J.Phy.Ast.
Print-ISSN: 2320-6756
Online-ISSN: 2320-6764

Journal of
Physics &
Astronomy

WWW.MEHTAPRESS.COM

Full Paper

S.B.Ota[1]*, Smita Ota[1,2]

[1]Institute of Physics, Bhubaneswar 751005, Orissa, (INDIA)
[2]DST project, DST, New Delhi, (INDIA)
E-mail: snehadri@hotmail.com
PACS: 73.40.Kp, 73.43.Fj, 83.30.-z

Received: December 7, 2012
Accepted: January 8, 2013

***Corrresponding aurhor's Name & Addess**

S.B.Ota
Institute of Physics, Bhubaneswar 751005, Orissa, (INDIA)
E-mail: snehadri@hotmail.com

Calibration of GaAlAs semiconductor diode for temperatures between 10-300 K

Abstract

The forward voltage of GaAlAs semiconductor diode has been measured for temperatures between 10-300 K and for current values between 10 nA and 450 μA. The forward voltage as a function of temperature is least-squares fitted in two temperature ranges 10-22 K and 50-300 K. The coefficients are given for 2nd order polynomials.

Key Words

Semiconductor; Temperature sensors; GaAlAs.

The measurement of temperature using diodes is based on the observation that the voltage across the forward-biased diode increases with decrease in temperature[1-10]. The forward characteristic of GaAlAs diode can be understood in terms of transport in high electric field which exists at a semiconductor junction[11]. This is also the basic aspect of quantum Hall effect[12]. The bend at low temperature can be associated with the characteristic of 'bulk' GaAs in GaAlAs diode[13]. 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. The diodes are generally operated with 10 μA of forward current. These diodes have been used in the temperature range 1.4 to 450 K with an accuracy of 50 mK. A temperature sensitivity of a few mV/K has been obtained at high temperatures (T>50 K). In the low temperature range (T<50 K), the sensitivity exceeds 100 mV/K. There have been several studies, such as linearity, stability, power dissipation, noise and effect of γ-radiation, of semiconductor diodes in the context of temperature measurement.

The forward characteristics of silicon diode temperature sensors are strongly magnetic field dependent, which limits their application in magnetic fields; although they have been used under magnetic field of 0.1 T. The problem of magnetic field dependence of the forward characteristic was overcome with the GaAlAs diode, which is a direct band gap semiconductor. Moreover, the low temperature sensitivity of GaAlAs diode with 10 μA of sensing current has been found to be several times higher than that of Silicon diods. Earlier, we have studied the GaAlAs semiconductor diode for current values between 10 nA and 450 μA, for ultra low temperature application. It was observed that GaAlAs semiconductor diode can be used in the ultra low temperature range (~mK) by reducing the current by several orders of magnitude. Semiconductor diodes have also been studied in other contexts. Some of these studies are: carrier transport in a GaAs p-n junction using light modulated scanning tunneling spectroscopy[14] and determination of the ideality parameter[15]. 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[16,17].

In this paper, we give the calibration of the temperature dependence of forward voltage of GaAlAs diode for various current values between 10 nA and 450 μA and for two temperatures ranges 10-22 K and 50-300 K. The coefficients are given for 2nd order polynomials.

The measurements were carried out using a computer controlled four-probe setup built around a closed cycle refrigerator. 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 o the sample space of the closed cycle helium refrigerator with 0.2mm 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 thermo-electromotive 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). Measurements were carried out between 10 K – 50 K, for forward current from 10 nA to 450 μA. The temperature increment was 2 K and the current increment was in 11 equal logarithmic steps. Each data point was obtained by averaging 50 reading. For temperatures between 50-300 K the temperature increment was 10 K and the current increment was in 11 equal logarithmic steps. 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.

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

$$\mathbf{I_f \approx \exp(qV_f/\eta kT)} \qquad (1)$$

where q is the electronic charge, k is the Boltzmann constant, T is the temperature, and η is the ideality factor. Depending on the value of η, four operating regions have been defined: recombination, diffusion, high injection and series resistance regions. The Eq.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:

$$\mathbf{V=\Sigma_{i=0}^{n} a_i T^i} \qquad (2)$$

For the least squares fitting only 7 points were used for temperatures between 10-22 K. The 1st and 2nd order least squares fittings were of similar natures in terms of roots and sign of the coefficients for both the temperature ranges and for all current values. The R^2 of the least squares fitting was nearly 1.00. TABLE 1 gives the coefficients of 2nd order least squares fitting for temperatures around 15 K. The coefficients of 2nd order least squares fitting for temperatures between 50-300 K are given in TABLE 2[18]. The 2nd order least squares fitting has three coefficients a_0. a_1 and a_2. The coefficient a_0 represents the maximum forward voltage. The coefficient a_1 represents the sensitivity or the linearity and a_2 represents the deviation from linearity.

TABLE 1 : The 2st order least squares fitting of GaAlAs diode around 15 K

Current	a_0	a_1	a_2	R^2	T_0 (K)
10 nA	3.22296	-1.15293×10^{-1}	1.93667×10^{-3}	1.00	-
30 nA	3.59690	-1.31390×10^{-1}	2.09518×10^{-3}	1.00	-
100 nA	3.90296	-1.33979×10^{-1}	1.83726×10^{-3}	1.00	-
300 nA	4.22005	-1.38386×10^{-1}	1.66679×10^{-3}	1.00	-
1 μA	4.71798	-1.56223×10^{-1}	1.82899×10^{-3}	1.00	-
3 μA	5.20579	-1.71532×10^{-1}	1.92919×10^{-3}	1.00	-
10 μA	5.71791	-1.80132×10^{-1}	1.78175×10^{-3}	1.00	-
30 μA	6.41416	-2.08524×10^{-1}	2.17747×10^{-3}	1.00	-
100 μA	7.10746	-2.27733×10^{-1}	2.30805×10^{-3}	1.00	-
300 μA	7.85295	-2.50554×10^{-1}	2.48469×10^{-3}	1.00	-
450 μA	8.08877	-2.50916×10^{-1}	2.23267×10^{-3}	1.00	-

TABLE 2 : The 2st order least squares fitting of GaAlAs diode for temperatures between 50-300 K

Current	a_0	a_1	a_2	R^2	T_0 (K)
10 nA	1.541	-2.496×10^{-3}	-3.030×10^{-6}	1.00	411.637
30 nA	1.543	-2.290×10^{-3}	-3.057×10^{-6}	1.00	428.549
100 nA	1.541	-2.014×10^{-3}	-3.247×10^{-6}	1.00	445.308
300 nA	1.535	-1.734×10^{-3}	-3.488×10^{-6}	1.00	459.896
1 μA	1.527	-1.416×10^{-3}	-3.763×10^{-6}	1.00	476.041
3 μA	1.519	-1.138×10^{-3}	-3.961×10^{-6}	1.00	492.070
10 μA	1.514	-8.977×10^{-4}	-3.975×10^{-6}	1.00	514.505
30 μA	1.519	-8.145×10^{-4}	-3.601×10^{-6}	1.00	546.084
100 μA	1.540	-9.455×10^{-4}	-2.631×10^{-6}	1.00	606.295
300 μA	1.581	-1.279×10^{-3}	-1.302×10^{-6}	0.99	715.318
450 μA	1.602	-1.450×10^{-3}	-7.288×10^{-7}	0.99	790.460

The calibration of the forward voltage of GaAlAs semiconductor diode is given which can be used to measure temperatures between 50 mK – 300 K. The forward voltage as a function of temperature is least-squares fitted in two temperature ranges 10-22 K and 50-300 K. The coefficients are given for 2nd order polynomials.

ACKNOWLEDGMENTS

The author is benefited from his visit to Europe in 1988-1992 for HTSC research, Xiamen, China during 1995 for statistical physics conference and New Orleans, USA during 2008 for APS March meeting.

REFERENCES

[1] H.Harris; Sci.Am., **204**, 192 **(1961)**.
[2] A.G.McNamara; Rev.Sci.Instrum., **33**, 330 **(1962)**.
[3] B.G.Cohen, W.B.Snow, A.R.Tretola; Rev.Sci.Instrum., **34**, 1091 **(1963)**.
[4] J.Unsworth, A.C.Rose-Innes; Cryogenics, **6**, 239 **(1966)**.
[5] G.K.White; Experimental techniques in low-temperature physics, Clarendon Press, Oxford, 115 **(1979)**.
[6] P.S.Iskrenovic, D.B.Mitic; Rev.Sci.Instrum., **63**, 3182 **(1992)**.
[7] Yu M.Shwarts, et. al.; Sensors and Actuators, **97-98**, 271 **(2002)**.
[8] H.H.Sample, L.G.Rubin; Cryogenics, 597 **(1977)**.
[9] S.B.Ota, S.Ota; Mod.Phys.Lett.B, **14**, 393 **(2000)**.
[10] S.B.Ota, J.Bascuňán, S.Ota; Mod.Phys.Lett.B, **15**, 319 **(2001)**.
[11] S.K.Ma; Statistical physics, World Scientific, Singapore, Ch.21, **(1985)**.
[12] K.von Klitzing; Rev.Mod.Phys., **58**, 519 **(1986)**.
[13] P.Y.Yu, M.Cardona; Fundamentals of semiconductors, Spinger, Ch.5 **(1996)**.
[14] S.Yoshida, et al.; Phys.Rev.Lett., **98**, 26802 **(2007)**.
[15] L.Kirkup, et al.; J.Appl.Phys., **101**, 23118 **(2007)**.
[16] S.B.Ota, E.Gmelin; Meas.Sci.Technol., **3**, 1047 **(1992)**.
[17] E.Gmelin; Cryogenics, 225 **(1967)**.
[18] S.B.Ota, S.Ota; J.Mod.Phys., **3**, 1490 **(2012)**.