International Journal of Advanced Research in Physical Science (IJARPS)
Volume 2, Issue 10, October 2015, PP 7-13
ISSN 2349-7874 (Print) & ISSN 2349-7882 (Online)
www.arcjournals.org

Opto-electrical Characteristics of AlGaAs Based Infrared Emitting Diode over a Wide Range of Temperature

P. Dalapati, N. B. Manik*, A. N. Basu

Condensed Matter Physics Research Center, Department of Physics,
Jadavpur University, Kolkata, India
**nbm_juphysics@yahoo.co.in*

Abstract: *The infrared emitting diode based on AlGaAs is tested on line at the temperature level between 350-110K and the obtained data are fitted to measure the relationship between temperature and the forward voltage, the ideality factor and the light intensity of the device. All experimental results show that temperature has a significant effect on different properties of such device. The variations of these parameters with temperature are tried to explain by associate theoretical models. Finally, it is mentioned that an optimization among these parameter values, as indicated in the present study, is very essential for any low temperature application as well as for its new design.*

Keywords: *AlGaAs-based LEDs, forward voltage, ideality factor, light intensity, low temperature.*

1. INTRODUCTION

Nowadays, the AlGaAs materials are used as active elements in different types of high performance optoelectronic and high-speed electronic devices [1]. Such materials have high internal quantum efficiency due to its short radiative lifetime [2, 3]. AlGaAs has a property that makes it interesting and also a temperature-stable high power device. This device has high radiative efficiency since the electrically injected carriers in such cases to a large extent recombine radiatively and is able to emit huge photons. Due to recent rapid progress in lighting technology many infrared emitters are available in the market but these devices has left unresolved many fundamental issues associated with material and the device properties. So, it is important to study the physical processes responsible for controlling the different parameters of such devices.

The main goal of the work is to elucidate some of these issues by carrying opto-electrical characterisation of AlGaAs based infrared emitting diode (IrLED) namely, OP232. Such characterization in OP232 can provide with important information about the current transport through the wide-band-gap $p - n$ hetero junctions as well as layer materials. The knowledge of the carrier transport mechanisms dominant in the device is essential for achieving a fundamental understanding and further improvement of the device performance. In spite of the significant research efforts invested by many researchers, these carrier transport mechanisms involve in such devices are still not well understood.

Recently several publications has been tried to come into light on the issue of the change of forward voltage, ideality factor and light intensity of LEDs with temperature [4-6]. To know the electrical operating point of LED at different temperature the variation of forward voltage (V_f) with temperature should be known. Depending on the type of applications, LEDs are operated at high current densities which lead to self-heating effect. When an LED heats up, its current-voltage (I-V) characteristic must be changed. Therefore, the adjustment of the LED's electrical operating point is necessary. Xi et al. [7] derived an expression for dV_f/dT. The authors also obtained the value of dV_f/dT at room temperature for lightly doped GaN, Si p-n junctions and moderately doped GaAs p-n junctions which are – 1.76 mV/K, –1.74 mV/K and –1.17 mV/K respectively. Meyaard et al. [8] showed that for GaInN based LEDs the forward voltage vs. temperature curve has two distinct slopes which are –1.7 mV/K and –8.0 mV/K at room temperature and cryogenic temperatures, respectively. They also give an explanation for two-slope characteristics by assuming that the p-type series resistance and the p-n junction are the determining factors for the dV_f/dT slope at room temperature and cryogenic, respectively. Such analyses for commercial infrared emitters are less studied. Hence, such study with commercial packaged device is very important to understand the physical significance.

To know the carrier transport mechanisms in such devices ideality factor n play a significant role. Generally, when the value of n lies between 1 and 2, the current flow is mainly diffusion recombination current; while if n is larger than 2, tunneling mechanism becomes dominant [9]. We have already undertaken such studies in GaAlAs based infrared emitter (880 nm) that has provided information for the conduction mechanism of this device in the temperature range 350–120 K [3]. It is reported that in GaN based blue LED n increases from 1.9 to 6.2 when the temperature is lowered from 300 to 100 K [9]. In our previous work we observed that in GaAlAs based emitters, n varies from 1.33 to 3.21, when temperature decreases from 350 to 120 K. These results show that there is no unique nature of the variation, so that we can understand the dominant carrier transport mechanisms.

It is well known that, light intensity (L) emitted by the LEDs is found to increase with lowering of temperature. For the lowering of temperature from 293 to 243 K, the relative light intensity of the InGaN based blue LEDs increased by about 9% whereas for AlGaInP based red power LEDs it increases about 10%, on average [5]. It is also reported that L increases by 3–4× for the blue and green LEDs, and 1700 × for the UV LED when the temperature decreases from 300 to 150 K [10]. In our previous work we also observed a quite similar trend of the variation of L with temperature for AlGaAs based red LED, where a 16% increase has been observed for a temperature change from 345 to 136 K [4]. These reported results show the variation of L which is sensitive to temperature and is also not same for all LEDs. More number of LEDs should be characterized so that a theoretical basis of this variation can be addressed.

In this work we have measured all these parameters for AlGaAs based IrLED and their variation with temperature which will have important implication for various low temperature applications. Moreover, all obtained experimental data in this work may have an importance for further design of such optoelectronic devices where the variation of these parameters with temperature may be minimized.

2. EXPERIMENTAL DETAILS

In our investigation we used one AlGaAs based IrLED having the code name OP232, procured from RS Components. The specification of the IrLED used in this experiment is mentioned in Table 1. The IrLED was placed inside a bath type optical cryostat which was designed in our laboratory [11]. The experimental set up to measure the intensity is shown in Fig. 1. The IrLED was driven by a constant current source with a 1 K resistance in series. The output of device was measured by a photodetector, namely, BPX 61 (p–i–n photodiode, TO-39, 55deg). The photodetector was suitably placed outside of the window of cryostat and it was reversely biased with a 2.5 V dc source and with a 390 K sensing resistance in series. Carefully, the cryogen (here we used LN_2) was poured inside the cryogen chamber of the cryostat which was pre-evacuated to a pressure 10^{-4} Torr by using a high vacuum pumping unit (Model No.PU-2 CH-8, manufactured by Vacuum Products and Consultants). Due to the high vacuum, the effect of moisture on the sample can be avoided. The temperature (350 K–110 K) measurement was done by using a Chromel-Alumel thermocouple (TC) and its output was recorded by Keithley 2000 multimeter. I-V measurements were performed by Keithley 2400 source measure unit.

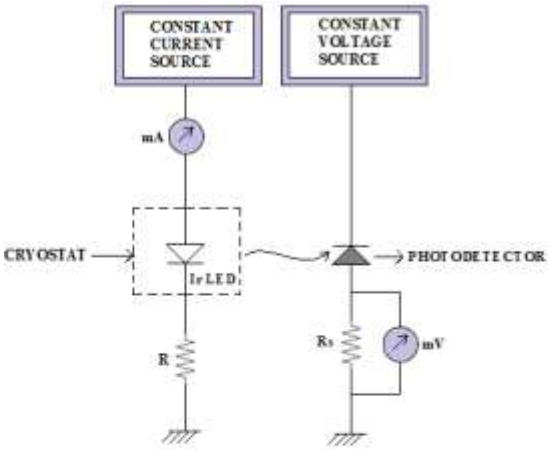

Fig1. *Schematic diagram of the experimental set up used for the IrLED intensity measurement*

Table1. *Specifications of IrLED used in our experiment*

Name of the IrLED	Material used	Viewing angle (degree)	Peak wavelength (nm)	Output rise time (nS)	Output fall time (nS)
OP232	AlGaAs	36	890	500	250

3. RESULTS AND DISCUSSIONS

3.1. Current-Voltage (I-V) Characteristics

Figure 2 shows forward *I-V* curves of the OP232 IrLED measured from 350 to 110 K plotted in semilog scale. The forward *I-V* relationship of the device can be simply described by

$$I = I_S exp\left(\frac{qV}{nKT}\right) \tag{1}$$

where, n is diode ideality factor, I_S is reverse saturation current, q is electron charge, K is Boltzmann's constant and T is absolute temperature.

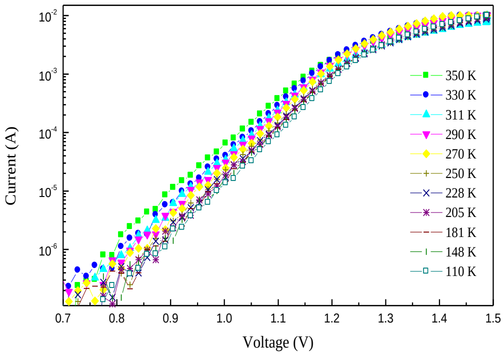

Fig2. *Temperature dependent semilog I-V characteristics OP232 IrLED*

3.1.1. Variation of Forward Voltage with Temperature

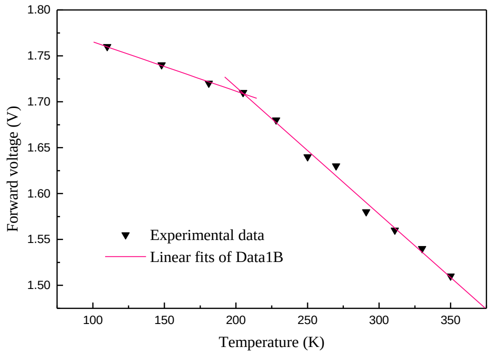

Fig3. *The variation of forward voltage as a function of temperature. Continuous lines show the linear fits of the experimental data in the figure*

From Fig. 2 we obtain the values of forward voltage (V_f) at different temperatures. Figure 3 shows the variation of V_f with temperature. It again shows that the LED device was driven on forward input current and got to heat balance at any operation temperature. The value of V_f was increased as the temperature (T) was decreased. Also, it is mentioned that V_f versus T curve is "two-slope" characteristics for this investigated device. However, the relationship between the forward voltage (V_f) of the LED and temperature for a constant input current can be described as [6]

$$V_{fT} = V_{fT0} + K(T - T_0), \tag{2}$$

where, T is the temperature inside the cryostat and T_0 is the room temperature, V_{fT} is the value of forward voltage at T, V_{fT0} is the value of forward voltage at T_0 and K is the temperature coefficient of forward voltage. In Eq. (2) we assumed, the change of series resistance with temperature is too small to show its effect on V_f. It is reported that the V_f versus T relation is very close to linear for GaN-based LEDs [5, 8]. In our previous work we also found approximately a linear relation for AlGaInP based red LED [6]. However, by fitting the experiment data we obtained the value of K coefficient for the present device. In the temperature range 350-205K we found the value of K coefficient is –1.38 mV/K and below 205 K it is –0.54 mV/K. This means that if the temperature of LED chip is increased by 1K, V_f of the LED decreases by –1.38 mV and –0.54 mV above and below 205 K, respectively. This “two-slope” characteristic of V_f versus T relation seems to suggest that the assumption of too small variation of series resistance with temperature is limited to a range of temperature for the present device. In our future study we will try to focus on this issue by assuming the change of series resistance with temperature.

3.1.2. Variation of Ideality Factor with Temperature

To know the carrier transport mechanisms in such devices ideality factor n plays a significant role. Generally, when the value of n lies between 1 and 2, the current flow acts mainly as diffusion recombination current; where n is larger than 2, tunneling mechanism becomes dominant [9]. The value of n is determined from the slope of the linear region of the forward bias lnI-V characteristics through the relation

$$n = \frac{q}{kT}\left(\frac{dV}{d(lnI)}\right) \tag{3}$$

The variation of the n with temperature is shown in Fig. 4 that shows the typical values of n are 1.28 at 350 K and 3.59 at 110 K. From Fig. 4 it is also found that below 205 K, n approaches 2 and above. The high value of n (> 2) suggests that, at high temperature the diffusion component starts to play a role in the total diode current and on the other hand i. e. at lower temperature (below 205K) the tunneling component gradually becomes dominant. The origin of high diode ideality factor (> 2.0) for such devices is quite complex to explain by any existing theories. Different ideas are predicted by some authors [9, 12] but it is not well cleared which of the ideas can account for and reproduce the empirical observation for the temperature dependence of n.

In absence of an adequate theory for the variation of the n with temperature for such devices we look for an empirical formula. The following relation is found to reproduce observation fairly well (see Fig. 4)

$$n = \frac{\alpha}{T^{\beta}}, \tag{4}$$

where, α and β are fitting parameters. For the present device α and β are 307.83 and 0.94 respectively. Hence, it is clear that the temperature dependence of n for the present device, shown in our experimental result is$T^{-0.94}$. However, such temperature dependence of n gives us the unrevealing physics of the device. We belief that due to lowering of temperature not only the tunneling component but also the defect states increase and that lead to the total recombination mechanism in the device as a result of increase of light intensity. Hence, it will be very meaningful to study the variation of light intensity emitted by IrLED with temperature.

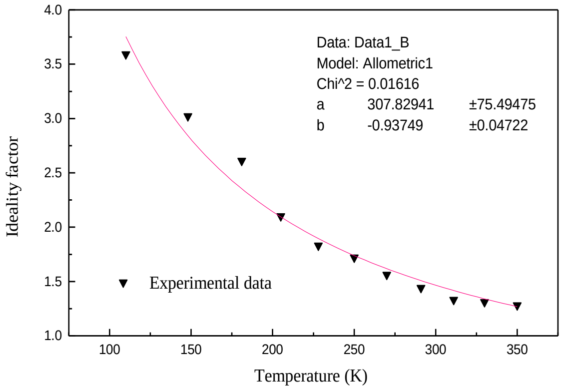

Fig4. *The variation of ideality factor with temperature. Continuous lines show the fit of the experimental data according Eq. (4)*

3.2. Variation of Light Intensity With Temperature

Figure 5 shows the variation of light intensity (L) with temperature at a constant driving current of 20 mA. The light intensity of IrLED is measured in terms of photo-voltage.

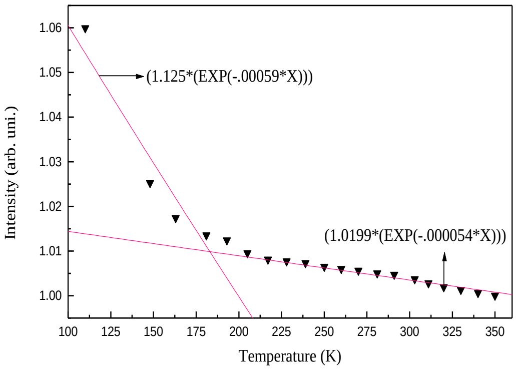

Fig5. *Variation of light intensity with temperature at a driving current of 15 mA*

Figure 5 shows that L increases with lowering of temperature and reveals 6% increase in intensity as the temperature is lowered from 350 K to 110 K.. Also, Fig. 5 shows the change of L with temperature is quite small in the temperature range 350-205K though it shows a sign of increasing its intensity gradually from 205 K. This increase of the light intensity at low temperature is due to several temperature-dependent factors. First, at low temperatures various defect states are frozen-out that leads to an enhanced in radiative recombination centers in the active region. Second, more of the injected carrier’s confinement in the active region which may improve due to lowering of temperature. Our experimental results show a dramatic change of L below 205 K which indicates that the non-radiative recombination significantly reduces with lowering of temperature as well as the carriers are less localized in this device, and have more opportunities to reach defect states [10, 13]. To know the temperature dependence of L in such devices many authors assume that L has an exponential dependence on the temperature (T) as [13-15]

$$L(T) = L_0 exp(-T_C T) \qquad (5)$$

where, L0 and TC are the constant value and the temperature coefficient, respectively. Generally, a small value of TC implies weak temperature dependence and is always desirable. However, we try to fit our experimental data by Eq. (5) above and below 205 K with different TC values. In the first temperature region (350-205 K) TC is 5.4 × 10–5 K–1 and below the temperature range it is 5.9 × 10–4 K–1.Also, it is mentioned that at lower temperature region Eq. (5) cannot be fitted well. This sharp break in L versus T curve at above and below certain temperatures where the gradient is different indicates that Eq. (5) is satisfied for a limited range of temperatures. However, it has to be pointed out that the above simple relation describes only the gross feature of the effect of temperature on the performance of the device.

4. CONCLUSIONS

In conclusion, the opto-electrical studies of available IrLEDs at different ambient temperatures are necessary to use them in this temperature range. Since these data are not available, in particular, for such commercial IrLEDs, the present measurements on these devices provide new information which will be proved to be beneficial to make the design as well as the execution of the application. Our experimental results reveal that V_f increases with lowering of temperature and V_f versus T relation is “two-slope” characteristics for the present device. This “two-slope” suggests that the assumption of too small variation of series resistance with temperature is not well accepted for entire range of temperature particularly for the lower temperature range.

From the variation of ideality factor n with temperature it is clear that the diffusion process is the major one up to 205 K and below it the tunneling component gradually increases with the value of n, larger from that of its value at room temperature. Further an analysis of the data on the ideality factor suggests an empirical formula ($n = \alpha/T^{\beta}$) for its temperature dependence, with α and β as temperature independent free parameters. In case of light intensity L it is observed that it increases with lowering of temperature which is the beneficial of LED applications. But the rising of forward voltage with lowering of temperature creates a difficulty for designing the driving circuit. Such problem occurs in the device, because a maximum voltage is set inside the protection circuit to prevent the LED from breakdown, and the rising voltage might cross this maximum value of voltage. When the maximum voltage is set inside the protection circuit LED cannot work well even worse cannot be lighted up.

This work is expected to stimulate further theoretical as well as experimental study to achieve better understanding of the carrier transport mechanism in such devices and the obtained results can be used to get a deep insight into the opto-electrical characteristics of IrLED to improve the temperature performance.

ACKNOWLEDGEMENTS

The authors acknowledge the Defence Research Development Organization (DRDO), India, for financial assistance, and one of the authors, P. Dalapati is thankful to DRDO for the award of a research fellowship. This work is also partially supported by Camellia Institute of Technology & Management. Moreover, he has shown his gratitude to M. Mukherjee for giving her support for preparing the manuscript.

REFERENCES

[1] S. A. Lourenco, I. F. L. Dias, J. L. Duarte, E. Laureto, L. C. Pocas, D. O. Toginho Filho and J. R. Leite, Brazilian Journal of Physics, 34, 517 (2004).

[2] J. P. Bergman, C. Hallin and E. Janzen, J. Appl. Phys., 78, 4808 (1995).

[3] P. Dalapati, S. Maity, N. B. Manik and A. N. Basu, Optik, 126, 2242 (2015).

[4] P. Dalapati, N. B. Manik and A. N. Basu, Journal of Semiconductors, 34, 092001 (2013).

[5] G. Weling, J. Xuejiao, Y. Fei, C. Bifeng, G. Wei, L. Ying and Y. Weiwei, Journal of Semiconductors, 32, 4007-1 (2011).

[6] P. Dalapati, N. B. Manik and A. N. Basu, Opt. Quant. Electron., 47, 1227 (2015).

[7] Y. Xi and E. F. Schubert, Appl. Phys. Lett., 85, 2163 (2004).

[8] D. S. Meyaard, J. Cho, E. F. Schubert, S. H. Han, M. H. Kim and C. Sone, Appl. Phys. Lett., 103, 121103 (2013).

[9] D. Yan, H. Lu, D. Chen, R. Zhang and Y. Zheng, Appl. Phys. Lett., 96, 083504 (2010).

[10] X. A. Cao, S. F. LeBoeuf, L. B. Rowland, C. H. Yan and H. Liu, Appl. Phys. Lett., 82, 3614 (2003).

[11] N. B. Manik, A. N. Basu and S. C. Mukherjee, Cryogenics, 40, 341(2000).

[12] C. L. Reynolds, Jr. and A. Patel, Appl. Phys. Lett., 103, 086102 (2008).

[13] C. Huh, W.J. Schaff, L.F. Eastman, and S.J. Park, *IEEE Elec. Dev. Lett.* 25, 61 (2004).

[14] Y. Tanaka, T. Toyama and R. Tohmon, IEEE Trans. Elect. Dev., 41, 1125 (1994).

[15] P. Dalapati, N. B. Manik and A. N. Basu, International Journal of Advanced Research in Physical Science, 2, 18 (2015).

AUTHORS' BIOGRAPHY

Pradip Dalapati, received the M.Sc degree in physics from Vidyasagar University, West Bengal, India, in 2010. He is currently working toward the Ph.D. degree in physics at the Jadavpur University of Kolkata, India. His research interests include low temperature characterisation of optoelectronics devices, temperature dependent characterisation of organic solar cells and analysis of device physics.

Dr. Nabin Baran Manik, Associate Professor, Department of Physics, Jadavpur University. Kolkata, India. He received the Ph.D. degree from Jadavpur University in 1998 and right after that he joined as lecturer in Physics Department of the same university. In 2004 he was awarded BOYSCAST Fellowship of DST, Govt. of India and did his Post Doctoral work at IFW, Dresden, Germany. He is working in the area of low temperature instrumentation, characterization of opto devices at low temperature. He has different publications both at national and international journals some of which are available in his website: www.nbmanik.in.

Professor Asok Nath Basu, Emeritus Professor of Physics, Department of Physics, Jadavpur University. Kolkata, India. He received the Ph.D. degree from Calcutta University, India, in 1972. About one hundred fifty papers and review articles published in different journals. His research interests are centered on various areas of Condensed Matter Physics, namely, Lattice Dynamics, Material Science, Solid State Polymers, Amorphous Materials at Low Temperature, Low Temperature Instrumentation. At present his interest ranges in the areas of Semiconductor and Device Physics and Foundation of Problems of Quantum Mechanics.