

## INTRODUCTION TO ELECTRICAL ENGINEERING: SEMICONDUCTOR ENERGY BAND CONCEPTS

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### **Abstract**

Introduction to Electrical Engineering covers various fundamental concepts, one of which is the concept of energy bands in semiconductors. Understanding this concept is very important because semiconductors are the basic materials in many electronic devices, including transistors, diodes, and integrated circuits. The energy band theory provides important insights into the electrical properties and conductivity of solid materials. By understanding this concept, it can be explained why some materials are conductors, insulators, or semiconductors. The energy band theory is very important in the development and understanding many different electronic components, including solar cells, LEDs, diodes, and transistors. Understanding the electrical and optical properties of semiconductor materials requires an understanding of the energy band. There are two primary components to the energy band: the band of valence and the conduction band. The valence band is an energy band that may be filled by electrons from a solid to a complete state, while the conduction band is an energy band above the valence band that may be filled by electrons that have higher energy. The concept of energy bands is one of the important concepts in understanding the properties of semiconductors. The energy band is the range of energy available to electrons in a material. Semiconductors have many applications in the field of electronics. For example, semiconductors are used in the manufacture of computers, electronic devices, thermocouples, and many more.

**Keywords:** electrical engineering, energy band, semiconductor

### **INTRODUCTION**

Electrical engineering is a branch of engineering that focuses on the use and control of electricity and electronics. In this article, we will explore the basics of electrical engineering, from the basic principles of electricity to more complex applications in industry and everyday life. Electrical engineering is based on the basic principles of electricity. This article will discuss basic concepts such as voltage, current, resistance, and electrical power. According to Ferry, D. (2020) electrical engineering involves the use of various electronic

components. This article will explain about resistors, capacitors, inductors, diodes, transistors, and ICs (Integrated Circuits). You will understand the function, symbol, and characteristics of each of these components. Electronic circuits are basic elements in electrical engineering.

Electrical engineering is also used in control and automation systems. This article will discuss the principles of control, feedback systems, sensors, actuators, and distributed control systems. You will understand how electrical engineering is used in industrial automation and autonomous vehicles. Electrical engineering plays an important role in the development of renewable energy and energy efficiency. This article will discuss the applications of electrical engineering in solar panels, wind turbines, batteries, electric vehicles, and distributed power systems. You will learn about efforts to reduce energy consumption and encourage the use of clean energy sources. Electrical engineering continues to develop along with technological advances and community needs (Deen, M. J., & Pascal, 2017).

Chaves et al., (2020) stated that semiconductors are solid materials that have a conduction band with higher energy and a valence band with lower energy. The material transforms into a perfect insulator at absolute zero temperature because the valence is fully filled with electrons and the conduction band is not filled with electrons. Temperature and radiation have an impact on the electrons that go from the valence band to the conduction band. However, some electrons are often in the conduction band at temperatures higher than absolute zero. If the electron energy is greater than or equal to the hole energy above it, the electrons can move. Electrons that transition to the conduction band will become free electrons and leave many holes called holes in the valence band, which will then recombine with electrons. These electrons and holes conduct current in semiconductor materials (Dorf, 2018).

Semiconductors are between conductors and insulators. This type of material has a conduction band that is close to the valence band, but there is no imbalance between the two. In other words, there is still a band gap between the two bands. This close band gap means that the valence electrons in the semiconductor can move to the conduction band easily. With a little energy such as heat energy, these electrons can become free electrons, so that electric current can occur (Zhang et al., 2019). In the series of moving charges, we know that electric current can flow in an object if an electric field is applied to it. Based on its ability to conduct electricity, each material can be categorized into two types, namely conductor materials that can conduct

electricity easily and insulators that cannot conduct electricity. The difference between the two can be seen by reviewing the energy bands of the electrons in the material. In the energy band theory, there are two energy level regions that can be occupied by electrons, namely the valence band and the conduction band. Electrons in the valence band can only orbit the nucleus of an atom, so some amount of energy is needed to pull the electrons out of the atom so that they can conduct electricity easily. In this situation, the electrons become free electrons and move to the conduction band (Wang et al., 2018).

According to Von Meier, A. (2024) the energy band is an important concept in understanding the properties of semiconductor materials. The energy band explains the material's electrons' energy level. The valence band and the conduction band are the two primary energy bands found in semiconductor materials. An energy band with electrons in it is called the valence band that are tightly bound to atoms in the semiconductor material (Helbig et al., 2019). These electrons do not have enough energy to move freely and contribute to electrical conductivity.

The conduction band is an energy band that contains electrons that have high enough allowing energy to flow freely and improve electrical conductivity. There exists a band gap, also known as a prohibited energy gap, between the conduction band and the valence band. The energy differential between the conduction and valence bands is known as the band gap. Electrons in semiconductor materials with tiny band gaps can readily transition from the valence band to the conduction band with the addition of a little amount of energy.

Conversely, higher energy is needed for electrons to go from the valence band to the conduction band in semiconductor materials with large band gaps. Silicon (Si) and germanium (Ge) are the two semiconductor materials that are most frequently utilized. The lowest value of the conduction band and the maximum value of the valence band do not meet at the same momentum value in silicon and germanium, resulting in an indirect bandgap structure. The conduction band in semiconductor materials is exposed to low temperatures is usually partially filled for conductor materials, while for insulators and semiconductors there are no electrons filling the conduction band. However, at higher temperatures, electrons can gain additional energy from the external electric field and jump to the conduction band, thus producing an electric current (Zhang, L., & Jaroniec, 2018).

## **RESEARCH METHOD**

This study deeply investigates the introduction to electrical engineering: the concept of semiconductor energy bands using a literature review approach. The results include a comprehensive understanding of the concept of semiconductor energy bands. The literature analysis involves an in-depth review of future electrical engineering literature, energy band theory, and the concept of semiconductors and semiconductor energy bands. With a strong conceptual foundation, this study provides an important contribution to enrich the discussion on what and how the introduction to electrical engineering and the concept of semiconductor energy bands.

## **RESULT AND DISCUSSION**

### **Electrical Engineering in the Future**

Husain et al., (2021) stated that electrical engineering continues to develop along with technological advances and the needs of society. In the future, there are several trends and developments that can be seen in electrical engineering. Here are some examples of developments that may occur in the future (Qadir et al., 2020):

1. Internet of Things (IoT): Electrical Engineering shall contribute to the creation and application of the Internet of Things (IoT). The Internet of Things (IoT) refers to the idea that different devices can share and communicate with one another by connecting to an internet network. Electrical Engineering will contribute to the development of communication systems, connectivity, and electrical energy management that support IoT. In the future, electrical engineering will play an important role in the development of more sophisticated and complex IoT systems. This includes the development of smaller, more energy efficient, and more integrated sensors, as well as the development of more efficient communication protocols.
2. Renewable Energy: In facing the challenges of climate change and the need for sustainable energy sources, Electrical Engineering will contribute to the growth and implementation of renewable energy technologies. This includes the development of innovative solar energy systems, wind energy, hydro energy, and energy storage technologies. In an effort to reduce dependence on fossil fuels, electrical engineering will continue to play a role in the development of renewable energy technologies, such as solar panels, wind turbines, and more efficient batteries. Electrical engineering

will focus on the development of better energy storage systems, smarter power management, and more efficient integration with the energy grid.

3. **Artificial Intelligence:** Electrical Engineering will be involved in the development and application of artificial intelligence (AI). AI is a technology that allows computers and systems to learn and make decisions independently. In the context of Electrical Engineering, AI can be used in the development of automation systems, signal processing, and control of systems that are smarter and more efficient. In the future, electrical engineering will be increasingly involved in the development of AI algorithms and systems used in data processing, pattern recognition, decision making, and automation. AI will provide higher capabilities in data analysis and control of electronic systems.
4. **Communication and Connectivity:** In the ever-evolving digital era, Electrical Engineering will continue to play a role in the development of communication and connectivity technologies. This includes the development of faster and more reliable telecommunications networks, more sophisticated wireless technologies, and the development of more efficient communication protocols.
5. **Industry 4.0:** Electrical Engineering will play a role in facing the challenges and opportunities offered by the Industrial Revolution 4.0. This involves the development of industrial automation systems, robotics, smart manufacturing, and the use of digital technologies in production processes.

Electrical engineering is based on the basic principles of electricity. Electrical engineering involves the use of various electronic components. This article will explain about resistors, capacitors, inductors, diodes, transistors, and ICs (Integrated Circuits). Electronic circuits are the basic elements in electrical engineering (Charaf et al., 2017).

Angadi et al., (2021) stated that electrical engineering has an important role in communication and networking. Electrical engineering is also used in control and automation systems. Electrical engineering plays an important role in the development of renewable energy and energy efficiency. In facing a future full of technological developments, Electrical Engineering graduates will have broad career opportunities. They can work in various sectors, including education, the energy industry, telecommunications, manufacturing, and many more. In addition, they can also be involved in research and development of innovative technologies.

## Energy Band Theory

According to Bößl et al., (2023) Energy Band Theory is a concept in solid state physics that explains the behavior of electrons in solid materials. This theory describes the energy levels of electrons that can only have values within a certain range called energy bands. Energy band theory is an important concept in materials physics and chemistry that is used to explain the electronic properties of solid materials, especially in semiconductors, insulators, and conductors. This theory describes how electrons are in various allowed energy bands and how they interact with the crystal structure of the material. The following is a brief explanation of the main components of energy band theory (Cayssol, J., & Fuchs, 2021):

### 1. Valence Band and Conduction Band

In energy band theory, there are two energy level regions that are available for electron habitation, the conduction band and the valence band. The energy level region occupied by electrons bonded to atoms or molecules is known as the valence band. the lowest energy band, which at absolute zero temperature is primarily occupied by electrons. Chemical bonds between atoms in crystals are formed by electrons in the valence band. The area of energy levels above the valence band where free-moving electrons can reside and contribute to electrical conductivity is known as the conduction band. a higher energy band that, at absolute zero temperature, is typically empty or partially empty. Electrical conductivity is facilitated by the free movement of electrons in the conduction band within the substance.

### 2. Energy Gap

The energy gap, also known as the forbidden gap, exists between the valence band and the conduction band. The energy range that separates an electron's filled valence band from its empty conduction band is known as the energy gap. The material possesses insulating qualities if the energy gap is sufficiently large, as it makes it difficult for electrons to move from the valence band to the conduction band. the energy separation between the conduction band and valence band. The size of the energy gap determines the electrical properties of the material Conductor: There is no significant energy gap, so that The transition from the valence band to the conduction band is simple for electrons. A semiconductor is a material that has a tiny energy gap, which allows electrons to flow from the valence band to the conduction band under specific circumstances (such as the application of heat or photon energy). Few electrons may migrate from

insulators to the conduction band due to their wide energy gap, making this material non-conductive.

### 3. Conductors, Insulators, and Semiconductor.

Based on the energy band theory, materials can be classified into conductors, insulators, or semiconductors. Conductors have a conduction band filled with electrons that are free to move easily, allowing electric current to flow well. Insulators have a large energy gap, so that electrons find it difficult to jump to the conduction band and electric current hardly occurs. Semiconductors have a smaller energy gap than insulators, so that under certain conditions, electrons can jump to the conduction band and electric current can flow, although not as well as in conductors.

### 4. Effect of Temperature

Temperature also affects the behavior of electrons in the energy band theory. At low temperatures, most electrons are in the valence band and none are in the conduction band. However, at higher temperatures, some electrons can gain additional energy and jump to the conduction band, thereby increasing the conductivity of semiconductor materials.

The energy band theory provides important insights into the electrical properties and conductivity of solid materials. By understanding this concept, we can explain why some materials are conductors, insulators, or semiconductors (Han et al., 2022).

Energy band theory is very important in the development and understanding of various electronic devices such as transistors, diodes, solar cells, and LEDs. Understanding how electrons behave in different energy bands allows scientists and engineers to design materials with desired electronic properties (Perdew et al., 2017).

## **Semiconductor Concept and Semiconductor Energy Bands**

Nowadays, as technology becomes more and more necessary, many businesses require electronic gadgets made of materials based on semiconductors. According to Sze, S. M., Li, Y., & Ng, K. K. (2021), semiconductors are components that are in high demand across multiple industries. because the application of this technology has a significant global influence on a number of sectors. As a result, many sectors require these components due to the use of semiconductors. Chips and other semiconductor devices are regrettably still uncommon in Indonesia. This increases the need for semiconductor chips among many businesses.

A semiconductor is an electrically conducting component situated between an insulator and a conductor. While conductors have good properties for conducting electric current, insulators have weak properties for doing so. As a result, a semiconductor is defined as an electrical conductor or middle component.

According to Zhu et al., (2021) a semiconductor is a material with between an insulator and a conductor electrical conductivity. It is impossible to isolate conductors and insulators from a semiconductor's characteristics. While conductors have good properties for conducting electric current, insulators have weak properties for doing so. Based on their uses, semiconductors are used in various industries and electronic equipment. Commonly used semiconductor materials are silicon, germanium, and gallium arsenide. Semiconductors play an important role in the world of electronics and modern technology. Some of the uses of semiconductors include (Keldysh, 2024):

**Electronic Equipment:** Semiconductors are used in the manufacture of various types of electronic equipment such as mobile phones, computers, televisions, cameras, and LED lights.

**Current, Voltage, and Power Amplifiers:** Semiconductors can function as current amplifiers, voltage amplifiers, and power amplifiers in electronic circuits.

**Sensors:** Semiconductors are also used in the manufacture of electronic sensors, such as temperature sensors, light sensors, and pressure sensors.

**Solar Panels:** Semiconductors are also used in solar panels to convert solar energy into electrical energy.

**Transistors:** Transistors, one of the important components in electronics, also use semiconductors in their structure and function.

Semiconductors have a different atomic structure from conductors and insulators. Atoms in semiconductors have a valence layer that is not completely filled with electrons, thus creating an energy difference between the conduction layer and the valence layer. Due to the enormous energy gap preventing any electrons from moving between the valence and conduction layers, semiconductors behave as insulators at low temperatures. Nevertheless, electrons in the valence layer can cross the energy gap and go to the conduction layer at high temperatures or in response to increased energy (Yuan et al., 2018).

Semiconductors can also be divided into two types according to the doping types, specifically P type and N type. P type semiconductors are made

of materials doped with other electron-deficient atoms to give them a positive charge. Nevertheless, materials doped with additional atoms that have extra electrons are known as N type semiconductors so that they have a negative charge. With the ability to conduct electricity that can be changed by controlling the amount and type of charge in it, semiconductors play an important role in the development of modern technology. Semiconductors' characteristics are intrinsically linked to those of insulators and conductors. The influence of temperature, light, and magnetism on these two electrical qualities does not readily alter their characteristics. Semiconductors are hence extremely sensitive. Resistances in semiconductors range from  $10^{-6}$  to  $10^4$   $\Omega$ m. The characteristics of semiconductors are as follows (Sangiorgi et al., 2017):

1. The temperature coefficient is negative.  
Negative attributes characterize semiconductors. In contrast, metals have a positive coefficient of resistance to temperature.
2. Elevated Thermoelectric Force  
Transistors have a high thermoelectric power capability. Due of the semiconductor's middle-of-the-road character, the metal involved can have a positive or negative sign.
3. Identification  
In order to prevent conflicts between its components, semiconductors have a rectifying relationship.

The semiconductor has specific uses and functions based on its nature. The applications of semiconductors are as follows according to Scharber, M. C., & Sariciftci, N. S. (2021):

1. Germanium (Ge) functions as a diode and early transistor
2. Silicon (Si) functions as a diode, transistor, IC and so on
3. Selenium (Se) functions as a rectifier
4. The thermoelectric generator function of germanium silicon (Ge Si)
5. An infrared detector made of tin telluride (PbTe)
6. Gallium arsenide (GaAs) serves as a laser, high-frequency transistor, and various other specialized instruments.
7. Barium Titanate, or Ba Ti, serves as a PTC thermistor.
8. Bi<sub>2</sub>Te<sub>3</sub> (Bismuth Telluride) serves as a thermoelectric converter
9. The properties of indium antimonide (In Sb) include magneto and plezo resistivity.
10. The plezo resistor is the function of indium arsenide (In As).
11. Si Cb, or silicon carbide, serves as a varistor

12. Al Sb (aluminum stridium) serves as a lighting diode
13. Ga P, or gallium phosphorus, serves as a lighting diode
14. The Use of Indium Phosphor (In P) as an Infrared Filter
15. Pb S sulfur plum (Pb S) serves as a photocell
16. Pb Se (selenium plum) serves as a photocell
17.  $GaxIn_{1-x}As$  has optical and high frequency capabilities.
18. The  $Hg_{1-x}CdxTe$  serves as an infrared sensor
19.  $GaAs_{1-x}P_x$  is a diode that emits light.

Semiconductors have applications in a wide range of industries, as evidenced by the uses listed above. Because of this, semiconductors will be very useful in the future for a variety of applications, including automotive and motor semiconductors. The benefits of semiconductors are numerous and include (Tsao et al., 2018):

1. Semiconductor chips have low voltage compared to vacuum
2. Relatively small size
3. Resistant to shocks
4. Relatively cheap price
5. Unlimited service life

However, there are drawbacks to semiconductors, such as the following:

1. Compared to vacuum, semiconductor chips generate large waves.
2. Reduced capability for power
3. Should the frequencies be high. Transistors typically react poorly

Energy bands are a key idea in comprehending semiconductor materials' optical and electrical characteristics. The valence band and the conduction band are the two primary components of the energy band. The conduction band is an energy band above the valence band that can be filled by electrons with higher energy, whereas the valence band is an energy band that can be completely filled by electrons from solids. The band gap is the name for the energy gap present in semiconductor materials. The energy differential between the conduction and valence bands is known as the band gap. Semiconductors have a smaller band gap compared to insulators, but larger compared to conductors. The smaller band gap in semiconductors allows electrons to jump from the valence band to the conduction band by providing a small amount of additional energy. Electrons in the valence band of semiconductors are less energetic than those in the conduction band. Electrons need additional energy that is at least equivalent to the energy difference between the valence band and the conduction band in order to

travel from the valence band to the conduction band (Oba, F., & Kumagai, 2018).

This process can occur by providing additional energy through heat or an external electric field. It is important to note that semiconductors can be controlled by doping, which is adding a small amount of impurity atoms to the semiconductor material. Doping can change the electrical properties of semiconductors by changing the number and type of dominant charge carriers. Silicon and Germanium are the most widely used semiconductor materials. Silicon has an indirect energy band structure, where the minimum value of the conduction band and the maximum value of the valence band do not meet at the same momentum value. Germanium is also a commonly used semiconductor material.

## **CONCLUSION**

Introduction to Electrical Engineering covers various fundamental concepts, one of which is the concept of energy bands in semiconductors. Understanding this concept is very important because semiconductors are the basic materials in many electronic devices, including transistors, diodes, and integrated circuits. In energy band theory, electrons in a material can be in different energy bands, namely:

1. Valence Band: This band is occupied by electrons that are tightly bound to atoms and are not free to move. Electrons in the valence band contribute to chemical bonds in the material.
2. Conduction Band: This band is above the valence band and is occupied by electrons that are energetic enough to move freely in the material. Electrons in the conduction band allow the material to conduct electricity.
3. Forbidden Band: This is the energy required to move electrons from the valence band to the conduction band. Semiconductors have a smaller forbidden band than insulators, but larger than conductors.

The energy band theory provides important insights into the electrical properties and conductivity of solid materials. By understanding this concept, we can explain why some materials are conductors, insulators, or semiconductors. The energy band theory is very important in the development and understanding of various electronic devices such as transistors, diodes, solar cells, and LEDs. Understanding how electrons behave in various energy bands allows scientists and engineers to design materials with desired electronic properties.

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