ULT Thermometry with GaAlAs Diodes

The use of GaAlAs diodes as temperature sensors may be extended to temperatures in the mK range. Semiconductor diodes are suitable as temperature sensors above 1.4 K because the voltages obtained across them are a fraction of a volt or higher. However, these diodes have not, so far, been routinely used at mK temperatures. Snehadri Bihari Ota of the Institute of Physics and Smita Ota of the Institute of Materials Science, in Bhubaneswar, India, have measured characteristics of such diodes which indicate their suitability in this range.

The application of semiconductor diodes as temperature sensors uses the characteristic that the forward voltage (V_f) increases with decreasing temperature (T). Figure 1, for example, is the T vs V_f characteristic of a GaAlAs diode, showing a rapid increase in forward voltage below a critical temperature (T*) of 35 K. Three sets of characteristics have been measured: the forward voltage as a function of current [1], the dependence of T* on current, and the temperature sensitivity ($|dV_f/dT|$) at 14 K, which was found to reduce with current according to a power law (Figure 1).

Extrapolation of these characteristics to lower temperatures and currents suggests that GaAlAs diodes can be used as temperature sensors below 1 K. For example, from figure 1, the value of $|dV_f/dT$ would be 32 mV/K at 10 pA. As the sensitivity of GaAlAs diodes increases steadily with decreasing temperature down to at least 4 K, this may be expected to be the *minimum* sensitivity at 50 mK.

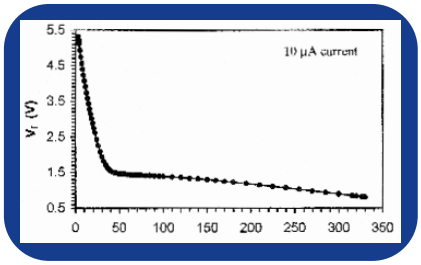

Fig.1: Temperature dependence of the forward voltage of a GaAlAs diode, serial number 9821, model TG-120

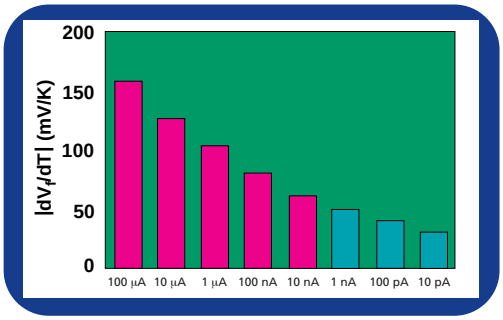

Figure 2: Temperature sensitivity at 14 K for various values of current.

Furthermore, from the dependence of T* on current (not shown), the value of T* is estimated to be 19 K at 10 pA, well above 1 K. Finally, extrapolating the low temperature characteristic of the diode to 50 mK gives a forward voltage of less than 3 V at 10 pA, and hence a Joule power dissipation of less than 30 pW at 50 mK, if the diode is biased with a current of 10 pA.
It should therefore be possible to use such temperature sensors in ^{3}He/^{4}He dilution refrigerators and ^{3}He refrigerators, which are currently available commercially. Temperature resolutions of 0.1 mK should be achievable. These would require V_f measurements of the order of a volt with a resolution of 1 in 10^6, within the capabilities of several commercially available digital voltmeters. The use of miniaturised semiconductor diodes with small thermal contact areas would also render problems in achieving thermal equilibrium almost negligible.

References

[1] A study of forward characteristics of a GaAlAs temperature sensor diode, S B Ota and Smita Ota, Meas.Sci.Technol. 11 (2000) 815-817

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