Comparative performance studies of indium and gold-tin packaged diode laser bars

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ABSTRACT

This paper is mainly dedicated to a short-time scale reliability study of different packages applied to the same type of laser diode bars: indium and gold-tin packaged laser bars are operated in cw hard-pulse mode with increasing currents until their destruction. The destruction currents serve as guide values for long-time aging tests that should be performed at lower currents. Gold-tin packaged diode lasers turn out to have clearly higher destruction currents in hard-pulse mode. This result is underlined by long-time aging tests at appropriate currents.

Keywords: high-power, diode, laser, solder, indium, gold-tin, reliability, cw, puls, mode, performance, hard-pulse

1. INTRODUCTION

Operating limits of high-power diode lasers may be classified into (A) operating power limits and (B) operating mode limits. The reliability of high-power diode lasers is a function of these (A) operating power limits – expressed in an optical output power limit $P_{opt,\max}$ or a corresponding electrical operating current limit $I_{\max}$ – and these (B) operating mode limits – expressed in a repetitive operating time τ, a repetition frequency f and a thermal power modulation depth ΔP_{th} represented by a minimum electrical current $I_{\min}$.
In this paper we restrict ourselves to continuous wave (cw) operating power and mode limits, which – in contrast to qcw and pulsed operation – correspond to an operating time that is sufficiently long to lead the diode laser across a transient thermal phase into a (nearly) stationary thermal phase. In actively cooled diode lasers minimum cw operating time is in the range of 200ms, in passively cooled lasers it is in the range of 10s. Even though repetitive cw mode operation is not a pulsed operating mode[1], for convenience, we call repetitive operating cycles in cw mode “cw pulses” or just “pulses”. Cw pulse lengths are thus commonly in the range of 200ms to 10s. Given a fixed duty cycle of 50%, the repetition rates are in the range of 0,1Hz to 5Hz. Two common power modulation modes are $I_{\min}$ = 0A and $I_{\min} = I_{thr}$ (I_{thr}: threshold current) called “hard-pulse mode” and “soft-pulse mode”, respectively, qualifying its thermal cycling ranges of load.
The operating limits of a diode laser are in principal fixed by its two constituents – the laser diode and its package. In general, a diode laser cannot be better than the weaker one of both partners.
Useful operating power limits correspond to optical output powers and electrical operating currents that are low enough to avoid immediate failures like COD in the laser diode (optical limit) or debonding of the package from the laser diode (thermal limit). Useful operating power limits do not exceed thermal roll-over (TRO) in the electro-optical characteristic of the diode laser (even though diode laser qualification can be useful beyond TRO).
Operating modes are generally specified by the applications a diode laser is used for. Pure cw mode implicates less wear for the constituents of a diode laser than soft-pulse mode. The highest wear is created in hard-pulse mode, because thermal cycling is highest. The selected operating modes will thus lead to specific operating power limits, that will be highest in cw mode and lowest in hard-pulse mode and levelled up by the quality of the laser diode and its package.

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2 STATE-OF-THE-ART INDIUM PACKAGING TECHNOLOGY

Current mounting technology of high-power diode laser bars consists of mounting laser bars epi-(p-)side down by indium soldering onto a copper heat sink and attaching a copper lid to the substrate-(n-)side[2]. The copper heat sink can be a solid block of 25 mm width by 29.5 mm length by 6 mm height for conductive ("passive") cooling (fig. 1) or a thin micro-channel cooler of 11.2 mm width by 28 mm length by 1.75 mm height for liquid convective ("active") cooling (fig. 2). As active coolers exhibit a lower thermal resistance (typically 0.5 K/W) than passive coolers (typically 0.7 K/W), optical output powers of active cooled diode lasers are generally higher (50 to 120 W cw, depending on emission wavelength) than those of passively cooled diode lasers (40 to 60W cw, depending on emission wavelength). Especially laser bars of 940 nm emission wavelength are highly reliable.

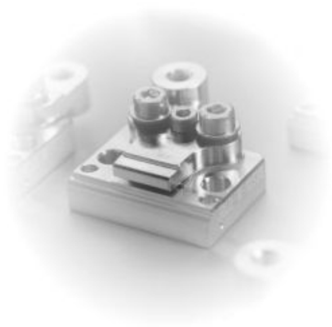


Fig. 1 (left)**:** passively cooled diode laser from *JENOPTIK Laserdiode GmbH*.
Fig. 2 (right)**:** actively cooled diode laser from *JENOPTIK Laserdiode GmbH*.

We limit ourselves to considering only 940 nm lasers in this study. Depending on the cooling and operation mode chosen – cw, soft-pulse or hard-pulse, different maximum allowable output powers have to be observed for a fixed life-time. Figures 3 to 6 show life-time tests for standard actively cooled products of *JENOPTIK Laserdiode GmbH (JOLD)* with laser diode bars from *JENOPTIK Diode Lab GmbH (JDL)*: Whereas hard-pulse mode should not be applied with a current higher than 70 A (60W, fig. 3), pure cw operation of diode lasers is possible for currents up to 130A (two different laser diode types: 120W and 125W, fig. 4). The soft-pulse mode allows for operating currents up to 110A (80W and 100W, figs. 5 and 6). In industrial production, suspicious lasers that might become defect are standardly sorted before they are shipped by *JOLDs* quality system. In research, these measures do not always fully apply for efficiency and comparability reasons.

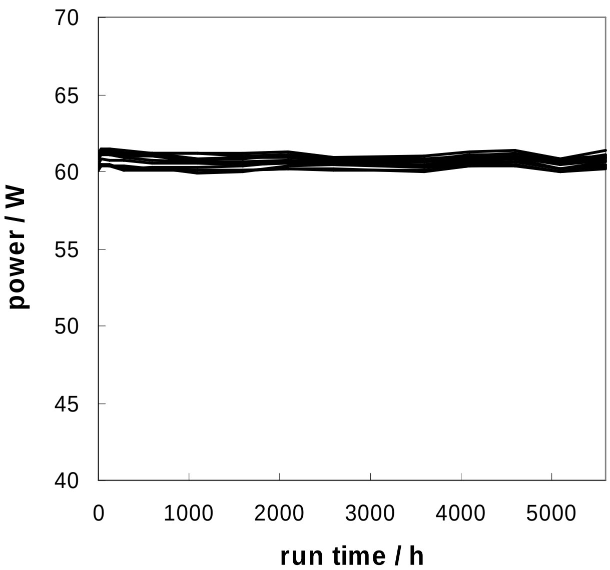


Fig. 3: Aging test of 12 diode lasers with JDL 940nm laser diode bars, 50% filling factor, 1.5mm resonator length, mounted with indium solder, actively cooled, in hard-pulse operation mode of 0-68A 500ms pulses at 1 Hz.

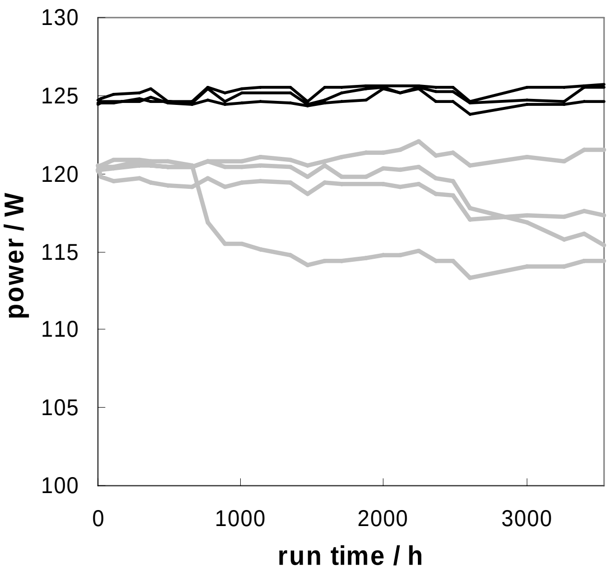


Fig. 4: Aging test of 7 diode lasers with JDL 940nm laser diode bars, 50% filling factor, 2.0mm resonator length, mounted with indium solder, actively cooled, in continous-wave operation mode of 127A.

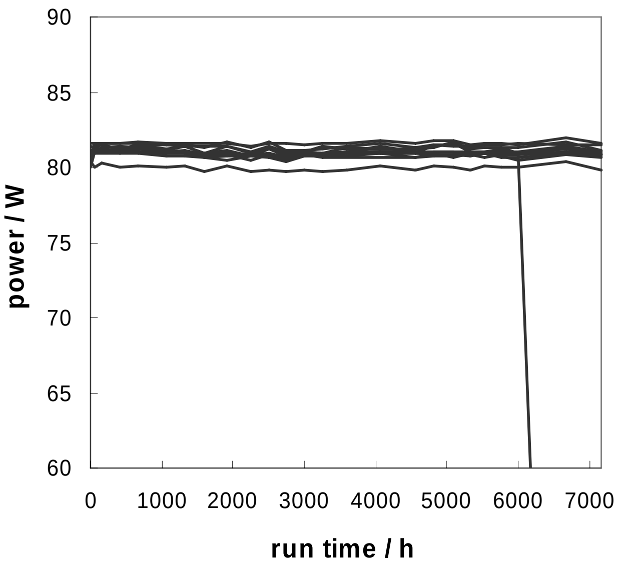


Fig. 5: Aging test of 12 diode lasers with JDL 940nm laser diode bars, 50% filling factor, 2.0 mm resonator length, mounted with indium solder, actively cooled, in soft-pulse operation mode of 15-91A 500ms pulses at 1 Hz.
Concerning the failure: see explanation in text above.

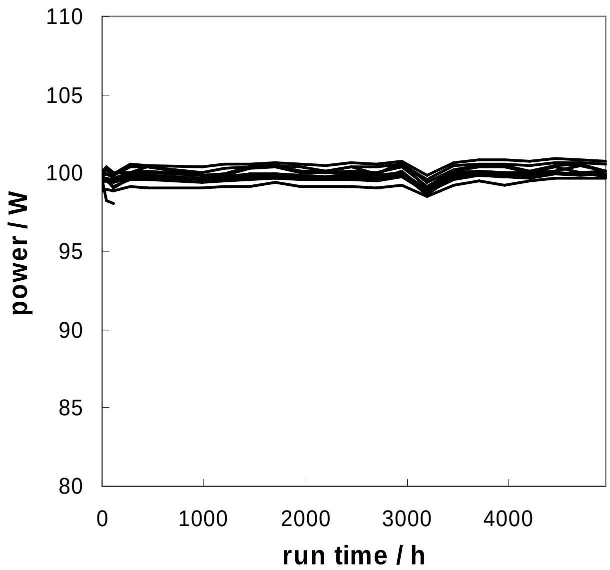


Fig. 6: Aging test of 12 diode lasers with JDL 940nm laser diode bars, 50% filling factor, 2.0mm resonator length, mounted with indium solder, actively cooled, in soft-pulse operation mode of 18-105A 500ms pulses at 1 Hz.
Concerning the failure: see explanation in text above.

3 THE CROSSOVER FROM INDIUM TO GOLD-TIN SOLDER

In favor of high reliability it is recommended to operate diode lasers in cw mode only – if possible. Nevertheless hard-pulse mode is the most efficient way to test the reliability of the laser diode package. There have been evidences that diode lasers mounted with hard gold-tin solder show a long-time hard-pulse reliability[3]. However, direct comparisons with indium solder are missing, perhaps because no institution masters both, indium and gold-tin soldering technology.
In order to conduct comparative experiments, *JOLD* changed the standard indium solder assembly in following way: The indium solder layer is replaced by a gold-tin solder layer deposited on a copper-tungsten (CuW) substrate and a tin solder preform (fig. 7).

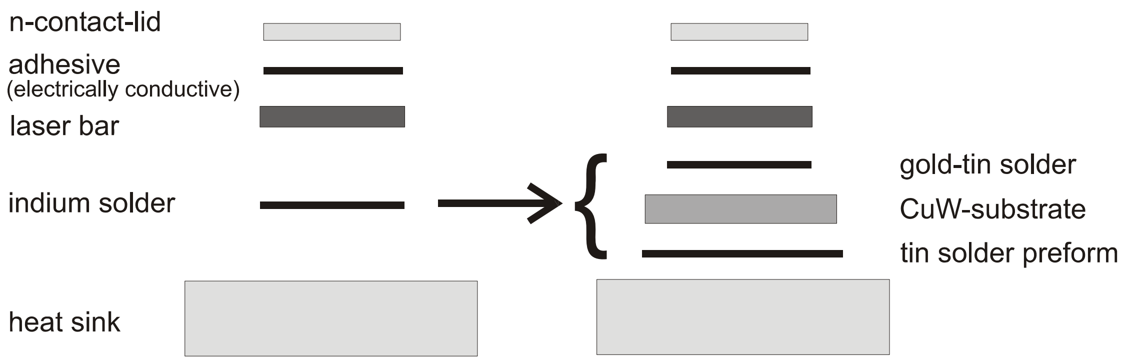
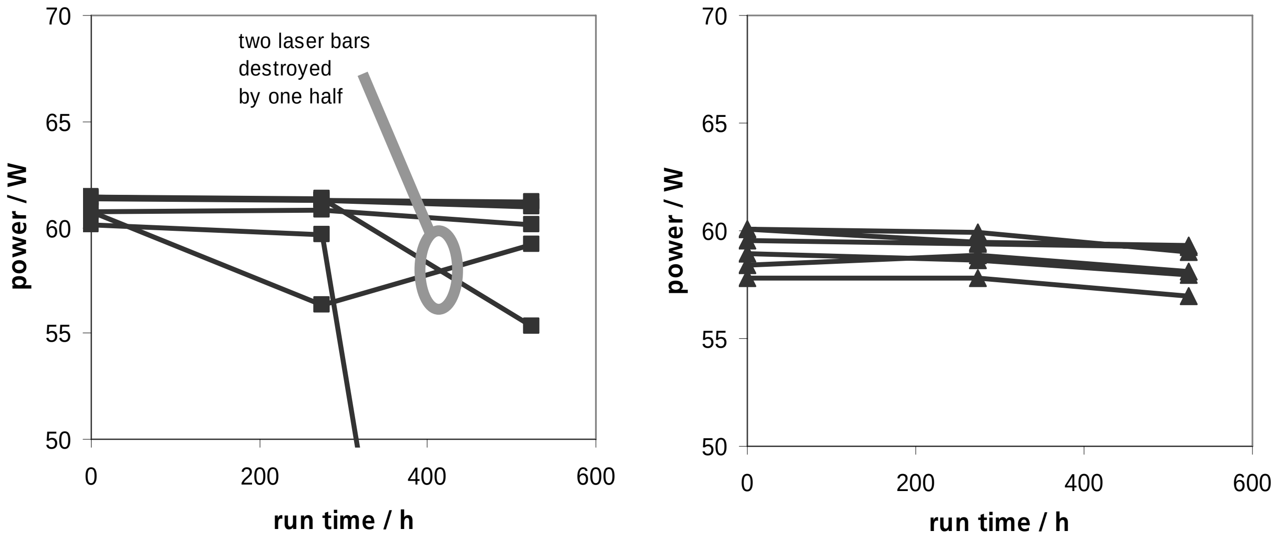


Fig. 7: The crossover of the standard diode laser packaging technology[4,5] at *JENOPTIK Laserdiode GmbH* from indium solder to eutectic gold-tin (80/20) solder. Expansion matching to the GaAs laser bar is achieved by the CuW-substrate, high thermal conductance through a copper heat sink, onto which the substrate is mounted by a tin solder preform.

This type of gold-tin package has only be applied to copper passive heat sinks, because the copper micro channel coolers tend to bend some micrometers when the copper-tungsten substrates are soldered onto them with tin solder. Instead of tin solder, of course, indium could be used to reduce the bending problem. For hard-pulse operation, however, it is always recommended to use solders with a shear strength considerably higher than indium.

In a very first approach, a short comparative test has been performed with 6 lasers of each packaging technology, passively cooled and rated at 71A in hard-pulse mode. This corresponds to optical output powers of about 60W in both cases, indium (fig. 8) and gold-tin packages (fig. 9). Within 500 hours of operation only, three lasers soldered with indium showed irreversible spontaneous failures. In one case, the laser bar was almost completely destroyed; in two cases the laser bars were destroyed by one half. In contrast to this, all gold-tin-soldered lasers operated well after 500h hours.



Figs. 8 (left) and **9** (right)**:** Results of a first comparative study of 12 passively cooled diode lasers, where 6 laser diode bars were soldered with indium (left) and 6 with eutectic gold-tin (right). The diode lasers with 940nm JDL laser diode bars of 50% filling factor and 1500µm resonator length were operated in hard-pulse mode. Three indium soldered lasers failed within 500h of operation, whereas all gold-tin soldered lasers remained unaffected.

4 COMPARATIVE PERFORMANCE TESTS – METHODOLOGY

Motivated by the first promising results, comparative performance tests (CPT) have been carried out together with *OSRAM Opto Semiconductors GmbH (OSRAM)* in the framework of a governmental-funded German national research project called BRILASI, which is part of project alliance BRIOLAS[6]. One of the goals of BRILASI consists in developing until the end of 2007 high-power diode lasers that exhibit an expected life-time of 10,000 hours in hard-pulse mode at optical output powers twice the currently available 50 to 100W. For 940nm lasers, 175W have to be proven reliable for a sufficiently long operation time. This report summarizes the steps that have been taken in the first project year, where *OSRAM* produced the laser diode bars and *JOLD* was packaging and testing them.

The tasks were mainly dedicated to a comparison of indium-soldered actively cooled diode lasers and gold-tin-soldered passively cooled diode lasers. This unusual type of comparison can be explained by the following reasons: (a) One goal is to achieve higher output powers, which can be more easily obtained with active micro channel cooling; (b) For the moment, AuSn soldering technology was more easily integrated in passive than in active cooling designs; (c) If AuSn solder technology turned out to permit higher powers in the passive cooling mode than indium solder technology in the active cooling mode, this would be a very convincing result in favor of gold-tin – the inverse case would leave us with some justified doubts.

In order to quickly characterize the quality of a diode laser – this is a laser diode in combination with its package – one has to determine the operation power limits of the hard-pulse operation in a regime with many pulses of a deep thermal power modulation ΔP_{th} resulting in large number of high thermo-mechanical wear-out amplitudes.

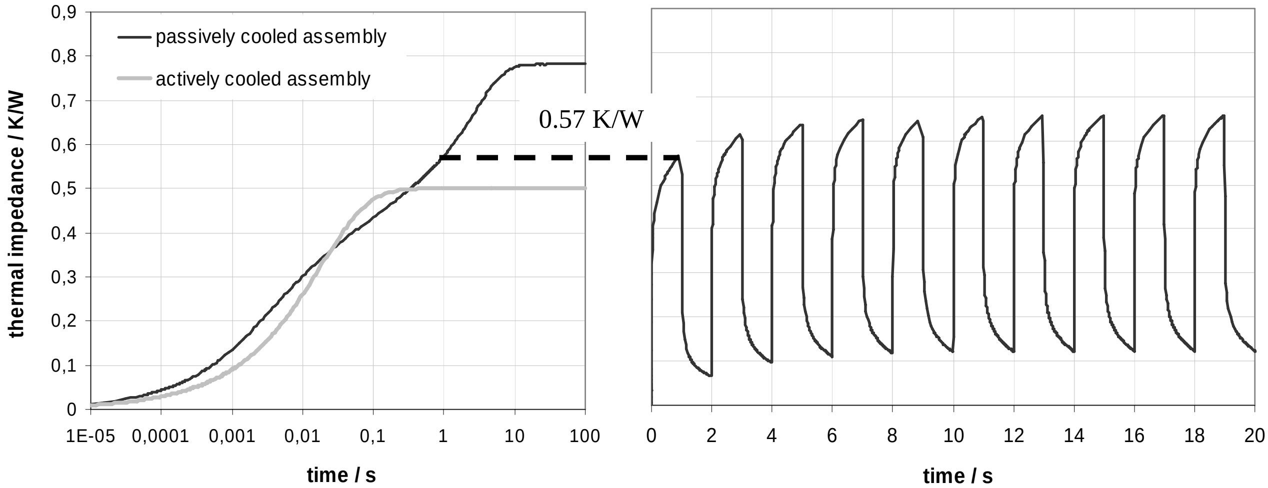


Fig. 10: FEM simulation results for the transient thermal behavior of l200µm long diode laser bars in the actively and passively cooled assemblies in the first 100s of cw mode.

Fig. 11: FEM simulation result for the transient thermal behavior of l200µm long diode laser bars in the passively cooled assemblies when operated at 1s pulses at 0,5 Hz.

As visualized in figure 10, a passively cooled laser takes a much longer time to reach its thermal steady-state at R_{th} = 0.78 K/W than actively cooled lasers at 0.5 K/W – about 10sec in contrast to only 200ms. This is due to the much longer thermal paths and larger volumes to heat in passive heat sinks. In order to fully expand the passively cooled package thermally up and down, one is thus required to apply pulses of 10sec with a duty cycle of 50% or less. Such long pulse periods are detrimental to the testing time, that should be kept reasonably short.

Comparing the transient temperature curves, which are normalized to the thermal impedance $Z_{th}(t)$ (transient thermal resistance) of both assemblies in fig. 10, it turns out that after 400ms, the passively cooled laser reached the (stationary) thermal resistance of the actively cooled laser. In other words: operating the passive laser with pulses of τ = 400ms at r = 50% duty cycle would generate the same temperature cycle as for actively cooled lasers – at a higher maximum temperature of course. As it is not desirable in this experiment to under-stress the gold-tin packaged lasers, the choice of 1s-pulses at 0.5 Hz seem to be a good compromise between depth and number of thermal power cycles.

For example, lasers of 1200µm resonator length in this operating mode would suffer from thermal cycles between

$$Z_{th,\min} = r\left(R_{th} - Z_{th}(\tau)\right) = 0.11\ \text{K/W} \quad \text{and} \quad Z_{th,\max} = rR_{th} + (1-r)Z_{th}(\tau) = 0.68\ \text{K/W}$$

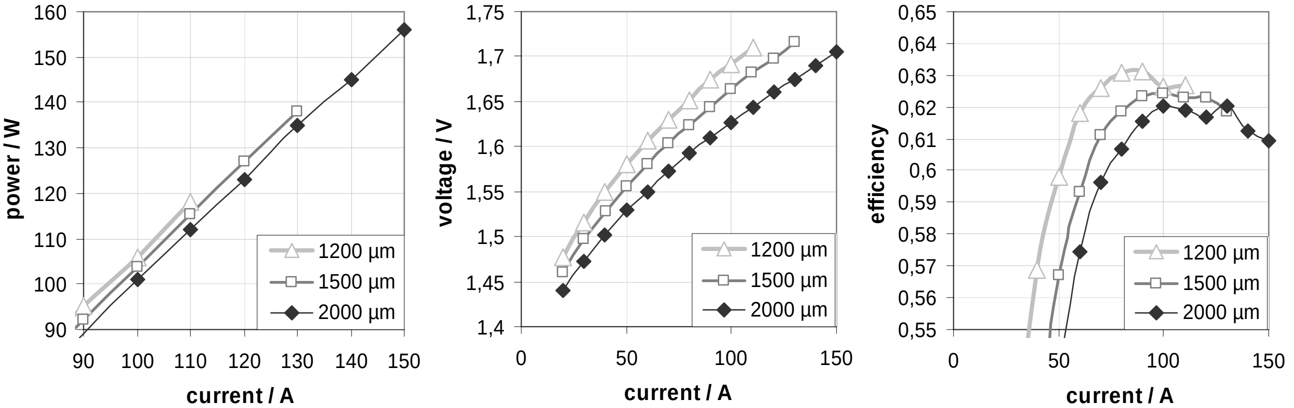
with a thermal impedance depth of $\Delta Z_{th}(\tau)$ = 0.57 K/W. This result is illustrated by a FEM simulation result in figure 11. For an estimated electro-optical efficiency of 60%, temperature cycle depth is $\Delta T = \Delta Z_{th}(\tau) \cdot P_{th}$ = 38K at 100W optical output power with a maximum temperature of $T_{\max} = P_{th} \cdot Z_{th,\max}$ = 45K above cooling temperature. For the same electro-optical conditions, an actively cooled diode laser would undergo complete temperature cycles of $\Delta T = R_{th} \cdot P_{th}$ = 33K.

In the reliability test, these 1s-pulses are applied to all lasers at an initial current of 60A. After a certain short period t_s of time, the aging current I is increased by a certain ΔI. This procedure is repeated until the lasers fail to determine their destruction current. Before each next current-step, the lasers are analyzed to determine degradation. In order to obtain a useful reliability statement, time periods must be long enough and current-steps high enough to ensure that the negative reliability result at a higher current is not too much affected by the aging at a lower current. Then, it is possible to propose an aging current for long-time aging tests, which is two steps ($2 \cdot \Delta I$) lower than the lowest destruction current in the batch of equivalent laser samples. We selected a time period t_s in the range of 100 to 300h and set the current-steps to ΔI = 20A. This type of reliability test is referred to as "current-step failure discrimination test" in the following.

For the comparative performance test including the described reliability test, *OSRAM* engineering samples of four different laser diode bar epitaxial designs (all with 25 emitters of 200µm emitter width at 50% filling factor) have been manufactured in three different resonator lengths (1200µm, 1500µm, 2000µm). The designs can be classified into one design with lower efficiency (L1) and three designs with higher efficiency (H1, H2 and H3). As a standard aging set at *JOLD* comprises 12 diode lasers maximum, 3 laser bars of each design have been combined to one set for each resonator length – as long as enough samples existed.

5 CPT – INDIUM ON ACTIVE COOLERS

Each laser life-time test starts and ends with an electro-optical characterization. Figures 12 to 14 display the effect of the resonator length on optical output power, voltage and efficiency. The longest resonators exhibit the highest theshold current and thus, a lower output power – as long als the TRO limit is not reached. For longer resonators, serial resistance is lower, but not sufficiently low, of course, to lead to a higher efficiency, which is dominated rather by optical internal losses in the resonator than by thermal or electrical resistance (see also performance data in table 1).



Figs. 12 (left), **13** (middle) and **14** (right)**:** Examples of electro-optical characterization of diode lasers with laser diode bar design H1 on active coolers for various resonator lenghts: A section of the LI-curves (left), VI-curves (middle) and efficiency plots (right).

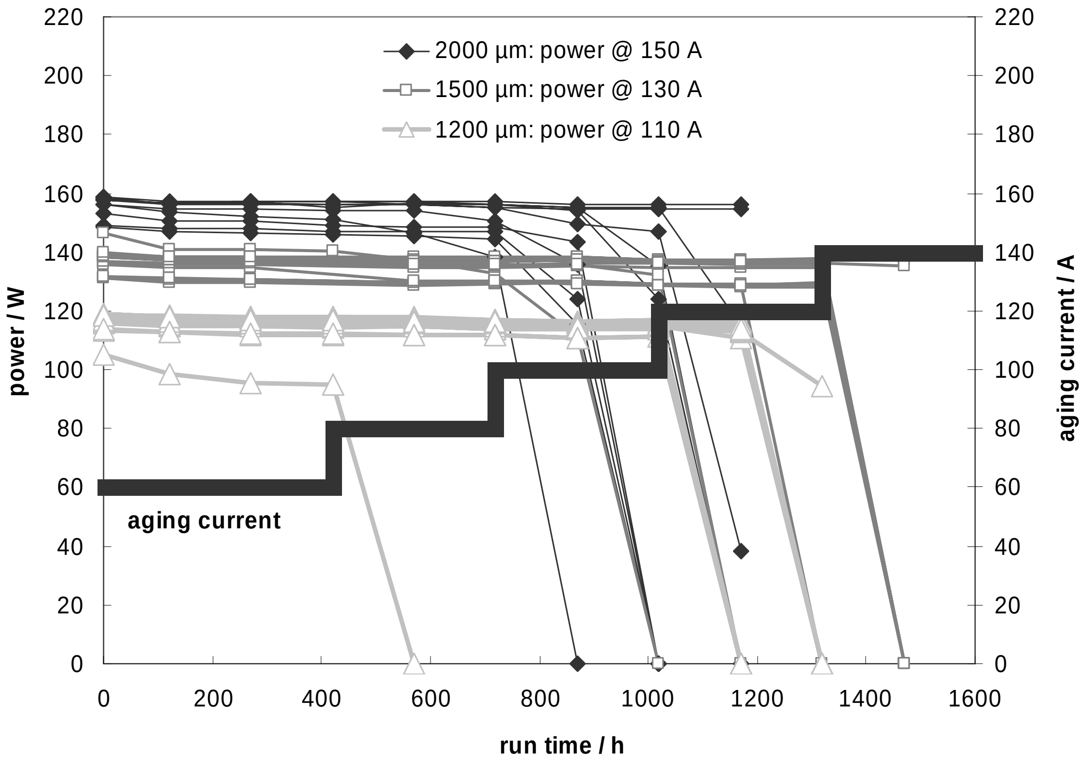


Fig. 15: Current-step failure discrimination test on 3 times 12 actively cooled diode lasers with indium-mounted laser diode bars. The optical output power has been measured every 150 h hours outside the aging test station at the currents mentioned for each resonator length.

resonator length	current	power	temperature	thermal resistance
1200 µm	110 A	118 W	60 °C	0,51 K/W
1500 µm	130 A	138 W	62 °C	0,44 K/W
2000 µm	150 A	156 W	62 °C	0,37 K/W

Tab. 1: performances of diode lasers with epitaxial design H1, actively cooled

The current-step failure discrimination tests have been carried out in time-frames of 300h for each current level (except the first 60A which have been applied for a longer time (420h) as in addition to standard Burn-In (120h+300h =420h)). 300h of hard-pulsed operation of 1s-pulses at 0.5 Hz corresponds to 540 kShots. Every 150h, the lasers have been measured. Fig. 15 displays the degradation and breakdown behavior.
Fig. 16 summarizes the failures at the destruction currents that led to the breakdowns for each resonator length. Diode lasers that were intact after the first the first 150h at the last current-step (120A for 2000µm and 140A for 1500µm), were nevertheless supposed to fail at that current, because as they represent the best results they do not influence the stipulation of an operating aging current for long-time aging tests.
The increase of the resonator length from 1200µm to 1500µm shows a significant improvement concerning the destruction levels (for 1200µm length, 11 of 12 lasers failed at 120A or below; for 1500µm length, only 4 of 12 lasers failed at 120A or below). This can be explained by the better cooling of longer laser and thus less deep thermal cycling. In some way, such a result had been expected. In the case of the 2000µm long lasers the destruction level is very clearly decreased to 6 failures at 100A and 6 failures at 120A. This had not been expected and explanations have to be found: The laser diode manufacturing process can be released, because for any design type, all resonator lengths have been processed in one epitaxial run. Concerning the packaging, the indium soldering process is a very sensitive procedure, that has to be properly set up and delicately optimized every time a new type of laser shall be mounted. 2000µm long lasers of *OSRAM* have not undergone this qualification procedure, due to their limited number. In an up-coming study, this work has to be accomplished.
From the failure histogramms of figure 16, the following maximum aging currents for long-time aging tests are proposed according to the stipulations made above: 1200µm: 80A, 1500µm: 80A, 2000µ: 60A. The failure at 80A for the 1200µm-lasers is discarded, because it exhibited defects from the beginning.
Since the results of the current-step hard-puls operation rather qualify the package than the laser, a comparison with fig. 3 seems to be justified: The hard-puls aging test of *JDL* laser diode bars at 68A shows that the achieved proposal of 60 to 80A aging current is a reasonable one. Life-time is expected to exceed 15,000 hours.

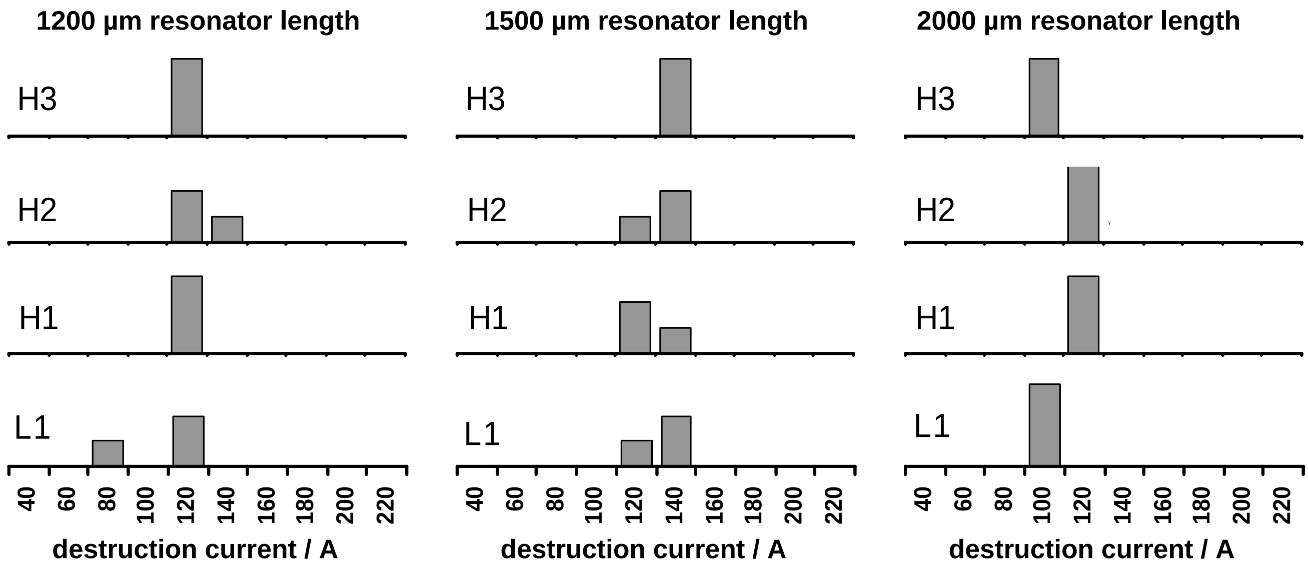
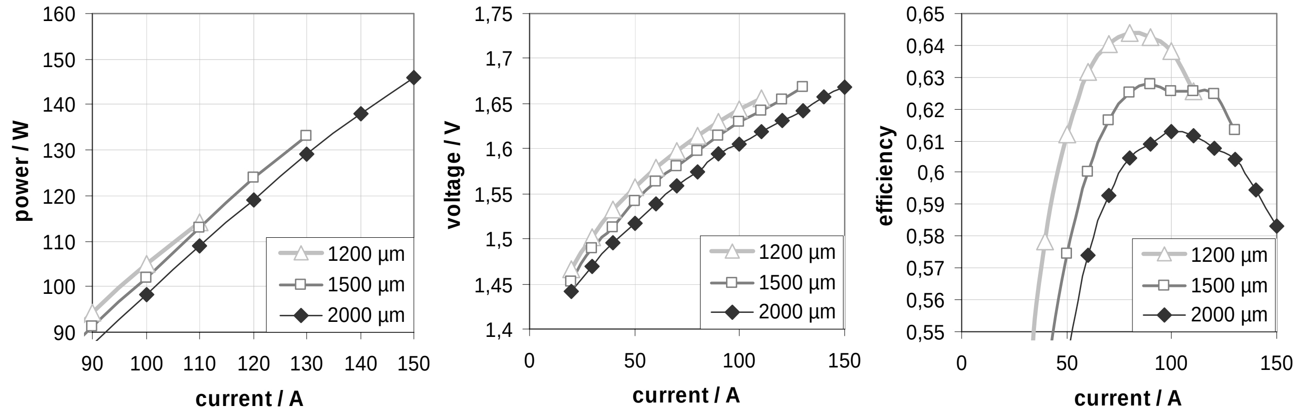


Fig. 16: Reliability histogramms of the number lasers failed at the responsible destruction current for each laser design. The smallest block corresponds to one laser, the biggest to three lasers.

6 CPT – GOLD-TIN ON PASSIVE COOLERS

As in this case the performance tests are expected to run up to very high currents with associated very high operating temperatures clearly above 100°C, the packaging technology for the n-contact was adapted to this situation. The standardly employed adhesive bond would have presented a risk to fail by surpassing its glass temperature.
In analogy to the last section, figures 17 to 19 display the effect of the resonator length on optical output power, voltage and efficiency, respectively. The effects of the resonator lengths on the electro-optical characteristics are similar.



Figs. 17 (left), **18** (middle) and **19** (right)**:** Examples of electro-optical characterization of diode lasers with laser diode bar design H1 on passive coolers for various resonator lenghts: A section of the LI-curves (left), VI-curves (middle) and efficiency plots (right).

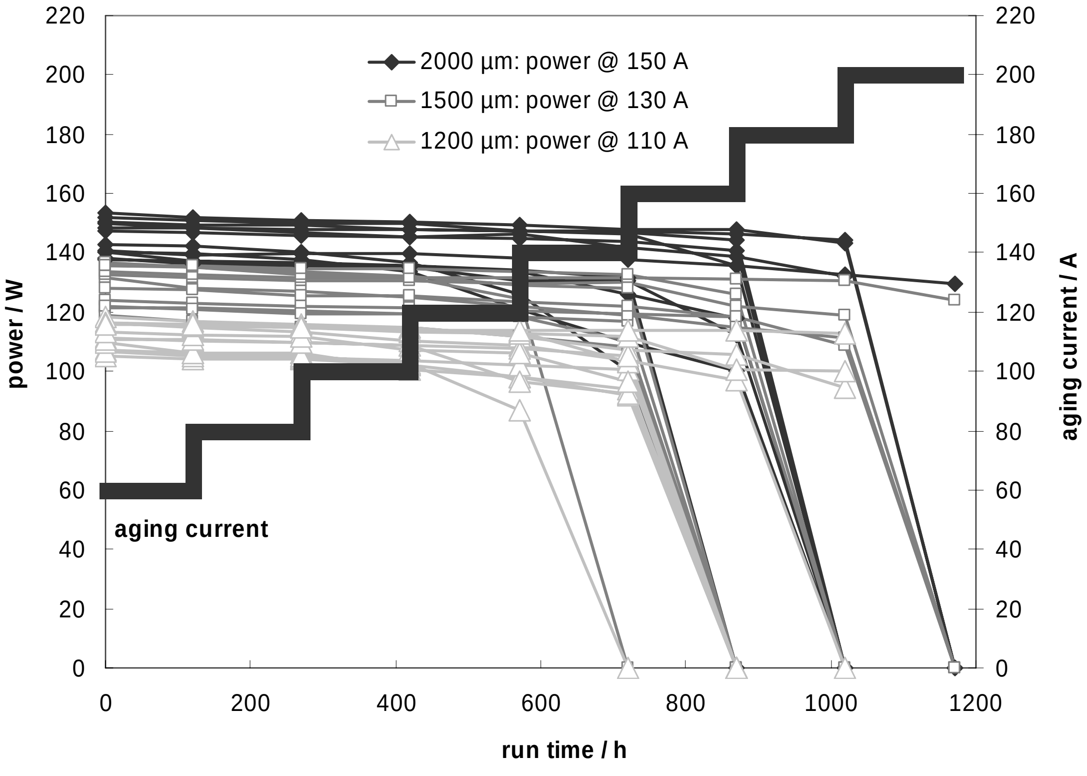


Fig. 20: Current-step failure discrimination test on 35 passively cooled diode lasers with gold-tin-mounted laser diode bars. The optical output power has been measured every 150 h hours outside the aging test station at the currents mentioned for each resonator length.

resonator length	current	power	temperature	thermal resistance
1200 µm	110 A	114 W	82 °C	0,83 K/W
1500 µm	130 A	133 W	83 °C	0,70 K/W
2000 µm	150 A	146 W	78 °C	0,51 K/W

Tab. 2: performances of diode lasers with epitaxial design H1, passively cooled

But overall, some differences are remarkable in comparison with figures 12 to 14: Even though passive heat sinks exhibit a clearly higher thermal resistance than active heat sinks (see table 2), the optical output power is not much less than those of the actively cooled lasers: for 1200µm, 1500µm and 2000µm resonator length, the differences are only 4W, 5W and 10W respectively. This is due to the very high T_0 (temperature coefficient of threshold current) of the laser diode bars of more than 200K.

Nevertheless, the passively cooled diode laser warms up much more when operated at high currents. This effect explains the reduction of voltage in fig. 18 compared to figure 13: The quantum film is the hottest area in the laser diode and contributes to the serial resistance with about 90%. The enhanced carrier mobility at higher temperatures reduces this contribution significantly. As a consequence, serial resistance is lower for the hotter laser diodes, and – what is even more impressive – the efficiency in the hotter laser diodes is in two cases slightly higher than in the colder ones. This is mainly the benefit from the high T_0-value.

In contrast to the performance test with indium solder, to save time, the current-step failure discrimination tests for gold-tin have been carried out in time-frames of only 150h for each current level (except the first 60A which have been applied for a shorter time (120h) representing the standard Burn-In only, and except a second period of 150h at 140A for 1200µm lasers (not indicated in fig. 20)). 150h of hard-pulsed operation of 1s-pulses at 0.5 Hz corresponds to 270 kShots. Every 150h, the lasers have been measured.

Fig. 20 displays the degradation and breakdown behavior. Fig. 21 summarizes the failures at the destructions currents that led to the breakdowns for each resonator length. Diode lasers that were intact after 150h at 160A (1200µm) and 200A (1500µm and 2000µm), were supposed to fail at that next higher current (180A and 220A, respectively) without further testing, because as best results they do not influence the stipulation of an operating aging current for long-time aging tests. We notice that two lasers even did not fail after 200A operation, though a certain degradation is noticeable. The 2000µm lasers are – in contrast to what happened with indium solder – the most reliable ones. This is an indication for the cited sensibility of the indium solder process and a reference to a more robust gold-tin solder process.

From figure 21 the following maximum aging currents for long-time aging test are proposed: 1200µm: 120A, 1500µm: 120-140A, 2000µ: 120-140A (corresponding to the suitability of the laser diode design).

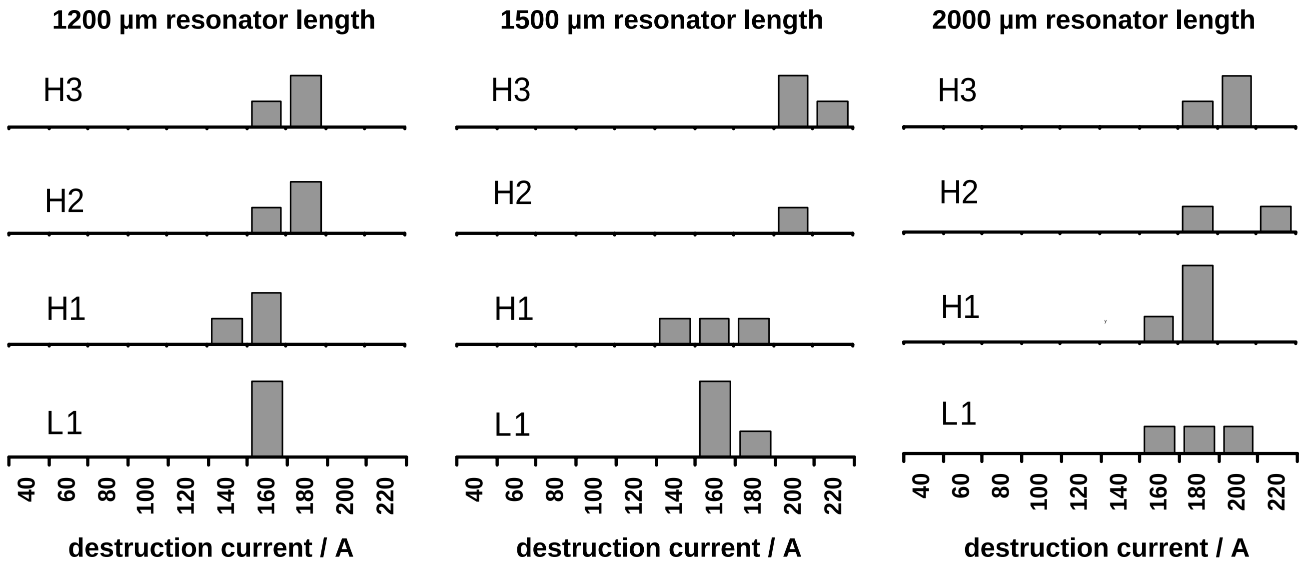


Fig. 21: Reliability histogramms of the number lasers failed at the responsible destruction current for each laser design. The smallest block corresponds to one laser, the biggest to three lasers.

7 LONG-TIME AGING TESTS OF GOLD-TIN PACKAGED DIODE LASERS

Independently from the CPT and much earlier than its positive results were available, long-time hard-pulse aging test had been started with diode lasers of *JDL* 940nm laser diode bars (1500µm resonator length) packaged with gold-tin according to fig. 7. In one case, the CuW substrates had a thickness of 0.4mm – the current necessary to reach 60W optical power was 74A (fig. 22) – in the other case, the CuW substrates had a thickness of 0.25mm. Due to the lower thermal resistance in this case, the electrical current for 60W was only 71A (fig. 23). In both experiments, hard pulses of 1s at 0.5Hz repetition rate have been applied for aging. In the older experiment, the aging current was raised up to 93A after 3000 hours of operation (corresponding to 80W output power). In the 60W-test of fig. 22, only a slight degradation is visible indicating a life-time of at least 20,000 hours (tolerable extrapolation by a factor of three maximum). In the 80W-test of fig. 23, no significant degradation is detectable. Life-time is thus expected to be at least 30,000 hours. One laser suffered from one emitter failure shortly after current increase, however, this did not affect the rest of the laser bar.

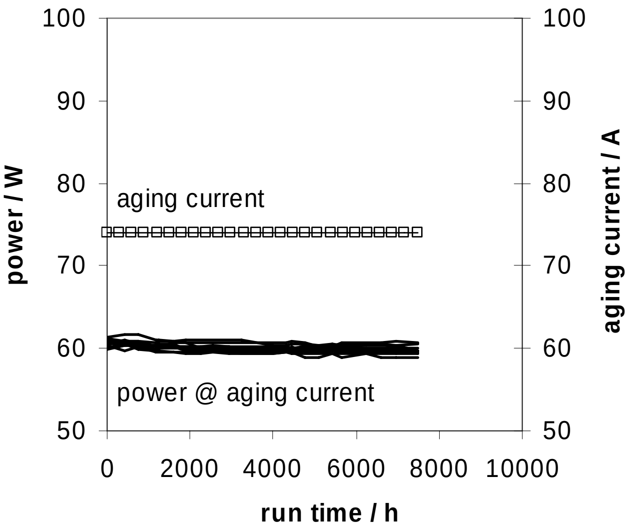


Fig. 22: Aging test of 12 diode lasers with *JDL* 940nm laser diode bars, 50% filling factor, 1.5mm resonator length, mounted with gold-tin solder, passively cooled, in hard-pulse operation mode of 0-74A 1s pulses at 0,5 Hz.

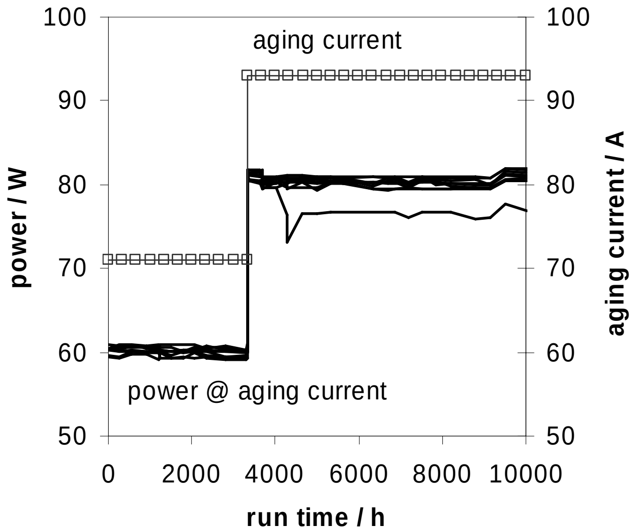


Fig. 23: Aging test of 9 diode lasers with *JDL* 940nm laser diode bars, 50% filling factor, 1.5mm resonator length, mounted with gold-tin solder, passively cooled, in hard-pulse operation mode of 0-71A / 0-93A 1s pulses at 0,5 Hz. Concerning the failure: see explanation in text above.

8 GENERAL POWER LIMITS

Even though gold-tin soldered lasers present an enhanced reliability in hard-pulse operation mode, the cw operating power is limited by the higher thermal resistance: In contrast to indium, the lasers cannot be soldered with gold-tin directly onto copper heat sinks of high thermal conductivity (about 400 W/m/K). Instead – according to the state-of-the art in gold-tin mounting technology – one has to chose a thermal detour by inserting a copper-tungsten substrate of lower thermal conductivity (about 200 W/m/K.). This substrate adds about 0,1 K/W to the thermal resistance of passive heatsinks as verified by thermal FEM simulation and measurements.

As a result, the maximum output power of passively cooled heatsinks in gold-tin solder technology is limited to below 200W due to thermal roll-over (TRO). This is revealed by measurements up to 200A (technical current limit in this case) in fig 24. Whereas lasers with shorter resonator lengths (1200µm and 1500µm) figure out a maximum power of 142W at 160A and 156W at 180A, the laser with 2000µm length emits 171W at 200A. It is estimated that this laser would not emit more than 180W. The temperature at TRO is for all lasers around 120°C. It is worthwhile to note that no laser was damaged by these measurements; this has been proved by subsequent measurements. Especially the 1200µm laser withstood a purely thermal power load of about 250W at 180A. This corresponds to a temperature of about 225°C.

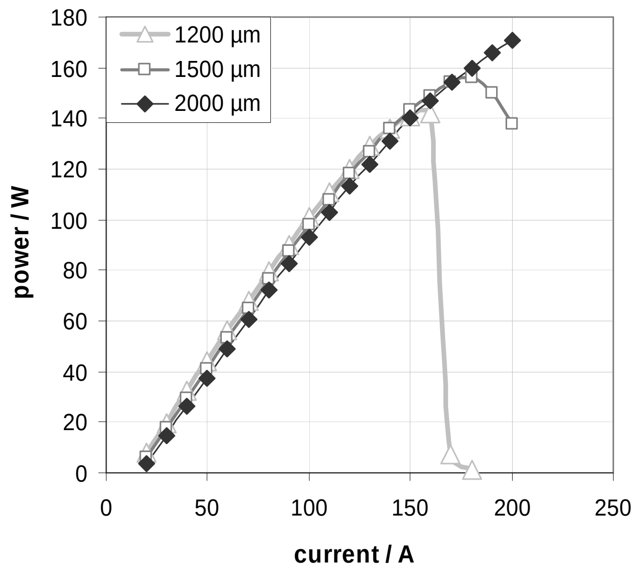


Fig. 24: Cw operation of diode lasers with *OSRAM* 940nm laser diode bars of various resonator lengths (50% filling factor) mounted with gold-tin solder on passive heatsinks, at optical output power limits around currents of 200A.

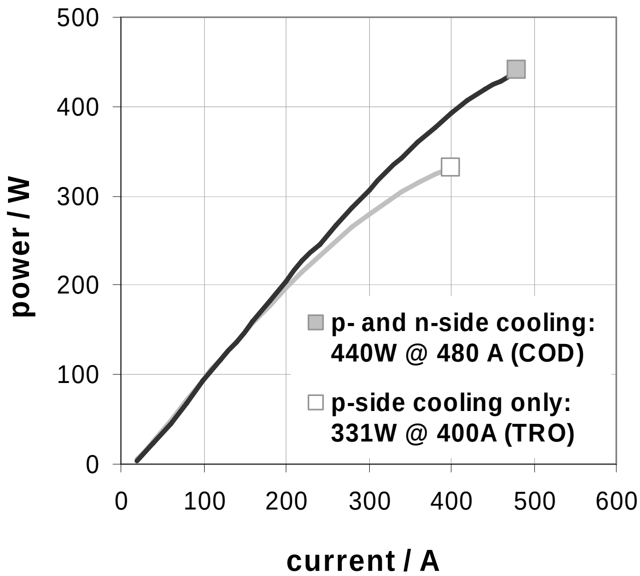


Fig. 25: Cw operation of diode lasers with *OSRAM* 940nm laser diode bars of 2mm resonator length (50% filling factor), mounted with indium solder on actively cooled heat sinks at output power limits at currents between 400 and 500A.

In contrast to this, indium-soldering onto actively cooled copper-micro channel heat sinks still enables the highest cw operation power limits (fig. 25). Standard p-side cooling is not enough to detect the limits of the laser bar material itself: The lasers achieve their optical output limit in thermal roll-over. As recently as p- and n-side cooling has been developed by soldering micro channel coolers to both contacts of the laser diode bar, the lasers suffer from sudden failures – in all cases COD (catastrophic optical damage) – before they could reach TRO.

As the COD-level also depends on temperature, still better cooling is needed to enhance the power. This is possible by increasing the resonator length up to 3mm – because more heat spreading is achieved in the laser bar itself. As before, two micro-channel coolers were soldered to both sides of 3mm laser bars, this time from *JDL* (940nm, fig. 26). The same operating conditions as before (appr. 40 l/h water flow rate per heat sink at 5-8°C water temperature) were set, the power measurement was carried out with a *COHERENT* laser power meter LM1000 (fig. 27). In this setup, the output power of 509W cw at 540A has been measured before the laser failed by COD (fig. 28). To our knowledge, this is the first time, that a cw optical output power higher than half a kilowatt has been demonstrated with a single laser diode bar.

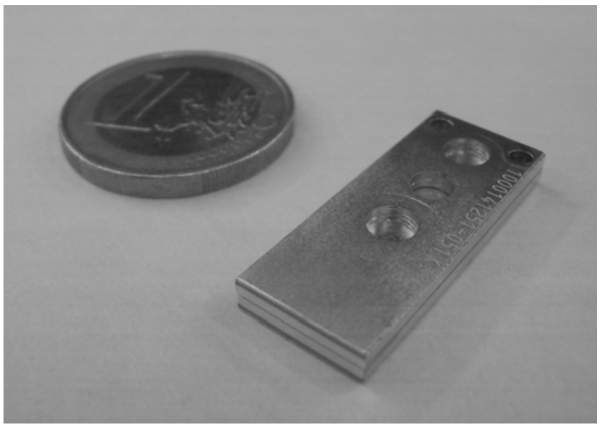


Fig. 26: *JOLDs* 500W diode laser with 3mm laser bar from *JDL* sandwiched between two copper micro channel coolers.

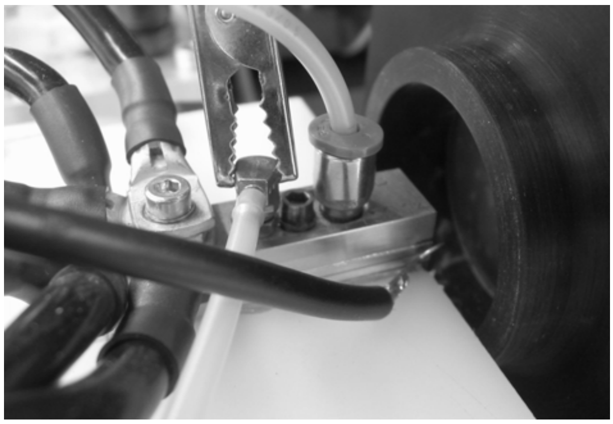


Fig. 27: Operation and mesurement setup for double micro channel cooled diode lasers in front of power meter.

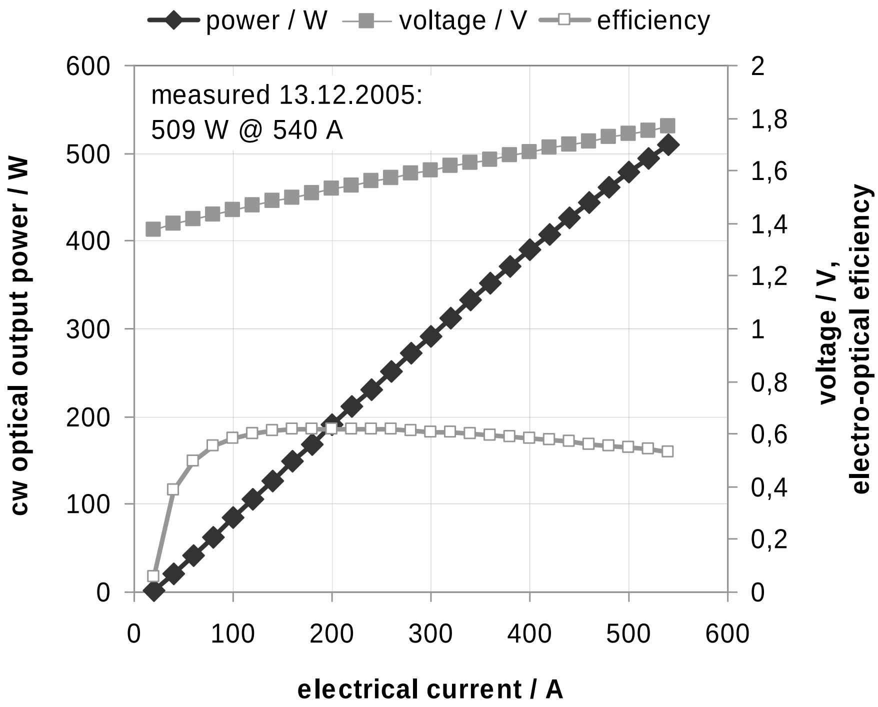


Fig. 28: Properties of a diode laser with a 3mm long *JDL* 940nm laser diode bar double-side micro channel cooled packaged with indium.

CONCLUSION

In conclusion, we presented the results of comparative performance studies of engineering samples of *OSRAM* 940nm laser diode bars that were soldered with indium and gold-tin onto actively and passively cooled heat sinks, respectively. In hard-pulse current-step failure discrimination tests, destruction currents have been determined. For indium-soldered actively cooled diode lasers, they are in the range of 100 to 140A, for gold-tin soldered passively cooled diode lasers they are in the range of 140 to 220A. From this result, we derived reasonable current levels for long-time hard-pulse aging tests of 60 to 80A in the first case and 100 to 140A in the second case.
Associated long-time hard-pulsed aging tests on diode lasers with *JDL* laser diode bars indicated expected life-times of more than 15,000 hours in both, indium- and gold-tin-packaged laser diodes.
Nevertheless the cw output power performance of diode lasers with indium solder mounting is still unsurpassed. This has been demonstrated by a diode laser with a *JDL* laser diode bar, which emitted more than 500 Watts at 540 Amps.

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REFERENCES

1 DIN EN ISO 11145
2 J. Biesenbach, Dissertation RWTH Aachen, Verlag Shaker Aachen (2002)
3 N. Lichtenstein et al., Proc. SPIE Vol. 6104, pp. 1-11 (2005)
4 US patent no. 6,621,839 B1, EP patent no. 1 143 584 B1
5 US patent no. 6,754,244 B2
6 www.briolas.de