85% Power Conversion Efficiency 975-nm Broad Area Diode Lasers at – 50°C, 76 % at 10°C

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Abstract: Optimized single stripe 975-nm broad area devices deliver 76% power conversion efficiency at 10°C. Cooling the material leads to 85% efficiency at –50°C. External differential quantum efficiency is the dominant term.

OCIS codes: (140.2020) Diode Lasers; (230.5590) Quantum-well devices; (140.5960) Semiconductor lasers

1. Introduction

The power conversion efficiency of high power diode lasers is of critical importance to many commercial applications. High power conversion devices result in lower levels of waste heat being left in the device, minimizing cooling requirements and maximising useful lifetime and useful optical output. Recent publications demonstrate power conversion efficiency in excess of 70 % from high power 1-cm laser diode bars and single emitters [1]. Testing of diode lasers to cryogenic temperatures (< 200 K) helps diagnose the physical mechanisms limiting the performance of diode lasers [2] and also reveals the maximum possible performance [3].

2. Device Construction and Test Approach

High power diode laser wafers were grown on GaAs substrates using a commercial low-pressure MOCVD reactor using the Al-In-Ga-As-P system. These were fabricated into 200-um stripe broad area single stripe devices, cleaved to 1-mm cavity length and high and low reflectivity coatings were applied to back and front facets respectively. Devices were bonded junction down on industry standard c-mount heat-sinks. Optical power was measured using a Labsphere SC5500 integrating sphere system, referenced to NIST power standards. Cryogenic testing was performed in a Janis Research SuperTran cryostat.

3. 83.5% Power Conversion Efficiency High Power 975-nm Broad Area Diodes at 138K

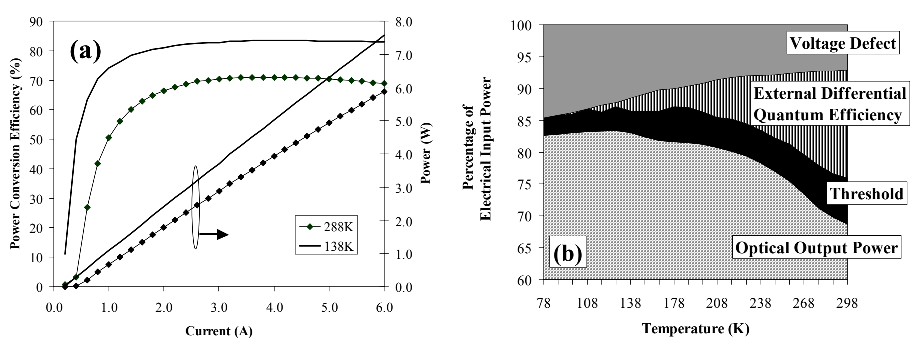

Fig. 1. (a) Power conversion efficiency of a 200-um stripe diode laser at 138K and 288K. (b) Temperature dependence of main terms limiting efficiency

Detailed measurements of the temperature performance were performed on one selected 975-nm broad area laser diode. Power conversion efficiency, PCE, is defined as PCE = (optical output power) / (voltage applied x current drawn) and is plotted in Fig. 1(a), along with the optical output power. The part tested had a peak power conversion efficiency of 71 % at 288 K heatsink temperature and cooling the material further improves the efficiency, reaching 83.5 % at 138 K, as shown in Fig. 1(a).

Numerical analysis of the test data reveals how the major terms limiting efficiency evolve over temperature, shown in Fig. 1(b). The voltage defect is the voltage in excess of the lasing wavelength of the device. The external differential quantum efficiency, η_D, is extracted from the slope of the light-current curve. The slope gives Watts per Amp. Scaling by the energy of the photon gives η_D. The laser threshold can simply be read off from the light-current curve. The most important limit to PCE at high temperatures in this device is η_D and this is eliminated at low temperatures, as shown in Fig. 1(b). However, as temperature reduces, the voltage degrades eliminating much of the benefit of improved η_D. Threshold also falls, but has a relatively small overall effect. Similar values of η_D have been demonstrated in VCSELs at cryogenic temperatures [3] – however high device resistance in these devices limits the peak PCE to 35%.

4. Optimized Structure Shows 76% PCE at Room Temperature, 85% PCE at –50C

The temperature dependence of η_D and threshold are compared in Fig 2(a). Both improve, with a clear link seen in the temperature characteristic, indicating that the quantum well limits PCE. By careful optimization of the characteristics of the quantum well, improved single stripe laser devices have been produced with 76.0 % PCE at 10°C. The PCE improves at low temperature, peaking at 85% at –50°C, shown in Fig. 2(b).

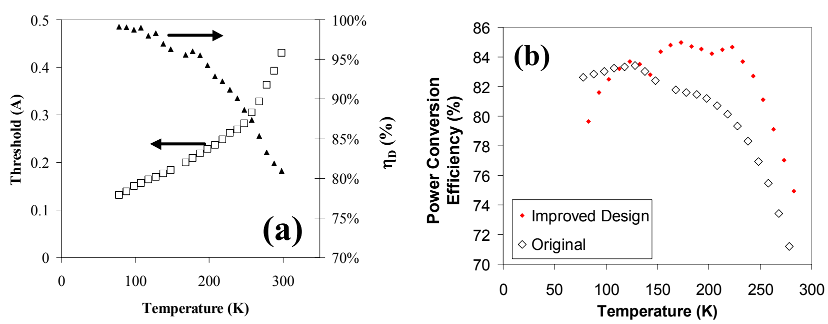

Fig. 2. (a) The temperature characteristic of threshold and external differential quantum efficiency, η_D, are closely linked. (b) Power conversion efficiency for an improved 975-nm device measured over temperature.

5. Summary

Cryogenic testing demonstrates that power conversion efficiency is mostly limited at higher temperatures by external differential quantum efficiency, η_D. Careful analysis shows that η_D is tied closely to the laser threshold current, and hence to the characteristics of the quantum well. Optimization based on these insights has yielded a device with 76 % peak efficiency at 10°C and 85% at –50°C.

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