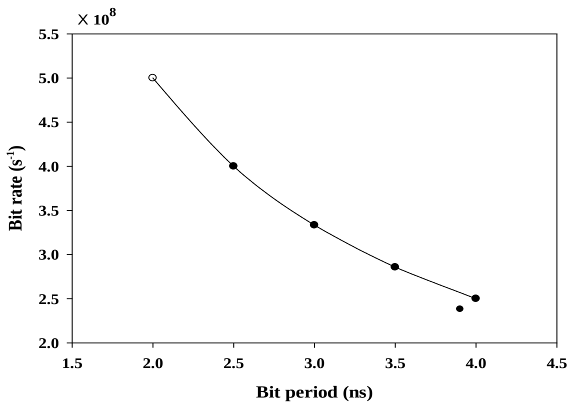

Figure 30: The relationship between the bit rate and the bit period of MQW violet InGaN LDs.

7. Turn-on and turn-off times and extinction ratio

Among the important parameters to be calculated for digital modulation are the turn-on and turn-off times and extinction ratio. Figure 31 shows turn-on and turn-off times of LD1 and LD2 as functions of the bias current. Turn-on and turn-off times represented in Figure 31 are calculated from Figures (7-11) for LD1 and from Figures (13-17) for LD2. As it can be seen from Figure 31, turn-on and turn-off times decrease with increasing of the injection current. This is due to the increase of the frequency of RO [35] with increasing of the injection current. Hence, it is suitable to plot turn-on and turn-off times as functions of the frequency of RO of LD1 and LD2. Figure 32 shows how turn-on and turn-off times change with frequency of RO of LD1 and LD2.

Another important parameter to be calculated is the extinction ratio. The value of extinction ratio is expected to affect turn-on and turn-off time values. Figure 33 represents the extinction ratio as a function of the injection current; the extinction ratio has been taken in (dB) unit because it is more common to measure the extinction ratio. It is obvious that extinction ratio decreases with increasing of the injection current due to the increase of the RO with increasing of the injection current.

In the ideal case, the zero bit optical power is zero which results in an extinction ratio of infinity. In practice, this is not achievable and when the extinction ratio decreases, the difference between zero bit and one bit average optical power decreases. This results in sensitive degradation and a higher probability to mistake zero bits for one bits (or vice versa) resulting in bit errors [36]. Therefore, the power penalty ($\delta_e(r_e)$) is expected to increase with decreasing the extinction ratio as indicated in Figure 34 and according to the following equation:

$$\delta_e(r_e) = \frac{r_e + 1}{r_e - 1} \quad (21)$$

To compare between LD1 and LD2, turn-on and turn-off times are calculated for both of them at the selected operating points above the threshold with 1 mA, i.e. at 17.42 and 14.76 mA for LD1 and LD2, respectively. Turn-on and turn-off times at the selected operating point at 17.42 mA of LD1 were found to be 0.484 and 0.522 ns, respectively; turn-on and turn-off times at selected operating point at 14.67 mA of LD2 were found to be 0.4 and 0.46 ns, respectively. These differences between turn-on and turn-off times of LD1 and LD2 are attributed to the difference of the frequency of the ROs of LD1 and LD2 as indicted in Figure 22 where the frequency of the RO of the LD2 is higher than that of LD1. Turn-on and turn-off times of LD2 are lower than turn-on and turn-off times of LD1 because turn-on and turn-off times are inversely proportional with the frequency of RO as indicted in Figure 32.

In addition, the extinction ratio of LD1 at 17.42 and of LD2 at 14.67 mA are 10.6 and 11.6 dB, respectively. This is another reason to make the turn-on and turn-off times of LD2 lower than those of LD1 as argued above.

Therefore, LD2 is better than the LD1 because LD2 exhibits lower turn-on and turn-off times and higher extinction ratio which means a faster digital communication can be achieved with LD2.

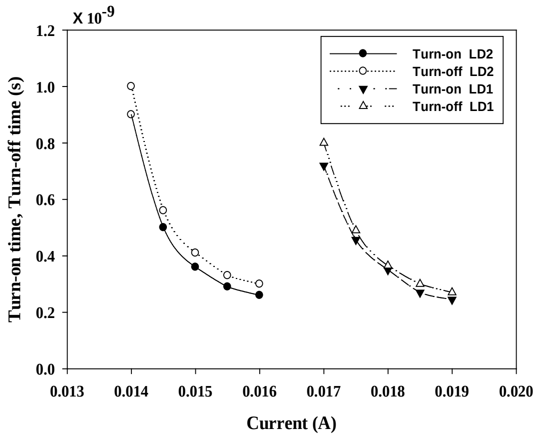

Figure 31: The turn-on and turn-off times as functions of bias current of the LD1 and LD2

.

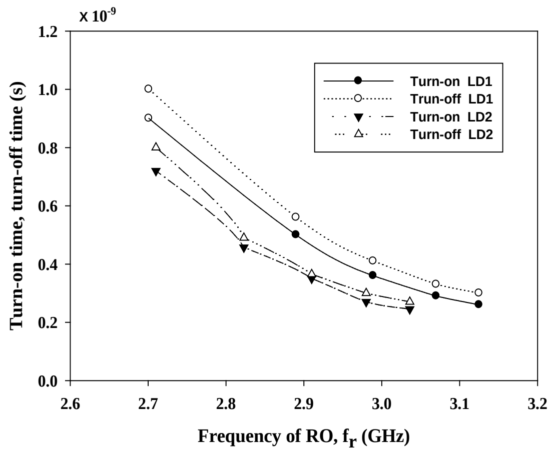

Figure 32: The turn-on and turn-off times as functions of the frequency of RO of LD1 and LD2.

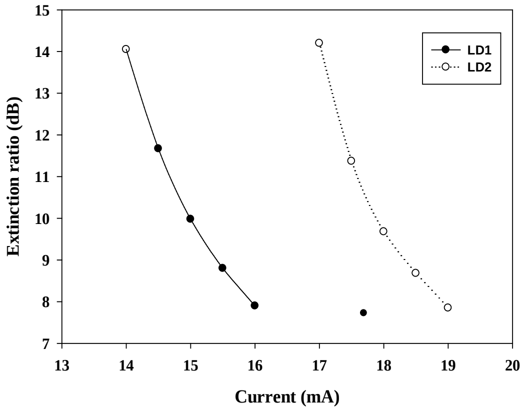

Figure 33: Extinction ratio as a function of the injection current of LD1 and LD2.

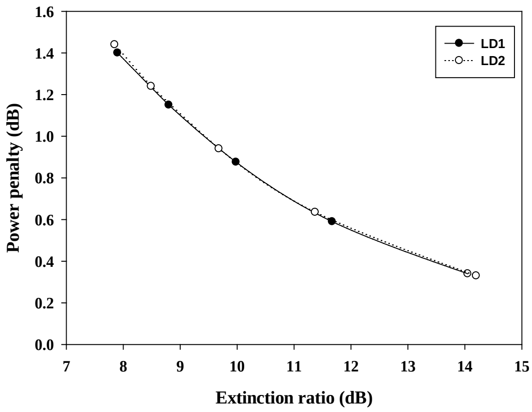

Figure 34: The power penalty as a function of extinction ratio of the LD1 and LD2.

8. Comparison with the Available Experimental Studies

The results of the pulse responses of the MQW violet InGaN LDs have been compared with some available experimental studies.

In term of digital modulation, S. Nakamura et al. have reported 3 GHz frequency of the RO of MQW violet InGaN LD with an emission wavelength near 405 nm [37]. This value is close to the theoretical values of frequencies of the ROs of LD1 and LD2 in this study.

The simulation results indicated that the bit rate in few hundred mega bit per second. This is common in direct digital modulation values of the other LDs. M. Kuramoto et al. modulated three MQW InGaN LDs with the pulse current. They found that the ROs are proportional to the damping constant [38]. Therefore, they concluded that the LD with higher damping constant has a higher RO. This is similar to simulation results in this study where it has been concluded that LD1 has higher RO than LD2 because the damping constant of LD1 is higher than that of LD2.

9. Conclusion

InGaN based-LDs may exhibit better digital modulation characteristic than some conventional LDs. Using AlInGaN BL in nitride based LDs gives good digital modulation characteristics than using conventional AlGaN BL where relatively the fast switching operating can be obtained. The photon and carrier lifetimes of these types of LDs can determine the digital modulation characteristics, designing and fabrication of LDs with appropriate photon and carrier lifetimes can improve their digital modulation characteristics.

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