

Energy gaps and semiconductors

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Abstract

In this essay, we explore semiconductors, which are materials that lie between conductors and insulators in terms of electrical conductivity. We introduce the concept of crystal lattices and how their alignment leads to the creation of "bands", which play a crucial role in determining the semiconductor's properties.

1 Introduction

Picture a traffic light, not always green or red, but able to switch between the two, controlling the flow depending on the signal received. That is precisely how semiconductors function. Their electrical behavior lies between a conductor and an insulator. In addition, their versatility makes them a fundamental part of the physical world, used in electrical components such as diodes and transistors, the essential building blocks of modern electronics, from computers and smartphones to advanced communication systems [1]. The significance of this material is evident in its crystal structure, where the atoms inside it are arranged in a repeated array, creating bonds between them. This is a definition of a "lattice". A lattice can be thought of as a Rubik's cube! Thinking of the colored squared as the atoms in the lattice, depending on how you rearrange them, different patterns will be displayed. The patterns correspond to the lattice's behavior, where the arrangement of atoms influences various properties, including electronic, optical, and physical characteristics [1].

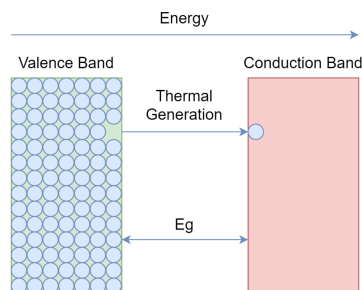


Figure 1: Band gap energy (E_g) between Valence band and Conduction Band.

2 Energy gaps

In a semiconductor, as more atoms align in the lattice, additional bonds are formed due to interference of the interacting atomic orbitals. This interaction leads to many close spaced levels being generated, forming energy bands [2]. There are three main bands in semiconductors. First, there is the **valence band**. Conduction in semiconductors occurs primarily because of *valence electrons*. In the atomic model, these types of electron are found in the outermost shell. This is referred to as the *valence shell* or band (hence, the name valence electrons). Not to forget, this is to the atomic level! In crystals (as we have seen so far) we are not at a microscopic scale but a macroscopic one; similar words but completely different meanings! Since we are referring to crystals, all of these valence shells would have overlapped, forming the valence band [2]. Because of their greater distance from the nucleus, the nuclear attraction weakens, causing valence electrons to be loosely bound to the atom. When the electron acquires enough additional energy, it will become a free electron by leaving the valence band and exist in the **conduction band**. The absence of the electron will create a "hole" in the valence band. These holes are quasi-static particles that coexist with other electrons in the valence band. This "jumping" of electrons from one band to the other can be showcased in **Fig. 1**. The difference between the conduction band and valence band is called energy gap or more commonly referred to as **energy band**. The likelihood of free electrons occupying these bands is determined by the Fermi-Dirac function as

$$f(E) = \frac{1}{1 + e^{\frac{E-E_F}{k_B T}}} \quad (1)$$

where E_F corresponds to the Fermi energy, k_B refers to the Boltzmann constant and T is the absolute temperature (measured in Kelvins).

The Fermi level lies in the middle of the energy band, which allows valence electrons to transition to the conduction band at temperatures lower than 0 Kelvin. This leads to the formation of electron-hole pairs on the semiconductor's surface.

3 Conclusion

Semiconductors are the foundation of our day-to-day life and the building blocks of every electronic device that surround us. They possess a wide range of electrical properties that are determined by the size and position of the bands that characterize them. This essay explored the purpose of the three bands in a semiconductor: the valence band, the conduction band, and the energy band. In addition, the significance of Fermi levels was examined. As we enter an era dominated by AI and the rise of quantum computing, semiconductors will play a crucial role in making this happen.

References

- [1] Ram K. Gupta Fundamentals to Emerging Applications, JHandbook on semiconductors, (2025).
- [2] Thomas L. Floyd Electronic Devices, Conventional Current Version, Ninth Edition (2013).