A New Package Structure for High Power Single Emitter Semiconductor Lasers

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Abstract

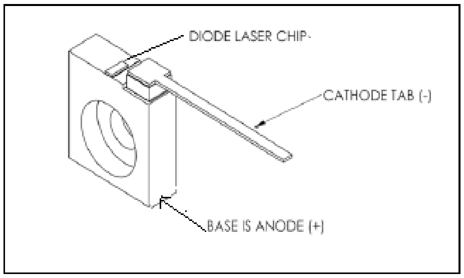
High power semiconductor lasers have found increased applications in pumping solid state or fiber laser systems for industrial, military and medical applications as well as direct material processing applications. The reliability requirement for high power semiconductor lasers has been increased in recent years and it has been proven that indium-free packaging is one of the most effective ways in improving lifetime. The performance including reliability of high power semiconductor lasers is highly depended on the package structure. We have designed a new package structure for high power single emitter semiconductor lasers which is called F-mount. In contrast to traditional single emitter package structures, the F-mount offers indium–free packaging while improving or at least not sacrificing the thermal management. The heat sink of this new structure is insulated and easy for system integration. Finite element numerical analysis was used to compare the thermal resistance between F-mount structure and traditional structure. It was found that F-mount has high power and high electrical-to-output efficiency than the traditional structure. Lifetime testing was conducted on the F-mount devices and it was found that there was no obvious degradation in power over 7000 hours.

Introduction

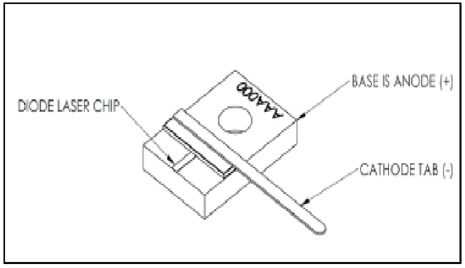
High power semiconductor lasers at the wavelength of 808nm are commonly used as an efficient pumping source for Nd-YAG solid state lasers, and as direct high power light sources for industrial, military and medical applications[1-2]. Package structure significantly influences the performances of high power semiconductor lasers, such as output power, reliability and electrical-to-optical efficiency[3]. There are three key performance parameters of semiconductor lasers: electrical-to-optical efficiency, power and reliability. Good package structure contributes to high efficiency, high power and high reliability. There is a continuous demand for high electrical-to-optical efficiency and high output power and high reliability. In this work, a new package structure called F-mount was designed for high efficiency, high power and high reliability single emitter semiconductor lasers. The thermal resistance of this package structure is lower than that of a traditional structure, and the max power at CW mode is higher than that of the traditional structure. This new package structure has more than 7000h long-term aging without any obvious degradation in performances.

Single emitter laser structure

Traditionally, single emitter semiconductor lasers package are in C-mount or CT-mount format, as shown in Fig.1. In this work,a new high power single emitter semiconductor laser package, named F-mount, has been designed [4], as shown in Fig.2. The chip was mounted epi-side down on ceramic substrate with AuSn solder which was then attached to a copper heatsink. Compared with the traditional structure, F-mount has following advantages. 1) Indium free packaging which improves operation lifetime and storage lifetime; 2) Efficient heat conduction path, which leads to lower thermal resistance and lower junction temperature; 3) The heatsink of F-mount is insulated, which avoids current being applied to the heatsink; 4) F-mount structure is easier for system integration.



(A) C-mount structure



(B) CT-mount structure

Fig.1Traditional single emitter semiconductor laser structures

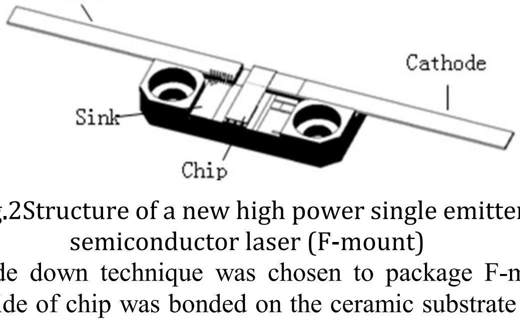


Fig.2Structure of a new high power single emitter semiconductor laser (F-mount)

P-side down technique was chosen to package F-mount. The P side of chip was bonded on the ceramic substrate using

AuSn solder, and ceramic substrate was attached to copper heatsink. Fig.3 shows the package structure of F-mount.

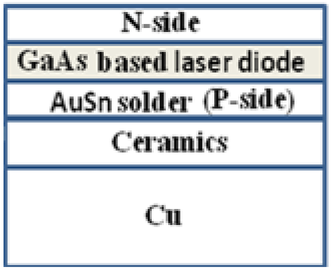


Fig.3 Package structure of a new high power single emitter laser (F-mount)

Indium solder is one of the most widely used solders in high power laser die bonding. It was found that indium solder bonded lasers have much shorter lifetime than AuSn solder bonded lasers due to indium electro migration, electro-thermal migration and chip cracking due to high thermal stress in a laser package [5-6]. For F-mount structure, ceramic with CTE (coefficient of thermal expansion) matches with that of GaAs chip, was used as sub-mount. It is the ceramic used as sub-mount that enables indium-free process in fabricating the F-mount single emitter laser. In this paper, the AuSn solder were used to fabricate F-mount structure laser.

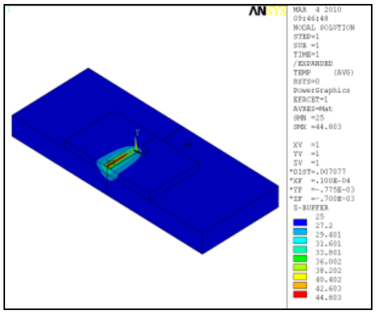
Thermal simulation

Finite element numerical analysis was used to simulate the F-mount and C-mount laser under the same condition: output power is 5W and temperature of the heatsink is 25℃. Usually the electrical-to-optical efficiency of 808nm semiconductor lasers are 50%[7]. The simulated results of the F-mount and C-mount are shown in Fig.4. The simulated results show that the maximum temperature of F-mount and C-mount are 44.6℃ and 47.2℃, respectively.

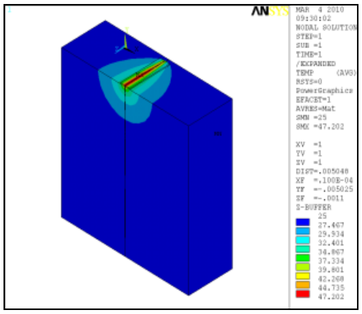
Thermal resistance can be calculated by formula

$$R_{th} = \frac{T_{chip} - T_{heatsink}}{Q}$$

where R_{th} is thermal resistance, T_{chip} is chip junction temperature, $T_{heatsink}$ is heatsink temperature and Q is heat generated. According to thermal resistance formula, the thermal resistance of F-mount laser and C-mount laser are 3.96℃/W and 4.44℃/W, respectively. The results show the thermal resistance of F-mount laser is 10.8% lower than that of C-mount laser.



(A) F-mount laser



(B) C-mount laser

Fig.4 Simulation results of thermal distribution at CW mode

LIV measurement

In order to compare the performances of F-mount and C-mount, 10 F-mount and 10 C-mount lasers were packaged and tested. The test results of power and electrical-to-optical efficiency of F-mount and C-mount lasers are shown in Tab 1. The results indicate that the electrical-to-optical efficiency of most F-mount is more than 54%. The test results show that the average power of F-mount laser is 0.45W higher than that of the C-mount and the electrical-to-optical efficiency of F-mount is 4% higher than that of the C-mount. The heat generated by a semiconductor laser at a given output power is given by conservation of energy

$$P_{heat} = P_{out}(1/\varepsilon - 1)$$

where ε is the fractional electrical-to-optical efficiency[8]. The above formula indicates that when the electrical-to-optical efficiency high, the heat generated by the semiconductor lasers is low. So the heat generated by the F-mount is low when both lasers operate at the same output power. Thus compared to the C-mount laser, F-mount laser has higher output power at same driving current.

Tab 1 Data of Power and Electrical-to-optical Efficiency at 5 A

F-mount		C-mount	
Pop(W)	Eff(%)	Pop(W)	Eff(%)
4.93	54.14	4.75	50.85
4.99	55.01	4.70	50.58
4.88	53.00	4.71	50.63
4.96	54.72	4.72	50.73
4.95	54.53	4.76	50.94
4.96	54.72	4.71	49.84
4.91	52.72	4.66	49.57
4.96	54.53	4.71	50.27
4.93	53.96	4.55	48.55
4.94	54.33	4.67	50.29

Maximum Power test

Reliable operation at high power is limited either by high thermal rollover or catastrophic optical mirror damage (COMD) at high current. The maximum power of F-mount and C-mount lasers were tested under the condition of 25℃ until thermal rollover[9], as shown in Fig.5. The output power of F-mount structure reaches 13.3 W at 808 nm from a 200 μm stripe width with 2 mm cavity length. After the thermal rollover testing, the laser is still operating well. The output power only reaches 10.4 W from C-mount structure with the same wafer, and the laser is still operating well too. Obviously at high driving current the LI curve is bending, which is due to thermal rollover. Thermal rollover is caused by more heat generated than heat dissipated, which leads to higher temperature in chip. The maximum power of F-mount laser is 27.9% higher than that of C-mount laser and the two LI curves clearly separated after 5A. This is because F-mount has higher cooling capability than C-mount. If both structures are used under same condition, the F-mount would have higher reliability than that of C-mount.

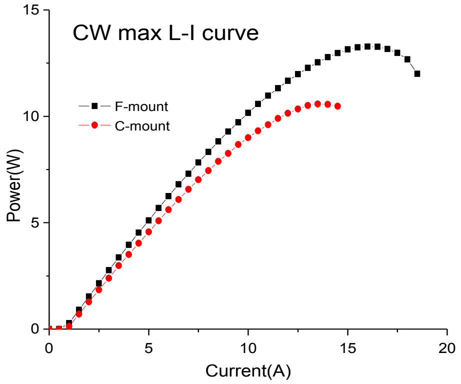


Fig.5 Output power of 808nm laser semiconductors versus the operational current in CW mode

The COMD level of F-mount laser was also tested at Quasi-continuous wave (QCW) mode under 1% and 0.5% duty cycle. At 1% duty cycle (100µs, 100Hz) the maximum output power reaches 27W at 22A, and at 0.5% duty cycle (100µs,50Hz) the output power reaches 30.8W at 25A, as shown in Fig.6. Both curves were limited by COMD. COMD usually occurs when devices are over-driven to destruction. COMD failure of a laser device happens at the facet and is caused by absorption of light at the facet which leads to local band-gap reduction with consequent increased absorption and temperature rise[10].

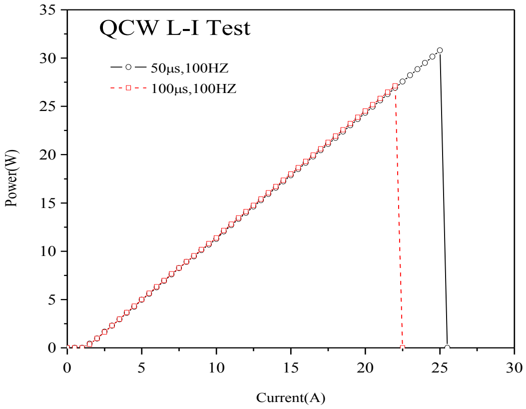


Fig.6 LI test curve at QCW mode

Lifetime testing

The lifetime of a semiconductor laser is directly related to its junction temperature defined by [11]

$$t = ce^{Ea/KT}$$

where Ea is the activation energy for the device in units of eV, k is Boltzman's constant, T is absolute temperature, c is the device constant in units of time, and e is electron charge. Higher cooling capacity contributes to lower thermal resistance and lower junction temperature, and it can lead to longer lifetime in high power semiconductor laser. On the other hand, the package itself could limit the lifetime of a semiconductor laser, especially indium electro migration and chip cracking due to high thermal stress in a laser package. The F-mount offers indium–free die bonding which improves operation lifetime and storage lifetime, low thermal resistance which leads higher output power. Lifetime test was conducted on eleven 808nm F-mount structure lasers under the condition of 5.5 A and 30℃. The lifetime testing result is shown in Fig.7. After operating more than 7000 hours, no degradation in power and no sudden failure for F-mount lasers have been observed.

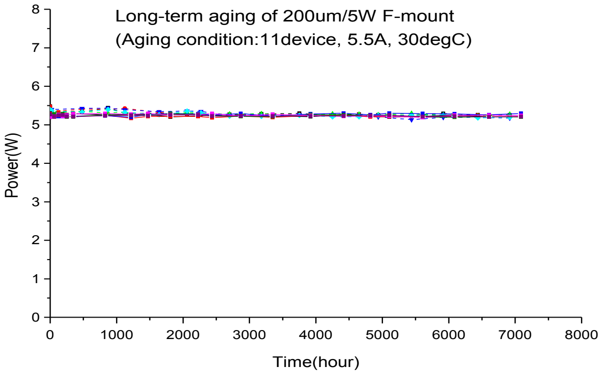


Fig.7 Lifetime testing results of F-mount semiconductor lasers

Conclusions

In conclusion, a new package structure with high power and high reliability is presented. The new package structure offers indium–free packaging while improving or at least not sacrificing the thermal management of the device. This new structure single emitter semiconductor laser has higher power and electrical-to-optical efficiency than traditional single emitter lasers, due to the lower thermal resistance and thus lower junction temperature. Single emitter semiconductor laser have been fabricated using this new package structure. The output power of 13.3W in CW mode was obtained from a 200µm stripe width and 2mm cavity length chip. Also COMD level of this new package structure reaches 30.8W from the same wafer. Lifetime data indicates that semiconductor laser devices fabricated by this new packaging structure have high reliability.

Acknowledgments

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