-n junction equal to the barrier potential (0.7 V), as indicated in Figure 4(b). An additional small voltage drop occurs across the p and n regions due to the internal resistance of the material. For doped semi-conductive material, this resistance, called the dynamic resistance, is very small and can usually be neglected.

Reverse Bias

Reverse bias is the condition that essentially prevents current through the diode.Figure 5 shows a dc voltage source connected across a diode in the direction to produce reverse bias. This external bias voltage is designated as V_{BIAS} just as it was for forward bias. Notice that the positive side of V_{BIAS} is connected to the n region of the diode and the negative side is connected to the p region. Also note that the depletion region is shown much wider than in forward bias or equilibrium.

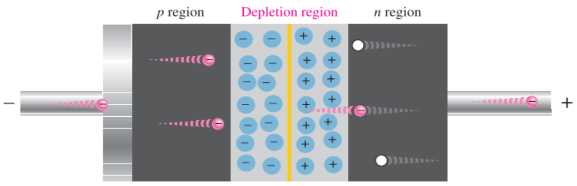


ions are created. This results in a widening of the depletion region and a depletion of majority carriers.



In the p region, electrons from the negative side of the voltage source enter as valence electrons and move from hole to hole toward the depletion region where they create additional negative ions. This results in a widening of the depletion region and a depletion of majority carriers. The flow of valence electrons can be viewed as holes being “pulled” toward the positive side. The initial flow of charge carriers is transitional and lasts for only a very short time after the reverse-bias voltage is applied. As the depletion region widens, the availability of majority carriers decreases. As more of the n and p regions become depleted of majority carriers, the electric field between the positive and negative ions increases in strength until the potential across the depletion region equals the bias voltage, V_{BIAS}. At this point, the transition current essentially ceases except for a very small reverse current that can usually be neglected.

Reverse Current: The extremely small current that exists in reverse bias after the transition current dies out is caused by the minority carriers in the n and p regions that are produced by thermally generated electron-hole pairs. The small number of free minority electrons in the p region is “pushed” toward the p-n junction by the negative bias voltage. When these electrons reach the wide depletion region, they “fall down the energy hill” and combine with the minority holes in the n region as valence electrons and flow toward the positive bias voltage, creating a small hole current. The conduction band in the p region is at a higher energy level than the conduction band in the n region. Therefore, the minority electrons easily pass through the depletion region because they require no additional energy. Reverse current is illustrated in Figure 6



Reverse Breakdown: Normally, the reverse current is so small that it can be neglected. However, if the external reverse-bias voltage is increased to a value called the breakdown voltage, the reverse current will drastically increase. This is what happens. The high reverse-bias voltage imparts energy to the free minority electrons so that as they speed through the p region, they collide with atoms with enough energy to knock valence electrons out of orbit and into the conduction band. The newly created conduction electrons are also high in energy and repeat the process. If one electron knocks only two others out of their valence orbit during its travel through the p region, the Numbers quickly multiply. As these high-energy electrons go through the depletion region, they have enough energy to go through the n region as conduction electrons, rather than combining with holes. The multiplication of conduction electrons just discussed is known as the avalanche effect, and reverse current can increase dramatically if steps are not taken to limit the current. When the reverse current is not limited, the resulting heating will permanently damage the diode. Most diodes are not operated in reverse breakdown, but if the current is limited (by adding a series-limiting resistor for example), there is no permanent damage to the diode.

True and False Quiz

1. The two regions of a diode are the anode and the collector.

2. A diode can conduct current in two directions with equal ease.

3. A diode conducts current when forward-biased.

4. When reverse-biased, a diode ideally appears as a short.

5. Two types of current in a diode are electron and hole.

1. When a diode is forward-biased and the bias voltage is increased, the forward current will

(a) increase (b) decrease (c) not change

2. When a diode is forward-biased and the bias voltage is increased, the voltage across the diode

(assuming the practical model) will

(a) increase (b) decrease (c) not change

3. When a diode is reverse-biased and the bias voltage is increased, the reverse current (assuming the practical model) will

(a) increase (b) decrease (c) not change

4. When a diode is reverse-biased and the bias voltage is increased, the reverse current (assuming the complete model) will

(a) increase (b) decrease (c) not change

5. When a diode is forward-biased and the bias voltage is increased, the voltage across the diode (assuming the complete model) will

(a) increase (b) decrease (c) not change

6. If the forward current in a diode is increased, the diode voltage (assuming the practical model) will

(a) increase (b) decrease (c) not change

7. If the forward current in a diode is decreased, the diode voltage (assuming the complete model) will

(a) increase (b) decrease (c) not change

8. If the barrier potential of a diode is exceeded, the forward current will

(a) increase (b) decrease (c) not change

Section 2–1

1. The term bias means

(a) the ratio of majority carriers to minority carriers

(b) the amount of current across a diode

(c) a dc voltage is applied to control the operation of a device

(d) neither (a), (b), nor (c)

2. To forward-bias a diode,

(a) an external voltage is applied that is positive at the anode and negative at the cathode

(b) an external voltage is applied that is negative at the anode and positive at the cathode

(c) an external voltage is applied that is positive at the pregion and negative at the nregion

(d) answers (a) and (c)

3. When a diode is forward-biased,

(a) the only current is hole current

(b) the only current is electron current

(c) the only current is produced by majority carriers

(d) the current is produced by both holes and electrons

4. Although current is blocked in reverse bias,

(a) there is some current due to majority carriers

(b) there is a very small current due to minority carriers (c) there is an avalanche current

5. For a silicon diode, the value of the forward-bias voltage typically

(a) must be greater than 0.3 V

(b) must be greater than 0.7 V

(c) depends on the width of the depletion region

(d) depends on the concentration of majority carriers

6. When forward-biased, a diode

(a) blocks current (b) conducts current

BASIC PROBLEMS

Section 2–1 Diode Operation

1. To forward-bias a diode, to which region must the positive terminal of a voltage source be connected?

2. Explain why a series resistor is necessary when a diode is forward-biased.

Global System for Mobile Communication (GSM)

Definition

Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard. It is estimated that many countries outside of Europe will join the GSM partnership.

Introduction: The Evolution of Mobile Telephone Systems

Cellular is one of the fastest growing and most demanding telecommunications applications. Today, it represents a continuously increasing percentage of all new telephone subscriptions around the world. Currently there are more than 45 million cellular subscribers worldwide, and nearly 50 percent of those subscribers are located in the United States. It is forecasted that cellular systems using a digital technology will become the universal method of telecommunications. By the year 2005, forecasters predict that there will be more than 100 million cellular subscribers worldwide.

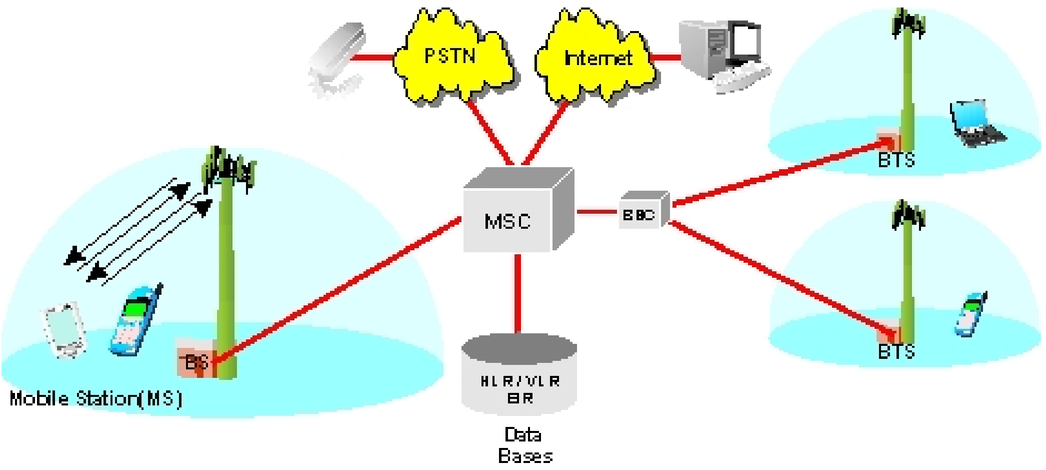
In the early 1980s, most mobile telephone systems were analog rather than digital, like today's newer systems. One challenge facing analog systems was the inability to handle the growing capacity needs in a cost-efficient manner. As a result, digital technology was welcomed. The advantages of digital systems over analog systems include ease of signaling, lower levels of interference, integration of transmission and switching, and increased ability to meet capacity demands.

GSM

Throughout the evolution of cellular telecommunications, various systems have been developed without the benefit of standardized specifications. This presented many problems directly related to compatibility, especially with the development of digital radio technology. The GSM standard is intended to address these problems. From 1982 to 1985 discussions were held to decide between building an analog or digital system. After multiple field tests, a digital system was adopted for GSM.

The GSM Network

The GSM network is divided into three major systems: the switching system (SS), the base station system (BSS), and the operation and support system (OSS). The basic GSM network elements are shown in the following Figure.



The Switching System

The switching system (SS) is responsible for performing call processing and subscriber-related functions. The switching system includes the following functional units:

- Home location registers (HLR)—The HLR is a database used for storage and management of subscriptions. The HLR is considered the most important database, as it stores permanent data about subscribers, including a subscriber's service profile, location information, and activity status. When an individual buys a subscription from one of the PCS operators, he or she is registered in the HLR of that operator.
- Mobile services switching center (MSC)—The MSC performs the telephony switching functions of the system. It controls calls to and from other telephone and data systems. It also performs such functions as network interfacing, common channel signaling, and others.
- Visitor location register: (VLR)—The VLR is a database that contains temporary information about subscribers that is needed by the MSC in order to service visiting subscribers. The VLR is always integrated with the MSC. When a mobile station roams into a new MSC area, the VLR connected to that MSC will request data about the mobile station from the HLR. Later, if the mobile station makes a call, the VLR will have the information needed for call setup without having to interrogate the HLR each time.
- Authentication center (AUC)—A unit called the AUC provides authentication parameters that verify the user's identity and ensure the confidentiality of each call. The AUC protects network operators from different types of fraud found in today's cellular world.
- Equipment identity register (EIR)—The EIR is a database that contains information about the identity of mobile equipment that prevents calls from stolen, unauthorized, or defective mobile stations.

The AUC and EIR are implemented as stand-alone nodes or as a combined AUC/EIR node.

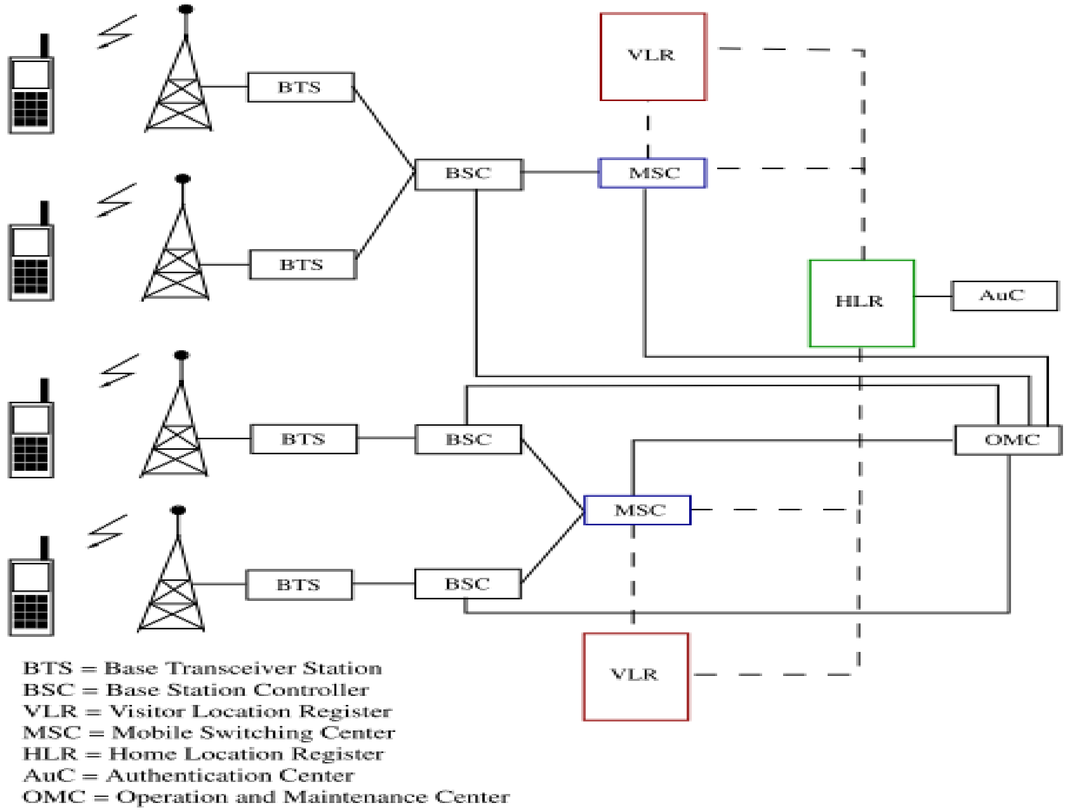
The Base Station System (BSS)

All radio-related functions are performed in the BSS, which consists of base station controllers (BSCs) and the base transceiver stations (BTSs).

- BSC—The BSC provides all the control functions and physical links between the MSC and BTS. It is a high-capacity switch that provides functions such as handover, cell configuration data, and control of radio frequency (RF) power levels in base transceiver stations. A number of BSCs are served by an MSC.
- BTS—The BTS handles the radio interface to the mobile station. The BTS is the radio equipment (transceivers and antennas) needed to service each cell in the network. A group of BTSs are controlled by a BSC.

The Operation and Support System

The operations and maintenance center (OMC) is connected to all equipment in the switching system and to the BSC. The implementation of OMC is called the operation and support system (OSS). The OSS is the functional entity from which the network operator monitors and controls the system. The purpose of OSS is to offer the customer cost-effective support for centralized, regional and local operational and maintenance activities that are required for a GSM network. An important function of OSS is to provide a network overview and support the maintenance activities of different operation and maintenance organizations.



The Sensor (Photodiodes semiconductor)

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.
A photosensor is an electronic component that detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy. Most photo sensors consist of semiconductor having a property called photoconductivity , in which the electrical conductance varies depending on the intensity of radiation striking the material.

Photodiodes

Silicon photodiodes are semiconductor devices responsive to high energy particles and photons. Photodiodes operate by absorption of photons or charged particles and generate a flow of current in an external circuit, proportional to the incident power. Photodiodes can be used to detect the presence or absence of minute quantities of light and can be calibrated for extremely accurate measurements from intensities below 1 pW/cm2 to intensities above 100 mW/cm2. Silicon photodiodes are utilized in such diverse applications as spectroscopy, photography, analytical instrumentation, optical position sensors, optical communications, and medical imaging instruments.

PLANAR DIFFUSED SILICON PHOTODIODE CONSTRUCTION

Planar diffused silicon photodiodes are simply P-N junction diodes. A P-N junction can be formed by diffusing either a P-type impurity (anode), such as Boron, into a N-type bulk silicon wafer, or a N-type impurity, such as Phosphorous, into a P-type bulk silicon wafer. The diffused area defines the photodiode active area. To form an ohmic contact another impurity diffusion into the backside of the wafer is necessary. The impurity is an N-type for P-type active area and P-type for an N-type active area. The contact pads are deposited on the front active area on defined areas, and on the backside, completely covering the device. The active area is then passivated with an antireflection coating to reduce the reflection of the light for a specific predefined wavelength. The non-active area on the top is covered with a thick layer of silicon oxide. By controlling the thickness of bulk substrate, the speed and responsivity of the photodiode can be controlled. Note that the photodiodes, when biased, must be operated in the reverse bias mode, i.e. a negative voltage applied to anode and positive voltage to cathode.

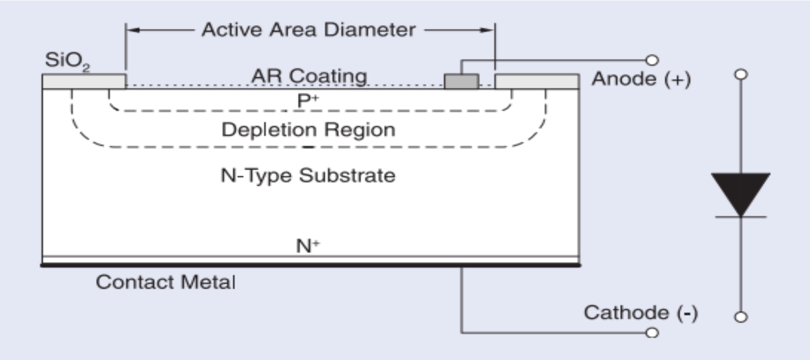
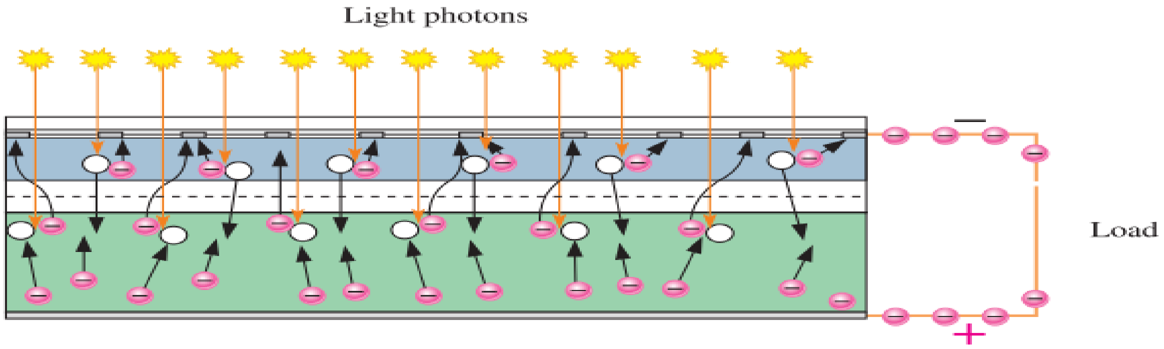


Figure 1. Planar diffused silicon photodiode

PRINCIPLE OF OPERATION:

Silicon is a semiconductor with a band gap energy of 1.12 eV at room temperature. This is the gap between the valence band and the conduction band. At absolute zero temperature the valence band is completely filled and the conduction band is vacant. As the temperature increases, the electrons become excited and escalate from the valence band to the conduction band by thermal energy. The electrons can also be escalated to the conduction band by particles or photons with energies greater than 1.12eV. The resulting electrons in the conduction band are free to conduct current. Due to concentration gradient, the diffusion of electrons from the Ntype region to the P-type region and the diffusion of holes from the P-type region to the N-type region develops a built-in voltage across the junction. The inter-diffusion of electrons and holes between the N and P regions across the junction results in a region with no free carriers. This is the depletion region. The built-in voltage across the depletion region results in an electric field with maximum at the junction and no field outside of the depletion region. Any applied reverse bias adds to the built in voltage and results in a wider depletion region. The electron-hole pairs generated by light are swept away by drift in the depletion region and are collected by diffusion from the undepleted region. The current generated is proportional to the incident light or radiation power. The light is absorbed exponentially with distance and is proportional to the absorption coefficient. Photons with energies smaller than the band gap are not absorbed at all.

PV solar cell: The key feature of a PV (solar) cell is the pn junction that was covered before. The photovoltaic effect is the basic physical process by which a solar cell converts sunlight into electricity. Sunlight contains photons or "packets" of energy sufficient to create electron-hole pairs in the n and p regions. Electrons accumulate in the n-region and holes accumulate in the p region, producing a potential difference (voltage) across the cell. When an external load is connected, the electrons flow through the semiconductor material and provide current to the external load. When a photon penetrates either the n region or the p-type region and strikes a silicon atom near the pn junction with sufficient energy to knock an electron out of the valence band, the electron becomes a free electron and leaves a hole in the valence band, creating an electron-hole pair. The amount of energy required to free an electron from the valence band of a silicon atom is called the band-gap energy and is 1.12 eV (electron volts). In the p region, the free electron is swept across the depletion region by the electric field into the n region. In the n region, the hole is swept across the depletion region by the electric field into the p region. Electrons accumulate in the n region, creating a negative charge; and holes accumulate in the p region, creating a positive charge. A voltage is developed between the n region and p region contacts, as shown in the Figure.



When a load is connected to a solar cell via the top and bottom contacts, the free electrons flow out of the n region to the grid contacts on the top surface, through the negative contact, through the load and back into the positive contact on the bottom surface, and into the p region where they can recombine with holes. The sunlight energy continues to create new electron-hole pairs and the process goes on.

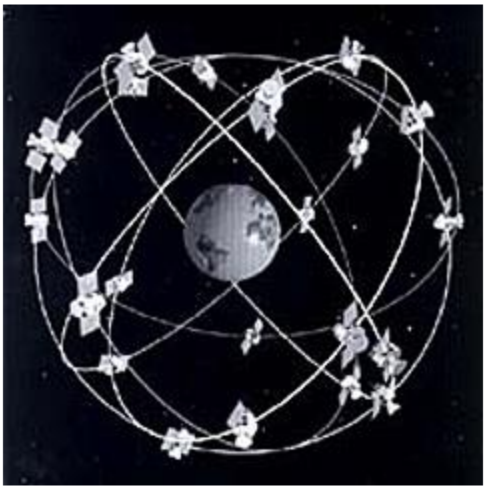
Satellite constellation

Introduction

A single satellite can only cover a part of the world with its communication services; a satellite in geostationary orbit above the Equator cannot see more than 30% of the Earth's surface [Clarke, 1945]. For more complete coverage you need a number of satellites – a satellite constellation.

We can describe a satellite constellation as a number of similar satellites, of a similar type and function, designed to be in similar, complementary, orbits for a shared purpose, under shared control. Satellite constellations have been proposed and implemented for use in communications, including networking. Constellations have also been used for navigation (the Global Positioning System [Kruesi, 1996] and Glonass [Börjesson, et al., 1999]), for remote sensing, and for other scientific applications.

A **satellite constellation** is a group of artificial satellites working in concert. Such a constellation can be considered to be a number of satellites with coordinated ground coverage, operating together under shared control, synchronized so that they overlap well in coverage and complement rather than interfere with other satellites' important coverage.



The GPS constellation calls for 24 satellites to be distributed equally among six circular orbital planes

Mobile satellite systems (MSS) may be classified according to orbit altitude as follows:

- GEO - geostationary earth orbit, approx altitude: 35 000 km
- MEO - mid-altitude earth orbit, approx altitude: 10 000 km
- LEO - low earth orbit, approx altitude: <1 000 km

LEOs can be further sub-divided into Big LEO and Little LEO categories. Big LEOs will offer voice, fax, telex, paging and data capability, whereas little LEOs will offer data capability only, either on a real-time direct readout ('bent pipe') basis, or as a store-and-forward service.

Since the satellite footprint decreases in size as the orbit gets lower, LEO and MEO systems require larger constellations than GEO satellites in order to achieve global coverage and avoid data delays.

Concept of LEO Satellite Constellations (The Technical Case)

A LEO communication satellite constellation system is a constellation of satellites that orbit the Earth at an altitude of about 500-1500 km and provide wireless communications between terminals on the ground. There are two major types of constellations: Polar and Walker (see Figure 1.). Both constellations are designed to provide the most efficient global coverage by using a minimum number of satellites, each with its own advantages and disadvantages. A polar constellation provides coverage for the entire globe, including the poles, while a Walker constellation only covers areas below a certain latitude (such as +/-70o in the case of Globalstar). With the same number of satellites, a Walker constellation can therefore provide a higher diversity than a polar constellation.

Diversity is the average number of satellites simultaneously in view of a user on the ground. A high diversity will bring technical benefits such as higher availability, fewer dropped connections and reduced multipath fading.

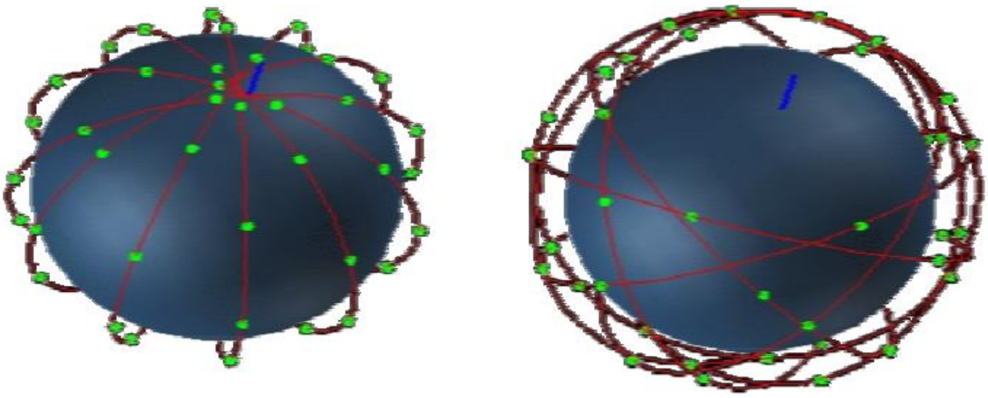


Figure 1. Polar (left) and Walker satellite constellation (right).

Some of the systems have inter-satellite links (ISLs) and onboard processing that allow transmission between neighboring satellites in the constellation, while other systems act as “bent pipes” that simply “bounce” the signals between different ground users. Ground users can be either an end user terminal in the form of a “satellite phone”2 or a gateway. The gateway has a larger antenna dish and is connected to the PSTN to allow communications between satellite phones and traditional wired ground telephones. The concept is illustrated in Figure 2.

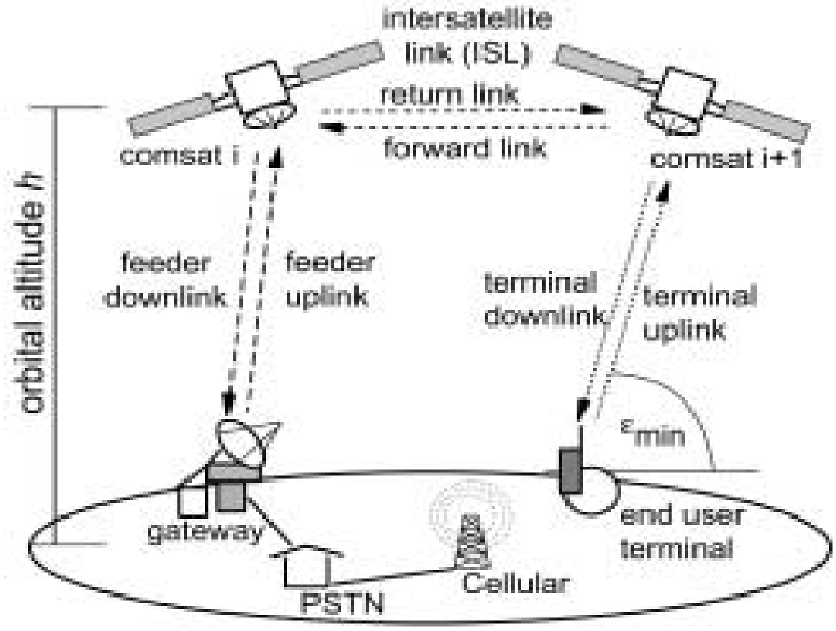


Figure 2. LEO communications satellite constellation concept. The orbital altitude, h, is typically between 500-1500 km. The minimum elevation angle, εmin, is typically 5-15 degrees.

LEO systems overcome the distance problem that plagues the GEO systems. Time delay for LEO systems is on the order of 10 milliseconds, negligible for voice communication. The short distance also reduces the requirement on power and antenna size. As a result, LEO satellite phones are much more compact, which enables them to be carried by individual users. The smaller distance, however, comes at a price. While three GEO satellites, separated by 120 degrees in longitude, can cover the entire globe below 70 degrees of latitude, LEO constellations typically require dozens of satellites to ensure continuous global coverage because the footprint of a LEO satellite is much smaller. Technically, these systems are more challenging than GEO satellites, because a LEO satellite will travel in the sky from West to East at roughly 7 km/sec and will only be visible between 7 and 20 minutes depending on satellite altitude and user position relative to the satellite's ground track. Longer calls must therefore be seamlessly switched over from one satellite to the next. This requires complex (and therefore expensive) switching hardware and software.

Also, many GEO satellites work in a one way broadcast mode, i.e. one source of transmission in orbit and many receivers on the ground. LEO satellites on the other hand require two-way many-tomany connections, which increases the need for frequency bandwidth as well as hardware and software complexity of both space and terrestrial elements. The following paragraphs will briefly cover the concepts of multiple access and spot beams, which are the foundation of LEO communications constellations. This will help explain satellite communications in general and will lay the foundation for subsequent units of this systems study.

Photovoltaic (PV) Cell Structure and Operation

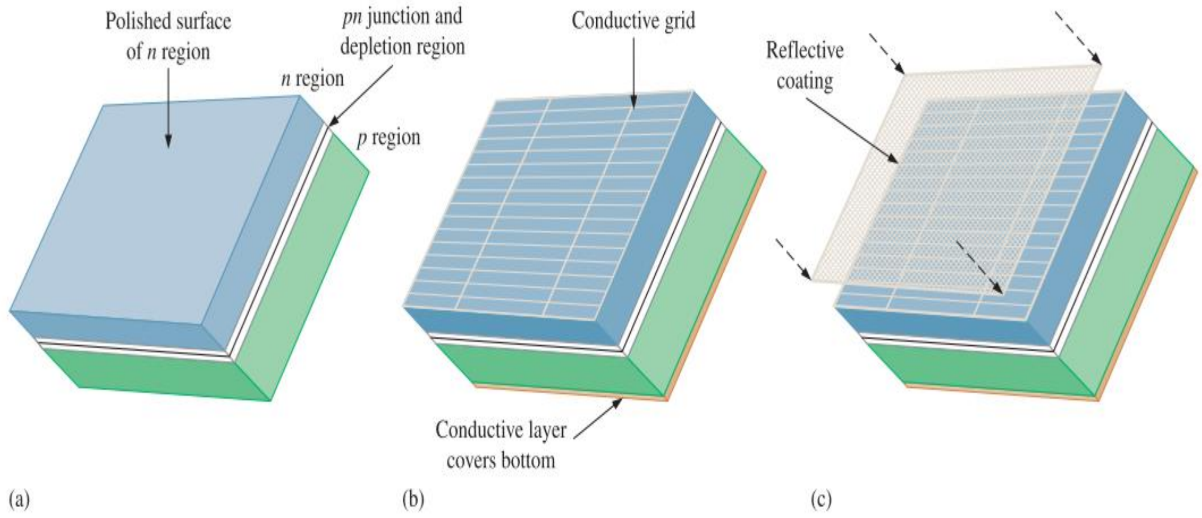
The key feature of a PV (solar) cell is the pn junction that was covered before. The photovoltaic effect is the basic physical process by which a solar cell converts sunlight into electricity. Sunlight contains photons or "packets" of energy sufficient to create electron-hole pairs in the n and p regions. Electrons accumulate in the n-region and holes accumulate in the p region, producing a potential difference (voltage) across the cell. When an external load is connected, the electrons flow through the semiconductor material and provide current to the external load.

The Solar Cell Structure Although there are other types of solar cells and continuing research promises new developments in the future, the crystalline silicon solar cell is by far the most widely used. A silicon solar cell consists of a thin layer or wafer of silicon that has been doped to create a pn junction. The depth and distribution of impurity atoms can be controlled very precisely during the doping process. The most commonly used process for creating a silicon ingot, from which a silicon wafer is cut, is called the Czochralski method. In this process, a seed crystal of silicon is dipped into melted polycrystalline silicon.

As the seed crystal is withdrawn and rotated, a cylindrical ingot of silicon is formed.

Thin circular shaped-wafers are sliced from an ingot of ultra-pure silicon and then are polished and trimmed to an octagonal, hexagonal, or rectangular shape for maximum coverage when fitted into an array. The silicon wafer is doped so that the n region is much thinner than the p region to permit light penetration, as shown in Figure 1(a).

A grid-work of very thin conductive contact strips are deposited on top of the wafer by methods such as photo-resist or silk-screen, as shown in part (b). The contact grid must maximize the surface area of the silicon wafer that be exposed to the sunlight in order to collect as much light energy as possible.

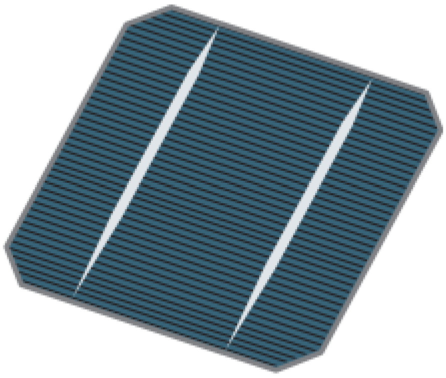


Basic construction of a PV solar cell

The conductive grid across the top of the cell is necessary so that the electrons have a shorter distance to travel through the silicon when an external load is connected. The farther electrons travel through the silicon material, the greater the energy loss due to resistance.

A solid contact covering all of the bottom of the wafer is then added, as indicated in the figure. Thickness of the solar cell compared to the surface area is greatly exaggerated for purposes of illustration.

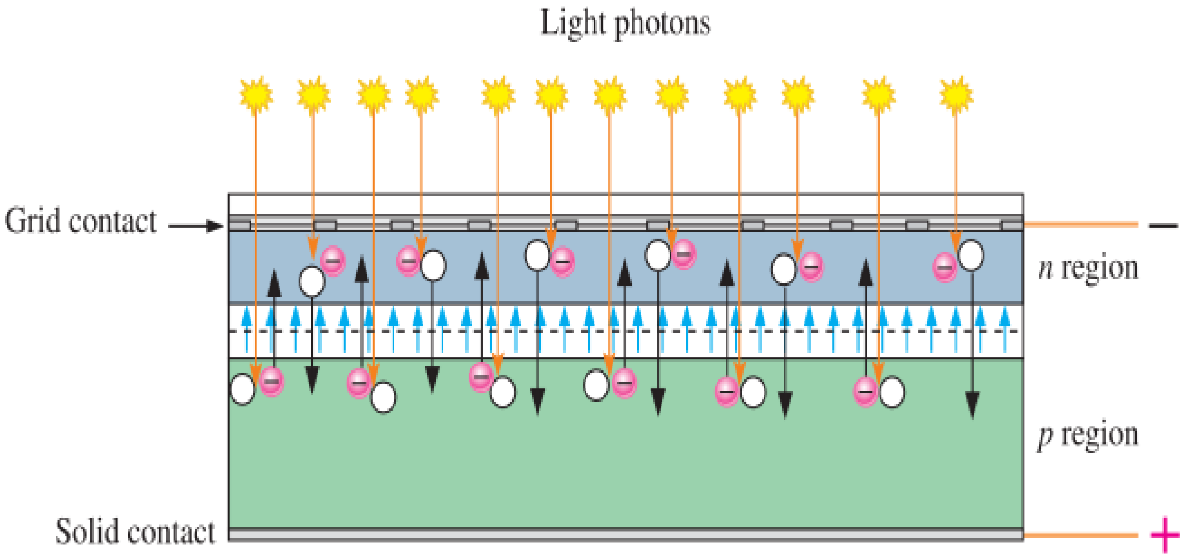
After the contacts are incorporated, an antireflective coating is placed on top the contact grid and n region, as shown in Figure 1(c). This allows the solar cell to absorb as much of the sun’s energy as possible by reducing the amount of light energy reflected away from the surface of the cell. Finally, a glass or transparent plastic layer is attached to the top of the cell with transparent adhesive to protect it from the weather. Figure 2 shows a completed solar cell.



Operation of a Solar Cell As indicated before, sunlight is composed of photons, or “packets” of energy. The sun produces an astounding amount of energy. The small fraction of the sun’s total energy that reaches the earth is enough to meet all of our power needs many times over. There is sufficient solar energy striking the earth each hour to meet worldwide demands for an entire year.

The n-type layer is very thin compared to the p region to allow light penetration into the p region. The thickness of the entire cell is actually about the thickness of an eggshell.

When a photon penetrates either the n region or the p-type region and strikes a silicon atom near the pn junction with sufficient energy to knock an electron out of the valence band, the electron becomes a free electron and leaves a hole in the valence band, creating an electron-hole pair. The amount of energy required to free an electron from the valence band of a silicon atom is called the band-gap energy and is 1.12 eV (electron volts). In the p region, the free electron is swept across the depletion region by the electric field into the n region. In the n region, the hole is swept across the depletion region by the electric field into the p region. Electrons accumulate in the n region, creating a negative charge; and holes accumulate in the p region, creating a positive charge. A voltage is developed between the n region and p region contacts, as shown in Figure3.



When a load is connected to a solar cell via the top and bottom contacts, the free electrons flow out of the n region to the grid contacts on the top surface, through the negative contact, through the load and back into the positive contact on the bottom surface, and into the p region where they can recombine with holes. The sunlight energy continues to create new electron-hole pairs and the process goes on, as illustrated in Figure 4.