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Calibration of GaAlAs Semiconductor Diode

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ABSTRACT

The forward voltage of GaAlAs semiconductor diode has been measured in the temperature range 50 K - 300 K and for current values between 10 nA and 450 μA. The forward voltage as a function of temperature is least-squares fitted and the coefficients are given. The 1st and 2nd order least-squares fitting has high temperature root between 400 K and 950 K. The presence of the high temperature root indicates that the fitted polynomials are of similar character. The high temperature root is found to increase for the least squares fitted polynomials corresponding to higher current values.

Keywords: Semiconductor; Temperature Sensors; GaAlAs

1. Introduction

GaAlAs semiconductor diodes have been used in the measurement of low temperatures in the presence of magnetic field. The measurement of low temperature using GaAlAs diodes is based on the usual observation that the voltage across the forward-biased diode increases with decrease in temperature [1-5]. The behavior of the diode has been understood in terms of conduction primarily by recombination-generation currents given by the theory of Shockley and coworkers [6]. Below about 50 K, the forward voltage increases more rapidly as the temperature is reduced, which gives rise to a bend in the temperature dependence of forward voltage [7-9]. The diodes are generally calibrated with 10 μA of forward current. The factors among others which decide the use of GaAlAs semiconductor diodes for the measurement of low temperature are sensitivity, linearity, stability, power dissipation and noise [10-16]. The GaAlAs diodes can possibly be used in the ultra low temperature range (0.05 - 1 K) by reducing the forward current to ~10 nA. In certain possible applications of semiconductor diodes for temperature measurement, a high precision in the measurement of temperature is needed. Such situations include, the measurement of temperature drift curve in low temperature heat pulse calorimetry [17]. In this article we have studied the calibration of GaAlAs diode and report the coefficients for five decades of current values, 10 nA to 450 μA and in the temperature range 50 K - 300 K.

In this paper, we give the temperature dependence of forward voltage of GaAlAs diode for various current values between 10 nA and 450 μA and in the temperature range 50 K to 300 K. The paper is organized as follows. In the following Section 2, the experimental details are given. Section 3 gives the least-squares fittings. The paper concludes with the conclusions in Section 4.

2. Experimental Details

The measurements were carried out using a computer controlled four-probe setup built around a closed cycle refrigerator [18]. The diode in the CU package configuration is epoxied into a flat cylindrical disk and the sensor leads are thermally anchored to the same disk. The metal encapsulation of the diode was fixed to the sample space of the closed cycle helium refrigerator with 0.2 mm thick indium foil and a thin layer of Apiezon-N grease by clamping with an aluminum disk with screws using moderate pressure. The leads were further anchored at the sample space to minimize any thermoelectromotive force developed. The temperature of the sample site was controlled using a calibrated type-D silicon diode thermometer in conjunction with a Leybold model LTC60 temperature controller (Leybold AG, Germany). The setup is automated using GPIB-IEEE-488 interface and the control program is written in MSDOS GWBASIC. Measurements were carried out between 50 K - 300 K, for forward current from 10 nA to 450 μA. The temperature increment was 10 K and the current increment was in 11 equal logarithm interval. Each data point was obtained by averaging 50 reading. A constant current was provided to the GaAlAs diode from a Keithley (Keithley Instruments, USA) model 224/2243 programmable current source. The forward voltage was measured using a Keithley model 182 sensitive digital voltmeter.

3. Least Squares Fitting and Discussions

The forward current I_f is related to the forward voltage V_f in a GaAs p-n junction, as follows:

$$I_f = \exp\left(qV_f/\eta kT\right) \quad (1)$$

where q is the electronic charge, k is the Boltzmann constant, T is the temperature, and η is the ideality factor [19,20]. Depending on the value of η, four operating regions have been defined: recombination, diffusion, high injection and series resistance regions. The Equation (1) gives rise to a linear temperature dependence of V_f, for a fixed value of current. However, for extended temperature range (~100 K), there is significant deviation of linearity. Therefore, the semiconductor diode are generally calibrated with respect to standard and interpolation data is made. However, in some situations a lower order polynomial covering a large temperature range is needed. The least-squares fitting provides such a polynomial. First the temperature is determined using the calibrated voltage value of the GaAlAs diode for 10 μA of current, which was provided by the manufacturer. The measured voltage as a function of temperature, for various current values, was then least-squares fitted to the following polynomials:

$$V = \sum_{i=0}^{n} a_i T^i; \; n = 1-4 \quad (2)$$

For the 1st order least squares fitting, there are two coefficients, which are given in **Table 1**, for various values of current. The coefficient a_0 and a_1 are found to be positive and negative, respectively. The R^2 of the least squares fitting was nearly 1.00. 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 450 μA. The T_0 is 454.100 K and 949.350 K for 10 nA and 450 μA, respectively. The presence of the high temperature root indicates that the fitted polynomials are of similar character. In case of 1st order least squares fitting the coefficient a_1, represents the average sensitivity of the diode, which is found to decrease with increase in current. a_1 varies from −3.562 × 10^{-3} to −1.706 × 10^{-3} V/K as the current is increased from 10 nA to 450 μA. The coefficients a_0 represent the extrapolated voltage at zero temperature, which was nearly constant and have a value of 1.6 V.

Table 1. The 1st order least squares fitting of GaAlAs diode.

Current	a_0	a_1	R^2	T_0 (K)
10 nA	1.61769	-3.56241×10^{-3}	1.00	454.100
30 nA	1.62027	-3.56578×10^{-3}	1.00	481.395
100 nA	1.62279	-3.15623×10^{-3}	0.99	514.155
300 nA	1.62340	-2.96112×10^{-3}	0.99	548.239
1 μA	1.62220	-2.74034×10^{-3}	0.99	591.970
3 μA	1.61955	-2.53210×10^{-3}	0.99	639.607
10 μA	1.61480	-2.29636×10^{-3}	0.99	703.200
30 μA	1.60964	-2.08137×10^{-3}	0.99	773.356
100 μA	1.60706	-1.87127×10^{-3}	0.99	858.807
300 μA	1.61385	-1.73685×10^{-3}	0.99	929.182
450 μA	1.61999	-1.70642×10^{-3}	0.99	949.350

In case of the 2nd order least squares fitting, there are three coefficients, which are given in **Table 2**. The coefficient a_0 is found to be positive, whereas, the coefficients a_1 and a_2 are found to be negative. The R^2 of the least squares fitting was nearly 1.00. It is seen from **Table 2** that there is high temperature root T_0 for all values of current. The T_0 increased from 411.637 K to 790.460 K as the current is increased from 10 nA to 450 μA. The presence of the high temperature root indicates that the fitted polynomials are of similar character. The coefficient a_0 varies more compared to the 1st order least-squares fitting for different values of current. The coefficient a_0 is nearly 1.5 V, which lower compared to that in the case of 1st order. The minimum of the coefficient a_1 occurs for a current value of 30 μA. Here, the coefficient a_2 represents the deviation from linearity. It is seen from **Table 2** that, there is maximum deviation from linearity, for current of 10 μA. The reason for choosing the 50 - 300 K range is that for low currents (~10 nA) the least squares fitting extends to ~50 K without systematic deviation. Moreover, the I-V characteristic changes significantly below 50 K.

In case of 3rd and 4th order least-squares fitting (**Tables 3** and **4**) there were no high temperature roots for all current values. Therefore, we conclude that the fitted polynomials for different values of current are not of similar nature.

4. Conclusions

The forward voltage of GaAlAs semiconductor diode is measured at low temperatures. The data is obtained for current values between 10 nA and 450 μA and in the temperature range 50 K to 300 K. The voltage as a function of temperature is least-squares fitted to polynomials. From the second order fitting it is found that there is maximum deviation from linearity, for current of 10 μA. There are high temperature roots for all current values, in case of 1st and 2nd order least-squares fittings.

There were no high temperature roots for all current values for 3rd and 4th order fitted polynomials.

Further study is being carried out on the 1/f noise which has been found to be current dependent.

Table 2. The 2st order least squares fitting of GaAlAs diode.

Current	a_0	a_1	a_2	R^2	T_0 (K)
10 nA	1.54101	-2.49623×10^{-3}	-3.03030×10^{-6}	1.00	411.637
30 nA	1.54291	-2.29010×10^{-3}	-3.05732×10^{-6}	1.00	428.549
100 nA	1.54063	-2.01391×10^{-3}	-3.24671×10^{-6}	1.00	445.308
300 nA	1.53514	-1.73395×10^{-3}	-3.48788×10^{-6}	1.00	459.896
1 µA	1.52699	-1.41643×10^{-3}	-3.76282×10^{-6}	1.00	476.041
3 µA	1.51931	-1.13836×10^{-3}	-3.96129×10^{-6}	1.00	492.070
10 µA	1.51420	-8.97665×10^{-4}	-3.97539×10^{-6}	1.00	514.505
30 µA	1.51854	-8.14531×10^{-4}	-3.60063×10^{-6}	1.00	546.084
100 µA	1.54048	-9.45485×10^{-4}	-2.63127×10^{-6}	1.00	606.295
300 µA	1.58091	-1.27878×10^{-3}	-1.30194×10^{-6}	0.99	715.318
450 µA	1.60155	-1.44998×10^{-3}	-7.28841×10^{-7}	0.99	790.460

Table 3. The 3rd order least squares fitting of GaAlAs diode.

Current	a_0	a_1	a_2	a_3	R^2	T_0 (K)
10 nA	1.49824	-1.52918×10^{-3}	-9.20392×10^{-6}	1.17004×10^{-8}	1.00	454.69
30 nA	1.48601	-1.00362×10^{-3}	-1.12708×10^{-5}	1.55664×10^{-8}	1.00	428.55
100 nA	1.47027	-4.22960×10^{-4}	-1.34033×10^{-5}	1.92490×10^{-8}	1.00	-
300 nA	1.45653	4.36255×10^{-5}	-1.48359×10^{-5}	2.15070×10^{-8}	1.00	-
1 µA	1.44679	3.97017×10^{-4}	-1.53398×10^{-5}	2.19409×10^{-8}	1.00	-
3 µA	1.44864	4.59626×10^{-4}	-1.41628×10^{-5}	1.93341×10^{-8}	1.00	-
10 µA	1.46903	1.23853×10^{-4}	-1.04967×10^{-5}	1.23594×10^{-8}	1.00	-
30 µA	1.50732	-5.60957×10^{-4}	-5.21944×10^{-6}	3.06799×10^{-9}	1.00	587.04
100 µA	1.57098	-1.63505×10^{-3}	1.77085×10^{-6}	-8.34299×10^{-9}	1.00	524.02
300 µA	1.65570	-2.96994×10^{-3}	9.49439×10^{-6}	-2.04614×10^{-8}	1.00	498.49
450 µA	1.69658	-3.59868×10^{-3}	1.29884×10^{-5}	-2.59971×10^{-8}	0.99	489.30

Table 4. The 4th order least squares fitting of GaAlAs diode.

Current	a_0	a_1	a_2	a_3	a_4	R^2	T_0 (K)
10 nA	1.42610	7.24218×10^{-4}	-3.23316×10^{-5}	1.06777×10^{-7}	-1.35152×10^{-10}	1.00	389.77
30 nA	1.40344	1.57558×10^{-3}	-3.77412×10^{-5}	1.24385×10^{-7}	-1.54686×10^{-10}	1.00	-
100 nA	1.38432	2.26200×10^{-3}	-4.09602×10^{-5}	1.32534×10^{-7}	-1.61035×10^{-10}	1.00	411.15
300 nA	1.38030	2.42464×10^{-3}	-3.92733×10^{-5}	1.21968×10^{-7}	-1.42805×10^{-10}	1.00	427.38
1 µA	1.39792	1.92366×10^{-3}	-3.10084×10^{-5}	8.63539×10^{-8}	-9.15631×10^{-11}	1.00	463.60
3 µA	1.43889	7.64118×10^{-4}	-1.72879×10^{-5}	3.21814×10^{-8}	-1.82625×10^{-11}	1.00	792.82
10 µA	1.50556	-1.01745×10^{-3}	1.21696×10^{-6}	-3.57950×10^{-8}	6.84515×10^{-11}	1.00	-
30 µA	1.57724	-2.74504×10^{-3}	1.71968×10^{-5}	-8.90838×10^{-8}	1.30994×10^{-10}	1.00	-
100 µA	1.67849	-4.99342×10^{-3}	3.62394×10^{-5}	-1.50041×10^{-7}	2.01425×10^{-10}	1.00	-
300 µA	1.82753	-8.33737×10^{-3}	6.45827×10^{-5}	-2.46927×10^{-7}	3.21921×10^{-10}	1.00	-
450 µA	1.90347	-1.00615×10^{-2}	7.93194×10^{-5}	-2.98681×10^{-7}	3.87620×10^{-10}	1.00	-

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