

Case Study of Semiconducting Material

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Abstract: *This electronic document is a “live” template and already There is no doubt that semiconductors changed the world beyond anything that could have been imagined before them. Although people have probably always needed to communicate and process data, it is thanks to the semiconductors that these two important tasks have become easy and take up infinitely less time than, e.g., at the time of vacuum tubes. Semiconductor materials are the building blocks of the entire electronics and computer industry. Small, lightweight, high speed, and low power consumption devices would not be possible without integrated circuits (chips), which consist of semiconductor materials. This paper provides a general discussion of semiconductor materials, their history, classification and the temperature effects in semiconductors. In this section we provide details about the impact of temperature on the MOSFET energy band gap, carrier density, mobility, carrier diffusion, velocity saturation, current density, threshold voltage, leakage current and interconnect resistance. We also provide the applications of semiconductor materials in different sectors of modern electronics and communications.*

Keywords: Semiconductor; History of Semiconductor; Temperature effects in semiconductors; Applications of Semiconductors

I. INTRODUCTION

There are certain substances that are neither good conductors (metals) nor insulators (glass). A substance which has crystalline structure and contains very few free electrons at room temperature is called semiconductors. At room temperature, it behaves like an insulator. Its resistivity lies between that of conductor and insulator. If suitable impurities are added to the semiconductors, controlled conductivity can be provided. Some examples of semiconductors are silicon, germanium, carbon etc. Semiconductors are the basic building block of modern electronics, including transistors, solar cells, light-emitting diodes (LEDs), and digital and analog integrated circuits. The modern understanding of the properties of a semiconductor lies on quantum physics to explain the movement of electrons and holes inside a crystal structure and also in a lattice. An increased knowledge of semiconductor materials and fabrication processes has made possible continuing increases in the complexity and speed of microprocessors. The electrical conductivity of a semiconductor material increases with increasing temperature, which is behavior opposite to that of a metal. Semiconductor devices can display a range of useful properties such as passing current more easily in one direction than the other, showing variable resistance, and sensitivity to light or heat. Because the electrical properties of a semiconductor material can be modified by controlled addition of impurities or by the application of electrical fields or light, devices made from semiconductors can be used for amplification, switching, and energy conversion. Current conduction in a semiconductor occurs through the movement of free electrons and "holes", collectively known as charge carriers. Adding impurity atoms to a semiconducting material, known as "doping", greatly increases the number of charge carriers within it. When a doped semiconductor contains mostly free holes it is called "p-type", and when it contains mostly free electrons it is known as "n-type". The semiconductor materials used in electronic devices are doped under precise conditions to control the location and concentration of p- and n-type dopants. A single semiconductor crystal can have many p- and n-type regions; the p-n junctions between these regions are responsible for the useful electronic behavior. Some of the properties of semiconductor materials were observed throughout the mid 19th and first decades of the 20th century. Development of quantum physics in turn allowed the development of the transistor in 1948. Although some pure elements and many compounds display semiconductor properties, silicon, germanium, and compounds of gallium are the most widely used in electronic devices. A large number of elements and



compounds have semiconducting properties, including [1]; certain pure elements are found in Group XIV of the periodic table; the most commercially important of these elements are silicon and germanium. Silicon and germanium are used here effectively because they have 4 valence electrons in their outermost shell which gives them the ability to gain or lose electrons equally at the same time. Binary compounds, particularly between elements in groups III and V, such as gallium arsenide, groups II and VI, groups IV and VI, and between different group IV elements, e.g. silicon carbide. Certain ternary compounds, oxides and alloys. Organic semiconductors, made of organic compounds. Most common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are also known. These include hydrogenated amorphous silicon and mixtures of arsenic, selenium and tellurium in a variety of proportions. These compounds share with better known semiconductors the properties of intermediate conductivity and a rapid variation of conductivity with temperature, as well as occasional negative resistance. Such disordered materials lack the rigid crystalline structure of conventional semiconductors such as silicon. They are generally used in thin film structures, which do not require material of higher electronic quality, being relatively insensitive to impurities and radiation damage. Now-a-days semiconductor materials are used in every sector of modern technology. In technical purpose the high temperature materials are used widely. Therefore it is needed to increase the temperature of semiconducting materials. For this reasons the different properties of these materials varied with temperature. In this paper we review the classification of semiconductors, early history of semiconductors and temperature effects in semiconductors. The rest of the paper is organized as follows: in Sec. 2, history of semiconductor is given; Sec. 3 classification of semiconductor is given; Sec.4 temperature effects in semiconductors are given. Finally, the conclusion is given in Sec.5..

II. EARLY HISTORY OF SEMICONDUCTING MATERIALS

The history of the understanding of semiconductors begins with experiments on the electrical properties of materials. The properties of negative temperature coefficient of resistance, rectification, and light-sensitivity were observed starting in the early 19th century. In 1833, Michael Faraday reported that the resistance of specimens of silver sulfide decreases when they are heated. This is contrary to the behavior of metallic substances such as copper. In 1839, A. E. Becquerel reported observation of a voltage between a solid and a liquid electrolyte when struck by light, the photovoltaic effect. In 1873 Willoughby Smith observed that selenium resistors exhibit decreasing resistance when light falls on them. In 1874 Karl Ferdinand Braun observed conduction and rectification in metallic sulphides, and Arthur Schuster found that a copper oxide layer on wires has rectification properties that ceases when the wires are cleaned. Adams and Day observed the photovoltaic effect in selenium in 1876[2]. A unified explanation of these phenomena required a theory of solidstate physics which developed greatly in the first half of the 20th Century. In 1878 Edwin Herbert Hall demonstrated the deflection of flowing charge carriers by an applied magnetic field, the Hall Effect. The discovery of the electron by J.J. Thomson in 1897 prompted theories of electron-based conduction in solids. Karl Baedeker, by observing a Hall Effect with the reverse sign to that in metals, theorized that copper iodide had positive charge carriers. Johan Koenigsberger classified solid materials as metals, insulators and "variable conductors" in 1914. Felix Bloch published a theory of the movement of electrons through atomic lattices in 1928. In 1930, B. Gudden stated that conductivity in semiconductors was due to minor concentrations of impurities. By 1931, the band theory of conduction had been established by Alan Herries Wilson and the concept of band gaps had been developed. Walter H. Schottky and Nevill Francis Mott developed models of the potential barrier and of the characteristics of a metal-semiconductor junction. By 1938, Boris Davydov had developed a theory of the copper-oxide rectifier, identifying the effect of the p-n junction and the importance of minority carriers and surface states [3]. Agreement between theoretical predictions (based on developing quantum mechanics) and experimental results was sometimes poor. This was later explained by John Bardeen as due to the extreme "structure sensitive" behavior of semiconductors, whose properties change dramatically based on tiny amounts of impurities [3]. Commercially pure materials of the 1920s containing varying proportions of trace contaminants produced differing experimental results. This spurred the development of improved material refining techniques, culminating in modern semiconductor refineries producing materials with parts-per-trillion purity. Devices using semiconductors were at first constructed based on empirical knowledge, before semiconductor theory provided a guide to construction of more capable and reliable devices. Alexander Graham Bell used the light-sensitive property of selenium to transmit sound over a beam of light in 1880. A



working solar cell, of low efficiency, was constructed by Charles Fritts in 1883 using a metal plate coated with selenium and a thin layer of gold; the device became commercially useful in photographic light meters in the 1930s [3]. Point-contact microwave detector rectifiers made of lead sulfide were used by Jagadish Chandra Bose in 1904; the cat's-whisker detector using natural galena or other materials became a common device in the development of radio. However, it was somewhat unpredictable in operation and required manual adjustment for best performance. In 1906 H.J. Round observed light emission when electric current passed through silicon carbide crystals, the principle behind the light emitting diode. Oleg Losev observed similar light emission in 1922 but at the time the effect had no practical use. Power rectifiers, using copper oxide and selenium, were developed in the 1920s and became commercially important as an alternative to vacuum tube rectifiers [2, 3].

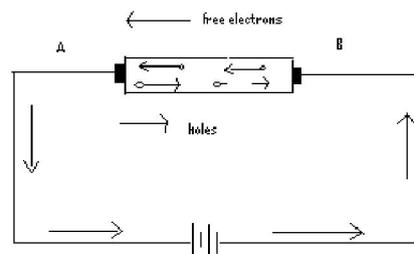
classification of semiconductors

Semiconductors may be classified broadly as

1. Intrinsic semiconductor
2. Extrinsic semiconductor

2.1 Intrinsic Semiconductor

There are two ways to define an intrinsic semiconductor. In simple words, an intrinsic semiconductor is one which is made up of a very pure semiconductor material. In more technical terminology it can be stated that an intrinsic semiconductor is one where the number of holes is equal to the number of electrons in the conduction band. The forbidden energy gap in case of such semiconductors is very minute and even the energy available at room temperature is sufficient for the valence electrons to jump across to the conduction band. Another characteristic feature of an intrinsic semiconductor is that the Fermi level of such materials lies somewhere in between the valence band and the conduction band. This can be proved mathematically which is beyond the scope of discussion in this article. In case you are not familiar with the term Fermi level, it refers to that level of energy where the probability of finding an electron is 0.5 or half (remember probability is measured on a scale of 0 to 1). If a potential difference is applied across an intrinsic semiconductor, electrons will move towards positive terminal while holes will drift towards negative terminal. The total current inside the semiconductor is the sum of the current due to free electrons and holes. If the temperature of the semiconductor increases, the number of hole-electron pairs increases and current through the semiconductor increases. If temperature falls, the reverse happens.

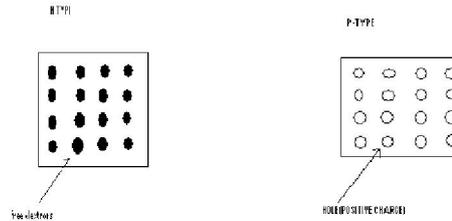


2.2 Extrinsic Semiconductor

These are semiconductors in which the pure state of the semiconductor material is deliberately diluted by adding very minute quantities of impurities. To be more specific, the impurities are known as dopants or doping agents. It must be kept in mind that the addition of such impurities is really very minuscule and a typical dopant could have a concentration of the order of 1 part in a hundred million parts or it is equivalent to 0.01. The materials chosen for doping are deliberately chosen in such a manner that either they have 5 electrons in their valence band, or they have just 3 electrons in their valence band. Accordingly such dopants are known as pentavalent or trivalent dopants respectively. The type of dopant also gives rise to two types of extrinsic semiconductors namely P-type and N-type semiconductors. A pentavalent dopant such as Antimony are known as donor impurities since they donate an extra electron in the crystal structure which is not required for covalent bonding purposes and is readily available to be shifted to the conduction band. This electron does not give rise to a corresponding hole in the valence band because it is already excess, therefore upon doping with such a material, the base material such as Germanium contains more electrons than holes, hence the nomenclature Ntype

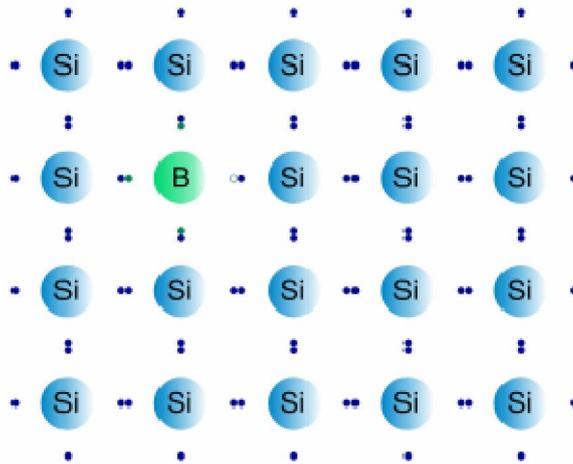


intrinsic semiconductors. On the other hand when a trivalent dopant such as Boron is added to Germanium additional or extra holes get formed due to the exactly reverse process of what was described in the upper section. Hence this dopant which is also known as acceptor creates a P-type semiconductor. Hence electrons are the majority carriers (of current) in N-type while holes are minority carriers. The reverse is true of P-type semiconductors. Another difference is that whereas the Fermi level of intrinsic semiconductors is somewhere midway between the valence band and the conduction band, it shifts upwards in case of N-type while it drifts downward in case of P-type due to obvious reasons. P-type semiconductor is shown in (figure 2.1) and N-type semiconductor is shown in (figure 2.2)

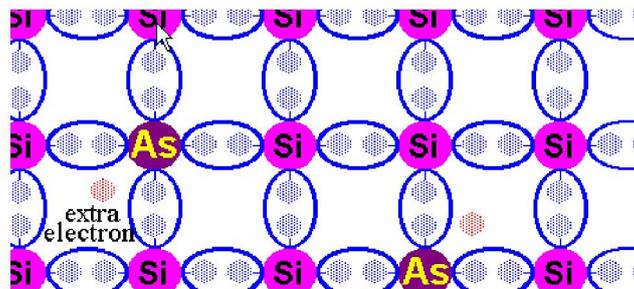


2.3 Semiconductor Materials

Semiconductors materials can be able to conduct electric current, can be easily regulated, and can act as insulators and conductors. These qualities have made semiconductors useful in the electronics field since its inception. The conductivity of the semiconductor is generally sensitive to temperature, illumination, magnetic field, and minute amount of impurity atoms. This sensitivity in conductivity makes the semiconductor one of the most important materials for electronic applications. Table 1 shows a portion of the periodic table related to semiconductors. Table 2 shows a list of some of the element and compound semiconductors.



p type semiconductor



n type semiconductor



III. APPLICATIONS OF SEMICONDUCTORS

3.1 Applications of Semiconductors in Electronic Devices

Semiconductors are the materials that conduct electric current, can be easily regulated, and can act as both insulators and conductors. These qualities have made semiconductors useful in the field of electronics. Semiconductor devices are all around us. They can be found in just about every commercial product we contact, from the family car to the pocket calculator. Today semiconductor devices are omnipresent in a wide range of industries, including computers, communications, aerospace, manufacturing, agriculture, and healthcare. Semiconductors have made electronic devices – such as MP3 players, HDTVs / TVs, CD players, computers, and cell phones – smaller, cheaper, faster, and more reliable. In the following section we will explore the most important applications:

1. Flat panel displays: Computers, television, mobile handheld devices
2. High brightness LEDs: solid state lighting, large display panels, automotive applications, LCD backlighting.
3. Imaging array sensors: Digital cameras.
4. Diode lasers.
5. Optical storage, mice.
6. Robotics.
7. Medical Electronics.
8. Industrial Electronics.
9. Telecommunications.
10. Wireless Communication.
11. Global Positioning By Satellite (GPS).
12. Smart Cards.
13. Memories.

3.2 Applications of Semiconductors in Solar Cell

Now-a-days most of the solar cells the absorption of photons, as a result of the generation of the charge carriers, and the subsequent separation of the photo-generated charge carriers take place in semiconductor materials. Therefore, the semiconductor layers are the most important parts of a solar cell and they form the central part of the solar cell. There are a number of different semiconductor materials that are suitable for the conversion of photons energy into electrical energy. The crystalline silicon (c-Si) solar cell, which dominates the PV market at present, has a simple structure, and provides a superior example of a typical solar cell structure. Figure 8 shows the essential features of c-Si solar cells. An absorber material is typically a moderately doped p-type square wafer having thickness around 300 μm and an area of $10 \times 10 \text{ cm}^2$ or $12.5 \times 12.5 \text{ cm}^2$. On both sides of the c-Si wafer a highly doped layer is formed, n+-type on the top side and p+-type on the back side, respectively. These highly doped layers help to separate the photo-generated charge carriers from the bulk of the c-Si wafer. The trend in the photovoltaic industry is to reduce the thickness of wafers up to 250 μm and to increase the area to $20 \times 20 \text{ cm}^2$.

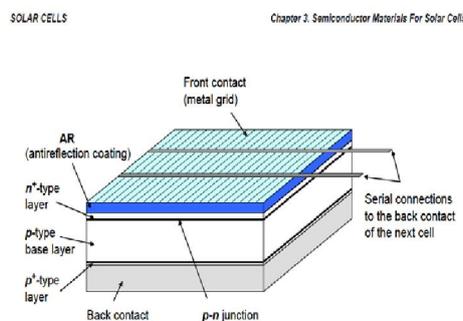


Figure 3.1. A typical structure of a c-Si solar cell.



In addition to semiconductor layers, solar cells consist of a top and bottom metallic grid or another electrical contact that collects the separated charge carriers and connects the cell to a load. Usually, a thin layer that serves as an antireflective coating covers the topside of the cell in order to decrease the reflection of light from the cell. In order to protect the cell against the effects of outer environment during its operation, a glass sheet or other type of transparent encapsulant is attached to both sides of the cell. In case of thin-film solar cells, layers that constitute the cell are deposited on a substrate carrier. When the processing temperature during the deposition of the layers is low, a wide range of low-cost substrates such as glass sheet, metal or polymer foil can be used. The first successful solar cell was made from c-Si and c-Si is still the most widely used PV material. Therefore we can use c-Si as an example to explain semiconductor properties that are relevant to solar cell operation. This gives us a basic understanding of how solar cells based on other semiconductor materials work. The central semiconductor parameters that determine the design and performance of a solar cell are:

IV. CONCLUSION

Silicon may be considered as the information carrier of our times. In the history of information there were two revolutions (approximately 500 years apart). The first was that of Johan Gutenberg who made information available to many, the other is the invention of the transistor. Currently the global amount of information doubles every year. Many things we are taking for granted (such as, e.g., computers, Internet and mobile phones) would not be possible without silicon microelectronics. Electronic circuits are also present in cars, home appliances, machinery, etc. Optoelectronic devices are equally important in everyday life, e.g., fiber optic communications for data transfer, data storage (CD and DVD recorders), digital cameras, etc. Since the beginning of semiconductor electronics the number of transistors in an integrated circuit has been increasing exponentially with time. In summary we have presented the outline of semiconductors, their early history and classification. We have also studied the temperature effects in semiconductors. The energy band gap, mobility, threshold voltage and saturation velocity are decrease with increasing temperature. On the other hand the conductivity, carrier density, leakage current and interconnect resistant increase with increasing temperature. We have also studied the applications of semiconductors in basic electronic devices, telecommunication and wireless systems and finally in solar system.

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