Temperature variation of resistance in silicon

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Abstract

The temperature dependence of resistance was investigated by measuring the resistance of a fairly pure sample of silicon at various temperatures. The resistance was measured using a potential divider circuit. The temperature of the silicon, in the form of a thermistor was measured using a thermocouple. The temperature of the sample was varied by heating it with a soldering iron. The results confirmed that the theory is valid at temperatures above 500 K. The energy gap of silicon was found to be (1.072 ± 0.011) eV which is consistent with the expected range of 1.0-1.1 eV.

1 Introduction

The aims of the experiment were to investigate the non-classical temperature variation of resistance in silicon and to determine the energy gap of silicon.

The electrical conductivity of silicon, a semiconductor, depends very strongly on temperature. The unique properties of semiconductors make them useful in many applications, and semiconductors are the foundation of modern electronics. A simple model assumes that the electrons can be in either the valence band or the conduction band, separated by an energy gap E_g. The model predicts a specific exponential relationship between temperature and resistance at temperatures in the *intrinsic region*:

$$R = R_0 \exp\left(\frac{T}{T_0}\right), \text{ where } T_0 = \frac{E_g}{2k_B}. \tag{1}$$

The theoretical background and method are described in the practical manual.[1] Section 2 gives a discussion of the results and uncertainties. The overall conclusions are presented in section 3.

2 Discussion

The experiment included both the intrinsic and extrinsic regions of the semiconductor, as seen in the first graph. It can be seen that the graph is in the linear regime for low values of $1/T$ (i.e. at sufficiently high temperatures). This relationship does not hold for the last nine points, suggesting that the theory is only valid for temperatures above 500 K.

The data points in the intrinsic region were used to calculate E_g, as shown in the second graph. The energy gap of silicon was calculated to be $E_g = (1.072 \pm 0.011)$ eV. This is consistent with the expected range of 1.0-1.1 eV.[1]

The uncertainty in E_g is dominated by the uncertainty in determining the voltages across resistors (i.e. the resistance of the thermistor), and the voltage across the thermocouple (i.e. the temperature). This gives the uncertainty in the slope translating to uncertainty in E_g of about one part in 100.

Possible systematic errors may have been introduced by the difference between the temperature of the thermistor and the thermocouple, and the resistance of voltmeters etc. The former is negligible compared to the random error in temperature readings. The latter can be estimated by taking the voltmeter's resistance $r \approx 10$ MΩ and expressing the resistance of the thermistor,

$$R = R_s \frac{V_1}{V_2}, \tag{2}$$

$$R = \frac{R_s r}{(R_s + r)} \frac{V_1}{V_2}. \tag{3}$$

By comparing the simple equation 2 used in calculations to the more accurate equation 3, the approximate relative error becomes $1 - \frac{r}{R_s + r}$ to be estimated as about one part in 1000. This is in the order of the random error in the voltage, and thus there it does not need to be taken into account.

The uncertainty in E_g is not affected by the uncertainty in the resistance of the fixed resistor, as it does not change the gradient which determines the energy gap. The value of this resistor $R_s = 1.2\text{k}\Omega$ was chosen to be of the same order as that of the thermistor to minimise random errors. Having a much higher or lower value would have changed the range of measurements significantly, increasing the random error.

3 Conclusions

A thermistor was used to determine the intrinsic region and the energy gap of silicon. The resistance of the thermistor was determined using a fixed resistor and measuring voltages across the two, and the temperature was obtained by measuring the voltage across a thermocouple placed in close proximity in the tip of a soldering iron used to heat the sample.

The set of measurements and accounting for the possible uncertainties allowed to test a simple linear model for the temperature dependence of the resistance of silicon, the range of the validity of the theory and the value of the energy gap.

The data support the theory for temperatures higher than 500 K. A value for E_g of 1.072 ± 0.011 eV was obtained – this is consistent with the reference value of 1.0–1.1 eV.

References

[1] *NST 1A Physics Practical Manual, Michaelmas Term 2013.* Laboratory Manual: Department of Physics, University of Cambridge