14. Diode Thermometers

Diodes can be used above room temperature (e.g. in clinical thermometry) but not with sufficiently-high accuracy to be considered in this monograph. There is an extensive literature on semiconducting diodes with possible application as cryogenic thermometers [e.g. Swartz and Swartz (1974), Lengerer (1974), and Rubin and Brandt (1982)] but only two types intended for use as thermometers are commercially available: GaAs and Si. The temperature-indicating parameter is the forward-biased junction voltage, which decreases approximately linearly with increasing temperature when the current is kept constant.

Because of their almost trivial cost, silicon diodes mass-produced for the electronics industry have been widely tested as thermometers. They would have particular appeal in large engineering projects requiring hundreds of sensors. It turns out, however, to be very costly to select the very small percentage that are adequate for thermometric use. The following discussion does not apply to these devices, but to diodes that are manufactured for specific use as thermometers. There are some specific drawbacks to diode thermometers:

a) The typical I-V characteristic is such as to make the internal impedance of the device very high (easily greater than 100 kΩ) at small currents; or else - using a larger current - one encounters unacceptably high power dissipation at low temperatures.

b) There is a transition region in the conduction mechanism around 20 K that makes fitting a V-T characteristic over the whole temperature range difficult for GaAs and impossible for Si (Figs. 14.1 and 14.2).

For GaAs the least-squares fitted equation [Pavese (1974)]

$$V = \sum_{i=0}^{7} A_i (\ln T')^i \tag{14.1}$$

(where $T' = (T/T_1) + 1$) fits to within about ± 0.1 K (~ ± 100 parts per million in voltage) from 4 K to 300 K. For higher accuracy, the range is subdivided into two sections with the junction near 90 K. An effective equation for the two-range fitting is [Swartz and Gaines (1972)]:

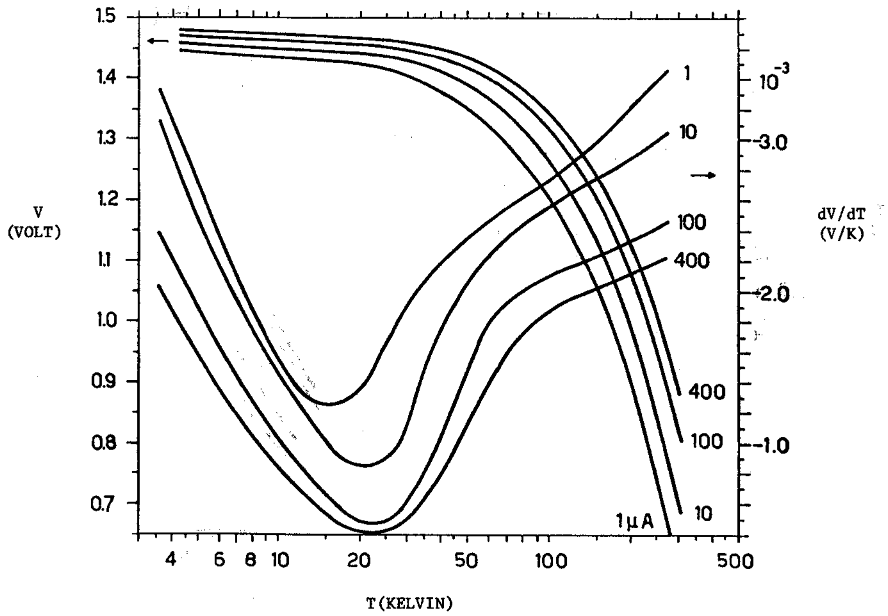

Fig. 14.1: Voltage and sensitivity of a gallium arsenide diode as a function of temperature and current (labels on curves) [after Pavese and Limbarinu (1972)].

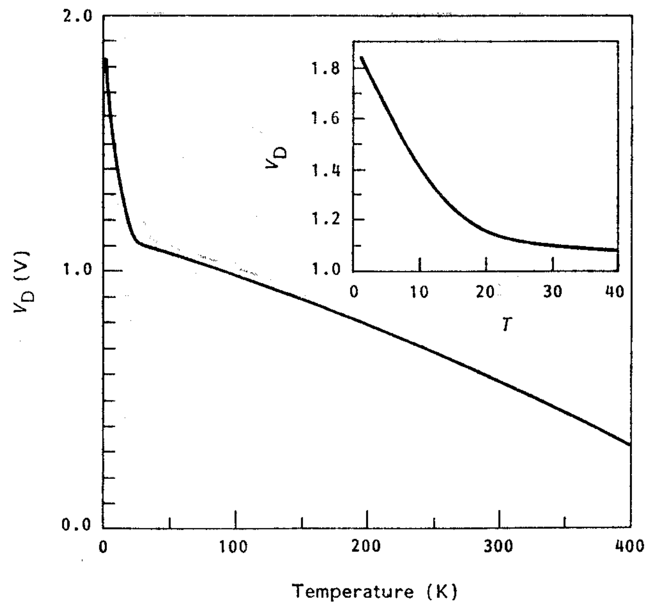

Fig. 14.2: Forward biased voltage of a silicon diode as a function of temperature. The lower temperature region is shown to larger scale in the inset [Lanchester 1989)].

$$V = E_0 - \frac{BT^2}{T + T_0} - CT\ln(DT) \quad . \tag{14.2}$$

Equation (14.2) fits experimental data to better than ± 15 mK below 54 K and ± 25 mK above 90 K.

With silicon diode thermometers, the complete range must be fitted in two sections, omitting a small range around 20 K where the thermometer cannot be used because of the afore-mentioned sharp change in slope. On either side of this critical region the V versus T characteristic is smooth, allowing non-critical fitting with simple polynomials. The fitting equations require a dozen or more calibration points, suitably spaced in temperature, in each range. An accuracy within ± 0.05 K cannot be obtained from calibration at a smaller number of fixed points.

No general statement can be made regarding the stability of diode thermometers. Selected ones can be as stable as ± 0.01 K on thermal cycling but much larger instabilities can occur unpredictably.

In zero magnetic field and below 20 K, diodes show high sensitivity associated with a readily-measurable voltage (millivolts in 1-2 V).