Study of the Key Aspects in Developing kW-Level Diode Lasers for Solid State Laser Pumping

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Abstract - In this paper, the key aspects, such as thermal management, thermal stress analysis and management, processes development, failure analysis and reliability evaluation, in developing kW-level diode lasers for solid state laser pumping are studied.

Key words: Diode Lasers, Solid State Laser, Pumping, kW-level, Stack

With the improvement of output power, lifetime, conversion efficiency and stability, high power diode lasers have found increased applications in material processing, medical and aesthetic, scientific research and display. Pumping of solid state lasers is one of the most important applications for diode lasers. The key criteria for diode laser pumping in solid state lasers are 1) efficient transport of pump power to the gain medium; 2) efficient absorption of pump radiation; 3) high uniformity of absorbed pump power density. Therefore, one should select diode laser pumping source with the right wavelength, narrow spectral width, proper beam distribution, and high reliability. kW-level diode lasers are used for pumping high power solid state lasers and they are made of multiple diode laser arrays (bars). They are typically in the form of a vertical stack, a horizontal array or an area array. The thermal, thermal stress and optical effects influence the performance of the kW-level diode lasers significantly. The fabrication process is rather complicated and the failure analysis is very important in achieving high reliability. In this paper, the key aspects, such as thermal management, thermal stress analysis and management, processes development, failure analysis and reliability evaluation, in developing kW-level diode lasers for solid state laser pumping are studied.

Thermal management of high power diode lasers is critical since the junction temperature rise originating from large heat fluxes strongly affects the device characteristics. Thermal modeling and analysis of kW-level diode lasers are presented. Thermal management techniques for reducing the junction temperature of the kW-level diode laser are proposed, including optimization of the packaging structure and materials.

Thermal stress is one of the most critical problems in packaging of kW-level diode lasers, which can have significant effects on wavelength, spectrum, polarization and “smile” of the device. The thermal stress is mainly caused by the coefficients of the thermal expansion (CTE) mismatch between the mounting substrate and laser bar. The formation of thermal stress in high power semiconductor laser is discussed, and approaches to reduce the thermal stress are proposed.

The packaging process is important in developing high power diode lasers. Solder voids may be generated during the die bonding process, and becomes worse due to the electro-migration of Indium solder at the high driving current. In additional, the beam quality of the laser is reduced sharply by the collimated beam pointing error caused during laser packaging process. Hence, the voids free bonding technology and beam control have been studied and implemented in the die bonding process.

High reliability is one of the most important requirements for diode lasers. There are multiple causes for the diode laser to fail during operation. Therefore, it is important to analyze and identify the root causes for laser failures and provide effective solutions to improve the reliability of the semiconductor laser. In this paper, different failure modes of diode lasers are introduced. By analyzing these failure modes, some approaches to improve reliability of the diode lasers are demonstrated.

The diode laser vertical stacks are chosen as the typically laser source for solid state laser pumping. The output power of the diode laser stack fabricated by multiple laser bars can reach several thousand watts CW power and tens of Watts QCW power. Based on the technologies discussed above, G-stack with 30 bars and V-Stack with 60 bars are fabricated and tested, as shown in Fig.1. The results indicated that the devices have the advantages of high power, high reliability and excellent beam directivity, which are suited for solid state laser pumping.

![G-Stack with LIV testing result (top) and V-Stack with LIV testing result (bottom)](Fig. 1. G-Stack with LIV testing result (top) and V-Stack with LIV testing result (bottom))