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Review Article On Semiconductor

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Abstract: Semiconductors are materials with electrical conductivity between that of conductors and insulators. They are the foundation of modern electronics, enabling the creation of smaller, faster, and more efficient devices. Semiconductors are used in a wide range of applications, including computers, smartphones, solar panels, and medical devices. The unique properties of semiconductors, such as their ability to control the flow of electrical current, make them essential for the development of advanced technologies. This abstract provides an overview of the properties, types, and applications of semiconductors, highlighting their significance in shaping the modern world. Semiconductors have indeed revolutionized the world, transforming the way we communicate, process information, and live our daily lives. Their impact on modern technology has been profound, enabling the development of smaller, faster, and more efficient devices that have transformed industries and societies.

Keywords: semiconductors, electronics, conductivity, materials science, technology

I. Introduction

Semiconductors are materials with unique electrical properties, falling between conductors and insulators. Their conductivity can be controlled by voltage, current, or radiation, making them essential for modern electronics. The characteristics of semiconductors depend on added impurities or dopants, which can create regions with excess electrons (N-type) or holes (P-type). Elemental semiconductors include antimony, arsenic, boron, mercury, germanium, selenium, silicon, sulfur, and tellurium, with silicon being the most widely used. Compound semiconductors like gallium arsenide, indium antimonide, and metal oxides are also popular. 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 behaviour 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.

- **Semiconductors are used in a wide range of applications, including:**
  - Electronic circuit manufacturing
  - Solar cells
  - Laser diodes
  - Transistors
  - LEDs
  - Digital and analog integrated circuits

  The properties of semiconductors can be described using quantum mechanics, and their conductivity can be controlled by temperature, impurities, and external factors. Semiconductors have revolutionized modern electronics, enabling the creation of smaller, faster, and more efficient devices. Semiconductors are a class of materials that have revolutionized the way we live, work, and communicate. Semiconductors are neither conductors nor insulators, but rather a unique class of materials that can control the flow of electrical current.

  What makes semiconductors special?

  Semiconductors have a number of remarkable properties that make them essential for modern technology and features that make semiconductors unique and important

- **Variable conductivity:** Semiconductors can conduct electricity under certain conditions, but not others.
- **Sensitivity to stimuli:** Semiconductors can respond to changes in temperature, light, or voltage.
- **Doping**: Semiconductors can be modified by introducing impurities to change their conductivity.
- **High Purity:** Semiconductors require extremely high-purity materials to achieve optimal performance.
- **Crystal Structure:** Semiconductors have a crystalline structure, which allows for precise control of conductivity.
- **PN Junction:** The combination of p-type and n-type semiconductors creates a PN junction, the building block of modern electronics.
- **Amplification:** Semiconductors can amplify weak electrical signals, making them useful for a wide range of applications.
- **Switching:** Semiconductors can act as switches, controlling the flow of electrical current.

II. Early History Of Semiconductor

The history 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 solid-state 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 rectifer, 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]. In the years preceding World War II, infra-red detection and communications devices prompted research into lead-sulfide and lead-selenide materials. These devices were used for detecting ships and aircraft, for infrared rangefinders, and for voice communication systems. The point-contact crystal detector became vital for microwave radio systems, since available vacuum tube devices could not serve as detectors above about 4000 MHz; advanced radar systems relied on the fast response of crystal detectors. Considerable research and development of silicon materials occurred during the war to develop detectors of consistent quality [3]. Detector and power rectifiers could not amplify a signal. Many efforts were made to develop a solid-state amplifier, but these were unsuccessful because of limited theoretical understanding of semiconductor materials [3]. In 1922 Oleg Losev developed two-terminal, negative resistance amplifiers for radio; however, he perished in the Siege of Leningrad. In 1926 Julius Edgard Lilenfeld patented a device resembling a modern field-effect transistor, but it was not practical. R. Hilsch and R. W. Pohl in 1938 demonstrated a solid-state amplifier using a structure resembling the control grid of a vacuum tube; although the device displayed power gain, it had a cut-off frequency of one cycle per second, too low for any practical applications, but an effective application of the available theory [3]. At Bell Labs, William Shockley and A. Holden started investigating solid-state amplifiers in 1938. The first p–n junction in silicon was observed by Russell Ohl about 1941, when a specimen was found to be light-sensitive, with a sharp boundary between p-type impurity at one end and n-type at the other. A slice cut from the specimen at the p–n boundary developed a voltage when exposed to light.

III Classification of Semiconductor

Semiconductor is classified into two types :

1. Intrinsic Semiconductor
2. Extrinsic Semiconductor

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 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.

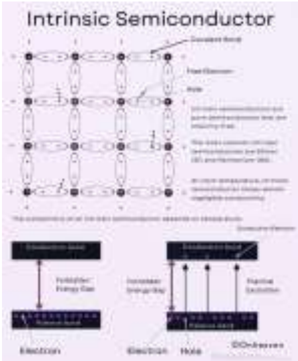

fig.1. Intrinsic Semiconductor

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 ppm. 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 N-type 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.

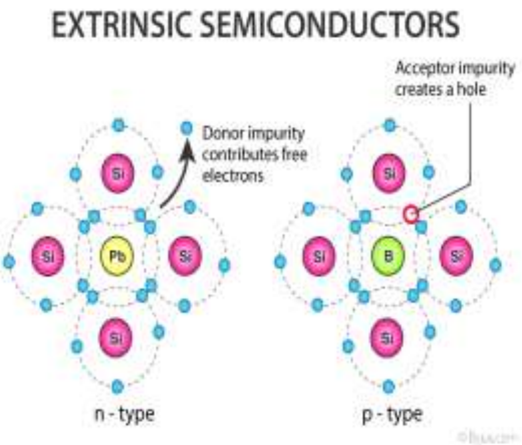

fig. 2 Extrinsic Semiconductor

IV Semiconductor Properties :

A. Electrical Conductivity and Resistivity

Conductivity (σ): ability to conduct electricity

Resistivity (ρ): opposition to electric current

Relationship: $\sigma = 1/\rho$

B. Sensitivity to Light and Temperatur

Photoconductivity: change in conductivity due to light exposure

Thermal conductivity: change in conductivity due to temperature changes

Bandgap energy (Eg): energy required for electrons to jump from valence to conduction band

C.Doping and Impurity Concentration

Doping: introducing impurities to modify conductivity

Impurity concentration (N): number of impurities per unit volume

Types of dopants: donors (N-type), acceptors (P-type)

C. Carrier Concentration and Mobility

Carrier concentration (n/p): number of electrons/holes per unit volume

Mobility (μ): ability of carriers to move through the material

Relationship: conductivity (σ) = carrier concentration (n/p) x mobility (μ)

These properties are crucial in understanding how semiconductors work and how they can be used in various applications.

These special properties make semiconductors the foundation of modern electronics, enabling the creation of:

- Fast and efficient computers
- Smartphones and mobile devices
- High-speed internet and communication networks
- Advanced medical equipment and healthcare technologies
- Efficient renewable energy systems
- Autonomous vehicles and smart transportation systems

V. Semiconductor Manufacturing:

These steps are crucial in creating the complex semiconductor devices that power modern electronics

- .Crystal Growth and Wafer Preparation :
  - Growing high-purity silicon crystals
  - Slicing crystals into thin wafers
  - Polishing and cleaning wafers for fabrication
- Doping and Diffusion :
  - Introducing impurities (dopants) to modify conductivity
  - Diffusing dopants into the wafer using heat or radiation
- Lithography and Patterning :
  - Coating wafers with photoresist material
  - Exposing patterns using ultraviolet light or other radiation
  - Developing patterns to create a mask
- Etching :
  - Using chemicals or plasma to remove material and create patterns
  - Creating transistors, diodes, and other semiconductor devices
- Packaging :
  - Encapsulating individual dies (chips) in protective packages
  - Connecting dies to external leads or pins
  - Final testing and inspection before shipping

VI. Semiconductor Devices :

a. **Diodes :**

- **PN Junction Diode**: A basic diode formed by combining p-type and n-type semiconductors, allowing current to flow in one direction.
- **Zener Diode:** A special diode designed to operate in reverse breakdown, used for voltage regulation and reference.
- **Tunnel Diode:** A diode with a negative resistance region, used in high-frequency applications and quantum tunneling.

b. **Transistors :**

- **Bipolar Junction Transistor (BJT):** A transistor with two junctions (emitter-base and base-collector), used for amplification and switching.
- **Field-Effect Transistor (FET**): A transistor controlled by voltage applied to a gate, used for amplification and switching.

c. **Thyristors:**

- **Silicon-Controlled Rectifier (SCR):** A thyristor that can be triggered to conduct current, used in power control and switching.
- **Triode for Alternating Current (TRIAC):** A thyristor that can conduct current in both directions, used in AC power control.

d. Integrated Circuits (ICs) and Microprocessors :

- **Integrated Circuits (ICs):** Miniature electronic circuits on a single semiconductor substrate, containing diodes, transistors, and resistors.
- **Microprocessors:** Central processing units (CPUs) that contain millions of transistors, executing instructions and performing calculations.

fig.3 Semiconductor devices

VII. Applications of Semiconductor :

Electronics and Computing :
- Microprocessors and central processing units (CPUs)
- Memory devices (RAM, ROM, Flash)
- Graphics processing units (GPUs)
- Motherboards and chipsets
- Laptops, desktops, mobile devices, and gaming consoles

2. Communication and Networking :
- Smartphones and mobile devices
- Network routers and switches
- Modems and broadband equipment
- Satellite communications and GPS
- Wireless communication systems (Wi-Fi, Bluetooth, 5G)

3. Energy and Power Systems :
- Solar panels and photovoltaic systems
- Wind turbines and renewable energy systems
- Power management ICs (PMICs) for energy efficiency
- Electric vehicles and charging infrastructure
- Smart grid and energy storage systems

4. Healthcare and Medical Devices:

- Medical imaging equipment (MRI, CT scans)
- Portable medical devices (glucose monitors, insulin pumps)
- Implantable devices (pacemakers, prosthetics)
- Diagnostic equipment (blood analyzers, DNA sequencers)
- Telemedicine and remote health monitoring

VIII. Future Developement :

The future of semiconductors holds much promise, with ongoing research and development focused on:

1. Quantum Computing: Harnessing quantum mechanics to create ultra-powerful computers.
2. Artificial Intelligence: Developing AI-specific semiconductors for faster, more efficient processing.
3. Internet of Things (IoT): Creating low-power, high-performance semiconductors for widespread IoT adoption.
4. 5G and 6G: Enabling faster, more reliable communication networks with advanced semiconductor technologies.

IX. Conclusion :

Semiconductors are the backbone of modern technology, playing a vital role in transforming the world around us. Their unique electrical properties, combined with advances in manufacturing and design, have enabled the creation of smaller, faster, and more efficient electronic device Many things we are taking for granted (such as, e.g., computers, Internet and mobilephones) 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.

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