DOI 10.1007/s10946-019-09788-2
Journal of Russian Laser Research, Volume 40, Number 2, March, 2019

IMPROVED THERMAL PERFORMANCE OF 640 nm LASER DIODE PACKAGED BY SiC SUBMOUNT

W. Xia,[1,2*] Z. Zhu,[2] X. Y. Li,[1] K. Jiang,[1] and X. G. Xu[2]

[1]*School of Physics and Technology, University of Jinan*
Jinan 250100, China

[2]*Shandong Huaguang Optoelectronics Co., Ltd.*
Jinan 250100, China

*Corresponding author e-mail: sps_xiaw@ujn.edu.cn

Abstract

We design high-power AlGaInP laser diodes emitting at ∼640 nm. AlN and SiC submounts are used as heat sinks for the laser chips. The laser diode with SiC submount showed a higher thermal rollover power of 3.9 W and higher maximum conversion efficiency of 39% at 25°C. In the range of 15 − 35°C, the two types of lasers have similar characteristic temperature T_0. At higher temperatures beyond 40°C, the laser chip mounted on SiC revealed an improved T_0, compared to that on AlN. By measuring the wavelength drift of the two types of lasers, we estimate the thermal resistance to be 9.1 K/W for the laser diode on AlN and 5.6 K/W for the laser diode on SiC.

Keywords: high-power AlGaInP laser diodes with AlN and SiC submounts, 640 nm laser diode packaged by SiC submount, characteristic temperature.

1. Introduction

High-power red laser diodes (LDs) have been attractive for several decades due to their small size, low cost, and easy integration. They are used for optical storage, laser display, photodynamic therapy, and pump sources of some unique solid-state lasers and fiber lasers [1, 2], which require high output power and high conversion efficiency.

The red LDs with wavelength beyond 650 nm have been widely investigated due to the expanded DVD market in 2000s. In recent years, the optical storage market of red LDs was replaced by blue-ray disca with larger storage capacity and portable flash memory technology, while the application of laser display represented by laser television and laser micro-projection is in emerging. In the red region, the visual sensitivity of the human eye increases with decrease in wavelength. For example, the sensitivity coefficient at 640 nm is three times higher than that at 660 nm [3]. To get a better visual experience, the wavelength of red LDs should be shortened. Unfortunately, the commonly used AlGaInP/GaInP materials for red LDs have a smaller conduction band offset than AlGaAs materials. The electrons can easily escape from the active layer to the guiding layer and the cladding layer, especially for the shorter wavelength LDs. The current leakage leads to a lower differential quantum efficiency. As a compromise, high-power red LDs emitting at 640 nm are generally chosen for the laser display source.

There are two constraints of high-power operation for 640 nm LDs. One problem is the catastrophic optical mirror damage (COMD), which is the root cause of sudden degradation for high-power LDs.

Manuscript submitted by the authors in English on November 27, 2018.

However, the COMD power of AlGaInP LDs has been enhanced effectively by the window-mirror structure [4] or facet passivation [5]. The other one is power thermal rollover at high injection current. This is important for 640 nm LDs due to the small band offset, low thermal conductivity, and low electrical conductivity of AlGaInP materials [6]. Recently, Mitsubishi Electric has developed a new broad-area LD emitting at 638 nm with multiple emitters in one chip. Due to the chip optimization and package design, it shows a peak power up to 1.7 W at 55°C [7]. However, no information on submount was presented in their reports. We think that the submount is an important issue for the thermal resistance of high-power LDs because of the fact that the laser chip is directly soldered on the submount and the heat spreads through it to the package. AlN ceramic is an often used submount in high-power LDs.

In this paper, we fabricated high-power AlGaInP laser chips and employed AlN and SiC submounts for chip soldering. Investigating the thermal performance of the two types of lasers, we demonstrate that the SiC submount is promising for high-power 640 nm LDs.

2. Fabrication

The chip layers were grown by metal-organic chemical vapor deposition on an off-cut GaAs (100) substrate. AlInP with a low refractive index was chosen as the cladding layer to effectively confine the guided light. An asymmetric AlGaInP waveguide with thinner *p*-side was employed not only for shifting the optical field to the *n*-side to reduce the optical loss from holes but also for low electrical and thermal resistances. A single tensile-strained GaInP quantum well was modified to emit at ∼640 nm. After epitaxial growth, a window-mirror structure was adopted to increase the COMD power by selective Zn diffusion. The GaAs contact layer was etched off and the SiO_2 insulating film was deposited outside a broad stripe of 100 μm for current injection. The *p*-side metal layers were Ti/Pt/Au, and the *n*-side metal layers were Ge/Ni/Au. The bars are cleaved by 1,500 μm long and coated with 5% antireflection and 95% high-reflection films on the front and rear facets, respectively. Finally, the laser chips were separated and soldered *p*-side down on the AlN and SiC submounts. Moreover, the AlN and SiC submounts had different buffer metal thickness to adjust the thermal expansion coefficient.

3. Results and Discussion

The power–current–voltage characteristics of 640 nm LDs mounted on AlN and SiC measured at 25°C are compared in Fig. 1. The threshold current is 0.45 A for a laser chip mounted on AlN and 0.42 A for that mounted on SiC. When the current increases to 2 A, the former LD shows fast degraded slope efficiency with a peak power of 2.9 W at 4.3 A, while the latter has a more linear power curve and the thermal rollover power is enhanced to 3.9 W at 5.4 A. No COMD is observed for a high injection current up to 6 A for both types of lasers. The LD mounted on SiC shows a maximum conversion efficiency of

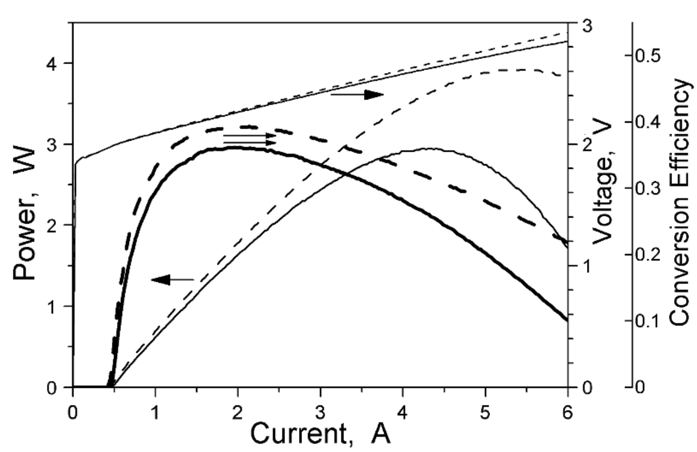

Fig. 1. Power–current–voltage characteristics of 640 nm laser diodes mounted on AlN (solid curves) and SiC (dashed curves) submounts at 25°C.

39% at 25°C, higher than that of 36% for the LD mounted on AlN.

In Fig. 2, we show the temperature dependence of light output power curves of 640 nm LDs mounted on AlN and SiC. The heat sink temperature is controlled in the range of 15–60°C by a thermoelectric cooler. At a low temperature of 15°C, both lasers have similar power–current characteristics. As the heat sink temperature increases, the threshold-current change and output-power deterioration for the LD mounted on SiC are much smaller compared to the LD mounted on AlN. The higher the temperature increase, the more obvious the difference. For example, at 60°C, the laser mounted on SiC provides an output power of 0.52 W at 1.5 A, which is twice that of 0.26 W for the LD mounted on AlN.

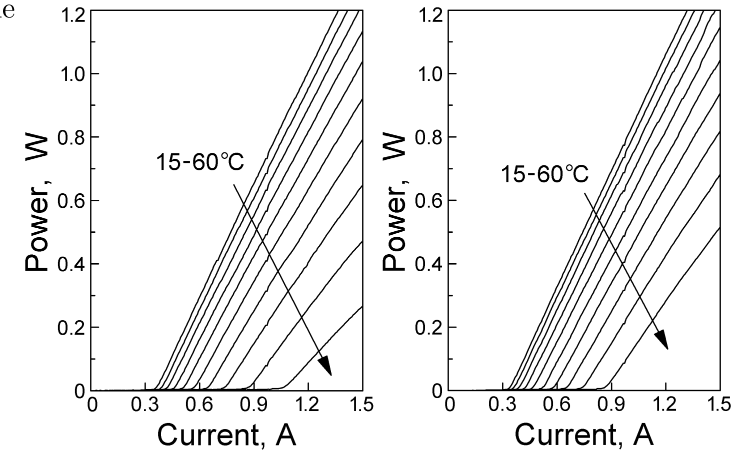

Fig. 2. Power curves of 640 nm laser diodes mounted on AlN (left) and SiC (right) submounts at different temperatures.

The threshold current $I_{\rm th}$, being dependent on the temperature, reads

$$I_{\rm th} = I_0 \exp\left(T/T_0\right), \tag{1}$$

where I_0 is a constant, T is the heat sink temperature, and T_0 is the characteristic temperature; it is an important parameter to describe the thermal performance of red LDs, which are sensitive to temperature. In Fig. 3, we show plots of log scale of the threshold current versus temperature for LDs mounted on AlN and SiC. Here, T_0 can be calculated from the linear simulation, and we see that the two types of lasers have similar T_0 of 59 K and 61 K in the lower temperature range of 15 − 35°C. At the higher temperature range of 40 − 60°C, the LD mounted on SiC shows a higher T_0 of 40 K, in contrast to 32 K on AlN. Therefore, the SiC submount is more suitable for high temperature use of 640 nm LDs.

In order to understand the difference in the thermal performance of both lasers, we determine the thermal resistance ($R_{\rm th}$) of each LD as follows [1]:

$$R_{\rm th} = \frac{\Delta\lambda/\Delta P_t}{\Delta\lambda/\Delta T} = \frac{\Delta\lambda/\Delta(UI - P_0)}{\Delta\lambda/\Delta T}\,, \tag{2}$$

where P_t is the thermal power, and P_0 is the output power. The lasing wavelength at different operating currents for the LDs mounted on AlN and SiC is given in Fig. 4. It can be seen that in the case of mounting on SiC, the wavelength shifts only by 1.9 nm when the operating current increases from 0.5 A to 2 A. It is smaller than the laser mounted on AlN with a shift of 3.3 nm. The thermal power can be calculated, in view of the equation $P_t = UI - P_0$, with the data shown in Fig. 1. The value of $\Delta\lambda/\Delta T$ is estimated to be 0.185 nm K^{-1} by measuring the temperature dependence of wavelength in the inset of Fig. 4. As a result, the calculated thermal resistance is 9.1 K/W for a laser on AlN and 5.6 K/W for that on SiC. The reduced thermal resistance improves the thermal performance of LDs mounted on SiC.

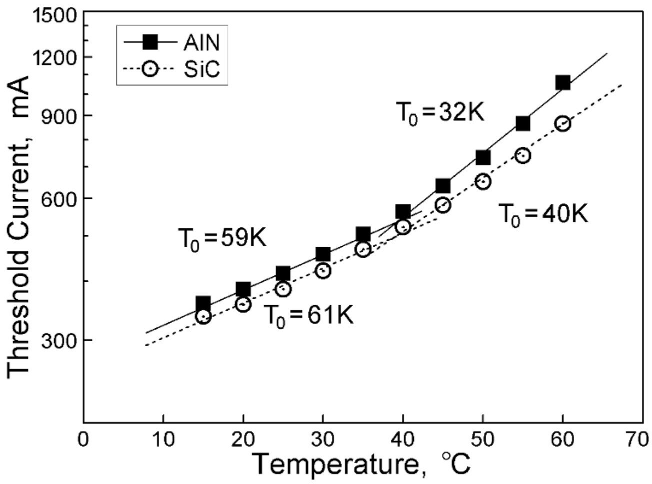

Fig. 3. Temperature dependence of the threshold current for 640 nm laser diodes mounted on AlN and SiC submounts.

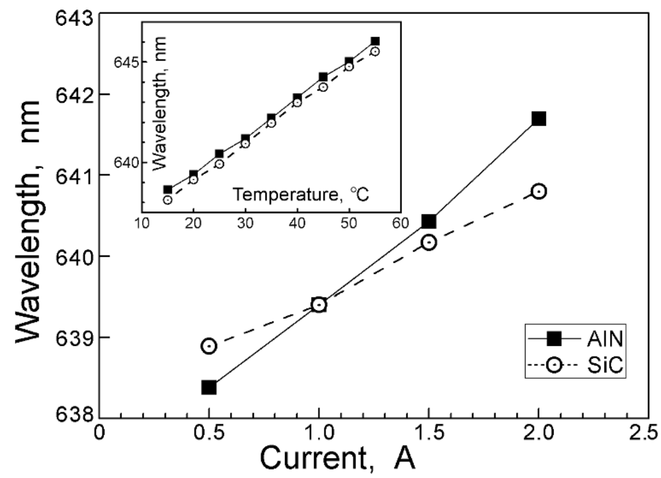

Fig. 4. Lasing wavelength at different operating currents for 640 nm laser diodes mounted on AlN and SiC submounts, with the temperature dependence of wavelengths in the inset.

4. Conclusions

Summarizing, we fabricated high-power AlGaInP 640 nm LDs on AlN and SiC submounts. In comparison to the commonly used AlN submount, the LD mounted on SiC showed higher peak power and maximum conversion efficiency. Meanwhile, the SiC submount are performed for high temperature applications for 640 nm LDs due to the improved characteristic temperature and output power at high temperatures.

Acknowledgments

This work was supported by the National Key R&D Program of China under Grant No. 2017YFB0404902.

References

1. B. Sumpf, J. Fricke, P. Ressel, et al., *Semicond. Sci. Tech.*, **26**, 105011 (2011).
2. D. Imanishi, Y. Sato, K. Naganuma, et al., *Electron. Lett.*, **41**, 1172 (2005).
3. N. Shimada, M. Yukawa, K. Shibata, et al., *SPIE*, **7198**, 719806 (2009).
4. K. Kuramoto, T. Nishida, S. Abe, et al., *SPIE*, **9348**, 93480H (2015).
5. B. Sumpf, M. Zorn, R. Staske, et al., *IEEE J. Sel. Top. Quantum Elecron.*, **13**, 1188 (2007).
6. M. Peters, V. Rossin, and B. Acklin, *SPIE*, **5711**, 142 (2005).
7. K. Kuramoto, S. Abe, M. Miyashita, et al., *SPIE*, **10514**, 1051404 (2018).