

## Solid State Physics: Experiment #5 Measuring the Band-Gap of a Semiconductor

According to the band theory of solids, insulators and semiconductors are materials which possess a band-gap (i.e., a range of forbidden energy values) at the Fermi level. Thus, these materials have a completely filled energy band below the gap and an empty band above the gap. The width of this band-gap is what distinguishes insulators from semiconductors. In semiconductors the band-gap is small enough ( $<2$  eV) that at finite temperatures thermal excitation of electrons across the gap, into the empty "conduction" band, is possible leading to a small but measurable conductivity. The band-gap in insulators is simply too large to have any appreciable concentration of charge carriers excited into the conduction band. The temperature dependence of the resistivity of a pure (i.e., intrinsic) semiconductor is given by

$$\rho_i = B(T) \exp(E_g/2k_B T)$$

where  $E_g$  is the width of the gap and the function  $B(T)$  is only very weakly dependent on temperature. To a good approximation we can take  $B(T)=\text{constant}$ . Thus, we can easily measure the gap energy of a semiconductor material by measuring the resistance of a sample over a range of temperatures. One additional complication here is that very small amounts of impurities in a semiconductor can have large effects on the conductivity. This is desirable in designing many semiconductor devices but can complicate the measurement of the intrinsic gap energy. These impurity effects can be minimized by working at high enough temperatures that all dopant-type impurities are fully ionized (the intrinsic regime of a doped semiconductor). [See Figs. 10.2 and 10.14-10.15 in Myers].

According to the equation given above, the resistivity of an intrinsic semiconductor is very sensitive to changes in temperature. This property is the basis for solid-state temperature measurement devices known as thermistors. In this lab we will measure the resistance of a thermistor as a function of temperature and thereby determine the gap energy for the semiconductor material used in the device.

**Procedure:** Use the water bath and hot plate/stirrer set up in Colton 14. The thermistor (PreCon Model ST-R3R) is sealed in plastic and can be operated in the range  $-40^\circ\text{C}$  to  $110^\circ\text{C}$ . Resistance measurements can be made with the Metex multi-meter. Take data for as wide a range of temperatures as possible.

**The Write-up:** Give a concise explanation of your experimental procedure and present your results in an appropriate plot (i.e.,  $\log(R)$  vs.  $1/T$ ). Report a gap energy and provide some uncertainty estimate in your final value. Discuss whether or not your data suggests the presence of impurities in the thermistor semiconductor material. If you do suspect impurities, redo your data analysis in such a way as to minimize the effects on your determination of the gap energy. What semiconductor material do you think is used in this thermistor?

**Write-up and lab notebooks due date: Monday, April 5.**