

Passively cooled 940 nm laser bars with 73% wall-plug efficiency at 70 W and 25°C

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940 nm laser bars with a vertical divergence of 27° (FWHM) and a filling factor of 30% were operated on passively cooled heatsinks at 25°C. The maximum output power was 95 W, the maximum wall-plug efficiency was 73% at 70 W. Reliability CW and quasi-CW operation up to 98 W was demonstrated.

Introduction: Owing to remarkable improvements in recent years, diode lasers with high output power and low cost per watt are becoming key devices in industrial laser based material processing, medical applications and solid-state laser pumping. Commercially available laser bars now have output powers of 40–80 W on actively cooled (i.e. micro-channel) heatsinks, depending on the wavelength and the filling factor [1, 2]. Laser bars on passively cooled heatsinks (CCP) emit 30–50 W [3]. Because of the high costs and the limited reliability of the commonly used actively cooled heatsinks, there is a strong need for laser bars with very high efficiency to realise >80 W output power on conductively cooled packages. Wall-plug efficiencies of laser bars reported to date are about 50–65% [4–6] depending on the laser wavelength and the mounting technique.

This Letter presents laser bars with wall-plug efficiency of >70% and CW output power of 100 W at 100 A current without the need of active cooling. The laser bars, mounted on passive heatsinks, combine such high efficiencies with a low far-field angle and a small filling factor for low-cost lateral beam shaping. Reliability tests at output powers of 70–98 W are presented in continuous-wave (CW) and pulsed operation.

Design and fabrication: The MOVPE-grown lasers have a waveguide structure of $Al_{0.35}Ga_{0.65}As/Al_{0.7}Ga_{0.3}As$ and an InGaAs quantum well embedded in GaAsP barriers. Using a multi-wafer planetary MOVPE reactor, the uniformity of the layer stack over the 3-inch wafer is excellent. The wavelength variation of the quantum well emission is as low as 1 nm over the wafer, excluding the 3 mm wafer edge. For the characterisation of the epitaxial layer structure, broad-area lasers with 100 μm stripe width, different resonator lengths and cleaved facets were fabricated. From the dependence of the differential efficiency on the resonator length the internal efficiency is determined at 99%, and the internal losses at less than $1 cm^{-1}$. From the threshold current density dependence on the resonator length the transparency current density is extrapolated to 75 A/cm². The fast axis divergence angle is 27° (FWHM). 95% of the output power is included in an angle of 48°.

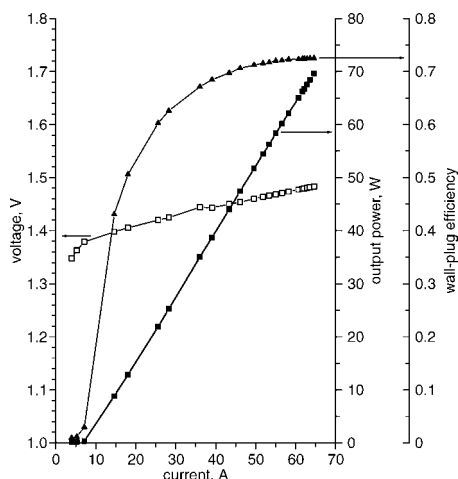


Fig. 1 Voltage-, output power-, and wall-plug efficiency-current characteristics of a passively cooled laser bar ($L = 1.5$ mm, $w = 150$ μm) in CW operation at 25°C

The 10 mm-wide laser bars have a resonator length of 1.5 mm and 19 emitters, each with a width of 150 μm . The filling factor is 30%. Facets were cleaved in air, passivated as described in [7], and coated for 6% and 94% reflectivity. The laser bars were soldered p-side down

onto CuW heat spreaders using hard AuSn solder. The CuW heat spreader was then soldered onto standard Cu heatsinks using PbSn. The n-contact was made by wire bonding.

Performance of bars mounted on CCP: Fig. 1 shows the voltage-, output power-, and wall-plug efficiency-current characteristics of a mounted laser bar in CW operation at 25°C, as measured on top of the CCP. The laser bar has a threshold current of 7 A and a slope efficiency of 1.2 W/A. The measured series resistance is as low as 1.6 m Ω , leading to a wall-plug efficiency as high as 73% at an output power of 70 W and an operation current of 65 A.

To analyse the slow axis far field, a laser bar was cleaved into single emitters and mounted with the same technique as the laser bar. The divergence of the lateral far field is relatively low; it increases from 5° at an output power of 2 W to 7° at 4 W (angle with 95% power inclusion); the first value is equivalent to 40 W, the latter to 80 W from the laser bar. These small angles in the slow and fast axis direction allow low-cost beam shaping.

The laser wavelength increases from 933 nm near the threshold to 939 nm at 50 A driving current. This wavelength shift corresponds to a junction temperature increase of 20 K. From the dependence of the wavelength on the generated heat the thermal resistance of the mounting technique is determined to be <1.5 K/W.

The data shown in Fig. 1 were collected with measurement equipment where the current is limited to 65 A. To investigate higher output powers measurement equipment with a 100 A current source and a temperature controller allowing temperatures of $-10^\circ C \leq T \leq 25^\circ C$ was used. Fig. 2 shows the output-power/current characteristics against the temperature $T_{@0A}$ on the bottom side of the CCP in contrast to the previous measurement equipment. The output power increases to 90 W at 100 A for the start temperature $T_{@0A} = 25^\circ C$. Because of insufficient heat removal during the few minutes of measuring time, the temperature on the bottom side of the CCP increases to $T_{@100A} = 32^\circ C$, when the current is increased to 100 A. This insufficient heat removal is the reason for the thermal rollover of the output power. At lower starting temperatures, the impact of thermal rollover is reduced. With a starting temperature $T_{@0A} = 15^\circ C$ the bar emits more than 95 W output power at 100 A and a $T_{@100A} = 26^\circ C$ was measured. For a starting temperature of $-10^\circ C$ no thermal rollover occurs up to 100 A. The maximum output power is 104 W, reached at $T_{@100A} = 6^\circ C$.

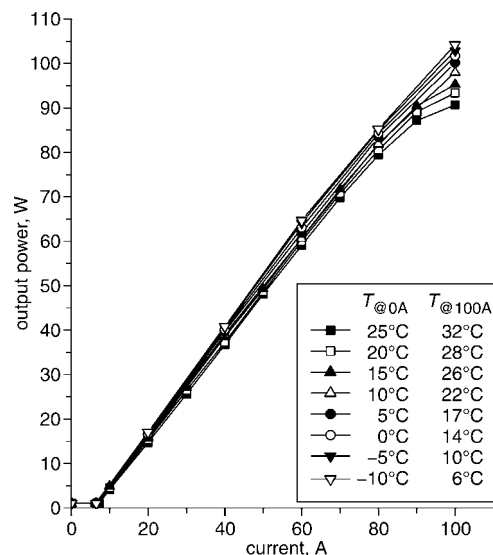


Fig. 2 CW output-power-current characteristics of mounted laser bar against cooler temperature

During measurement temperature on bottom side of the CCP increases from $T_{@0A}$ to $T_{@100A}$

Besides the high efficiency, a high stability of laser bars is essential for all industrial applications. To investigate the reliability of the laser bars, degradation tests were performed in CW as well as in quasi-CW operation. Fig. 3a shows degradation tests in CW operation of two laser bars in constant power mode at 25°C. Laser bar A was operated for 50 h at 40 W and for 250 h at 60 W. The following lifetime test at 70 W shows no degradation during more than 4400 h test time. The degradation rate is below $1 \times 10^{-6} h^{-1}$ and limited by the measurement

accuracy of the aging equipment. Laser bar B was tested at 75 W without burn-in. The degradation rate is also below the measurement limit. Both lifetime tests are still in progress.

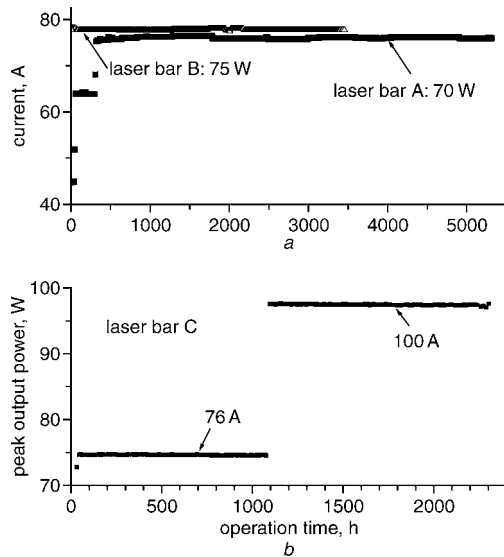


Fig. 3 Lifetime test of passively cooled laser bars at 25°C
a With constant power mode in CW operation; laser bars A and B
b With constant current mode in quasi-CW pulsed operation (repetition rate 1.7 Hz, duty cycle 1:1); laser bar C

For laser bars in industrial applications, such as materials processing, a quasi-CW pulse-mode operation is essential. Because of the temperature cycling during operation with frequencies in the Hz range, this is an even harder stress for the laser bars compared to the CW test. To simulate these more realistic conditions, laser bar C was tested in pulsed operation with 1.7 Hz repetition rate and a duty cycle of 1:1; this test was started after a CW aging test at 70 W for 1000 h without degradation. During the test time the current was switched between 0 A and the nominal current. Fig. 3*b* shows the lifetime test at 76 A and 75 W peak output power for 1080 h. Despite a power increase to 98 W at 100 A the degradation rate is still as low as $3 \times 10^{-6} \text{ h}^{-1}$ during the next 1200 h test time. This test is also still running.

Conclusions: 940 nm laser bars are reported, mounted on passive heatsinks with output powers up to 104 W at 100 A driving current despite a low filling factor of 30%. The wall-plug efficiency achieves 73% at 70 W output power. The beam divergences in fast and slow axis are quite small (48° and 7° for 95% power content). The reliability tests confirm the excellent stability of the reported laser bar structure, i.e. the epitaxial structure, the processing and especially the facet stability.

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7 December 2004

Electronics Letters online no: 20058180

doi: 10.1049/el:20058180

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