3 W – broad area lasers and 12 W – bars with conversion efficiencies up to 40% at 650 nm

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***Abstract*—650 nm broad area diode lasers with an output power of 3 W and a conversion efficiency of 40% at 15°C are presented. 5 mm wide laser bars reach 12 W output power.**

I. INTRODUCTION

Red-emitting high-power laser diodes are key components for laser display technology, photodynamic therapy, and analytical systems based on fs-Cr:LiSAF/Cr:LiCAF solid-state lasers.

Broad area (BA) lasers and bars emitting at 650 nm are reported by Orsila *et al.*[1], OSRAM[2], Osinski *et al.*[3], and Imanishi *et al.*[4]. These results are achieved with devices having a large vertical far-field angle of 40° (FWHM). For BA-lasers (100 µm x 1 mm) as best result an output power of $P = 2$ W and a conversion efficiency of 37% were published[1]. For passively cooled bars at 630 nm an output power of 11.5 W at T = 10°C was achieved[3]. A conversion efficiency of 30% was given for actively cooled bars at T = 10°C.

In this paper results for highly-efficient BA-lasers and bars emitting around 650 nm with a small vertical far field of only 31° (FWHM) more suitable for efficient beam shaping will be presented. The conversion efficiency and maximal output power surpass the values reported up to now. The laser design, the fabrication process, the electro-optical properties, and results on long time stability will be given.

II. DEVICE STRUCTURE, FABRICATION, MOUNTING

The structure is based on an InGaP single quantum well (SQW) active layer embedded in AlGaInP waveguide layers. The thickness of the AlInGaP waveguide layers, d_{wg}=1 µm, is chosen for a small vertical divergence. The n-cladding layer consists of the commonly used AlInP whereas the p-cladding layer is formed by an $Al_{0.85}Ga_{0.15}As$ layer. The replacement of the p-AlInP layer by AlGaAs results in a slightly lower barrier height. However, the AlGaAs layer has a higher thermal conductivity and allows a higher p-doping level resulting in a lower series resistance. Furthermore, well-established AlGaAs processing tools can be used[5]. The vertical far field angle of this structure is 31° (FWHM).

The electro-optical data for this structure were determined from uncoated 100 µm stripe devices of different lengths. The transparency current density is j_{TR} = 220 A/cm^2, the modal gain Γg_0 = 18 cm^{-1}, the internal efficiency η_i = 0.83, and the internal losses are α_i = 1.0 cm^{-1}. 1 mm long devices show a threshold current of I_{th} = 444 mA and a differential efficiency of η_D = 0.77. The characteristic temperature of the threshold current is T_0 = 55 K.

Low-mesa structures were fabricated in the stripe region using selective etching of the contact layer and the p-doped cladding layer. The wafer was cleaved to obtain a laser length of 1500 µm. The facet coating was performed including a facet passivation as described by Ressel *et al.*[6]. The front facets of the devices were AR and HR coated (4% and 94%, respectively). The lasers were soldered (epi-side down) on expansion matched CuW submounts with AuSn. The subassemblies are mounted on Cu heat sinks using PbSn. The n-side contact has been performed by wire bonding. This package has a thermal resistance of about 8 K/W for 100 µm stripe lasers and 2 K/W for 5 mm bars consisting of ten 100 µm stripe lasers.

III. RESULTS FOR BROAD AREA LASERS

In Fig. 1 the power-voltage-current characteristic for a 100 µm stripe width BA-laser in the temperature range -10°C ≤ T ≤ 15°C is given.

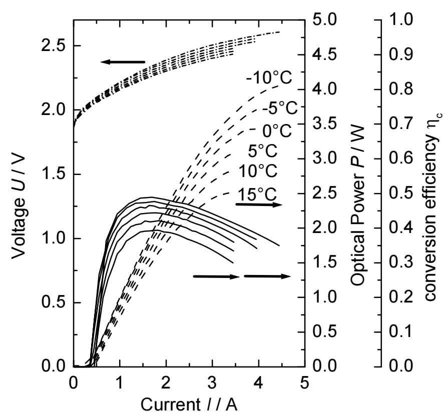

Figure 1: Power-voltage-current characteristics for a 650 nm BA-laser 100 µm x 1.5 mm at –10°C ≤ T ≤ 15°C

At T = 15°C the threshold current is I_{th} = 500 mA corresponding to a current density of j_{th}=333 A/cm². The slope efficiency is S = 1.2 W/A. The maximum output power is limited by thermal rollover to 2.5 W at I = 3.4 A and a maximum conversion efficiency of 39% at P = 1.6 W was measured. A reduction of the temperature down to -10°C decreases the threshold current to 350 mA (j_{th}=233A/cm²), increases the slope efficiency to 1.4 W/A, the maximum output power to 4.0 W, and the conversion efficiency to nearly 50% at 2 W.

The result of an aging test at T = 15°C is given in Fig. 2. All diodes survived the test at output powers larger than 600 mW. Even at 800 mW, the 100 µm-stripe width lasers do not show any degradation within 570 h (facet load 8 mW/µm).

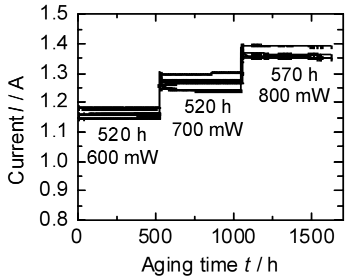

Figure 3: Aging test for five 650 nm BA-lasers 100 µm x 1.5 mm at T = 15°C (mounted on CuW)

A further increase of maximum output power was achieved by a package with a CVD-diamond heat spreader and a larger Cu heat sink. The thermal resistance for this package is 5.5 K/W. The improvement in the maximum output power to P = 3.1 W can be seen in Fig. 3, where the power-voltage-current characteristic at T = 15°C is given. The measured efficiency of the mounted laser is slightly lower due to the higher series resistance of the non-optimized CVD-diamond metallization.

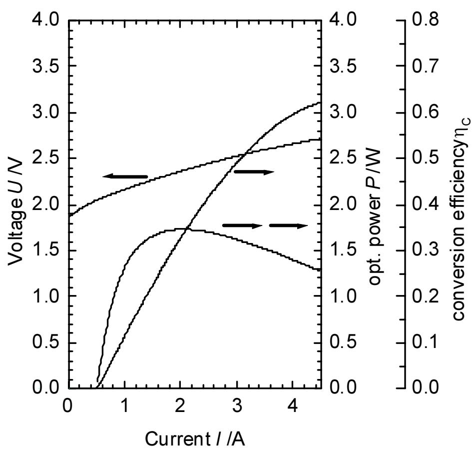

Figure 3: Power-voltage-current characteristic of a 100 µm x 1.5 mm 650 nm BA-laser at T = 15°C mounted on CVD-diamond submount

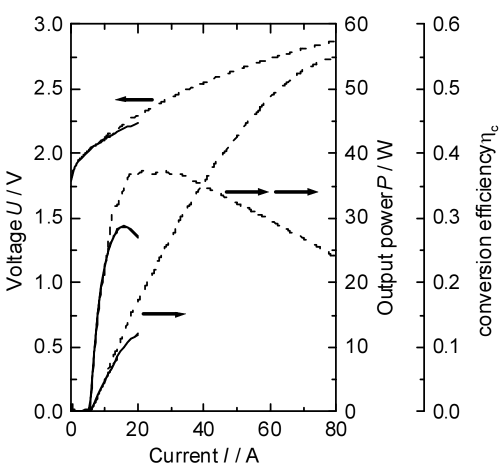

Figure 4: Power-voltage-current characteristics of a 5 mm wide ten emitter 100 µm x 1.5 mm bar at T = 15°C;
Solid lines: CW-operation;
Dashed lines: pulsed operation at 150 µs, 10 Hz

IV. Results for 5 mm wide Laser Bars

5 mm wide laser bars with ten 100 µm stripe width lasers were mounted on CuW submounts. In Fig. 4 typical power-voltage-current characteristics in CW-operation and in pulse mode are given. In CW-operation the threshold current is 5.8 A, the slope efficiency 1.1 W/A. The maximum output power for this passively cooled bar is P = 12.1 W, the best conversion efficiency is 0.29 at P = 10 W. Aging experiments show a good reliability at P = 5 W over now 2000 h.

The excellent facet stability is illustrated by the measurement under pulsed conditions (τ = 150 µs, f = 10 Hz). A maximum output power of P = 55 W at I = 80 A was measured, corresponding to more than 5 W per emitter.

V. Conclusion

High power broad area lasers and bars for the wavelength range near 650 nm were developed. At T = 15°C a maximum output power of P = 3.0 W from a 100 µm stripe width laser and of 12.0 W from a 5 mm bar were achieved in CW-operation. In pulsed excitation the laser bar was capable to emit 55 W maximum output power, illustrating the high stability of the laser facets of up to 55 mW/µm. For the broad area lasers at 15°C a maximum conversion efficiency of 40% was measured. To the best of our knowledge, these data represent the highest measured output powers and the best conversion efficiencies for 650 nm lasers.

Moreover reliable operation at a facet load of 8 mW/µm was shown, which is the highest reported value for such short wavelength lasers. Aging tests at higher output power are in progress and will also be reported.

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