(a) Metals, Semiconductors and Insulators

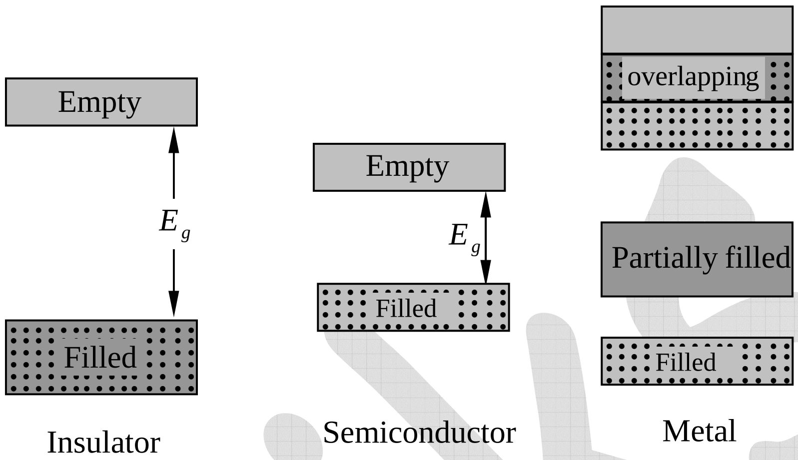
Every solid has its own characteristic energy band structure. This variation in band structure is responsible for the wide range of electrical characteristics observed in various materials. The diamond band structure for example, can give a good picture of why carbon in the diamond lattice is a good insulator. To reach such a conclusion, we must consider the properties of completely filled and completely empty energy bands in the current conduction process.

Before discussing the mechanisms of current flow in solids further, we can observe here that for electrons to experience acceleration in an applied electric field, they must be able to move into new energy states. This implies there must be empty states (allowed energy states which are not already occupied by electrons) available to the electrons. For example, if relatively few electrons reside in an otherwise empty band, ample unoccupied states are available into which the electrons can move. On the other hand, the diamond structure is such that the valence band is completely filled with electrons at $0\,K$ and the conduction band is empty. There can be no charge transport within the valence band, since no empty states are available into which electrons can move. There are no electrons in the conduction band, so no charge transport can take place there either. Thus carbon in the diamond structure has a high resistivity typical of insulators.

Semiconductor materials at $0\,K$ have basically the same structure as insulators-a filled valence band separated from an empty conduction band by a band gap containing no allowed energy states (Figure). The difference lies in the size of the band gap E_g which is much smaller in semiconductors than in insulators. For example, the semiconductor Si has a band gap of about $1.1\,eV$ compared with $5\,eV$ for diamond. The relatively small band gaps of semiconductors allow for excitation of electrons from the lower (valence) band to the upper (conduction) band by reasonable amounts of thermal or optical energy.

For example, at room temperature a semiconductor with a $1\,eV$ band gap will have a significant number of electrons excited thermally across the energy gap into the conduction band whereas an insulator with $E_g = 10\,eV$ will have a negligible number of such excitations. Thus an important difference between semiconductors and insulators is that the number of electrons available for conduction can be increased greatly in semiconductors by thermal or optical energy.

In metals the bands either overlap or are only partially filled. Thus electrons and empty energy states are intermixed within the bands so that electrons can move freely under the influence of an electric field. As expected from the metallic band structures, metals have a high electrical conductivity.



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