Study on the Thermal Characteristics of GaN-based Laser Diodes

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Abstract— **In this work, we have analyzed the thermal properties of a GaN-based LD (Laser Diode) as functions of input powers, cooling conditions, and ambient temperatures. It was found that the thermal resistance has a slight change with input current under the forced cooling condition. In contrast to the forced cooling condition, significant change of thermal resistance was observed under the natural cooling condition. When the ambient temperature was increased from 0 ˚C to 50 ˚C, the measured thermal resistance was increased from 20 K/W to 27.5 K/W.**

I. Introduction

Laser diodes have great potential applications such as light source of optical communication, laser print, compact disk and bar code reader device, etc. The optical powers of LD products are dependent on the application and can be controlled by the driving power. Generally, the optical power of LD products can be improved by increasing their driving powers. However, with increasing the operating power of LD, junction temperature and threshold current are also increased. It is known that thermal performance of optical devices is directly related with degradation and life time of devices [1, 2]. Therefore, it is imperative to make a dependable thermal characterization for the various operating conditions and establish thermal design rules for the development of high power LD.

In this paper, we investigated thermal behavior of GaN-based LDs as functions of input powers, cooling conditions and ambient temperatures. The GaN-based LD stripe structure, used for this experiment, was formed on the sapphire substrate and was installed in TO (Transmitter Optical) package. The thermal transient method was employed for the measurement of junction temperature and thermal resistance. The finite volume method was employed for the thermal simulation of the LD packages.

II. Experimental Method

The thermal behavior of the GaN-based LDs was investigated by the thermal transient method. The thermal resistance measurement was carried out using the thermal transient tester (T3Ster 2000/100, Mentor Graphics Ltd.) [3].

In the forced cooling system, LD was surrounded by a copper jig. The copper jig was fixed on an Al (aluminium) chamber. The Al chamber was seated on a TEC (Thermo-Electric Cooler) and the temperature was kept constant during the measurement. In the natural cooling system, LD was centered in a chamber of still air condition and the measurement was carried out at room temperature. In LD package, chip was mounted on an AlN submount as an epi-down type with eutectic solder and AlN submount was attached to heat sink with die attaching material.

Thermal simulation of LD package was made by FLOTHERM (V8.1, Mentor Graphics Ltd) [4]. The modeled LD package has same dimensions (TO-18 CAN, ϕ5.6mm) and boundary conditions as the measured samples. Thermal conductivities of employed packaging materials are listed in Table I. Then, thermal behavior of LD package was analyzed as functions of input powers, cooling conditions, and ambient temperatures.

III. Results and Discussion

Fig. 1 and 2 show the changes of junction temperature and thermal resistance of LD under the forced and natural cooling conditions, respectively. The measured thermal resistance was changed from 22.4 K/W to 23.5 K/W while the junction temperature was increased from 27.8 ˚C to 33.9 ˚C under the forced cooling condition in the range of input power from 0.1 W to 0.4 W. The calculated thermal resistance from the simulation was kept as a constant of 25.8 K/W, while the junction temperature was increased from 27.7 ˚C to 36.1 ˚C for the input power range from 0.1 W to 0.4 W. There was only a slight change in thermal resistances under the forced cooling system. However, the thermal resistance of the LD under the natural cooling system showed a significant change both in the thermal resistance from 410.3 to 308.3 K/W and in the junction temperature from 58.3 ˚C to 121.2 ˚C for the input power range from 0.1 to 0.4 W. In the simulation, the thermal resistance was decreased from 496.8 K/W to 407.3 K/W and the junction temperature was increased from 74.7 ˚C to 187.9 ˚C for the input current range from 0.1 W to 0.4 W.

The different trends of the change in thermal resistances for these two cooling systems were explained as follow. Starting from the hot spot of the LD, heat can be transferred through two thermal paths. The first heat transfer path starts from the junction, and then transferred into the packaging materials by conduction and dissipates out to the air by convection.

In the second heat path, heat flow starts from the junction of

TABLE I
THERMAL CONDUCTIVITIES OF LD PACKAGING MATERIALS

Materials	Thermal conductivity(W/mK)
Saphire (substrate)	28
GaN (chip)	130
SnAg (eutectic solder)	78.4
AlN (submount	285
PbSn (die attach)	25
Cu (heatsink)	401

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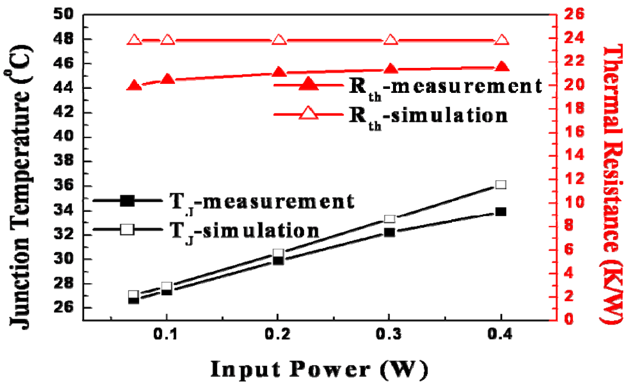

Fig. 1. Measured and simulated thermal characteristics of an LD package under the forced cooling condition.

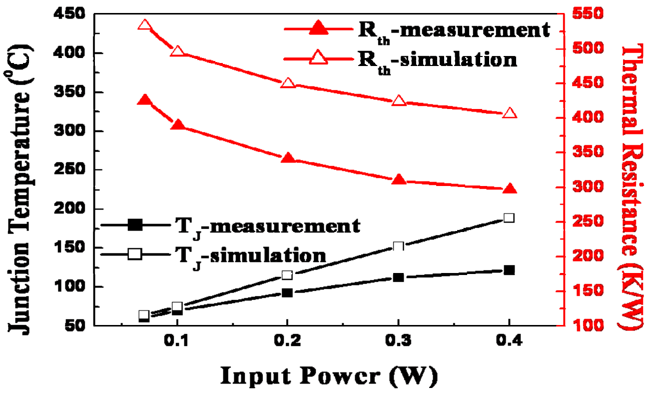

Fig. 2. Measured and simulated thermal characteristics of an LD package under the natural cooling condition.

the device through the body and copper jig into the chamber by conduction and finally flows into the cold side of TEC. The dominant cooling mechanism for the natural cooling system was convection. Meanwhile, conduction was the dominant cooling mechanism for the forced cooling system. In the convection mechanism, the efficiency of heat dissipation mainly depends on the heat transfer coefficient, h [5]. The coefficient, h, is increased when the input current and junction temperature are increased. The relationship between the temperature and h can be expressed as follow:

$$h = 0.52\,C\left(\frac{\Delta T}{L}\right)^{0.25} \tag{1}$$

where C is a constant based on the geometry of the surface, L is the length of heat flow path, and ΔT is temperature difference between package surface and ambient temperature.

Thermal behavior of LD package was analyzed with the ambient temperature range from 0 ˚C to 50 ˚C in the input current of 70 mA. Fig. 3 shows the change of thermal characteristics as a function of ambient temperature. From both the measurement and the simulation results, we can find that the junction temperature of LD increased with ambient temperature. The calculated thermal resistance from the simulation was kept as a constant of 25.8 K/W, while the measured thermal resistance from the measurement was increased from 20 K/W to 27.5 K/W for the ambient temperature range from 0 ˚C to 50 ˚C. This result can be attributed to the temperature dependence of thermal conductivity of packaging material. The temperature

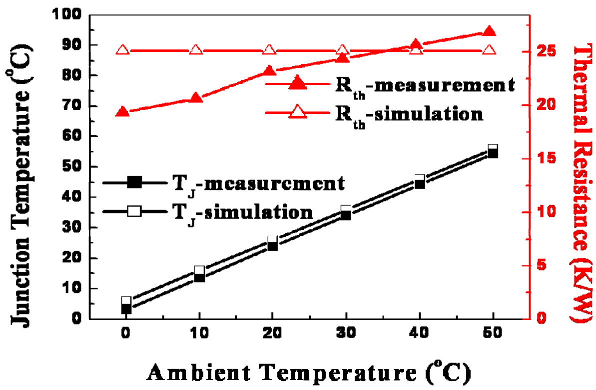

Fig. 3. Thermal characterizations of LD with different ambient temperatures.

dependence of the thermal conductivity of different materials can be expressed as follow [6],

$$K = K_0 \exp\left(\alpha_K \left(T - T_0\right)\right) \tag{2}$$

where, K is value of the thermal conductivity, K_o is thermal conductivity at the reference temperature T_o, T is temperature, α_k value is equal to the relative change of K for 1 ˚C temperature rise. Within the measuring temperature range, LD packaging materials such as GaN, Cu, AlN show decrease in their thermal conductivity with temperature increase because α_k has a negative value. Therefore, junction temperature and thermal resistance of LDs are increased when the ambient temperature is increased.

IV. Conclusion

Thermal behavior of GaN-based LDs was analyzed by the thermal transient method and finite volume method as functions of input powers, cooling conditions, and ambient temperatures. Significant change in the thermal resistance with input current was observed in the LD package under the natural cooling condition. The results were explained by the relationship between the temperature and the heat transfer coefficient. The increase of thermal resistance with the operation temperature was attributed to the temperature dependence of thermal conductivity of packaging materials.

Acknowledgment

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