



Full Paper

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The forward voltage of a semiconductor diode is known to increase by decreasing the temperature^[1-4]. The characteristic has therefore found application in the measurement of low temperature^[4,5]. Semiconductor diodes exclusively made for sensing low temperature are nowadays available commercially which can provide accuracy of 50 mK. Recently, the calibration of GaAlAs diode^[6-8] and Si1N4007 diode^[9] have been communicated. In this article the forward voltage variation with temperature of cryogenic silicon diode^[10] of CRYO Industries of America, Inc., Model No. DT-470-SD-13 for a range of current values in the temperature range 30-210 K has been presented.

The measurements were carried out using a computer-controlled four-probe setup built around a Leybold closed cycle helium refrigerator. A Keithley model 224/2243 programmable current source provided a stable constant current to the experimental diode. The forward voltage was measured using a Keithley model 182 digital voltmeter. The temperature of the sample site was controlled using a calibrated silicon diode in connection with a Leybold model LTC-60 temperature controller. Each data point was obtained by averaging 500 voltage readings.

Calibration of cryogenic Si diode for temperatures between 30-210 K

Abstract

The variation of forward voltage with temperature of a cryogenic silicon diode of CRYO Industries of America Inc. Model No. DT-470-SD-13 is measured in the temperature range 30-210 K and for current values between 10 nA and 200 μ A. The characteristic is least squares fitted by a 1st order polynomial and the coefficients are given. The least squares fitting has high temperature root between 420 K and 625 K.

Key Words

Forward characteristic; Silicon; Temperature sensors.

The relation between the forward current I_f and forward voltage V_f is given by:

$$V_f = (nk_B T/e) \ln(I_f/I_s + 1) \quad (1)$$

where I_s is the saturation current, e is the electronic charge, k_B is the Boltzmann constant and n is a parameter depending on the material, temperature and current level. The sensitivity $S = |dV_f/dT|$ is linear in $\ln(I_f)$ and is given by:

$$S = (nk_B/e) \ln(I_f/I_s + 1) \quad (2)$$

Figure 1 shows the temperature dependence of V_f for currents between 10 nA to 200 μ A. The measured voltage as a function of temperature, for various current values, was least-squares fitted to a 1st order polynomial.

$$V_f = a_0 + a_1 T \quad (3)$$

For the 1st order least-squares fitting there are two coefficients, a_0 and a_1 , which are given in TABLE 1 for various values of current. The coefficients a_0 and a_1 are found to be positive and negative respectively. The R^2 of the least squares fitting was nearly 1.0. There is high temperature root T_0 for the least squares fitting which is found to increase as the corresponding values of the current is increased from 10 nA to 200 μ A. The T_0 is 420 K and 625 K, for I_f of 10 nA to 200 μ A, respectively. In case

of 1st order least squares fitting the coefficient a_1 represents the average sensitivity of the diode which is found to increase with decrease in current which is given in Eq.2.

$$S = 1.26 - 7.45 \times 10^{-2} \ln(I) \tag{4}$$

where I is in A and S is in mV/K. Therefore, S is found to reduce linearly with $\ln(I)$.

The coefficient a_0 represents the extrapolated volt-

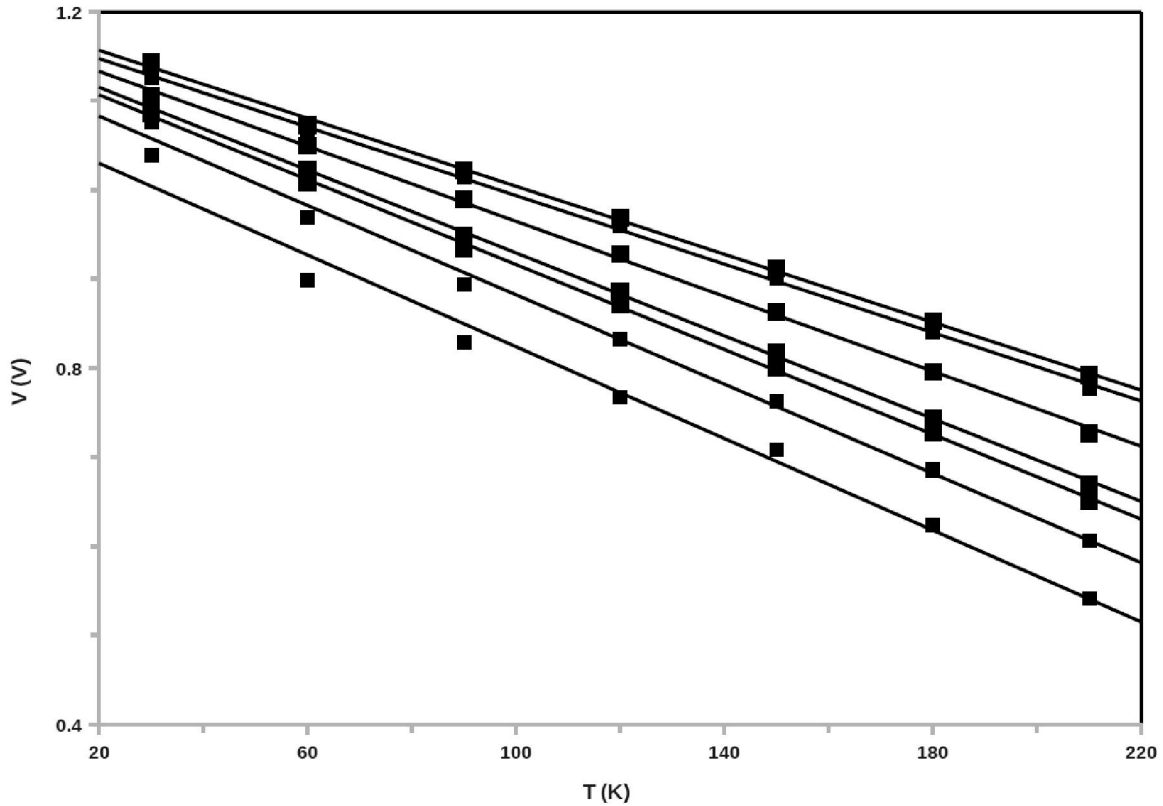


Figure 1 : The temperature dependence of the forward voltage of the cryogenic Si diode temperature sensor for various current values: 10 nA (lowest curve); 100 nA; 500 nA; 1 μA; 10 μA; 100 μA and 200 μA (topmost curve). The solid line through the data are 1st order least-squares fits.

TABLE 1 : The 1st order least squares fitting of cryogenic Si diode

Current	a_0	a_1	R^2	T_0 (K)
10 nA	1.08166	-0.00258	0.98	420
100 nA	1.13319	-0.00251	1.00	450
500 nA	1.15438	-0.00238	1.00	485
1 μA	1.16175	-0.00232	1.00	500
10 μA	1.17522	-0.00210	1.00	560
100 μA	1.18602	-0.00192	1.00	620
200 μA	1.19516	-0.00191	1.00	625

age at zero temperature. Although it agrees approximately with the band gap of Si which has a value of 1.2 eV, there is noticeable increase from 1.08 V for 10 nA to 1.20V at 200 μA unlike Si1N4007 diode^[9].

In conclusion the forward voltage of a cryogenic Si diode is measured at low temperatures. The data is obtained for current values between 10 nA and 200 μA and in the temperature range 30 K 210 K. The voltage as function of temperature is least-squares fitted to a 1st order polynomial. Flicker 1/f noise has also been observed in the cryogenic diode.

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