High Power Laser Diodes

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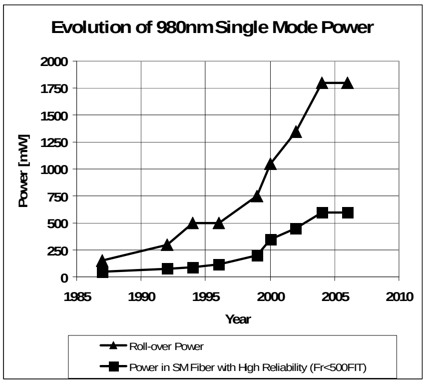
In the recent past tremendous progress has been made in the area of high power laser diodes. We will review the state of the art in the field of 9xxnm high power laser diodes and will discuss new requirements as well as physical and engineering limits.

High power laser diodes have been far too weak to be used directly for industrial applications, such as marking and material processing (brazing, annealing, welding and cutting of steel). Therefore, high power diode lasers were (and still are) mostly used only indirectly to power up the lasing crystals of high power DPSS lasers, mostly as 808nm bars for YAG rods, and, more recently, 940nm bars for YAG disks. The 808nm application makes poor use of the diode capability, the 940nm application is already much better matched to the laser diode. However, but both systems still rely heavily on open space opto-mechanics (a hybrid assembly of open diodes, free space lenses and mirrors) and on micro channel cooling for heat removal, both with its associated reliability challenges.

Electronic technology (transistors and VLSI integration), originally developed for electronic data processing, has revolutionized power electronics and we see today that photonic technology (pigtailed hermetic lasers, passive cooling, active fibers), originally developed for data transmission, is on the verge of revolutionizing Power Photonics. With these building blocs from telecom technology, fully integrated systems (with neither open space opto-mechanics nor micro channel cooling) can reach now power levels for material processing with full solid state reliability and cost savings. Fiber lasers cover the power and beam quality range needed for material processing while direct diode systems are still limited to lower power applications. The two key elements of the Power Photonic technology are undoubtedly, the active Yb fiber and the 9xxnm single emitter (100um wide stripe) diode laser.

The high power 980nm single mode narrow stripe laser diodes, first developed for frequency doubling in KTP 20 years ago, in 1987, delivered reliable 50mW in a single mode fiber. This power level was increased by more than an order of magnitude thanks to the telecom development drive to 600mW in a single mode fiber (with a reliability <500FIT) within one decade.



Evolution of 980nm power in single mode fiber with telecom reliability. Each points represents one generation (courtesy Bookham Switzerland AG)

The latest (and last for the foreseeable future) product in the development pipeline, G08, a narrow stripe InGaAlAs ridge waveguide laser, was released in 2004 with a roll-over power of close to 2000mW and a reliable 600mW power in a single mode fiber pigtail. Over this period many other design variants (phased arrays, surface emitters, MOPA, alpha laser, Z-laser, taper laser and VCSEL) and other (aluminum free) material systems were investigated for high power single mode operation. Due to a lack of reliability, beam stability, power conversion efficiency and ease of fiber coupling, none of these designs has gained any commercial use and today's high power single mode diode lasers are all based on the narrow stripe design. Arrays of such single mode lasers can be used for industrial applications and, in addition, the single mode development provided the bases for the improvement of single broad stripe emitters during the last few years.

Today, single emitter broad stripe (90um emission area, matched to a NA=0.15, 105um core MM fiber) 9xx pump diodes are available with up to 8W of reliable CW power and with roll-over power in excess of 20Watts. Due to the improvement of power conversion efficiency (70%), the stripe geometry and the cavity length these diodes can be used with passive cooling, i.e. they operate without micro-channel cooling. The performance is achieved by fully utilizing length scaling of edge emitters. Today it is believed that length scaling (and thus available power and power conversion efficiency) is finally limited by the material parameters (ratio of mobility to free carrier absorption) and process capability to implement a delicate design (index as well as doping profile of the vertical structure). The lateral beam quality can be as low as NA=0.12 and is limited by small index variations across the width of the active stripe. Care must be taken to avoid any inhomogeneities and by keeping the effective alpha "material factor" (ratio of real index to imaginary index change) as low as possible. Such can be switched on and off with high speed, high contrast and no impact on reliability because their small size (soldered with AuSn). These single emitter broad stripe diodes, hermetically pigtailed to a 100um MM fiber (single or multiple diodes in one package) are and will be the main driving engine for Power Photonics, analogous to the MOSFET for Power Electronics.

More power can be achieved if the emission area is widened; a standard width of such a laser bar is 1cm. Usually, the 1cm wide emission area is broken up in an array of single emitter stripes with fill factors of typically 50%. Reliable power levels of 150W emission and record power levels in excess of 500W have been demonstrated at 9xxnm. Even tough bars have a very high conversion efficiency (>70%) a very high density of dissipated power is generated. This massive amount of dissipated power has to be removed by mounting the bars on micro channel coolers which are still very delicate to operate (expansion mismatch to the diode and erosion and galvanic degradation if operated outside the optimum window). Very high performance application will easily deal with the micro-channel coolers, but, today there is consensus that bars will only become widely used in the future if they are improved so much in performance that the dissipated heat can be removed with passive coolers at the required optical output power levels.

Fully integrated Power Photonic systems (no open free space optics) have reached today power levels for material processing across the board. These systems are based on high power and highly efficient diode lasers and it is believed that with further improvement (power conversion, efficiency and commercial aspects) these systems will become even more attractive. Integrated Power Photonic systems have a good chance at replacing the free space optics high power lasers (rod and disk YAG) in many areas in the next few years and even be able to compete with CO_2 lasers.