SEMICONDUCTORS AND P-N JUNCTIONS pdf

1: semiconductor | Definition, Types, Materials, Applications, & Facts | www.enganchecubano.com

A p-n junction is a boundary or interface between two types of semiconductor materials, p-type and n-type, inside a single crystal of semiconductor. The "p" (positive) side contains an excess of holes, while the "n" (negative) side contains an excess of electrons in the outer shells of the electrically neutral atoms there.

They have a moderate range of electrical conductivity. The examples of such materials are germanium, silicon, carbon etc. As the conductivity of those materials lies between good conductors and insulators, and these materials are called semiconductors. The atoms of semiconductor elements have exactly four valence electrons. Because of these four valence electrons, the semiconductor elements do have some special electrical characteristics and properties, which make them useful in using extensively in electronic circuit elements like diodes , transistors , SCRs , etc. Although a semiconductor has many physical properties, semiconductor name is given to this material because of its moderate electrical conductivity. Where the resistivity of copper is about 1. Copper is good conductor and glass is insulater. We have already told that semiconductor is useful in electronic circuit elements not only because of its moderate resistivity but because of its many other special properties. Some main properties of semiconductors are, The resistivity is less than an insulator and more than a conductor. The temperature coefficient of resistance is negative. When impurities are added to a semiconductor , the resistivity of the semiconductor changes abruptly. Bonds in Semiconductor The valence electrons in semiconductor atoms take a vital role in bonding between atoms in the semiconductor crystal. Bonding between atoms occurs because each atom has a tendency to feel its outer most cell with eight electrons. Each semiconductor atom has four valence electrons, hence the atom can share four other valence electrons of neighbouring atoms to complete eight electrons in its outer most cell. The bonding between atoms by sharing valence electrons is called the covalent bond. Each semiconductor atom creates four covalent bonds with four neighbouring atoms in the crystal. That means, one covalent bond is created with each of four neighbouring semiconductor atom. The figure below shows the covalent bonds formed in a germanium crystal. In germanium crystal, each atom has eight electrons in its last orbit. But in an isolated single germanium atom, there are 32 electrons. The first orbit consists of 2 electrons. The second orbit consists of 8 electrons. The third orbit consists of 18 electrons and rests 4 electrons are in fourth or outer most orbit. But in a germanium crystal, each atom shares 4 valence electrons from four neighbouring atoms to fill its outermost orbit with eight electrons. In this way, each of them in the crystal will have eight electrons in its outermost orbit. By forming these covalent bonds, each of the valence electrons in the crystal becomes associated with atoms, hence there will not be any free electron in the crystal in ideal condition. In a semiconductor , the atoms are orderly arranged due to atom to atom covalent bonds. This forms the crystal structure of a semiconductor. Commonly Used Semiconductor There are many semiconductors but few of them are used for electronic circuits. Two most commonly used semiconductors are silicon and germanium. The silicon and germanium require lower energy to break their covalent bonds in the crystal. This is the main reason for using these two semiconductors most commonly. Silicon Silicon has total 14 electrons in its isolated atom. The second orbit consists of 8 electrons and the third orbit consists of 4 electrons. As there are four electrons in the outer most orbit of a silicon atom, the silicon is a tetravalent element. Each silicon atom in silicon crystal creates covalent bonds with four neighbouring silicon atoms. In this way, each atom of a silicon crystal gets 8 electrons in its outermost orbit. The atom to atom covalent bonds arrange the silicon atoms in the crystal in an orderly manner. Germanium Germanium has 32 electrons in its isolated atom. The first, second and third orbit of the germanium atom consists of 2, 8, 18 electrons respectively. In the similar way of silicon atoms in the crystal, germanium atoms in germanium crystal make four covalent bonds with four adjacent germanium atoms. For same reasons as in the silicon crystal, germanium atoms in germanium crystal arrange themselves in an orderly manner. Energy Band Theory of Semiconductor In a semiconductor crystal, the valence bands are filled with valence electrons. Due to atom to atom covalent bonds, the entire valence band is filled with valence electrons in ideal condition. Hence, in ideal condition, the entire conduction band is empty. But the typicality about the semiconductor is that the band gap between conduction band and valence band is moderately small. It is about 1 eV. Hence, for any external energy supplied to the crystal, the electrons of valence band can acquire an ability to migrate to the conduction band and increase the conductivity. We call the energy gap between conduction and valence as forbidden energy gap. The forbidden energy gap of silicon is 1. As the forbidden energy gap is quite moderate, an electron in valence band requires a small energy to cross the forbidden energy gap to become free. Even at room temperature, there are numbers of free electrons available in a silicon or germanium semiconductor crystal. Not only in silicon or germanium semiconductor, in all other semiconductors there are numbers of free electrons at room temperature, because of the same reason. These free electrons, which are in conduction bands, cause the conductivity of semiconductor. Although there are numbers of free electrons in a semiconductor at room temperature, but still the number is quite small compared to number of atoms in a piece of semiconductor crystal. It is found that, at room temperature out of semiconductor atoms, there will be only one free electrons. Because of these small number of free electrons, the semiconductors possess moderate conductivity i. At absolute zero temperature, there will be no external energy available in a semiconductor crystal. There will be no valence electron crossing the forbidden energy gap. Hence, there will be no free electron available in the semiconductor crystal. Consequently, the semiconductor will behave as a perfect insulator at absolute zero temperature. Now when the temperature of the semiconductor rises from absolute zero, the electrons of valence band get energy and cross the forbidden gap, hence becomes free electrons. As the temperature rises continually, the number of free electrons gets increased in the semiconductor crystal and therefore the conductivity of the semiconductor increases. The conductivity is the inverse of resistance. That means, with an increase in temperature, the resistance of a semiconductor decreases. Hence, we can say a semiconductor has the negative temperature coefficient of resistance. Hence, at a room temperature, if we apply a potential difference across a semiconductor, there will be a small current flowing through the semiconductor because of its moderate conductivity developed in the semiconductor at room temperature. Whenever there will be an electron migrated from valence band to conduction band, a vacant place in created in the valence band, where a new electron can sit. We refer this vacant place in valence band where an electron can sit, as a hole. As soon as an electron becomes free, there will be a hole created behind it in the valence band. Hence for each free electron in a pure semiconductor, there will be a hole. Hence we can say, any external energy, mainly thermal energy creates not only free electrons in the semiconductor crystal rather it creates electron-hole pairs. Each covalent bond in the semiconductor, consists of two valence electrons contributed by two neighbouring atoms. When one of the valence electrons leaves the bond, the bond becomes incomplete. This incomplete bond has a strong tendency to complete itself by attracting an electron. The hole is the electron vacancy created in the covalent bond and as this hole can attract electron, we can assume the hole as an equivalent of positive charge. But there is no physical existence of positive charge but till it can act as a positive charge. In other words, a hole in the semiconductor is a virtual positive charge. Like free electrons, holes in the semiconductor crystal move from one point to other. But the movement of holes in the semiconductor is different from that of free electrons. The free electrons move physically in the semiconductor crystal structure. The holes move in the semiconductor crystal virtually. Each hole created in the crystal is strongly associated with its parent atoms. Hence, physically it does not move. When an electron from other covalent bond comes and sits on the hole, the hole vanishes. But the electron sitting on the hole coming from any other covalent bond hence the electron has created a hole in its previous bond. So, a new hole has already appeared there. In this way, one hole vanishes and another hole appears at the same time. Virtually as such a hole moves from its old position to its new position. When we apply a potential difference across a semiconductor , free electrons move from negative to the positive side of the potential. At the same time holes move from positive side negative side. Intrinsic Semiconductor Intrinsic semiconductor is extremely pure semiconductor. At room temperature, electron-hole pairs created in the intrinsic semiconductor crystal only due to thermal excitation. An intrinsic semiconductor does have a moderate conductivity of electricity due to the concentration of free electrons and holes thermally created in the crystal, at room temperature. Extrinsic Semiconductor We can change the conductivity of the semiconductor significantly by adding some impurities in it. We refer to the process of adding impurities in a semiconductor for changing its conductive property, as doping. Added impurities in the semiconductor either increase the number of free electrons or increase the number of holes depending upon the type of impurities added. When we add pentavalent elements as impurities, the number of free electrons in the extrinsic semiconductor crystal increases.

2: Metalâ€“semiconductor junction - Wikipedia

P-N Junction One of the crucial keys to solid state electronics is the nature of the P-N junction. When p-type and n-type materials are placed in contact with each other, the junction behaves very differently than either type of material alone.

Forward and reverse bias A p-n junction consists of two semiconductor regions with opposite doping type as shown in Figure 4. The region on the left is p-type with an acceptor density Na, while the region on the right is n-type with a donor density Nd. The dopants are assumed to be shallow, so that the electron hole density in the n-type p-type region is approximately equal to the donor acceptor density. Cross-section of a p-n junction We will assume, unless stated otherwise, that the doped regions are uniformly doped and that the transition between the two regions is abrupt. We will refer to this structure as an abrupt p-n junction. Frequently we will deal with p-n junctions in which one side is distinctly higher-doped than the other. We will find that in such a case only the low-doped region needs to be considered, since it primarily determines the device characteristics. We will refer to such a structure as a one-sided abrupt p-n junction. The junction is biased with a voltage Va as shown in Figure 4. We will call the junction forward-biased if a positive voltage is applied to the p-doped region and reversed-biased if a negative voltage is applied to the p-doped region. The contact to the p-type region is also called the anode, while the contact to the n-type region is called the cathode, in reference to the anions or positive carriers and cations or negative carriers in each of these regions. Flatband diagram The principle of operation will be explained using a gedanken experiment, an experiment, which is in principle possible but not necessarily executable in practice. We imagine that one can bring both semiconductor regions together, aligning both the conduction and valence band energies of each region. This yields the so-called flatband diagram shown in Figure 4. Energy band diagram of a p-n junction a before and b after merging the n-type and p-type regions Note that this does not automatically align the Fermi energies, EF,n and EF,p. Also, note that this flatband diagram is not an equilibrium diagram since both electrons and holes can lower their energy by crossing the junction. A motion of electrons and holes is therefore expected before thermal equilibrium is obtained. The diagram shown in Figure 4. This name refers to the horizontal band edges. It also implies that there is no field and no net charge in the semiconductor. This process leaves the ionized donors acceptors behind, creating a region around the junction, which is depleted of mobile carriers. The charge due to the ionized donors and acceptors causes an electric field, which in turn causes a drift of carriers in the opposite direction. The diffusion of carriers continues until the drift current balances the diffusion current, thereby reaching thermal equilibrium as indicated by a constant Fermi energy. This situation is shown in Figure 4. Energy band diagram of a p-n junction in thermal equilibrium While in thermal equilibrium no external voltage is applied between the n-type and p-type material, there is an internal potential, fi, which is caused by the workfunction difference between the n-type and p-type semiconductors. This potential equals the built-in potential, which will be further discussed in the next section. The built-in potential The built-in potential in a semiconductor equals the potential across the depletion region in thermal equilibrium. Since thermal equilibrium implies that the Fermi energy is constant throughout the p-n diode, the built-in potential equals the difference between the Fermi energies, EFn and EFp, divided by the electronic charge. It also equals the sum of the bulk potentials of each region, fn and fp, since the bulk potential quantifies the distance between the Fermi energy and the intrinsic energy. This yields the following expression for the built-in potential. Calculate the thermal equilibrium density of electrons and holes in the p-type region as well as both densities in the n-type region. Calculate the built-in potential of the p-n junction Calculate the built-in potential of the p-n junction at K. Solution The thermal equilibrium densities are: In the p-type region: Similarly, the built-in potential at K equals: Forward and reverse bias We now consider a p-n diode with an applied bias voltage, Va. A forward bias corresponds to applying a positive voltage to the anode the p-type region relative to the cathode the n-type region. A reverse bias corresponds to a negative voltage applied to the cathode. Both bias modes are illustrated with Figure 4. The applied voltage is proportional to the difference between the Fermi energy in the n-type and p-type quasi-neutral regions. As a negative voltage is applied, the potential across the semiconductor increases and so does the depletion layer width. As a positive voltage is applied, the potential across the semiconductor decreases and with it the depletion layer width. The total potential across the semiconductor equals the built-in potential minus the applied voltage, or:

3: ASDN - Physics - P-N Junctions

The Fermi Level Energy Semiconductors & Insulators Energy Metals The Fermi level (EF) is the chemical potential for www.enganchecubano.com is the (possibly hypothetical) energy level at which the probabilityof.

We can form a p n junction practically by doping one side of a semiconductor crystal by trivalent impurity and another side by pentavalent impurity. The side of semiconductor crystal where we doped trivalent impurity, is formed p-type semiconductor and the side of semiconductor crystal where we doped pentavalent impurity formed an n-type semiconductor. The middle portion of the crystal where these p-type and n-type semiconductors meet a typical junction formed which is known as P-N junction. Due this junction the semiconductor crystal block gets a typical voltage-current characteristic. This voltage-current characteristic is the basis of all semiconductor elements. Let us now examine how this pn junction is created. We all know that there are plenty of holes in p-type semiconductor and plenty of free electrons in the n-type semiconductor. Again in p-type semiconductor there are numbers of trivalent impurity atoms, and ideally, each hole in the p-type semiconductor is associated with one trivalent impurity atom. Here we used the word ideal because we neglect here thermally generated electrons and holes in the crystal. Now if one electron seats on one hole, the impurity atom which was associated that hole now becomes negative ions. Because that now contains an extra electron. As the trivalent impurity atoms accept electrons and becomes negatively charged, the impurity is called acceptor impurity. The impurity atoms replace an equal number of semiconductor atoms in the crystal and place themselves in the crystal structure. Hence, the impurity atoms are statics in the crystal structure. When these trivalent impurity atoms accept free electrons and become negative ions, the ions remain still static. Similarly, when a semiconductor crystal is doped with the pentavalent impurity, each atom of impurity replace semiconductor atom in the crystal structure hence these impurity atoms become static in the crystal structure. Each pentavalent impurity atom in the crystal structure has one extra electron in the outermost orbit which it can easily remove as a free electron. When it removes that electron it becomes positively charged ions. As the pentavalent impurity atoms donate electrons to the semiconductor crystal, the pentavalent impurity is called donor impurity. During discussion of pn junction, we have discussed static acceptor and donor impurity atoms because these play a primary role in the formation of pn junction. Let us come to the point when a p-type semiconductor comes in contact with an n-type semiconductor , free electrons on n-type semiconductor nearer to the junction first migrate to the p-type semiconductor due to diffusion because the concentration of free electrons is much more in the n-type region than that of the p-type region. The electrons come to the p region will combine with holes they first find. That means the free electrons come from n-type region will combine with acceptor impurity atoms nearer to the junction. This phenomenon makes negative ions. As the acceptor impurity atoms nearer the junction in the p-type region, becomes negative ions, there will be a layer of negative static ions in p region adjacent to the junction. It is obvious that the free electrons in the n-type region will migrate first to the p-type region than the free electrons in the n-type region away from the junction. This makes a layer of static positive ions in the n-type region adjacent to the junction. After formation of the sufficiently thick positive ions layer in n-type region and negative ions layer in the p-type region, there will be no more diffusion of electrons from n-type region to p-type region as because there is a negative wall in front of free electrons. These both layers of ions form the pn junction. As one layer is negatively charged and other is positively charged, there will be an electrical potential across the junction and the junction behaves like a potential barrier. The barrier potential depends on the semiconductor material, the amount of doping and temperature. It is found that barrier potential for germanium semiconductor is 0. This potential barrier does not contain any free electron or hole since all free electrons are combined with holes in this region and due to the depletion of charge carriers electrons or holes in this region it is also called depletion region. Although diffusion of free electrons and holes stop after the creation of certain thick depletion layer but practically this thickness of depletion layer is very tiny it in a range of micrometers.

4: Semiconductor p-n junctions - Chemistry LibreTexts

Contact potentials and space charge layers With the Ansatz that the charge is distributed evenly with x (homogenous doping) one considers the relation of.

After joining p-type and n-type semiconductors, electrons from the n region near the pâ€"n interface tend to diffuse into the p region leaving behind positively charged ions in the n region and being recombined with holes, forming negatively charged ions in the p region. Likewise, holes from the p-type region near the pâ€"n interface begin to diffuse into the n-type region, leaving behind negatively charged ions in the p region and recombining with electrons, forming positive ions in the n region[further explanation needed]. The regions near the pâ€"n interface lose their neutrality and most of their mobile carriers, forming the space charge region or depletion layer see figure A. A pâ€"n junction in thermal equilibrium with zero-bias voltage applied. Electron and hole concentration are reported with blue and red lines, respectively. Gray regions are charge-neutral. Light-red zone is positively charged. Light-blue zone is negatively charged. The electric field is shown on the bottom, the electrostatic force on electrons and holes and the direction in which the diffusion tends to move electrons and holes. The log concentration curves should actually be smoother with slope varying with field strength. The electric field created by the space charge region opposes the diffusion process for both electrons and holes. There are two concurrent phenomena: The carrier concentration profile at equilibrium is shown in figure A with blue and red lines. Also shown are the two counterbalancing phenomena that establish equilibrium. Under the junction, plots for the charge density, the electric field, and the voltage are reported. The log concentration curves should actually be smoother, like the voltage. The space charge region is a zone with a net charge provided by the fixed ions donors or acceptors that have been left uncovered by majority carrier diffusion. When equilibrium is reached, the charge density is approximated by the displayed step function. In fact, since the y-axis of figure A is log-scale, the region is almost completely depleted of majority carriers leaving a charge density equal to the net doping level , and the edge between the space charge region and the neutral region is quite sharp see figure B , Q x graph. The space charge region has the same magnitude of charge on both sides of the pâ€"n interfaces, thus it extends farther on the less doped side in this example the n side in figures A and B. Forward bias[edit] In forward bias, the p-type is connected with the positive terminal and the n-type is connected with the negative terminal. PN junction operation in forward-bias mode, showing reducing depletion width. The panels show energy band diagram, electric field, and net charge density. Reducing depletion width can be inferred from the shrinking charge profile, as fewer dopants are exposed with increasing forward bias. Observe the different quasi-fermi levels for conduction band and valence band in n and p regions red curves With a battery connected this way, the holes in the p-type region and the electrons in the n-type region are pushed toward the junction and start to neutralize the depletion zone, reducing its width. The positive potential applied to the p-type material repels the holes, while the negative potential applied to the n-type material repels the electrons. The change in potential between the p side and the n side decreases or switches sign. Electrons that cross the pâ€"n junction into the p-type material or holes that cross into the n-type material diffuse into the nearby neutral region. The amount of minority diffusion in the near-neutral zones determines the amount of current that can flow through the diode. Only majority carriers electrons in n-type material or holes in p-type can flow through a semiconductor for a macroscopic length. With this in mind, consider the flow of electrons across the junction. The forward bias causes a force on the electrons pushing them from the N side toward the P side. With forward bias, the depletion region is narrow enough that electrons can cross the junction and inject into the p-type material. However, they do not continue to flow through the p-type material indefinitely, because it is energetically favorable for them to recombine with holes. The average length an electron travels through the p-type material before recombining is called the diffusion length, and it is typically on the order of micrometers. The flow of holes from the p-type region into the n-type region is exactly analogous to the flow of electrons from N to P electrons and holes swap roles and the signs of all currents and voltages are reversed. Therefore, the macroscopic picture of the current flow through the diode involves electrons flowing through the n-type region toward the junction, holes flowing through the p-type region in the opposite direction toward the junction, and the two species of carriers constantly recombining in the vicinity of the junction. The electrons and holes travel in opposite directions, but they also have opposite charges, so the overall current is in the same direction on both sides of the diode, as required. The Shockley diode equation models the forward-bias operational characteristics of a pâ€”n junction outside the avalanche reverse-biased conducting region. Reverse bias[edit] A silicon pâ€”n junction in reverse bias. Connecting the p-type region to the negative terminal of the battery and the n-type region to the positive terminal corresponds to reverse bias. If a diode is reverse-biased, the voltage at the cathode is comparatively higher than at the anode. Therefore, very little current flows until the diode breaks down. The connections are illustrated in the adjacent diagram. Likewise, because the n-type region is connected to the positive terminal, the electrons are pulled away from the junction, with similar effect. This increases the voltage barrier causing a high resistance to the flow of charge carriers, thus allowing minimal electric current to cross the pâ€”n junction. The increase in resistance of the pâ€”n junction results in the junction behaving as an insulator. The strength of the depletion zone electric field increases as the reverse-bias voltage increases. Once the electric field intensity increases beyond a critical level, the pâ€”n junction depletion zone breaks down and current begins to flow, usually by either the Zener or the avalanche breakdown processes. Both of these breakdown processes are non-destructive and are reversible, as long as the amount of current flowing does not reach levels that cause the semiconductor material to overheat and cause thermal damage. This effect is used to advantage in Zener diode regulator circuits. Zener diodes have a low breakdown voltage. A standard value for breakdown voltage is for instance 5. This means that the voltage at the cathode cannot be more than about 5. This, in effect, limits the voltage over the diode. Another application of reverse biasing is Varicap diodes, where the width of the depletion zone controlled with the reverse bias voltage changes the capacitance of the diode.

SEMICONDUCTORS AND P-N JUNCTIONS pdf

5: The P-N Junction | Solid-state Device Theory | Electronics Textbook

SEMICONDUCTORS AND P-N JUNCTIONS SEMICONDUCTORS In Becquerel observed that certain materials, when exposed to light, produced an electric current (Becquerel,).

In this tutorial you will learn how to build a p-n junction device and how to study the current-voltage characteristic of such a device. You will compare two different methods: You will also analyze the electronic structure of the p-junction by studying and plotting the device density of states at zero bias and at reverse and forward bias. Finally, send it to the Job Manager and run it! Once the calculation is done it will only take a few seconds you can find in the LabFloor your Bandstructure object. Select it and use the Bandstructure Analyzer plugin on the right hand side to plot the bandstructure. You can zoom in a region closer to the band edges and precisely measure the calculated band gap, 1. Throughout this tutorial you will use this fitted c parameter for the MGGA calculations. Send the script to the Editor and modify the exchange correlation section as shown in the figure below. Also, add a loop over the c values to run the four calculations with a single python script: You can download a copy of the script here. Run the job which will take around a minute to complete. In the log window you can read the fitted c parameter Fitted c parameter: In particular, you can see that the indirect band gap is calculated from the bandstructure with the function: Choose 1, 0, 0 Miller indices to cut the surface and define the [] transport direction of your device; Keep the 1x1 surface unit cell; Select a thickness of 52 layers and press Finish. The 52 layers will constitute the central region of your device. Still, as you will see in the Finite-bias calculation section, this device is not long enough to have perfectly converged results. However, you will use the "52 layers" device throughout this tutorial to be able to perform the MGGA calculations faster. Keep the default parameters as such and press OK. In this step you will assign two different tag names to the atoms on the half left and half right side of the device corresponding to the p-type and n-type doping. Si basis set and uncheck "No SCF iteration" box. In the next sections you will use the results from these analysis to study in more details the electronic properties of your p-n junction. Add the IVCurve analysis object. A full explanation of all the parameters is given here and here. Double click on IVCurve and change the parameters as follow: The last operation you have to do before running the calculation is set up the proper doping to finally have a p-n junction. Depending on the anaysis you have included, the job may take a few minutes for the zero bias part and up to few hours to calculate the whole IV curve. The above calculations are run in parallel on different Intel Xeon e 3. All the oter parameters are set as in this tutorial. Note that the Slater-Koster calculation is much faster compare to the calculation of the transmission spectrum. Only change the New Calculator:

6: P N Junction Theory Behind P N Junction

PN Junction Theory A PN-junction is formed when an N-type material is fused together with a P-type material creating a semiconductor diode In the previous tutorial we saw how to make an N-type semiconductor material by doping a silicon atom with small amounts of Antimony and also how to make a P-type semiconductor material by doping another.

We have two conductive blocks in contact with each other, showing no unique properties. The problem is two separate and distinct crystal bodies. The number of electrons is balanced by the number of protons in both blocks. Thus, neither block has any net charge. However, a single semiconductor crystal manufactured with P-type material at one end and N-type material at the other in Figure below b has some unique properties. The P-type material has positive majority charge carriers, holes, which are free to move about the crystal lattice. The N-type material has mobile negative majority carriers, electrons. Near the junction, the N-type material electrons diffuse across the junction, combining with holes in P-type material. The region of the P-type material near the junction takes on a net negative charge because of the electrons attracted. Since electrons departed the N-type region, it takes on a localized positive charge. The thin layer of the crystal lattice between these charges has been depleted of majority carriers, thus, is known as the depletion region. It becomes nonconductive intrinsic semiconductor material. In effect, we have nearly an insulator separating the conductive P and N doped regions. This separation of charges at the PN junction constitutes a potential barrier. This potential barrier must be overcome by an external voltage source to make the junction conduct. The formation of the junction and potential barrier happens during the manufacturing process. The magnitude of the potential barrier is a function of the materials used in manufacturing. Silicon PN junctions have a higher potential barrier than germanium junctions. In Figure below a the battery is arranged so that the negative terminal supplies electrons to the N-type material. These electrons diffuse toward the junction. The positive terminal removes electrons from the P-type semiconductor, creating holes that diffuse toward the junction. If the battery voltage is great enough to overcome the junction potential 0. This frees up space within the lattice for more carriers to flow toward the junction. Thus, currents of N-type and P-type majority carriers flow toward the junction. The recombination at the junction allows a battery current to flow through the PN junction diode. Such a junction is said to be forward biased. Depletion region thickness increases. No sustained battery current flows. If the battery polarity is reversed as in Figure above b majority carriers are attracted away from the junction toward the battery terminals. The positive battery terminal attracts N-type majority carriers, electrons, away from the junction. The negative terminal attracts P-type majority carriers, holes, away from the junction. This increases the thickness of the nonconducting depletion region. There is no recombination of majority carriers; thus, no conduction. This arrangement of battery polarity is called reverse bias. The diode schematic symbol is illustrated in Figure below b corresponding to the doped semiconductor bar at a. The diode is a unidirectional device. Electron current only flows in one direction, against the arrow, corresponding to forward bias. The cathode, bar, of the diode symbol corresponds to N-type semiconductor. The anode, arrow, corresponds to the P-type semiconductor. To remember this relationship, Not-pointing bar on the symbol corresponds to N-type semiconductor. Pointing arrow corresponds to P-type. If a diode is forward biased as in Figure above a , current will increase slightly as voltage is increased from 0 V. In the case of a silicon diode a measurable current flows when the voltage approaches 0. As the voltage increases past 0. Increasing the voltage well beyond 0. The forward voltage, VF, is a characteristic of the semiconductor: The forward current ranges from a few mA for point contact diodes to mA for small signal diodes to tens or thousands of amperes for power diodes. If the diode is reverse biased, only the leakage current of the intrinsic semiconductor flows. This is plotted to the left of the origin in Figure above c. This current does not increase appreciably with increasing reverse bias until the diode breaks down. At breakdown, the current increases so greatly that the diode will be destroyed unless a high series resistance limits current. We normally select a diode with a higher reverse voltage rating than any applied voltage to prevent this. Silicon diodes are typically available with reverse break down ratings of 50, , , , V and higher. It is possible to fabricate diodes with a lower rating of a few volts for use as voltage standards. This is the leakage that can be explained by theory.

Thermal energy produces few electron hole pairs, which conduct leakage current until recombination. In actual practice this predictable current is only part of the leakage current. Much of the leakage current is due to surface conduction, related to the lack of cleanliness of the semiconductor surface. For germanium, the leakage current is orders of magnitude higher. Since germanium semiconductors are rarely used today, this is not a problem in practice. PN junctions are fabricated from a monocrystalline piece of semiconductor with both a P-type and N-type region in proximity at a junction. The transfer of electrons from the N side of the junction to holes annihilated on the P side of the junction produces a barrier voltage. A forward biased PN junction conducts a current once the barrier voltage is overcome. The external applied potential forces majority carriers toward the junction where recombination takes place, allowing current flow. A reverse biased PN junction conducts almost no current. The applied reverse bias attracts majority carriers away from the junction. Reverse biased PN junctions show a temperature dependent reverse leakage current.

SEMICONDUCTORS AND P-N JUNCTIONS pdf

7: Semiconductors/PN Junctions - Wikibooks, open books for an open world

P-n junction, in electronics, the interface within diodes, transistors, and other semiconductor devices between two different types of materials called p-type and n-type semiconductors. These materials are formed by the deliberate addition of impurities to pure semiconductor materials, such as silicon.

The oldest method of making a p-n junction is by diffusion. The dopant diffuses in under heating so that the surface acceptor concentration exceeds the donor concentration. The starting material, n-type only, is bombarded with the required species of ions, say acceptors. This produces sharper junctions, but causes damage to the crystal lattice structure increasing the number of dislocations and interstitial atoms. Epitaxial deposition techniques are now widely established. The starting material is a single crystal in all cases, so it is possible to grow further crystal layers which are in register with the starting crystal. Ions of the semiconductor together with dopants are fired at the crystal surface. Under the right conditions ultrahigh vacuum, correct ion fluxes, correct substrate temperature the crystal grow epitaxially with the required dopant included. This technique can produce very sharp junctions and there is no counter-doping, i. Discussion on fabrication from crystal growth to etching, other expitaxial growth methods, up to metalisation and etching is outlined here. We are supposed to be discussing p-n junctions! We now consider a p-n junction in the absence of voltage bias, so that it is in thermodynamic equilibrium. This means that the chemical potential must be constant across the junction. Since is near the valence band edge in a p-type region and near the conduction band in an n-type region, the bands must bend through the junction as shown below: This is therefore called the depletion region. Since N A and N D are the densities of ionised acceptor and donor ions, this means that there is a net negative charge on the p-type side of the junction, and a net positive charge on the n-type side. These separated charges generate an electric field, which is the physical cause of the band bending. The overall picture is summarised below. We now calculate charge, electric field and potential. First we find the band offset. These give 3 Using the definition of the intrinsic density n i 24, semiconductor basics , gives 4 This is the difference in the electrostatic potential between the two sides since is the energy difference between electrons at the bottom of the conduction band on the two sides, as may be seen from the diagram. The variation of and the electric field 5 across the junction can be calculated as long as the variations with x of N D and N A are known. If we assume an abrupt junction then the charge distribution has the form:

SEMICONDUCTORS AND P-N JUNCTIONS pdf

8: How a PN Junction Diode Works | Electronics Notes

The middle portion of the crystal where these p-type and n-type semiconductors meet a typical junction formed which is known as P-N junction. Due this junction the semiconductor crystal block gets a typical voltage-current characteristic.

Sodium is a metal. This means that it is a good conductor of heat and electricity. Household wires are usually made of copper, which does a fine job of conducting current. Sodium metal In comparison, nonmetallic elements and most compounds are poor conductors. Diamond, an allotrope of the nonmetal carbon, is a very good insulator. Ironically, graphite, another carbon allotrope, is a very good conductor. Graphene â€”atomic monolayers of graphiteâ€”is even better at this conduction business. Happens regularly around thunderstorms. Extremely high potential differences between the Earth and thunderstorm clouds breaks down the insulation of air, forming forked lightning. Most natural materials found on Earth are either insulators or conductors. Semiconductors Intrinsic semiconductors Some elements and compounds, however, do not identify themselves as either. Elements such as silicon and germanium, and binary compounds such as gallium arsenide and silicon carbide are semiconductors. When heated, semiconductors begin to conduct electricity. This behaviour is quite the opposite of conductors, where resistance increases with increasing temperature. These are intrinsic semiconductors. Atomic orbitals Before we proceed, a quick review of atomic orbitals might be helpful. A more detailed overview can be found here. Electrons are arranged within atoms in orbitals. The energy of the electrons residing in them groups orbitals together in shells. Shells further away from the nucleus have higher energy than those closer to the nucleus. The most commonly encountered orbitals are s, p, and d. Each orbital can have at max 2 electrons. A neutral silicon atom has 14 electrons. These are arranged thus: The first shell of silicon has 2 electrons lowest energy residing in the filled s-type orbital 1s. The second shell has 8 electrons higher energy , 2 in the 2s and six in the 2p. The third shell has the remaining 4 electrons highest energy ; 2 in 3s and 2 is 3p. The 3d orbitals are completely vacant. Silicon electronic configuration Extrinsic semiconductors The behaviour of intrinsic semiconductors can be altered by adding small amounts of another element. For instance, silicon semiconductors can be thus doped using boron or phosphorus. Boron is trivalent, meaning it has three electrons in its outer shell 1s22s22p63s23p1 ; phosphorus is pentavalent, meaning it has five electrons in its outer shell 1s22s22p63s23p3. Since silicon has only four, phosphorus doped silicon has extra electrons which are free to move about. Similarly, boron doped silicon has fewer electrons, the absent electrons leaving behind holes, which are also free to hop about. The former is a n-type semiconductor, where electrons are the charge carriers 2. The latter is a p-type semiconductor, where the holes are the charge carriers 3 These extrinsic semiconductors are far more conductive than their undoped counterparts. When electrodes are attached to the two sides, this becomes the basic building block of all semiconducting electronic devices. Depletion region When a p-n junction is fabricated, there are more holes on the p-side and more electrons on the n-side. Immediately, holes and electrons begin migrating across the junction 4. This sets up a diffusion current pointing from the p-side to the n-side. As holes diffuse over to the n-side, they leave behind negative bound ions. Similarly, diffusing electrons leave behind positive bound ions. Once on the n-side, the holes recombine with the electrons there and disappear. The electrons emulate this behaviour on the p-side. Soon enough, a region forms around the junction which has very few charge carriers. This is the depletion region. Formation of the depletion region in a p-n junction semiconductor The cations and anions left behind set up an electric field pointing from the n-side to the p-side, thus opposing the diffusion current. Once a sufficient number of electrons and holes have diffused, this opposing field is strong enough to stop the diffusion current altogether, and set up its own drift current pointing from the n-side to the p-side. This makes it a p-n junction diode. There are two ways this can be done. This is the forward bias condition. The anode will inject holes into the p-side, while the cathode will inject electrons into the n-side. This will push and squeeze the depletion region so that it is narrow enough for electrons and holes to jump across. Once this happens, a current flows across the p-n semiconductor. As the forward bias voltage increases, the depletion region gets narrower and finally collapses. This allows current to flow through the diode. Energetically speaking, the depletion region creates an energy barrier. In forward bias, if the voltage is not high enough, electrons and holes will not have sufficient energy to surmount the depletion barrier. Which is why the current-voltage graph of a p-n junction diode shows a knee in forward bias. The voltage above which the diode turns on is called the cut-in or the forward voltage VF. Reverse bias In the second scenario, reverse the polarity 5. Connect the anode to the n-side and the cathode to the p-side. They will inject holes and electrons as before, though this time this will lead to greater recombinations and will serve to further widen the depletion region. Reverse bias widens the depletion region, making it almost impossible for current to flow through the diode. Energetically, the reverse voltage will raise the height of the depletion region potential barrier. In this reverse bias state, the diode does not let current pass. Well, not unless the voltage is high enough so that the current flows in the opposite direction as before. Transistors Diodes are electronic valves; they allow current to pass in one direction. As such, they are very useful in circuits. However, they can be made much more useful if two p-n junction semiconductors are attached end-to-end in series, creating three separate zones. Attach electrodes to these three zones and you have a bipolar junction transistor BJT. There are two ways to do this; you either get a p-n-p transistor or an n-p-n transistor. The middle zone is called the base, and the ones on the two ends are called the collector and the emitter. Now, connect electrodes to each of these regions and apply potentials. An n-p-n transistor, with n-type collector and emitter, and p-type base. Of course, BJTs are not the only type of transistor around. Field effect transistors work in a slightly different fashion. Switch and amplifier The transistor can operate in four modes. In what follows, I shall use an n-p-n transistor to illustrate the mechanism. This setup behaves like a closed circuit; current flows freely between the collector and the emitter. For n-p-n, the collector current IC points from the collector to the emitter. Electrons, the majority carriers in n-p-n, are emitted by the emitter and collected by the collector 6. The transistor is now ON. Both the BE and BC junctions are reverse biased. No current flows in the transistor, and it behaves like an open circuit. The transistor is now OFF. By reversing the voltages, one can thus use the transistor as a switch. In this mode, the transistor acts as an amplifierâ€”a small input base current IB gives rise to a very large output collector current IC. A transistor in forward active mode, acting as an amplifier. The n-type emitter emits electrons, a majority of which reach the collector due to the large potential difference between C and E. This mode is seldom used in practice. The four modes of a transistor; saturation ON , cutoff OFF , forward active amplifier , and reverse active. Applications Transistors are the basic building blocks of computers and modern electronics, and have wide-ranging applications. The transistor now functions as a bit, the fundamental unit of classical computing. You can string a few transistor switches together and form logic gates. Bits and logic gates can be used together to implement a series of instructions. This implementation of an algorithm is a computer program. Finally, by connecting transistors together in certain ways, it is possible to make it stay either in the saturation or the cut-off states until a new input has been applied. Such flip-flops can either be in 0 or 1 states, and thus can store bits. These are the building blocks of computer memory.

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What is a P -- N junction semiconductor and how is it formed? The PN junction semi conductor is a combination of P type semiconductor with N type semiconductor to achieve the practical utility of.

Materials are classified as conductors, insulators, or semiconductors according to their electric conductivity. The classifications can be understood in atomic terms. Electrons in an atom can have only certain well-defined energies, Semiconductor materials Solid-state materials are commonly grouped into three classes: At low temperatures some conductors, semiconductors, and insulators may become superconductors. The conductivities of semiconductors are between these extremes and are generally sensitive to temperature, illumination, magnetic fields, and minute amounts of impurity atoms. For example, the addition of about 10 atoms of boron known as a dopant per million atoms of silicon can increase its electrical conductivity a thousandfold partially accounting for the wide variability shown in the preceding figure. The study of semiconductor materials began in the early 19th century. The elemental semiconductors are those composed of single species of atoms, such as silicon Si , germanium Ge , and tin Sn in column IV and selenium Se and tellurium Te in column VI of the periodic table. There are, however, numerous compound semiconductors, which are composed of two or more elements. Pure silicon is the most important material for integrated circuit applications, and III-V binary and ternary compounds are most significant for light emission. Prior to the invention of the bipolar transistor in , semiconductors were used only as two-terminal devices, such as rectifiers and photodiodes. During the early s germanium was the major semiconductor material. However, it proved unsuitable for many applications, because devices made of the material exhibited high leakage currents at only moderately elevated temperatures. Since the early s silicon has become by far the most widely used semiconductor, virtually supplanting germanium as a material for device fabrication. The main reasons for this are twofold: Thus, silicon technology has become very advanced and pervasive , with silicon devices constituting more than 95 percent of all semiconductor products sold worldwide. Many of the compound semiconductors have some specific electrical and optical properties that are superior to their counterparts in silicon. These semiconductors, especially gallium arsenide, are used mainly for optoelectronic and certain radio frequency RF applications. Electronic properties The semiconductor materials described here are single crystals ; i. Part A of the figure shows a simplified two-dimensional representation of an intrinsic pure silicon crystal that contains negligible impurities. Each silicon atom in the crystal is surrounded by four of its nearest neighbours. Each atom has four electrons in its outer orbit and shares these electrons with its four neighbours. Each shared electron pair constitutes a covalent bond. The force of attraction between the electrons and both nuclei holds the two atoms together. For isolated atoms e. However, when a large number of atoms are brought together to form a crystal, the interaction between the atoms causes the discrete energy levels to spread out into energy bands. When there is no thermal vibration i. The highest filled band is called the valence band. The next band is the conduction band, which is separated from the valence band by an energy gap much larger gaps in crystalline insulators than in semiconductors. This energy gap, also called a bandgap, is a region that designates energies that the electrons in the crystal cannot possess. Most of the important semiconductors have bandgaps in the range 0. The bandgap of silicon, for example, is 1. In contrast, the bandgap of diamond, a good crystalline insulator, is 5. Three bond pictures of a semiconductor. At low temperatures the electrons in a semiconductor are bound in their respective bands in the crystal; consequently, they are not available for electrical conduction. At higher temperatures thermal vibration may break some of the covalent bonds to yield free electrons that can participate in current conduction. Once an electron moves away from a covalent bond, there is an electron vacancy associated with that bond. This vacancy may be filled by a neighbouring electron, which results in a shift of the vacancy location from one crystal site to another. When an electric field is applied to the semiconductor, both the free electrons now residing in the conduction band and the holes left behind in the valence band move through the crystal, producing an electric current. The electrical conductivity of a material depends on the number of free electrons and holes charge carriers per unit volume and on the rate at which these carriers move under the influence of an electric field. In an intrinsic semiconductor there exists an equal number of free electrons and holes. The electrons and holes, however, have different mobilities; that is, they move with different velocities in an electric field. The electron and hole mobilities in a particular semiconductor generally decrease with increasing temperature. Electrical conduction in intrinsic semiconductors is quite poor at room temperature. To produce higher conduction, one can intentionally introduce impurities typically to a concentration of one part per million host atoms. This is called doping , a process that increases conductivity despite some loss of mobility. For example, if a silicon atom is replaced by an atom with five outer electrons, such as arsenic see part B of the figure , four of the electrons form covalent bonds with the four neighbouring silicon atoms. The fifth electron becomes a conduction electron that is donated to the conduction band. The silicon becomes an n-type semiconductor because of the addition of the electron. The arsenic atom is the donor. Similarly, part C of the figure shows that, if an atom with three outer electrons, such as boron, is substituted for a silicon atom, an additional electron is accepted to form four covalent bonds around the boron atom, and a positively charged hole is created in the valence band. This creates a p-type semiconductor, with the boron constituting an acceptor. The p-n junction If an abrupt change in impurity type from acceptors p-type to donors n-type occurs within a single crystal structure, a p-n junction is formed see parts B and C of the figure. On the p side, the holes constitute the dominant carriers and so are called majority carriers. A few thermally generated electrons will also exist in the p side; these are termed minority carriers. On the n side, the electrons are the majority carriers, while the holes are the minority carriers. Near the junction is a region having no free charge carriers. This region, called the depletion layer, behaves as an insulator. A Current-voltage characteristics of a typical silicon p-n junction. B Forward-bias and C reverse-bias conditions. D The symbol for a p-n junction. The most important characteristic of p-n junctions is that they rectify. Part A of the figure shows the current-voltage characteristics of a typical silicon p-n junction. When a forward bias is applied to the p-n junction i. However, when a reverse bias is applied as in part C of the figure , the charge carriers introduced by the impurities move in opposite directions away from the junction, and only a small leakage current flows. As the reverse bias is increased, the leakage current remains very small until a critical voltage is reached, at which point the current suddenly increases. This sudden increase in current is referred to as the junction breakdown, usually a nondestructive phenomenon if the resulting power dissipation is limited to a safe value. The applied forward voltage is typically less than one volt, but the reverse critical voltage, called the breakdown voltage, can vary from less than one volt to many thousands of volts, depending on the impurity concentration of the junction and other device parameters. Although other junction types have been invented including p-n-p and n-p-n , p-n junctions remain fundamental to semiconductor devices. For further details on applications of these basic semiconductor properties, see transistor and integrated circuit.

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