The Effect of Temperature and γ-ray Radiation on the Electrical and Optical Characteristics of Quantum well Structure Based Laser Diode

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ABSTRACT

Analysis of effect of temperature and γ-ray radiation on the AlGaInP Quantum Well (QW) structure based laser at 665 nm emission wavelength has been carried out. I-V and P-I characteristics were measured. From these, we determine series resistance (**R_s**), threshold Current (**I_{th}**), Optical output power (**P_{out}**) and differential efficiency (**η_d**). I-V curves vary over temperature and radiation. I_{th} increases exponentially with temperature. **P_{out}** decrease in non-linear manner with temperature. It was observed that **η_d** decrease gradually at low temperature and decrease rapidly at high temperature. It is because of significant increase of non radiative recombination at higher temperature. After irradiating LD from **γ**-ray source, **I_{th}** increase and **η_d** decrease slightly, but **P_{out}** remains constant. Such LD proved to be immune to γ-ray radiation at room temperature and degraded rapidly as the temperature increased.

Keywords: AlGaInP, optical output power, nonradiative recombination, γ-ray radiation.

1 INTRODUCTION

Optoelectronic devices are mostly used in data transmission through optical fiber, diagnostics, range finding, interior mechanical parts inspection and testing of stress and aging of integrated sensors in robotics [1].But, these advances are at threat, until confirmation of reliability is completed. Optoelectronic devices are extensively used in our surroundings, where reliability is much important [2, 3]. Extensive researches for the semiconductor devices that can function properly in a radiation atmosphere provide a guideline for the design engineers. LDs have huge potential in optical fiber communication due to low threshold current, high efficiency and stable mode operation [4].Red emitting AlGaInP QW structure LDs have many applications such as laser pointers, data storage in optical disk system particularly in CDs and DVDs, bar code readers and full colour flat displays [5,6]. LDs are increasingly used for space application in satellite communication. Thus, LD should radiation be resistant to function properly during the entire emission in space [7]. It is useful to investigate the function of LD in radiation atmosphere, which are used in nuclear plant and space application [4]. It is complicated to determine the junction temperature directly of LD [8]. In our experiment we use, low power (3-5mW) visible LDs. These are fabricated with AlGaInP materials with QW structure having wavelength of 665 nm. These LDs have a glass window and an integrated photodiode for monitoring optical power. We measured I-V and P-I characteristics of LDs in different temperatures and radiation environment. Thermal, mechanical or electrical stress was not applied to LD during measurement.

2 EXPERIMENTAL SETUP

LDs were driven in CW (continuous wave) mode with APC (Automatic Power Control) driver circuit .To see the temperature effect, I-V and P-I characteristics of LD in the temperature range (295-315k) were investigated. For radiation effect, LDs without bias were exposed to **γ**-rays (Co^{60}) at room temperature. I-V and P-I characteristics were measured before and after irradiation. We have to investigate the total dose rate effect on LD characteristics, thus dose of 4, 8, 14 Mrad were applied. For I-V measurement, we measure the voltage across LD only, not including any resistor or photodiode, and note the corresponding current flowing through the LD. For optical power measurement, transimpedence amplifier is used shown in figure 1.

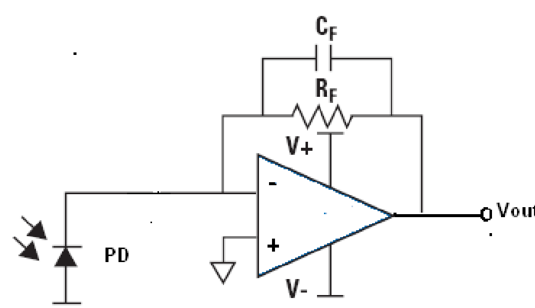


Figure 1: Transimpedence amplifier circuit

3 DISCUSSION

In the following section, several results of temperature and γ-ray radiation effect on the characteristics of LD will discussed.

3.1 Effect of Temperature

The electrical characteristics of LD are represented by the classical diode equation, including the series resistance term.

$$I = I_s[e^{(qV_j/nKT)}\text{-}1] \tag{1}$$

Where V_j = Junction voltage, and calculated from the equation, $V_j = V\text{-}\ IR_s$, where R_s is the series resistance of the LD and can behave nonlinearly due to different mechanisms. V= external applied voltage, I_s = saturation current, I= current, q= charge on the electron, $\eta = (q/nKT)$ is ideality factor, T= operating temperature and K= Boltzmann's constant and. Thus, the applied voltage across the terminals of LD is

$$V = V_j + IR_s \tag{2}$$

During forward bias, -1 term is neglected from equation (1) and solving this equation for V yields

$$V = \frac{nKT}{q}\log\frac{I}{I_s} + IR_s \tag{3}$$

Differentiating equation (3) with respect to I

$$\frac{dV}{dI} = \frac{nKT}{q}\frac{1}{I} + R_s$$

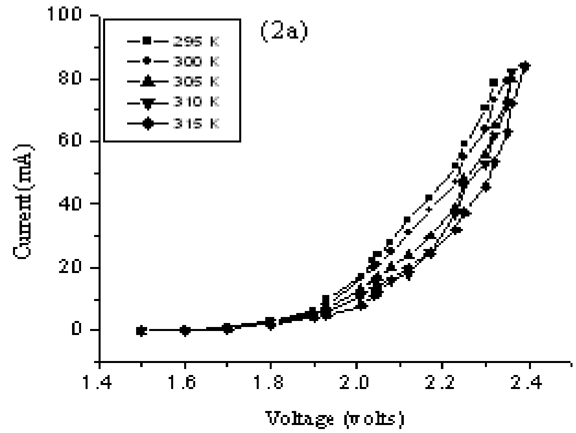
$$\frac{dV}{dI} = R_s\left(\frac{i}{\eta I}\right) \tag{4}$$

Above and at the threshold point, V_j remains constant, thus equation (2) becomes

$$V = IR_s \ \&\ dV/dI = R_s \tag{5}$$

Above threshold, the junction voltage saturates and remains almost constant, hence (dV/dI) remain at a constant value provided by the series resistance. The region of the I-V curve, which is almost flat beyond threshold, shows the effect of series resistance.

The effect of temperature on the I-V characteristics are illustrated in figure (2a). From these curves we determine the R_s. Variation of R_s with temperature is shown in figure (2b).



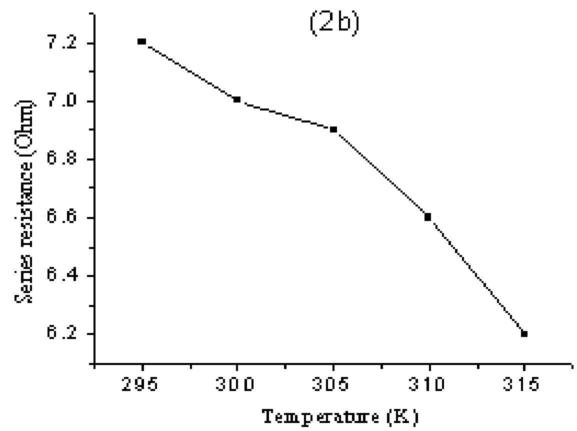


Figure 2: The direct voltage vs. the driving current characteristics a) and change of serial resistance b) at different temperature

These I-V curves changes very little with increase of temperature. Increase in temperature (R_s decreases) also increases in current. It is because LD is made of semiconductor, which has negative temperature coefficients. With the increase of temperature, more electrons and holes jump to conduction and valence band respectively, causing increase in carrier concentration.

Effect of temperature on (P-I) characteristics are illustrated in figure (3). From the (P-I) curves, we found.

- The differential efficiency
- The threshold current, where laser action begins

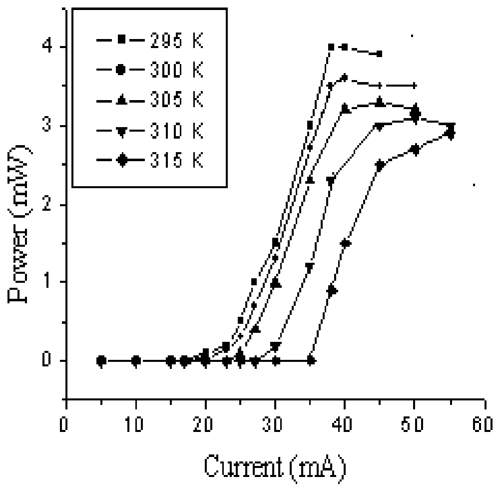


Figure 3: The Optical output power vs. driving current characteristics at different temperature

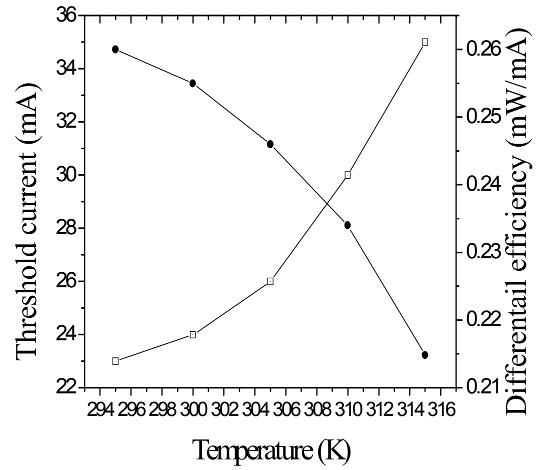


Figure4: Variation of series resistance and differential efficiency with temperature

Figure (4) shows the variation of $\mathbf{I_{th}}$, $\boldsymbol{\eta_d}$ and $\mathbf{P_{out}}$ with temperature. We see that $\mathbf{I_{th}}$ increases exponentially with temperature. Increasing temperature causes quasi-Fermi distribution functions of holes and electron to spread more, which demands a larger injection carriers to fulfill the condition of laser action and it results in a higher value of $\mathbf{I_{th}}$ to obtain gain in the active region. This red emitting LD has a differential efficiency of 0.26 mW/mA. We observed that $\boldsymbol{\eta_d}$ decreases gradually at lower temperature and decrease more sharply at higher temperature. $\mathbf{P_{out}}$ also decrease with rise in temperature. This decrease in $\mathbf{P_{out}}$ & $\boldsymbol{\eta_d}$ is due to increase in nonradiatve recombination at higher temperature, in the active layer of the LD. A decrease of about 32.5% in $\mathbf{P_{out}}$ is observed at 315 K.

3.2 Effect of γ-Ray Radiation

Current values at different bias voltage were measured for LD before and after irradiation, were plotted in figure (6a).It was observed that current values decrease after irradiation. The current decreased due to radiation-induced defects. These defects are in the form of dislocation, imperfections, deep levels and vacancies. All these effects acts as traps. Traps are undesirable because a number of charge carriers are lost, causing a reduction in its current. $\boldsymbol{R_s}$ measured from forward (I-V) curve in its flat region of LD, before and after irradiation is shown in figure (6b).This $\boldsymbol{R_s}$ has a non-linear behavior with the increase of dose rate.

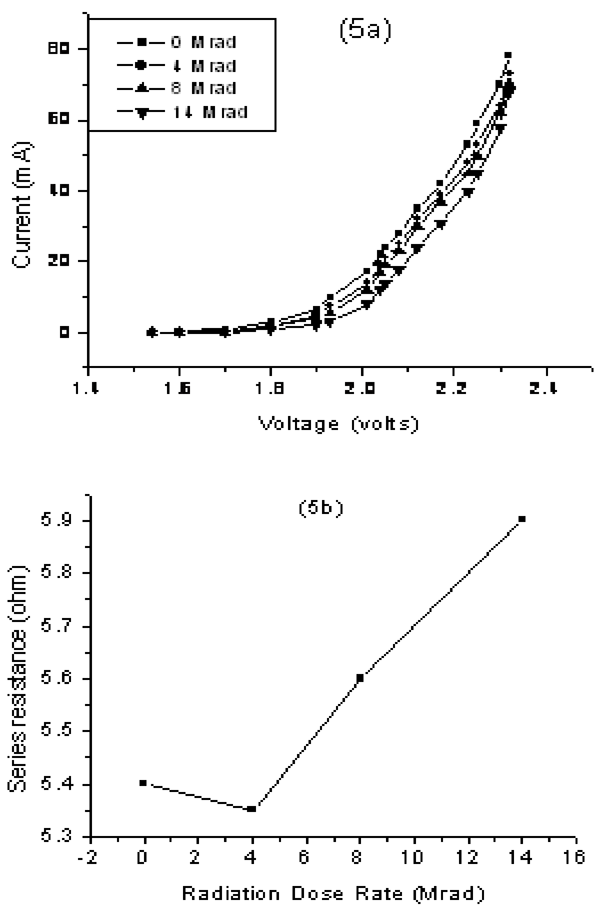


Figure5: The direct voltage vs. the driving current a) and the change of series resistance b) for different total irradiation dose

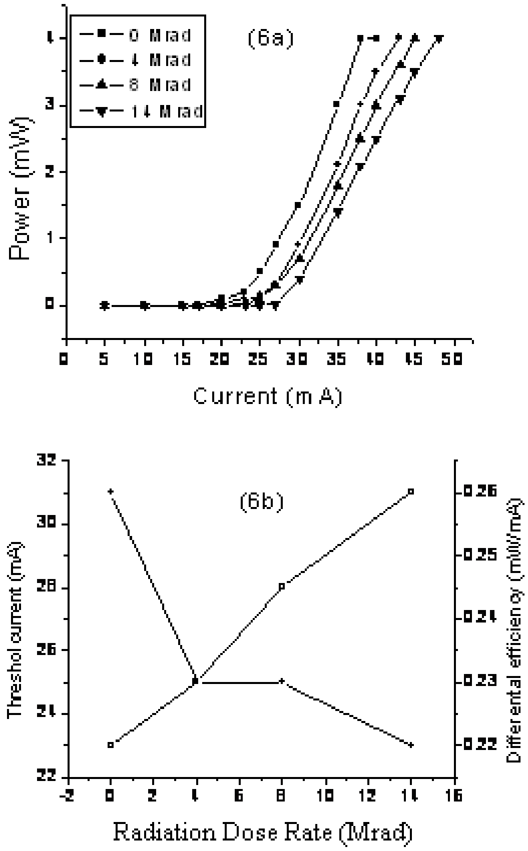


Figure6: The optical output power vs. the driving current characteristics a) and variation of threshold current and differential efficiency b) for different total irradiation dose.

Figure (6a) shows the influence of irradiation on LD's $\mathbf{P_{out}}$ as the driving current changed. This LD has a $\mathbf{P_{out}}$ of 4 mW, which do not influenced by the γ-irradiation. However, $\mathbf{I_{th}}$ increases $\boldsymbol{\eta_d}$ decrease with increase of irradiation dose as shown in fig (6b).The positive shift of $\mathbf{I_{th}}$ is due to decrease of electron concentration due to radiation –induced defects formed in AlGaInP quantum well active region. We see that $\mathbf{I_{th}}$ increases but the power remains constant, and the slope of (P-I) curve changes, with irradiation dose, causing change in $\boldsymbol{\eta_d}$. A decrease of 15.3% is observed at 14 Mrad. A reduction of $\boldsymbol{\eta_d}$ means getting the same power at the large driving current.

4 CONCLUSION

Effect of temperature and γ-ray radiation on the electrical and optical characteristics of LD was investigated. LDs degrade rapidly as the temperature increase and perform well in gamma radiation environment. With the increase of temperature, $\mathbf{I_{th}}$ increases but $\mathbf{P_{out}}$ and $\boldsymbol{\eta_d}$ decreases. Slight changes occur in the $\boldsymbol{\eta_d}$ and $\mathbf{I_{th}}$ but $\mathbf{P_{out}}$ remain constant after gamma irradiation. This constant in $\mathbf{P_{out}}$ is achieved by increasing operating current in APC mode. As can be seen that, the two parameters are correlated Increase of threshold current accompanies the decrease of differentially efficiency.

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