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Semiconductor diodes for measurement of low temperatures

Abstract

The forward voltage of Si and GaAlAs diodes have been studied in the temperature range 10-300 K and for various current values (10 nA to 0.5 mA). The temperature sensitivity of these diodes have been obtained. Flicker 1/f noise has been observed in the GaAlAs diode. Possible use of GaAlAs diode for measurement of mK temperatures has been suggested. For Si diode the 'reduced' forward voltage at T = 0 is found to be 1.0 V.

Key Words

Si diode; GaAlAs diode; 1/f noise.

The forward voltage (V_f) of semiconductor diode is known to decrease linearly with increase in temperature (T)[1]. This characteristic has therefore found application in the measurement of low temperatures. Si and GaAlAs semiconductor diodes have mainly been studied in the past. The linear variation is understood in terms of transport in high electric field which exists at the 'depletion layer' of the diode where V_f is shown to be related to T and the forward current (I) as follows:

$$V_f = (nk_BT/e)\ \ln(I/I_S + 1) \quad (1)$$

where I_S is the saturation current which is temperature dependent, e is the electronic charge and k_B is the Boltzmann constant, n is a parameter depending on the material, temperature and current level and typically has a value between 1 and 2. The observed increase in sensitivity ($S = |dV_f/dT|$) with decrease in forward current is also apparent in Eq. (1).

The measurements were carried out on Si 1N4007, cryogenic Si and GaAlAs diodes from 10 to 300 K using an automated setup built around a closed cycle refrigerator. The Si 1N4007 diode characteristic between 30-300 K could be least squares fitted to a 3rd order polynomial[2]. The polynomials have high temperature root (T_0) for all current values (10 nA to 200 μA). S at 150 K was obtained from the 2nd (LSF) polynomial:

$$S = -1.27\times10^{-4}\ln(I) + 1.27\times10^{-3} \quad (2)$$

where I is in A and S is in V/K. Similarly for cryogenic Si the S is given by:

$$S = -7.45\times10^{-5}\ln(I) + 1.26\times10^{-3} \quad (3)$$

The S at 150 K for GaAlAs diode was obtained from 2nd order LSF polynomial[3]:

$$S = -1.70\times10^{-4}\ln(I) + 2.16\times10^{-4} \quad (4)$$

The extrapolated value of the V_f at T = 0 was found to be 1.2 V, 1.2 V and 1.5 V for Si 1N4007, cryogenic Si and GaAlAs diodes, respectively. This agrees with the band gap of 1.2 eV and 1.5 eV of Si and GaAlAs, respectively which can be understood theoretically[4]. The measured dc voltages in these systems show fluctuations and the standard deviations of the voltage values show the statistics of flicker 1/f noise (Figure 1)[5]. The 1/f noise in GaAlAs diode is found to be temperature independent but current dependent. It is found to increase with decrease in forward current below 0.01 mA. 1/f

noise has been explained using modified thermal equation[6,7].

At low temperatures V_f increases more rapidly as T is reduced which gives rise to a bend in the temperature dependence of V_f. In both Si and GaAlAs diodes the temperature at which the bend occurs was found to reduce as the current is reduced.

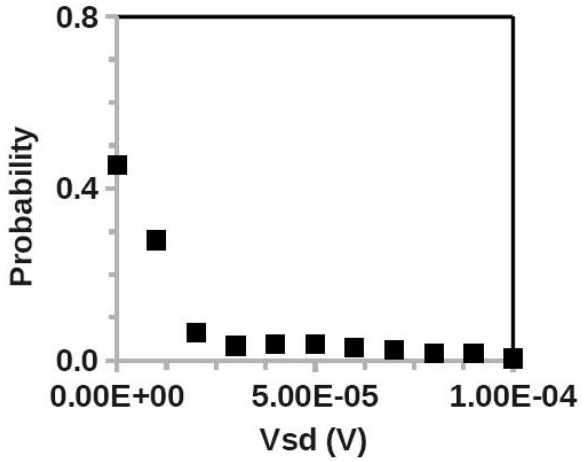

Figure 1 : The probability distribution of V_{sd} for GaAlAs semiconductor diode in the temperature range 50-300 K. The forward current was varied from 10 nA to 450 μA in steps. Low voltages occur with high probability in 1/f noise.

The sensitivity of GaAlAs diode around 15 K is obtained by least squares fitting the characteristic to a 2nd order polynomial. The current dependence of sensitivity is found to be:

$$S = 1.17 \times 10^{-2} \ln(I) + 2.67 \times 10^{-1} \quad (5)$$

It is important to note here that with the current reduced by several orders of magnitude the GaAlAs diodes can be used in the ultra-low temperature (ULT) range (0.05-1 K).

In case of Si 1N 4007 diode V_f was found to saturate with decrease in T below the bend. The reduced forward voltage (V_R) below 25 K is obtained by subtracting the 3rd order least squares fitted characteristic between 30 -300 K (Figure 2). It is interesting to note that V_R extrapolated to T = 0 has a value of 1.0V.

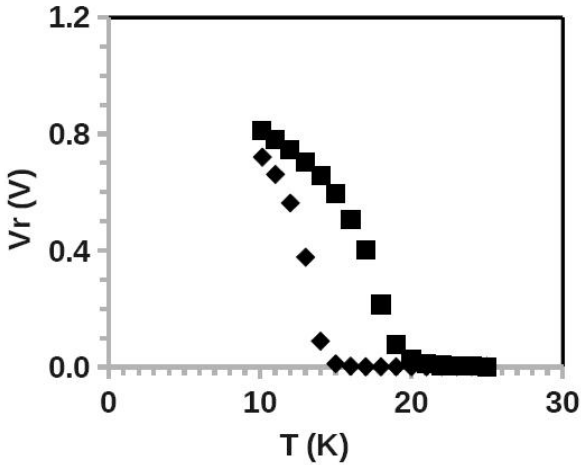

Figure 2 : The 'reduced' forward voltage (V_R) as a function of T for Si 1N4007 diode for 1 μA (♦) and 100 μA (■). V_R extrapolated to T = 0 has a value of 1.00 V.

In conclusion temperature sensitivity of Si and GaAlAS diodes have been obtained. Flicker 1/f noise has been observed in GaAlAs diode. The characteristics of the diodes have low temperature bend. From the sensitivity at 15 K it has been concluded that GaAlAs diode can be used in ULT range. It has been found that for Si 1N4007 diode V_R at T = 0 has a value 1.0 V.

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