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The semiconductor: Application in everyday existence

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Abstract
The main aim of this paper is to assess the suitability of modern power semiconductor devices application in daily life. The majority of people are familiar with microchips, but how much do you know about the parts that enable them? In this paper talk about the various uses for semiconductors here. A substance that possesses electrical conductivity in between that of an insulator (such as rubber) and a conductor (such as metal) is called a semiconductor. Though not as readily as conductors, it can conduct electricity in some situations. Semiconductors are essential parts of electronics and are found in integrated circuits, diodes, and transistors.

Keywords: Semiconductor, Intrinsic and Extrinsic Semiconductors, silicon, microchips

Introduction
So, a semiconductor is basically this thing that's not quite a conductor, but not quite an insulator either... It's kinda in-between, conductivity-wise. You can actually mess with how well it conducts electricity by adding stuff - they call it "doping" - to its crystal structure. And when you have different levels of this doping in one crystal, you get a semiconductor junction thingy.

Like, what happens at those junctions, with all the electrons, ions, and electron holes moving around, is like, the whole point of diodes, transistors, and pretty much all modern electronics. Silicon is one example of a semiconductor. So are germanium, gallium arsenide... oh, and those elements kinda near the "metalloid staircase" on the periodic table. Gallium arsenide? After silicon, it's like, the second most common semiconductor. They use it in laser diodes, solar cells, microwave integrated circuits, and all sorts of other stuff. Oh yeah, and silicon? Silicon is super important. Like, practically all electronic circuits use it.

Semiconductor devices have some cool features. For instance, they usually let current flow easier in one direction compared to the other, and their resistance can be changed. Plus, they respond to light or heat changes. You can tweak a semiconductor material's electrical stuff by doping it or by using electric fields or even light. Because of all this, we can use semiconductors to make things like amplifiers, switches, and stuff for converting energy. By the way, the term "semiconductor" is also used for insulation in high-capacity cables. Usually, that's like, plastic XLPE - you know, cross-linked polyethylene - mixed with carbon black.

So, you can make silicon conduct better by adding a tiny little bit (like, one in every 100 million atoms or so) of certain elements. These elements are either pentavalent (like antimony, phosphorus, or arsenic) or trivalent (like boron, gallium, or indium). This whole process is doping. And the semiconductors you get are called doped or extrinsic semiconductors. Also, conductivity can go up when a semiconductor's temperature goes up. That's different from metal, where conductivity drops when the temperature goes up.

To really get how semiconductors work, you need quantum physics. Like, it explains what those charge carriers do inside the crystal lattice. Doping really boosts the number of these carriers. If you dope a semiconductor with those Group V elements, it makes free electrons. These act as donors, so it's called "n-type" doping. But, if you add Group III elements, they act as acceptors, making free holes. That's "p-type" doping. The semiconductor materials you find in electronics are specially doped to carefully control where the p- and n-type dopants are and how many of them there are. One single crystal can have both p-type and n-type areas, and the p-n junctions where these areas meet are super important for the good electronic stuff that happens. If you use a hot-point probe, you can quickly figure out if a semiconductor sample is p-type or n-type.

People saw some of this semiconductor behavior way back in the mid-1800s and early 1900s. But the first time they were used in electronics in a real way was with the cat's-whisker detector back in 1904. That was basically a simple semiconductor diode they used in early radios. Later, with all the quantum physics advancements, we got the transistor in 1947 and the integrated circuit in 1958.

Properties of Semiconductors

Okay, so basically, semiconductors? Yeah, they can conduct electricity - but only if the conditions are just right. It's kinda like, 'cause of this cool thing it does, it's really good for controlling how electricity flows when you need it to.

Unlike conductors, semiconductors get their charge carriers from like, external energy. Think thermal stuff, like things heating up and all that. This energy kinda knocks some valence electrons into the conduction band, leaving behind these 'holes' - and the number of holes and electrons are like, roughly the same. Both electrons and holes play an important role in conducting.

A semiconductor is, um, a material that's sort of in-between a conductor - which easily lets electricity flow - and an insulator that. like stops electricity from flowing at all. It's like a halfway point, ya know?

What this means is, semiconductors can act as either an insulator or a conductor, depending on the situation. And, yeah, Semiconductors can be like compounds, like gallium arsenide or elements... like silicon! And silicon, that's the one everyone uses, mostly.

- **Resistivity:** 10^{-5} to 10^{6} Ωm
- **Conductivity:** 10^{5} to 10^{-6} mho/m
- **Coefficient of resistance with temperature:** Negative
- **Present current:** Caused by electrons and holes

Some other Properties of Semiconductors

1. At 0 Kelvin, semiconductors behave like insulators. They become conductors when the temperature rises.
2. Because of their remarkable electrical characteristics, semiconductors can be doped to create devices that are appropriate for energy conversion, switches, and amplifiers.
3. Lesser power losses.
4. Smaller in size and lighter in weight are semiconductors.
5. They have a higher resistivity than conductors but a lower resistivity than insulators.
6. As the temperature rises, semiconductor materials' resistance falls, and vice versa.

Types of Semiconductors

There are two main types of Semiconductors, named:

1. Intrinsic Semiconductors
2. Extrinsic Semiconductors

Intrinsic Semiconductors

So, semiconductors, like, when they're totally pure, we call them Intrinsic Semiconductors, and honestly, they're kinda useless. They're just not good at conducting electricity or stopping it. When they're pure, the outer shell — valence shell — of the semiconductor stuff has the same amount of holes and electrons. Like, silicon? It's got 4 valence electrons.

Like, chemically, these intrinsic semiconductors are supposed to be super, super pure. Just one type of element, ya know? The big ones are silicon (Si) and germanium (Ge). They're tetravalent, which just means they got, uh, four valence electrons. And at absolute zero, a covalent link… it kinda just holds them to the atom.

As things warm up, electrons break free and wander through the crystal structure 'cause of collisions, leavin' behind a "hole" where they used to be. This is good, cause it helps the semiconductor carry electricity, 'cause of these free electrons and those holes. It's like, the number of positive and negative charges is the same. Heat can like ionize a few atoms and kinda reduce how well they conduct too, I think.

Extrinsic Semiconductors

Doping is the process of adding impurities (such as boron, antimony, etc.) to pure semiconductors to improve their conductive behavior; these doped semiconductors are referred to as extrinsic semiconductors. (We'll talk about doping soon.)

Extrinsic semiconductors are further separated into two categories based on the doping substance utilized, which are called:

1. N-Type semiconductors.
2. P-Type semiconductors.

The significance of semiconductors

Advances in communications, computers, healthcare, military systems, transportation, clean energy, and a myriad of other fields are made possible by semiconductors, which are a crucial part of electronic gadgets.

Alongside consumer gadgets, semiconductors play a crucial role in the operation of communications, the internet, bank ATMs, railways, and various aspects of social infrastructure, including the healthcare system for the elderly. Additionally, efficient logistics frameworks promote energy savings and global environmental safeguarding.

N-Type Semiconductor

A pentavalent impurity (like P, As, Sb, or Bi) mixed into a pure semiconductor (such as silicon or germanium) causes four out of the five valence electrons from the semiconductor to bond with the other four electrons in the semiconductor.

Dopant gives away its fifth electron. An impure atom is called a "donor" due to its ability to provide a free electron for electrical conductivity within the crystal structure.

Adding impurities increases the number of free electrons, thus boosting the negative charge carriers. An n-type semiconductor is called thus.

The donating particle becomes a stationary positive charge, whereas the crystal maintains neutrality. In an n-type semiconductor, majority carriers are electrons due to their abundance, whereas minority carriers are holes resulting from a scarcity of free electrons during conductivity.

- Mainly due to electrons
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority - Electrons and Minority - Holes

P-Type Semiconductor

A trivalent impurity (Such as B, Al, In, or Ga) when introduced into a pure semiconductor causes these impurities' three valence electrons to bond with three of the semiconductor's four valence electrons.

The impurity has no electrons (holes) because of this. Impurities in materials can accept electrons by giving up their own electrons.

As the amount of impurities rises, so does the count of positively charged particles present in the system. Hence it is called a p-type semiconductor.

The acceptors become a static negative ion, whereas the crystal stays neutral. A large number of gaps lead to electricity flow; therefore, in a p-type semiconductor, there are more holes than electrons as majority carriers, whereas electrons are minority carriers.

- Mainly due to holes
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority - Holes and Minority - Electrons

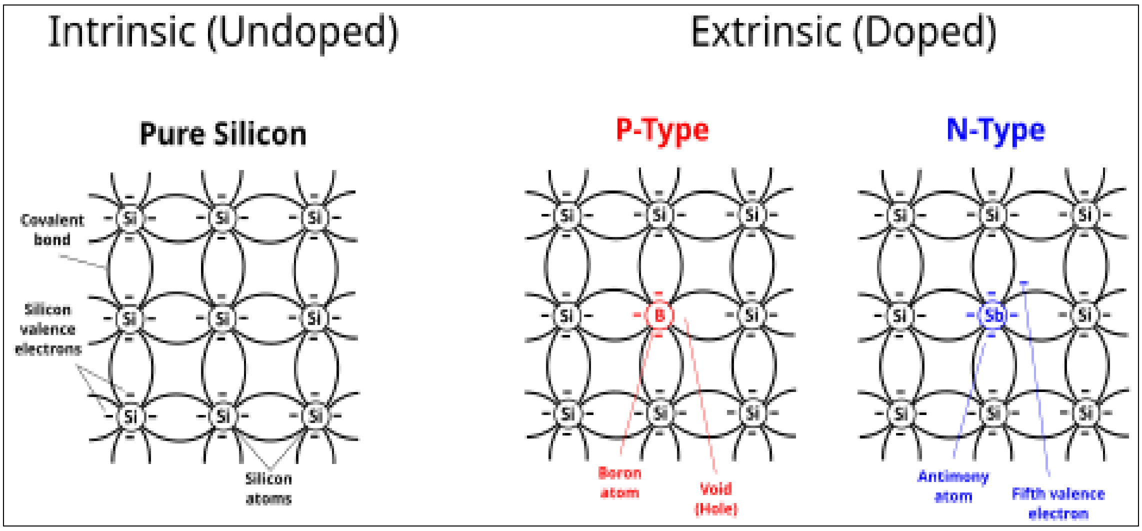

Fig 1: doping an array of pure silicon. When impurities like boron and antimony are added, a silicon-based intrinsic semiconductor turns extrinsic.

Applications of Semiconductors

Semiconductors are used primarily to create semiconductor components that are crucial in numerous electronic gadgets. Semiconductor devices have taken over from vacuum tubes in most applications because they can carry electric current directly within a solid material rather than relying on free electrons in a vacuum.

A diode, an essential electronic part, functions as a one-directional switch within circuits, permitting current flow exclusively in one path. Conversely, allowing current to flow in either direction.

Transistors, made of semiconductors, help amplify current quickly and switch efficiently.

The metal-oxide-semiconductor field-effect transistor, or MOSFET, is the most commonly used semiconductor device globally.

Although semiconductors aren't found at stores like electrical appliances, understanding them can be challenging, but they're used in many electronic gadgets.

Semiconductors are used in temperature sensors that measure temperatures inside air conditioners. Rice cookers work well by controlling heat precisely due to semiconductor technology. Personal computers' processors are made from semiconductors too. Numerous electronic gadgets used in everyday living, such as cell phones, digital cameras, TVs, washers, freezers, and LED lights, incorporate semiconductors.

Besides electronic gadgets, semiconductors are crucial for banking machines, trains, internet services, communication networks, and other parts of society's basic structures, such as those used in elderly care, alongside many other uses. Moreover, efficient logistics reduce energy consumption and safeguard the global environment. The number of semiconductors used in cars keeps going up steadily. Cars have many types of electronic parts inside them. Especially for future ADAS systems, more semiconductors will likely be needed.

By means of semiconductors, we enjoy a life that's quite convenient.

In addition to enabling cutting-edge medical technologies like implantable devices, targeted therapies, and diagnostic sensors that monitor health, restore lost functions, and aid in early disease detection, semiconductors also power critical infrastructure for communication, computing, and smart devices, all of which enhance human welfare. Additionally, they aid in the creation of safe, interconnected healthcare networks, sustainable energy developments, and smart home products and transportation systems that enhance daily living.

Semiconductors, due to its unique property is widely used in various devices that we use in our daily lives. The real life applications of semiconductors are mentioned below:

In Healthcare

- **Implantable Devices:** Cochlear implants, which restore hearing, pacemakers, neurostimulators, and other devices that control heart rate and cure neurological conditions depend on semiconductors.
- **Advanced Diagnostics:** Semiconductor sensors are employed in imaging and biosensing, offering extremely sensitive biomolecule detection and improved visualization for illness identification.
- **Chronic Condition Monitoring:** To assist treat chronic illnesses like diabetes and heart disease, implantable devices continually monitor vital indicators using semiconductors.
- **Targeted Therapies:** By delivering drugs or therapeutic agents straight to the afflicted regions, semiconductor-based devices can minimize adverse effects and enhance treatment results.

Diode as an Application of Semiconductor

Semiconductor devices can be used in some of the simplest ways. Silicon fragments contain both N-type and P-type impurities in equal parts. Diodes play crucial roles in both digital and electronic circuits. The diode allows current to pass through in one direction but stops it from flowing in the opposite way.

- Direct current (DC) is produced by Half-Wave Rectifier. At half a cycle, the strength of something changes, but when it reaches the other half, it disappears.
- A Full-Wave Rectifier converts AC electricity into DC power. It produces only continuous currents, so it's used in solar cells and many battery-powered gadgets.
- A varactor diode modifies an electric circuit's resonant frequency by adjusting it. A phase-locked loop, which creates an output signal's phase matching the input signal's phase, serves as another use case for this technology. Cell phones, TVs, radios, and other devices rely on this technology for communication.
- Photodiode: The energy of the incident light's photons is absorbed by silicon in the photodiode, which produces more pairs of electrons and gaps and significantly alters the current's strength. Street illumination bulbs, digital cameras, light sensors in cellphones, solar cells, and shopping center entrances all use it.
- LED: LEDs are light-emitting diodes that have a longer lifespan, a small size, and a quick reaction. It is extensively used as a substitute for tungsten and fluorescent lights.

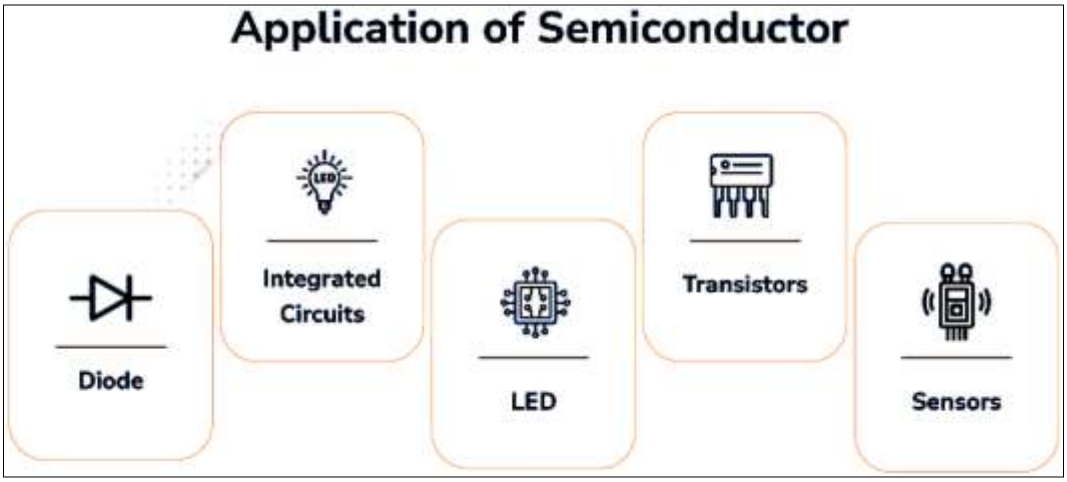

Fig 2: Different types uses of Semiconductor

In Infrastructure & Everyday Life

- **Communication and Connectivity:** Mobile phones, the internet, and other communication tools that link individuals and society are all built on semiconductors.
- **Smart Home equipment:** They improve comfort and convenience by enabling precise control over equipment like rice cookers and air conditioners.
- **The Electronics Sector:** Modern electrical products like computers, cellphones, and televisions are built on semiconductors. The most common semiconductor material, silicon is essential to the production of microchips and integrated circuits (ICs). These parts are necessary for information processing and storage, which makes electronic devices possible. Memory devices are also made with them.
- **Transportation:** Advanced driver-assistance systems (ADAS) and more intricate electrical systems in automobiles and other vehicles are powered by semiconductors.
- They serve as the foundation for smart health products, which enable supported living, preventative healthcare, and remote health monitoring.
- **Production of Energy:** Through the photovoltaic effect, semiconductor-based solar cells directly transform sunlight into electrical power. The most popular kind of photovoltaic cells found in solar panels are silicon-based ones. An electric current is produced when sunlight strikes semiconductor material, exciting electrons. By reducing our need on fossil fuels, this clean and renewable energy source has completely changed the way we produce power.
- **Consumer electronics:** Semiconductor components including integrated chips, diodes, and transistors are used in mobile phones, computers, gaming consoles, microwaves, and refrigerators. Many consumer electronic goods today have lengthy wait periods, in part due to the huge demand for these devices.
- Embedded systems are small computers incorporated into larger machines. They facilitate user interaction and provide control over the device. Examples of embedded systems that we commonly use include central heating systems, digital watches, GPS systems, fitness trackers, televisions, and car engine management systems.

Application of Semiconductor in Physics

- In experimental physics, semiconductors are used as detectors. Semiconductor detectors are employed to locate particles found within particle accelerators, specifically those of the Large Hadron Collider (LHC), for high-energy physics research. Particle energy, momentum, and charge can all be accurately determined by these instruments. Scientists use it to understand the fundamental building blocks and interactions of the universe.
- Quantum computing involves developing machines that can solve complex problems faster than conventional computers, potentially revolutionizing semiconductor technology. Quantum states in semiconductors, such as quantum dots, superconducting circuits, and trapped ions, form qubits essential for quantum information. Research into semiconductor-based quantum computing aims to simulate and compute complex tasks using principles from quantum mechanics.
- Condensed matter physics studies solids and liquids under very cold conditions and high pressure, relying mainly on semiconductors. Quantum effects discovered in semiconductors involve the quantum Hall effect, electron movement in tiny structures, and spintronics—manipulating electron spins for computing and data storage.

- Electrons and holes in semiconductors follow specific rules that are essential for understanding semiconductor physics. This field studies doping, band patterns, electron flow, and semiconductors' connections. Semiconductor devices with many uses in electronics, photonics, and optoelectronics were created through research into semiconductor physics that included both theory and experimentation.
- Optoelectronics and photonics involve most devices that generate, capture, and manage light using semiconductors. Photodetectors, solar cells, laser diodes, and LEDs are some examples of devices. Semiconductor materials and devices used in optical data storage, imaging, sensing, telecommunications, and optical computing are studied under the fields of optoelectronics and photonics.
- Nanotechnology involves working with materials at the atomic level, often utilizing semiconductors for precise control. Quantum confinement in semiconductors creates unique properties such as special electrical and optical behaviors in structures like quantum dots, nanowires, and nanotubes. Semiconductor nanostructures are created and characterized for their applications in electronics, photonics, and quantum information processing, which are central objectives of nanotechnology research.

In Medical and Environmental Applications

- **Drug Delivery Systems:** When activated by external stimuli, nanomaterials, such as semiconductor nanoparticles, can be employed to transport and deliver medications selectively to cancer cells.
- **Energy Technology:** The development and advancement of technology for clean and renewable energy sources depend heavily on semiconductors.
- **Water Treatment:** To improve the welfare of the environment, semiconductors are also utilized in photocatalysis techniques for water purification.

Materials and Methods

The suggested approaches were effectively implemented with the help of certain data collection instruments. A questionnaire was used in the study to gather information for additional analysis.

Conclusion

A semiconductor is a material that has electrical conductivity falling between that of an insulator, which resists electricity, and a conductor, which transmits electricity quickly. Semiconductors, often made from silicon, can function as either type based on their environment.

Semiconductors play a crucial role in electronic devices, facilitating progress in communications, computing, healthcare, military systems, transportation, clean energy, and numerous other uses.

Besides consumer electronics, semiconductors are crucial for the functioning of bank ATMs, trains, the internet, communications, and various elements of social infrastructure, including the medical network utilized for elderly care, among other applications.

Moreover, effective logistics systems contribute to energy conservation and support the protection of the global environment.

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