5-W Reliable Operation Over 2000 h of 5-mm-Wide 650-nm AlGaInP–GaInP–AlGaAs Laser Bars With Asymmetric Cladding Layers

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***Abstract*—Reliable operation of 650-nm laser bars with GaInP quantum wells embedded in AlGaInP waveguide layers and n-AlInP and p-AlGaAs cladding layers is reported. The 5-mm-wide bars consisting of ten emitters with 100-μm-wide stripe width showed reliable operation over 2000 h at 5 W.**

***Index Terms*—Continuous-wave (CW) lasers, laser reliability, red laser bars, semiconductor lasers.**

I. INTRODUCTION

HIGH-POWER red-emitting laser diodes are required for the pumping of Cr : LiSAF–Cr : LiCAF solid-state lasers, laser display technology, and for photodynamic therapy. Up to now, these devices suffer from relatively large vertical far-field angles above 40° [full-width at half-maximum (FWHM)] and relatively small wall-plug efficiencies.

Red emitting laser bars were reported by Osinski *et al.* [1]. At a wavelength of $\lambda \approx 637$ nm, an output power of $P = 15$ W at $T = 10°$C from an actively cooled 10-mm laser bar was shown. Due to the temperature sensitivity of the devices, a passively cooled bar reached only $P = 12$ W. The wall-plug efficiency of the actively cooled device was 30%. Aging tests showed a reliable operation over 700 h at $T = 15°$C and $P = 3$ W from a fiber-coupled device. Assuming a coupling efficiency of about 70%, one can assume a reliable output power of $P = 4.3$ W, i.e., a facet load (= output power per stripe width) of about 4.3 mW/μm. Imanishi *et al.* [2] presented red emitting laser bars at 644 nm. For a 10-mm laser diode array consisting of 25 emitters with 60-μm stripe width, a maximum output power of $P = 10$ W and a wall-plug efficiency of 15.4% was reported. The vertical far field was 38° (FWHM). Reliable operation over 900 h at $T = 15°$C and $P = 7$ W (facet load: 4.7 mW/μm) was reported [3].

For 100-μm stripe width broad-area lasers at 650-nm reliable operation at $T = 15°$C and $P = 250$ mW over 1000 h was reported by Orsila *et al.* [4]. At $T = 20°$C and $P = 500$ mW in [5], a lifetime of 4000 h is given. Here the facet load of 5 mW/μm is slightly larger than for the bar devices.

In comparison to these broad-area devices, narrow stripe width lasers have usually a higher facet load. An example for this is reported for devices manufactured with a much more sophisticated technology, including two-step epitaxy, buried heterostructures, and nonabsorbing mirrors by Onishi *et al.* [6]. They reported up to 150-mW kink-free output power from a 2.5-μm stripe width laser, i.e., 60-mW/μm facet load.

In this letter, we present reliable operation diode laser bars manufactured with a standard bar technology. These passively cooled high-power laser bars emitting at a wavelength of about 650 nm have a vertical far field of only 32° (FWHM) and wall-plug efficiencies up to 30%. Information concerning the design and fabrication process, the power-current-voltage characteristics, and the spectral behavior will be given. The long time stability of these devices at a facet load of 5 mW/μm over more than 2000 h will be presented.

II. LASER STRUCTURE AND FABRICATION

The design of the structures for red emitting lasers is more challenging compared to longer wavelength devices. The major reason is the smaller barrier height for electrons and holes. This results in higher temperature sensitivity and smaller wall-plug efficiencies. The Zn-doping of the typically used AlInP cladding layers limits the maximum doping concentration to below 5×10^{17} cm^{-3}. A Zn oversupply leads to Zn diffusion towards the quantum well and thus to a deterioration of the quantum well. One possible solution of this problem was presented in [6]. Here magnesium doping of the AlGaInP cladding was used for the manufacturing of narrow stripe width laser diodes.

In our case, an asymmetric layer structure was developed to overcome these problems [7], [8]. The active layer, consisting of a $Ga_{0.55}In_{0.45}P$ double quantum-well (DQW), was embedded in $Al_{0.36}Ga_{0.16}In_{0.48}P$ waveguide layers. The n-side cladding layer was formed by $Al_{0.52}In_{0.48}P$, but the p-side cladding was made from $Al_{0.85}Ga_{0.15}As$. This allows this layer to be doped with carbon, which is much less prone to diffusion. An additional advantage is that the application of a standard AlGaAs device process becomes possible.

The vertical far field of the DQW laser structure used for the manufacturing of the laser bars is given in Fig. 1. The vertical far-field angle is 32° (FWHM); the width measured at the $1/e^2$-value is 57.5° (95% of power). The threshold current density for an uncoated 100-μm-wide and 750-μm-long device is $j_{\mathrm{th}} = 620$ A/cm^2, and the differential efficiency η_D is 81%.

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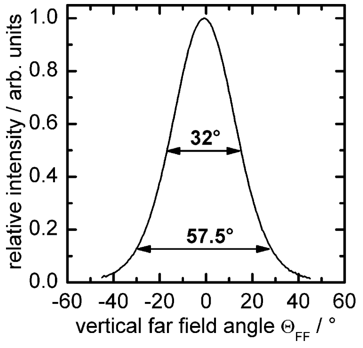


Fig. 1. Vertical field of the 650-nm laser structure.

Typically, the characteristic temperature of the threshold current T_0 is about 60 K, the transparency current density is $j_{\rm TR} = 390\ {\rm A/cm^2}$, and the modal gain $\Gamma g_0 = 34\ {\rm cm^{-1}}$. The internal efficiency was $\eta_i \approx 0.86$ and the internal losses $\alpha_i \approx 1.5\ {\rm cm^{-1}}$.

This layer structure was processed into 10-mm-wide bars containing 19 single emitters with 30-, 60-, and 100-μm stripe width. The pitch was 500 μm.

Low-mesa structures were fabricated in the stripe region using reactive ion etching of the contact layer and the p-doped cladding layer. Outside the stripe, an insulator layer was deposited. The p-side contact was formed by evaporating a Ti–Pt–Au contact.

The wafer was cleaved to obtain a laser length of 750 μm. The front facets of the devices were antireflection- and high-reflection-coated (10% and 94%, respectively) including a facet passivation as described by Ressel *et al.* [9], [10]. From this coated material, laser bars were cleaved to a width of 10 or 5 mm. These bars were soldered with AuSn p-side (epi-side) down on CuW heat spreader. This subassembly is mounted on conductively cooled copper heat sinks (dimension: $25 \times 25 \times 7.5\ {\rm mm^3}$) by PbSn soldering. The n-side contact was wire bonded.

For the experiments presented in this letter two types of laser bars were investigated. Type A bars have a width of 10 mm and contain 19 emitters with 30-μm stripe width, while Type B are devices with 5-mm width and ten emitters with 100-μm stripe width. All bars have a length of 750 μm.

III. EXPERIMENTAL DATA

Fig. 2 shows the power–voltage–current characteristic for a bar of Type A and a bar of Type B. For the Type A bar the threshold current is $I_{\rm th} = 2.6$ A, the slope efficiency is $S = 1.17\ {\rm W/A}$. At $P = 7$ W, the conversion efficiency is $\eta_C = 0.32$. A maximum output power of 9.7 W was reached at 12.2 A. At higher currents catastrophic optical mirror damage (COMD) failures occurred on single emitters. The maximum short-time facet load was about 17 mW/μm.

For the Type B bar the threshold of the devices is about a factor of two larger ($I_{\rm th} = 4.8$ A) as expected from the ratio of the active area. The slope efficiency is $S = 1.1\ {\rm W/A}$. For this type the output power is limited by thermal rollover. Due to this, the conversion efficiency is smaller ($\eta_C = 0.23$).

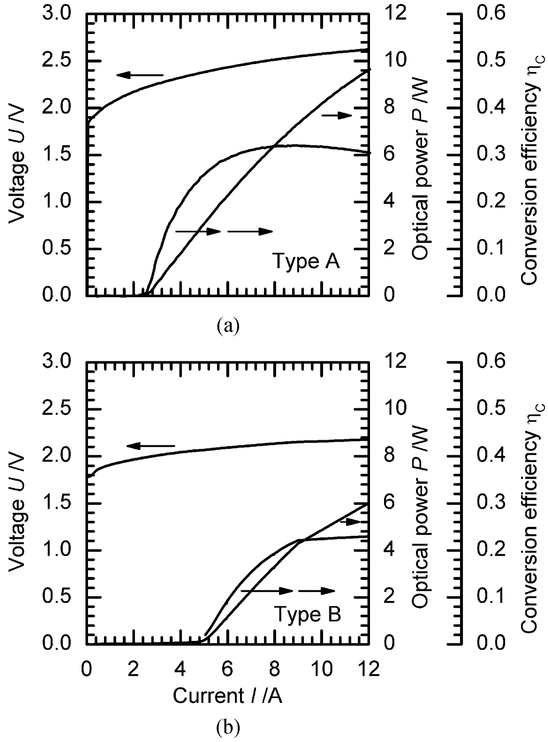


Fig. 2. Power–voltage–current characteristics for two types of 650-nm laser bars at $T = 15\,^\circ{\rm C}$: (a) Type A: 10 mm wide, 19 emitter with 30-μm stripe width. (b) Type B: 5 mm wide, 10 emitter with 100-μm stripe width.

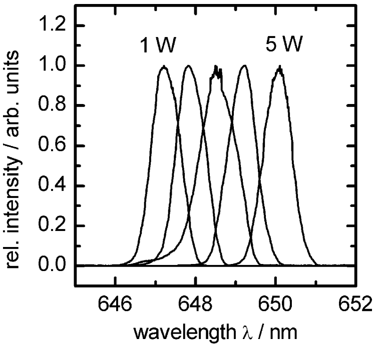


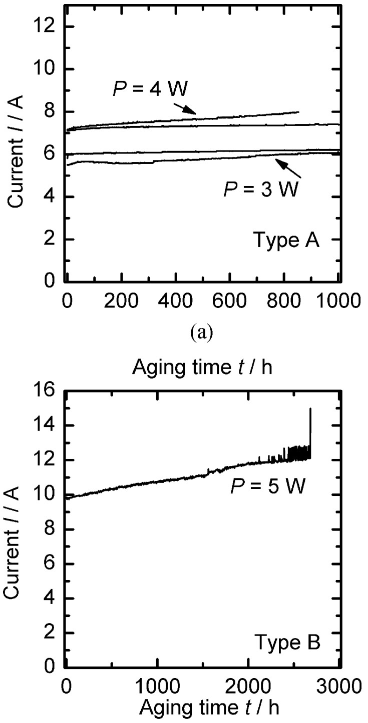
Fig. 3. Spectra of Type A 650-nm laser bars at $T = 15\,^\circ{\rm C}$ and $P = 1$ W, 2, 3, 4, and 5 W.

A spectrum for a Type A laser bar is given in Fig. 3. It can be seen that from $P = 1$ W up to $P = 5$ W the peak wavelength shifts from 647.2 nm up to 650.1 nm, i.e., about 0.7 nm per 1 W of output power. The spectral width in all cases is smaller than 0.8 nm. From the tuning dependence of the peak wavelength on the heat power, the thermal resistance of the mount could be determined. The thermal resistance for the Type A device is 2.2 K/W.

IV. AGING TEST

Finally, four bars from Type A and one bar of Type B were tested concerning their long-term stability. The results of these experiments are compiled in Fig. 4.

The two bars which were tested at 3-W output power do not show any degradation over a time of 1000 h. The facet load in this test was 5.3 mW/μm. The current increase to keep the output power constant was smaller than 0.6 A, i.e., the aging rate over the whole test is smaller than $1 \times 10^{-4}\ h^{-1}$.



(a)

(b)

Fig. 4. Aging test at $T = 15°\mathrm{C}$. (a) Bars of Type A. (b) Bar of Type B.

At $P = 4$ W, a lifetime of 1000 h could be demonstrated for one of the two tested bars. The second device failed after 820 h. The facet load in this experiment was 7.0 mW/μm.

A laser bar of Type B was tested at 5 mW/μm, i.e., 5-W output power. In Fig. 4(b) the result is given. Reliable operation over more than 2100 h was observed. During this time a monotonous increase of the excitation current of about 2.4 A occurred, i.e., an aging rate of $1.2 \times 10^{-4}\, h^{-1}$ was determined. This value is comparable to the rate for the Type A bars tested at $P = 3$ W. This shows that at comparable current densities and at a comparable facet load, the aging rate is identical. After 2100 h the laser current necessary to reach $P = 5$ W fluctuates, and finally after 2680 h the bar failed. The reason for the defect was COMD of four emitters.

The obtained lifetime at this output power and facet load is to the best of our knowledge, the highest reliability reported for 650-nm laser bars.

V. CONCLUSION

High-power laser bars for the wavelength range near 650 nm were successfully developed. A maximum output power $P = 9.6$ W from a 10-mm bar was achieved.

Reliable operation at a facet load of 5 mW/μm over 2100 h was shown. The 1000-h operation at 7 mW/μm was demonstrated.

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