Passively cooled diode lasers in the cw power range of 120 to 200W

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ABSTRACT

Improvements of laser diode bar efficiency and mounting technology have boosted output powers of passively cooled 940nm diode lasers beyond the 100W cw limit. After an introduction about reliablity statements and reliability assessment, the performance increase by technology improvements is documented in current-step failure discrimination tests. Electro-optical parameters of improved diode lasers are subsequently presented in detail as well as the results of lifetime tests at various powers and operation modes – steady-state and repetitive/ intermittent ("hard pulse") cw mode.

Keywords: diode laser, passive cooling, conductive cooling, gold tin solder, reliability, lifetime, statistics, 200W

1. INTRODUCTION

A passively cooled diode laser is a package of a laser diode and a heat distributing component ("submount") that distributes heat generated by the laser diode by heat conduction only and is provided with a thermal interface arranged for being attached to a heat sink, from which it can be released without any residues.

Due to such a detachment or exchange ability, the thermal interface of a passively cooled diode laser constitutes a certain thermal barrier which can be quantified in terms of a heat transfer coefficient that includes both, the thermal resistance of the thermal interface and the heat sink. This heat transfer coefficient of passive cooling is in the order of 0,01 W/mm²/K, whereas the heat transfer coefficient of active cooling – the heat removal by a liquid coolant flowing through a micro channel structure – is about one order of magnitude larger.

Consequently, heat spreading in the diode laser submount is much more important in the passively cooled case than in the actively cooled case. Though this heat spreading moderates the difference of the heat removal capacity of both types of cooling, the thermal resistance of passive cooling is – depending on the cavity length – in general roughly about 0.15 K/W (3mm cavity length) to 0.35 K/W (1mm cavity length) higher than that of active cooling [1].

Assuming a thermal resistance R_{th} of 0,25 K/W for an actively cooled diode laser and 0,45 K/W for a passively cooled laser at thermal roll-over (TRO), and for both a TRO temperature of the laser diode of T_{TRO} = 130°C, a reference temperature of the heat sink respectively the coolant of T_{ref} = 25°C and a TRO electro-optic efficiency of η_{TRO} = 45%, the maximum optical output power at TRO,

$$P_{opt,\mathrm{TRO}} = \frac{\eta_{\mathrm{TRO}}}{1-\eta_{\mathrm{TRO}}} \frac{T_{\mathrm{TRO}} - T_{\mathrm{ref}}}{R_{th}}, \quad (1)$$

is 190 W for the passively cooled laser and 340 W for the actively cooled laser.

Currently, passively cooled diode lasers available in the market reach powers of 80 to 100W cw, that is 50% of the TRO power level. The power of commercially available actively cooled diode lasers ranges from 100 to 120W cw, that is about 30% of the respective TRO level. For actively cooled diode lasers long-term aging tests have been demonstrated up to 180W cw at approximately 50% TRO power [2].

The reliability of a diode laser package is best characterized by the number and the level of thermo-mechanical cycles it supports during life-time tests. It is thus an excellent proof of diode laser quality if it works reliable in proximity to the TRO. In the following, the reliability of passively cooled diode lasers at 60 to 90% TRO power level is demonstrated.

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2. RELIABILITY STATEMENTS AND RELIABILITY ASSESSMENT

The output of a reliability assessment provides a reliability statement in terms of a time of reliable operation t_R. This output is based on a set of four input informations comprising:

1.) a failure or end-of-life (EOL) criterion to attribute lifetimes t_F to the test data,
2.) an appropriate cumulative failure distribution function $F(t)$ to fit the lifetimes,
3.) a survival probability $R_R = R(t_R)$ or corresponding failure probability $F_R = F(t_R)$ and
4.) a lower confidence limit c_L for R_R or F_R, respectively, to limit the error of the reliability statement

These four input informations have to be specified and used to generate the reliability statement after performing:

- a reliability test on a reasonable sample size n during a reasonable test time t_t to create lifetime data and
- a choice of a reasonable type of failure probability density function $f(t)$ to fit the lifetime data to the corresponding cumulative failure distribution function

$$F(t) = \int_0^t f(t')\,\mathrm{d}t' . \tag{2}$$

or corresponding cumulative reliability function $R(t) = 1 - F(t)$ as close as possible.

The failure distribution can for example be of normal, exponential, lognormal or Weibull type. Whereas the sample size n and the number m of measurements during a test time t_t should be large enough, the measurement errors should be small enough to provide a reliability statement with sufficient high accuracy, e. g. a minimized confidence band width. Ideally, test time t_t should be large enough to cover the failures of all tested units, but in practice, failures of reliable diode lasers do not occur during 10.000 or 20.000 hours of testing, so that extrapolation measures have to be performed to provide the requested reliability statement.

A reasonable specification for the failure probability at the time of reliable operation F_R is 5% and for the lower confidence limit c_L is 90%. We have to note that a reliability statement is worthless (not comparable with other reliability statements) without specifying the underlying input informations used to create it.

2.1 Linear degradation

In many cases, the reliability of diode lasers is subject to linear degradation of output power $P(t)$ initiating from P_0 at constant operation current I,

$$P(t) = P_0 - \beta\, t , \tag{3}$$

where β is the degradation rate in terms of W/h. A failure occurs at time t_F, whenever the output power $P(t)$ has decreased by a certain percentage $D_{\lim}$ – let's assume 20% – down to a percentage of $R = 1 - D_{\lim}$ (here 80%) of the initial power level P_0, so that

$$t_F(\beta) = D_{\lim} \frac{P_0}{\beta} \quad \text{or} \quad \beta(t_F) = D_{\lim} \frac{P_0}{t_F} . \tag{4}$$

Assuming a normal distribution of the degradation rates β centered around β_0 and scaled by their standard deviation σ_β like

$$f(\beta) = \frac{1}{\sigma_\beta \sqrt{2\pi}} \exp\left\{ -\frac{1}{2\sigma_\beta^2} (\beta - \beta_0)^2 \right\} \tag{5}$$

as displayed in fig. 1, the failure times t_F are distributed as

$$f(t_F) = \frac{1}{\sigma_\beta \sqrt{2\pi}} D_{\lim} \frac{P_0}{t_F^2} \exp\left\{ -\frac{1}{2\sigma_\beta^2} \left(D_{\lim} \frac{P_0}{t_F} - \beta_0 \right)^2 \right\} . \tag{6}$$

This failure distribution function is plot in fig. 1 with black dots. As it can easily be seen, this function differs considerably from a Weibull distribution. Instead, this function is much better approximated by a lognormal failure distribution

$$f(t_F) = \frac{1}{s\, t_F \sqrt{2\pi}} \exp\left\{ -\frac{1}{2s^2} \left[\ln(t_F) - \mu \right]^2 \right\} \tag{7}$$

with $\mu = \ln(t_F(\beta_0))$ and $s \approx \sigma / \beta_0$, denoted by the grey dots in fig. 1.

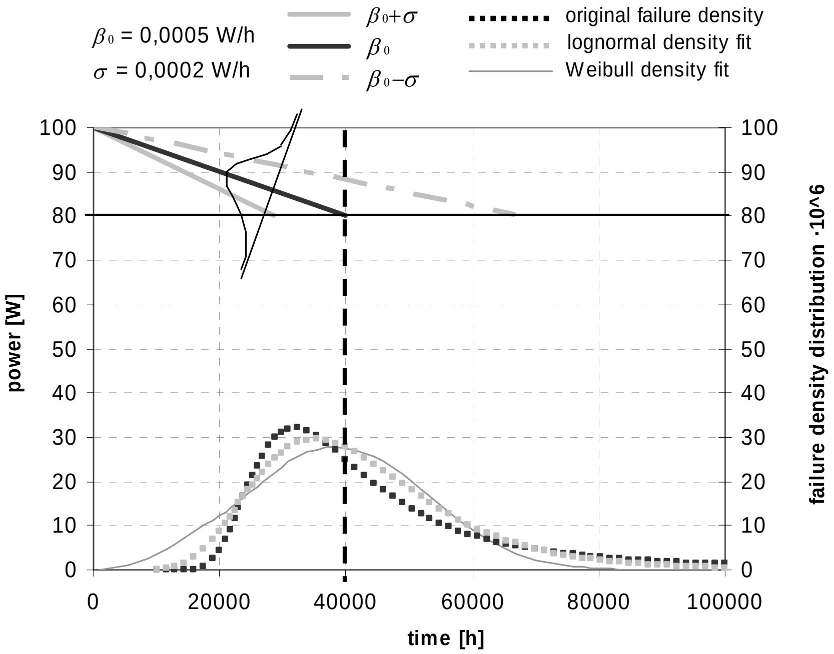


Fig. 1: Failure probability density distribution in a set of diode lasers with normally distributed linear degradation.

Regarding the cumulative failure distribution, it is worthful to note that – compared to the original density function of eq. (6) – the lognormal failure function is a conservative estimation. Nevertheless, if the degradation rates are not distributed normally, the failure density function could be any other than lognormal-like. However, in practice, it has been observed that failure time data are fit indeed much better by a lognormal distribution than by a Weibull distribution.

2.2 Determination of degradation

In a degradation test of a set of n units, data values of powers $P_{ij} = P_i(t_{ij})$ of unit i are discretely sampled m times at times t_{ij}, whereby the real degradation $P_{\mathrm{degr},\,ij}$ is hidden by a residual deviation ΔP_{ij}, for example a measurement uncertainty:

$$P_{ij} = P_{\mathrm{degr},\,ij} + \Delta P_{ij} \tag{8}$$

For all tests ending up at a test time t_t before any failure, degradation rates β_i have to be determined from the so far measured data and used for extrapolation of the degradation behavior until the failure criterion is met in order to provide a set of estimated failures times $t_{F,\,i}$. Affected by the uncertainty of residual deviations, these estimated failure times are themselves probability statements.

Related to this, the question arises concerning the lowest degradation that can be identified with sufficient certainty. If a zero degradation is measured, a true degradation of

$$\beta_{\min} = \sigma_\beta \cdot t(2\alpha, m-2)\,, \tag{9}$$

is possible within a certain confidence of 1-α, where the unit index i has been omitted, t is the α-quantile of the students t-distribution with one-sided confidence limit and

$$\sigma_\beta^2 = \sigma_P^2 \left(\sum_{j=1}^{m} \left(t_j - \bar{t}\right)^2 \right)^{-1} , \qquad (10)$$

where σ_P is the standard deviation of the power measurement values according to eq. (8). Assuming m-1 equidistant measurement intervals $\Delta t = t_t / (m-1)$, this expression can be simplified by

$$\sum_{j=1}^{m} \left(t_j - \bar{t}\right)^2 = \frac{1}{6} (\Delta t)^2 \, m(m-1)\left(\frac{m}{2} + 1\right). \qquad (11)$$

For a test time of t_t = 10,000 hours and m = 41 measurements, it is, for example, less than α = 0,5% probable that the real degradation is larger than $\beta_{min} = 7.2\cdot10^{-5}$ W/h when β = 0 has been measured with a standard deviation of σ_P = 0,5 W.

2.3 Extrapolation of lifetime test data

According to ISO 17526, linear extrapolation of lifetime test results is allowed up to k times of the performed test time t_t, if the number of test lasers is high enough and if the degradation rate is constant within a small admissible standard deviation. We recall these values of k and their corresponding test conditions in table 1.

number of test lasers	standard deviation of the degradation rate	permitted extrapolation factor k
5 to 10	5 % to 10 %	3
	< 5 %	5
> 10	5 % to 10 %	5
	< 5 %	7

Tab. 1: Permitted extent of linear extrapolation according to ISO 17526

According to the same document, in the case of non-linear degradation, a polynomial fit can be used for extrapolation and determination of lifetimes, but an extrapolation range or factor has not been proposed. We propose that non-linear extrapolation should be allowed up to k times of the performed test time t_t, where k is given by

$$k = \sqrt[a]{\frac{D_{\mathrm{lim}}}{D_{\mathrm{t}}}} , \qquad (12)$$

$a \in \mathbb{N}$, $a > 1$ is the highest reasonable order of the polynomial fit and D_t is the mean power decrease ratio of the test laser set at the end of the test time t_t.

In many cases of very small degradation or large power decrease D_{lim}, extrapolation of lifetime tests – when not of all, then at least of some lasers – does not permit to reach the EOL criterion. After a test time of t_t , a degradation of less than

$$\beta_{\mathrm{lim}} = D_{\mathrm{lim}} \frac{P_0}{k \cdot t_{\mathrm{t}}} \qquad (13)$$

does not permit to determine the failure time $t_F = k \cdot t_t$ within the permitted extrapolation. In the case of t_t = 10,000 hours, P_0 = 100W, D_{lim} = 20% and k = 7, the minimum fully extendable degradation is $\beta_{\mathrm{lim}} = 2{,}9\cdot10^{-4}$ W/h. This is well above the minimum detectable degradation β_{min} cited in the previous section. Subsequently, even a low number of 6 measurements is sufficient to fulfill the evaluation requirement of $\beta_{min} = \beta_{\mathrm{lim}}$.

ISO 17526 proposes to note that the lifetime is longer than $k \cdot t_t$ in the cases where $\beta < \beta_{\mathrm{lim}}$. On the other hand, in order to provide a reliability statement based on the statistical evaluation of a set of several lasers, such a statement according to ISO 17526 is not exhaustive.

We propose a set of three procedures to provide the desired reliability statement nevertheless:

1.) As long as only a limited number of lasers (let's say less than 50%) exhibit a degradation of less than β_{lim} these lasers can be treated as right-censored in the statistical evaluation of the probability plot of lifetimes $t_{F,i}$ extrapolated using the initial failure criterion of D_{lim}.

2.) If more than 50% of the lasers exhibit a degradation of less than β_{lim}, it is recommended to redefine a tightened failure criterion of $D_{\text{red}} = r \cdot D_{\text{lim}}$ with $0 < r < 1$ and proceed with it like in point 1 with a smaller number of right-censored data of less than 50%. The reduced time of reliable operation $t_{\text{R, red}}$ hereby determined is then divided by r to provide the requested time of reliable operation $t_{\text{R}} = t_{\text{R, red}} / r$.

3.) If 100% of the lasers exhibit a degradation of less than β_{lim}, no failure can be detected by extrapolation. In this case we recommend to proceed with a zero-failure-test (ZFT) as explained in the following section.

2.4 Case of no detectable failure or degradation

It is possible that a reliability test does not show any failures. This is the case if, within the permitted extrapolation, no laser reaches the end-of-life criterion – in other words: if all determined degradations β_i are smaller than $\beta_{\text{lim},\,i}$ according to equation (13). The same situation arises in general for all degradations β_i smaller than $\beta_{\text{min},\,i}$ according to equation (9).

In such a case, no cumulative failure distribution function $F(t)$ can be determined and hence no reliability funcion $R(t) = 1\text{-}F(t)$ can be deduced. It is nevertheless possible to formulate a reliability statement in terms of t_{R} by estimating a lower limit of reliability from a zero-failure-test providing a zero-failure probability of R_{ZFT} , see reference 3:

The probability to find d defect units in a sample of n units from an infinite population with a failure ratio of p is binomially distributed as

$$\alpha = \binom{n}{d} p^d (1-p)^{n-d} \; . \tag{14}$$

Thus with $d = 0$, a conservative lower limit of reliability

$$R_{\text{ZFT}} = 1 - p = \sqrt[n]{\alpha} \tag{15}$$

depends on the choice of a reasonable low α of – for example – 10%. To be able to provide an analytic expression of the time of reliable operation t_{R} , we further assume conservatively that failure times t_{F} are exponentially distributed as

$$R(t_F) = \exp\left(-\frac{t_F}{\theta}\right). \tag{16}$$

In the zero-failure-test, t_F equals the extrapolated test time $k \cdot t_{\text{t}}$, wheras the reliability statement requires that t_F equals t_{R} with $R_{\text{R}} = 1\text{-}F_{\text{R}} = 95\%$ and the same characteristic life-time θ in both cases. Together with eq. (15), this leads finally to

$$t_{\text{R}} = n\,k\,\frac{\ln R_{\text{R}}}{\ln\alpha}\,t_{\text{t}} \; . \tag{17}$$

For example, if testing of $n = 12$ lasers ends up after $t_{\text{t}} = 10{,}000$ hours without any laser reaching the failure criterion after extrapolation, the time of reliable operation that can be stated is $t_{\text{R}} = 18{,}700$ hours assuming an admissible extrapolation factor of $k = 7$.

2.5 Summary of reliability assessment procedures

The assessment of reliability is generally performed by determination of the lifetime at the 95%-quantile of the lower 90% confidence level of the Maximum-Likelihood (ML) fit of the measured failure times – determined by extrapolation according to ISO 17526 – in the survival lognormal probability plot. The EOL limit of in terms of power decrease should be adapted to low degradations to limit the number of right-censored lasers. Zero failures need a ZFT.

3. HIGH-POWER ADAPTED PACKAGING

3.1 Technology improvements

Technology improvement measures were governed by the requirement of high-current and high-temperature operation stability necessary for reliable high-power operation. Since a passively cooled diode laser has got a thermal resistance R_{th} of 0.55 K/W, which is about 0.2 K/W higher than the thermal resistance of an actively cooled diode laser, the temperature of a laser diode at high powers is considerably higher in the passively cooled case than in the actively cooled case. The temperature rise ΔT in a diode laser rated at optical power P at efficiency η_{eff} is

$$\Delta T = R_{th}\ P\left(\frac{1}{\eta_{\text{eff}}} - 1\right). \tag{18}$$

At P=150W the temperature rise in the actively cooled case (η_{eff} = 65%) is ΔT = 28K and ΔT = 55 K in the passively cooled case (η_{eff} = 60%), which is nearly two times the value of the actively cooled case. Interfaces in close arrangement to the heat source have thus been reviewed concerning reliability under high thermal and high thermo-mechanical loads. Both joints, the n-side joint and the p-side joint, of the laser diode bar have been modified to correspond to the increased requirements, as displayed in fig. 2:

The n-side joint – which is a continuous copper lid bonded with an electrically conductive adhesive to the cathode of the laser bar (see reference 4) in the medium power case of 50 to 100W, has been replace by a series of wire bonds to be operable at powers of 120 to 200W. Two reasons may explain this change: Firstly, an adhesive suffers from glass transition at higher temperatures resulting in a debonding of the lid from the laser. Secondly, an extended self-contained contact body provides more stress to the laser and the joint under thermally induced deformation than a mechanically compliant array of individual contact members. The numbers and the size of the bonding wires are adapted to conduct the high current at a low electrical resistance.

The p-side joint has benefit from general improvements of the gold-tin mounting technology since its implementation in the year 2005.

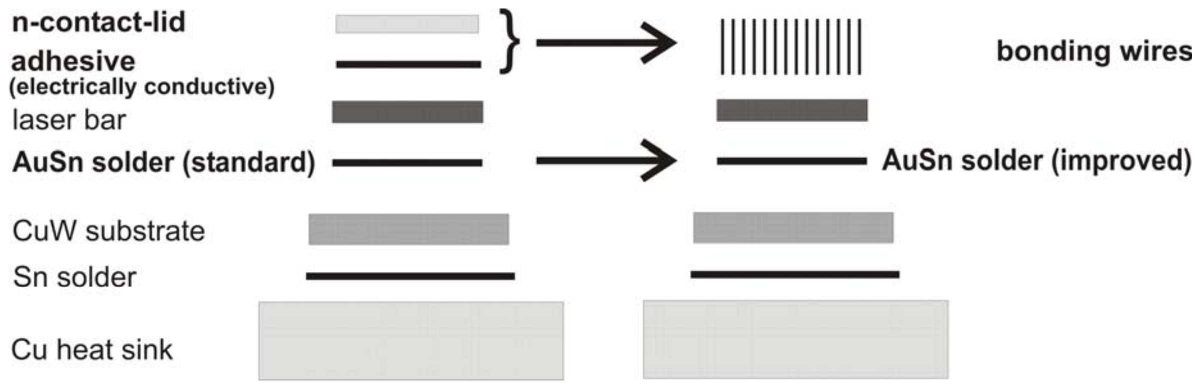


Fig. 2: Technological improvements allowing the transition from a medium-power to a high-power operation

3.2 Demonstration of improvements

Improvements of the AuSn mounting technology have been demonstrated by current-step failure discrimination test (shortly “step test”), where a set of diode lasers of standard technology and a set of diode lasers of improved technology have been operated with 1s pulses at 0.5 Hz raising the electrical current by 20A after each 120h of testing. Fig. 3a and 3b clearly show the effect of the technology improvement during the test for two times four lasers with 10mm laser diode bars of 940 nm emission wavelength, 50% filling factor and 2 mm cavity length from JENOPTIK Diode Lab GmbH, Berlin, Germany, from the same batch. In the case of the standard technology, the lasers fail at a mean value of 180A; at

200A all four lasers failed. In the case of the improved technology, none of the four lasers did fail even during the 200A operation.

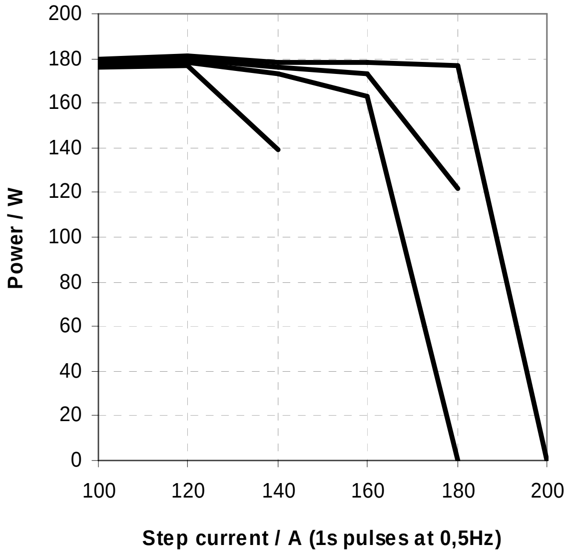


Fig. 3a: Results of a current step test for **standard** AuSn mounting technology with a set of four diode lasers. Power is measured at 200A after every current step.

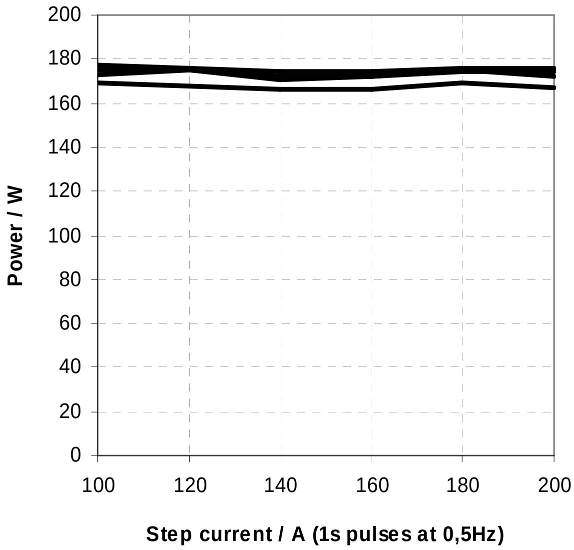


Fig. 3b: Results of a current step test for **improved** AuSn mounting technology with a set of four diode lasers. Power is measured at 200A after every current step.

A further evidence of the improved package could be demonstrated by Catastrophic Optical Mirror Damage (COMD) limit measurements of 808 nm laser diode bars with 75% filling factor and 1.5mm cavity length. As displayed in fig. 4, the improved AuSn solder enables a 50% higher COMD limit than the standard solder in the range of 85 W/mm. Test conditions were 200µs pulses at 2% duty cycle.

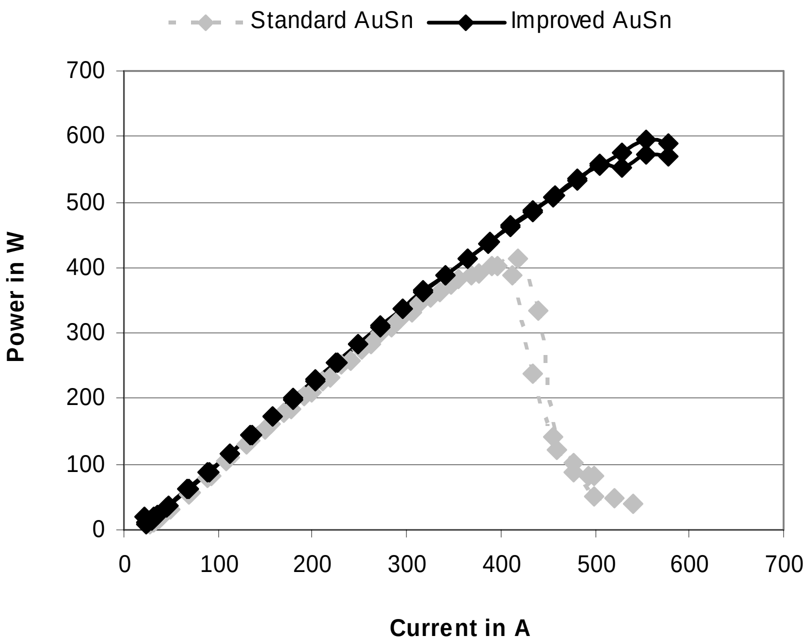


Fig. 4: COMD test result for 808nm laser diode bars with standard and improved AuSn mounting technology

4. HIGH-POWER AND TRO CHARACTERIZATION

High-power electro-optical characterization of the improved diode laser package has been performed with standard 50% filling factor 940nm 10mm laser diode bars of 2mm cavity length from JENOPTIK Diode Lab GmbH, Berlin, Germany. Fig. 5 presents the electro-optical key properties of passively cooled diode lasers. Maximum power at TRO is 195 W @ 240 A, maximum efficiency is 59% at 110A, efficiency at TRO is 45%.

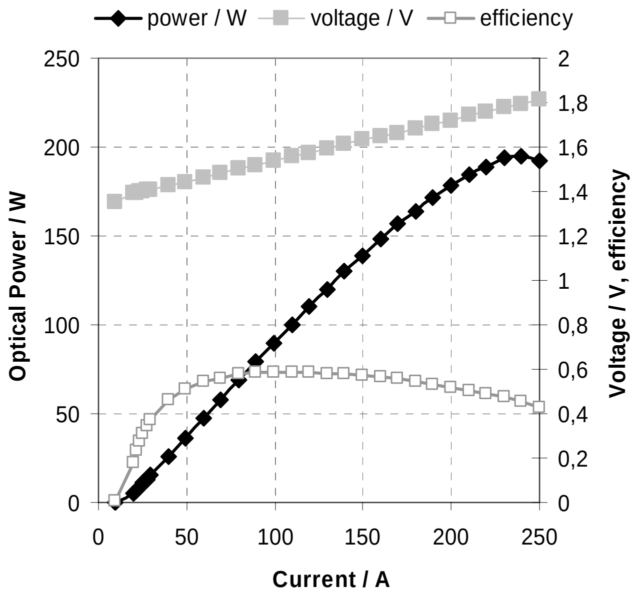


Fig. 5: LI and VI characteristics of passively cooled 940 nm diode laser bar at 25°C heat sink temperature.

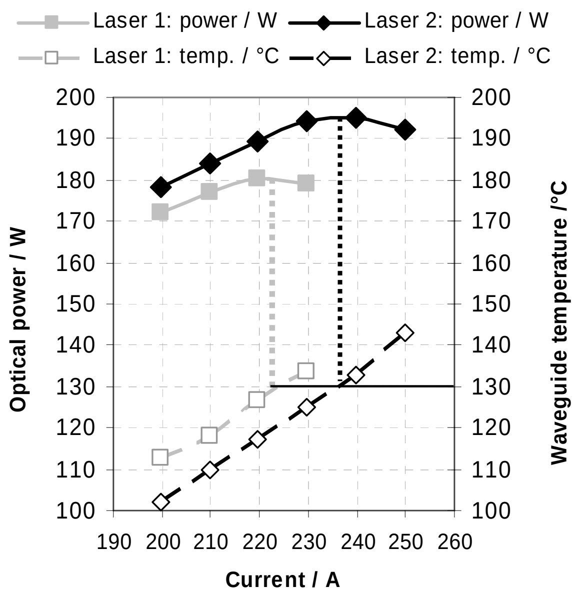


Fig. 6: TRO behavior of two lasers with different TRO efficiency: TRO waveguide temperature is 130°C.

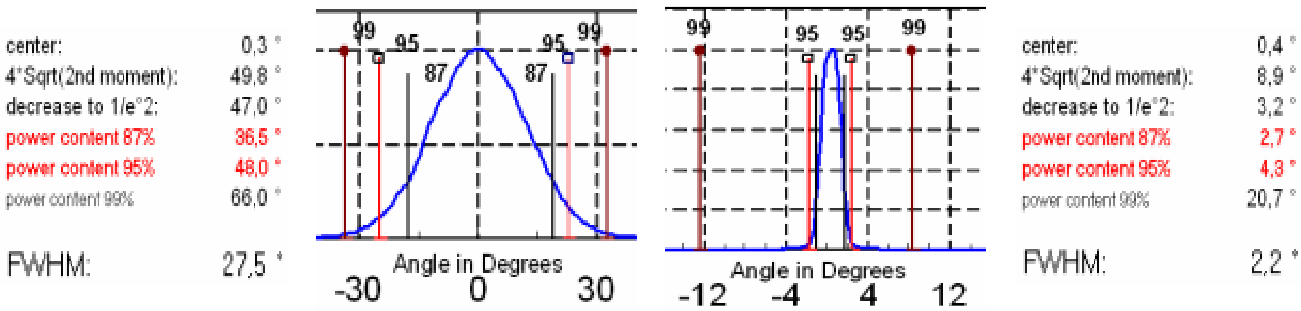


Fig. 7a: Optical far field in the fast-axis direction (left) and the slow-axis direction (right) **at 20 A** operation current

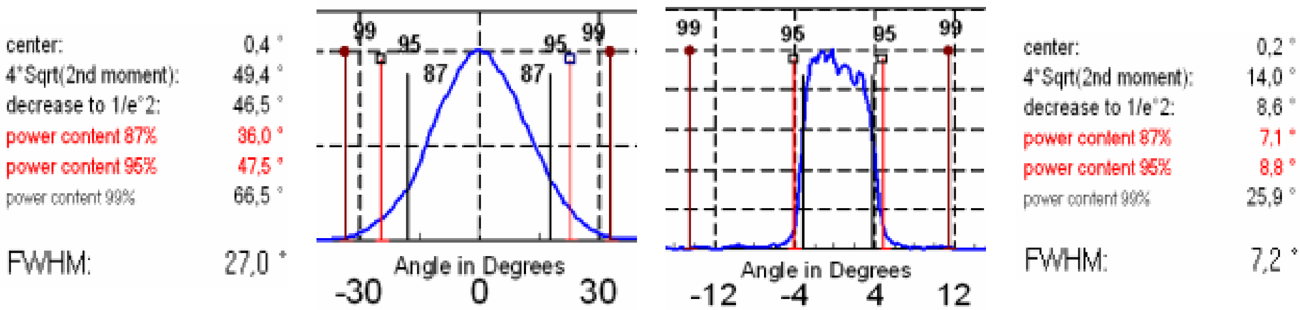
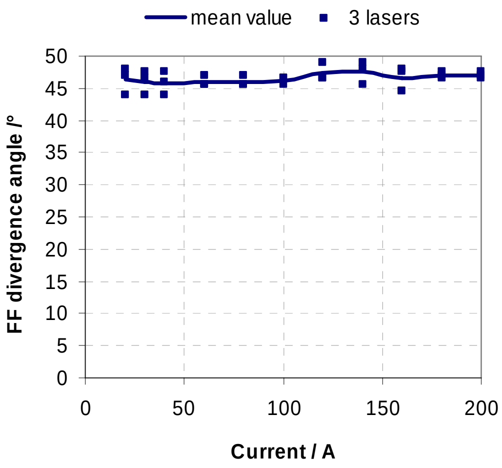


Fig. 7b: Optical far field in the fast-axis direction (left) and the slow-axis direction (right) **at 200 A** operation current

It is very instructive to study the TRO behavior of different laser diode bars of different TRO efficiency (45% and 42%) in detail. By measuring the barycentric wavelength of the emission spectra, the temperature of the waveguide can be calculated using $d\lambda / dT = 0{,}315$ nm/K. As illustrated in fig. 6, TRO takes place at the same temperature of about 130 °C.

The spatial power distribution of the optical far field is known to be dependent on the optical output power; especially the slow-axis far field divergence angle increases with increasing operation current. Fig. 7a and 7b show the far field pattern in both, fast-axis and slow-axis direction at 20A and 200A operation current.

The evolution of the far field divergences for a power content of 95 % with increasing operation current is displayed in fig. 8a and 8b. The solid line represents the mean value of the measurement dots of three lasers. It is worthful to note that the slow-axis divergence remains below 10° at 200A (170 to 180 W) and that the fast-axis is constant at all currents.



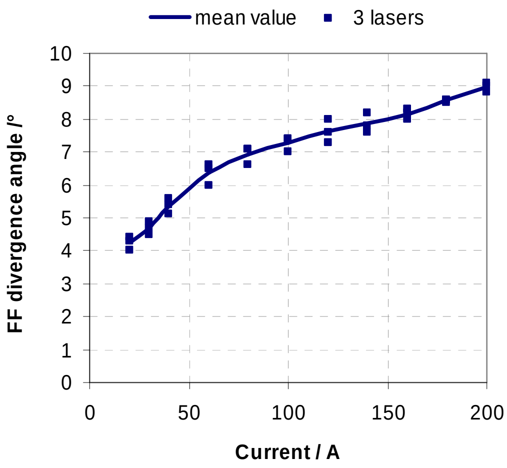


Fig. 8a (left): fast-axis and Fig 8b (right): slow-axis divergence angle at 95% power content up to currents of 200A

5. AGEING BEHAVIOR AT HIGH-POWER OPERATION

The reliability assessment of passively cooled 940nm high power diode lasers can be performed in maximum constant temperature mode or in maximum thermal cycling mode. Whereas the former mode tests the stability of the package against high thermal load, the latter one tests the stability of the package against (thermo-)mechanical cycling. For passively cooled diode lasers operated in cw steady-state mode and in cw repetitive (hard pulse) mode, at the same power, the maximum temperature is about 20% lower in the repetitive mode than in the steady-state mode [1]. Nevertheless it turned out, that diode lasers are more sensitive to the repetitive mode than to the steady-state mode. A full reliability characterization should, however, always include both modes, especially at very high powers.

Fig. 9 shows the constant-current characteristics of the optical output power of a set of 12 lasers during 9300 h of operation under hard pulse condition. The worst power decrease during the test time is 4,4%. Linear extrapolation of the power data reveals that 5 of 12 lasers exhibit a degradation of lower than $9.2 \cdot 10^{-5}$ W/h which represents about a quarter of the required degradation to reach the EOL criterion of 20% power decrease within 7 times 9300 hours.

The lognormal probability plot of fig. 10 is therefore based on a tightened failure criterion of 5% power decrease with 5 right-censored lasers at plotting positions of

$$R(i) = 1 - \frac{i - 0.5}{n} \qquad (19)$$

for the i-th failed laser [3]. The time of reliable operation at 95% survival probability at the lower 90% confidence limit has thus to be multiplied by a factor of 4 resulting in 16,900 hours of reliable operation.

As only one laser reaches the EOL criterion within the permitted extrapolation, it is interesting to assume a hypothetic zero-failure test for comparison. The application of eq. (17) yields a time of reliable operation of 17,400 hours which is quite close to the time investigated by the ML fit in the probability plot.

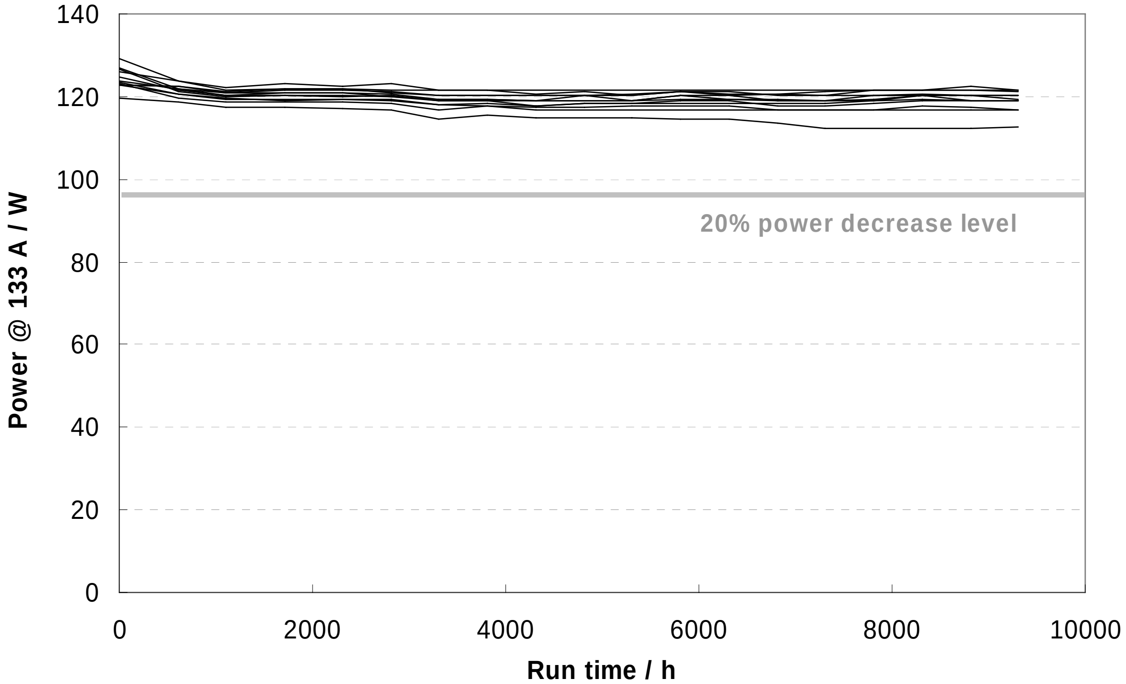


Fig. 9: Reliability of a set of 12 passively cooled diode lasers operated at 133 A in 1s pulses at 0.5 Hz; heat sink temperature is 25 °C.

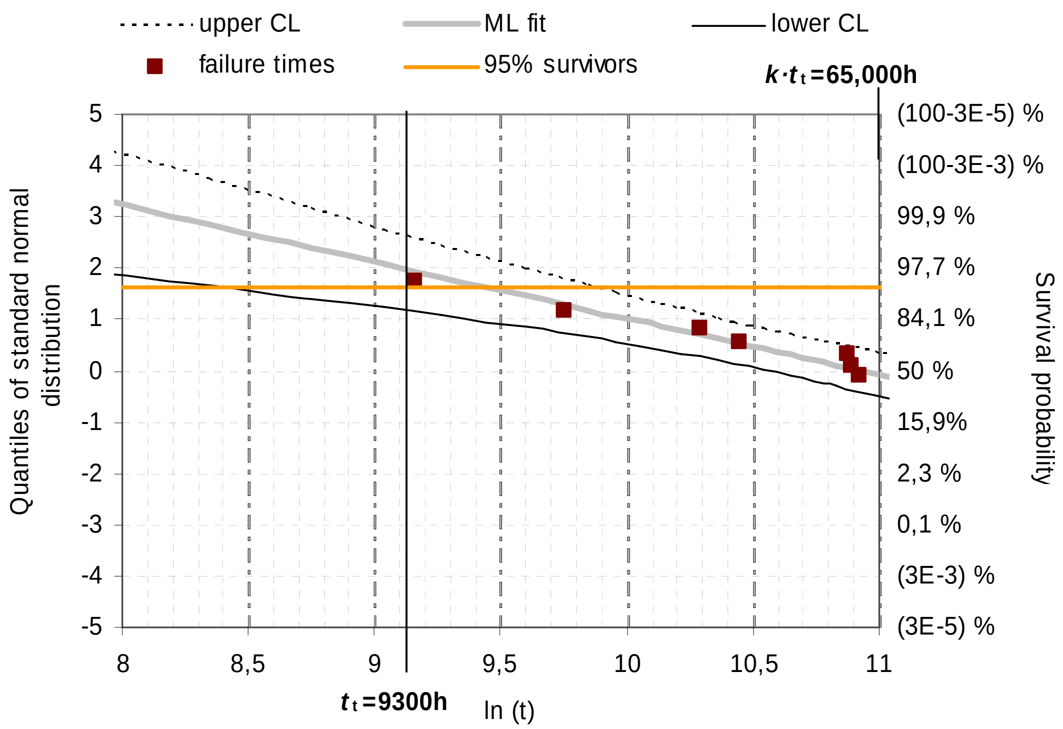


Fig. 10: Survival probability plot for an EOL criterion of 5% power decrease of the 12 lasers (5 lasers right-censored) from fig. 9 displaying a time of reliable operation of 4200 h at the lower 90% confidence level of 95% surviving lasers.

Fig. 11 and 12 show the power evolution of a set of 12 lasers operating in steady-state cw mode around 155 W at 170A and a set of 11 lasers operating in repetitive cw mode of 1s pulses at 0,5 Hz around 155 W at 170A. Both sets have so far been operating during 2400 hours. Degradation is in both cases higher than in the preceding 120W test.

The lognormal probability plots of fig. 13 and 14 at reduced EOL criteria of 10% (steady-state) and 7% (hard pulse) power decrease with 2 right-censored lasers in both cases provide times of reliable operation of 4250 h and 4820 h, respectively. A ZFT would give times of 4490 h and 4120 h for those 12 and 11 lasers, respectively. A probability plot of the steady-state cw lasers for the 20% power decrease EOL criterion with 7 right-censored lasers gives a t_R of 4800 h.

We finally note, that at this stage of testing, no reliability difference between both operation modes could be identified.

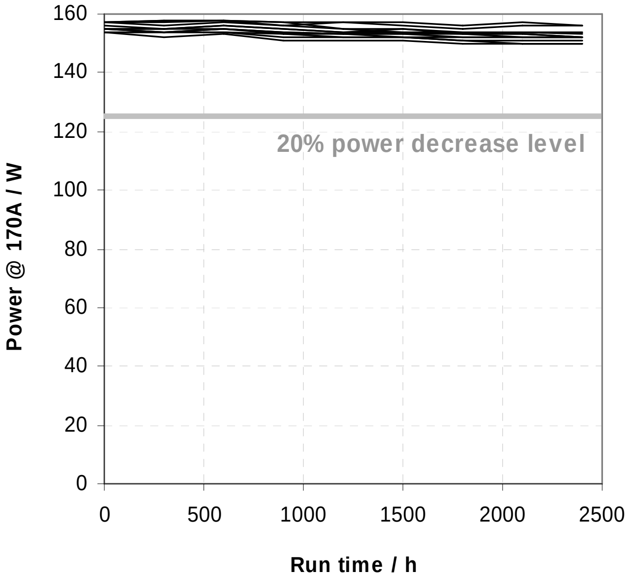


Fig. 11: Reliability of a set of 12 passively cooled diode lasers operated at 170 A cw

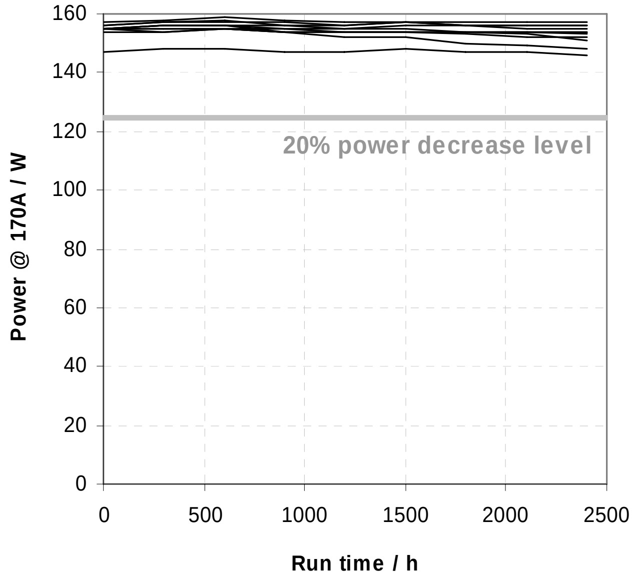


Fig. 12: Reliability of a set of 11 passively diode lasers operated at 170 A in 1s pulses at 0.5 Hz

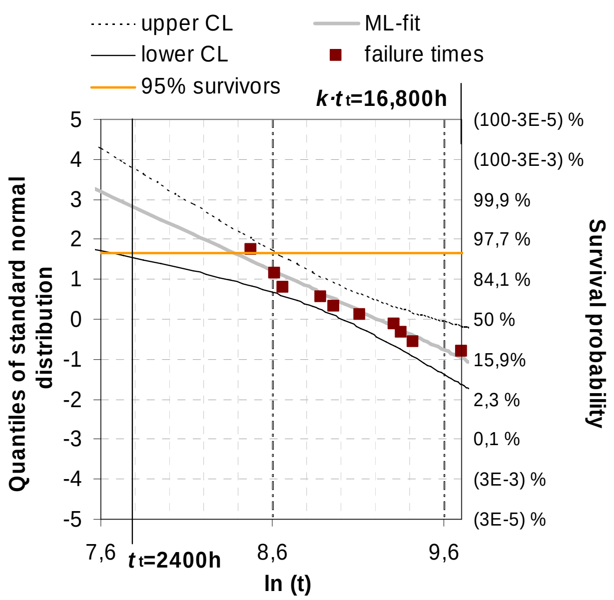


Fig. 13: Survical probability plot for 12 diode lasers from fig. 11 operated in steady-state cw mode with EOL criterion of 10% power decrease.

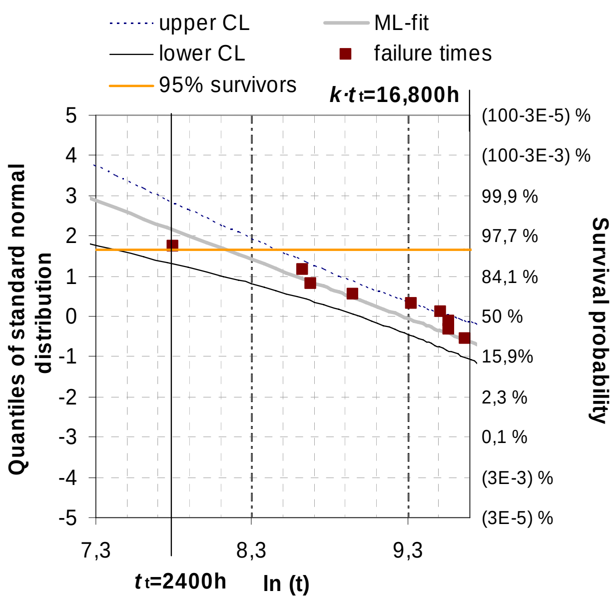


Fig. 14: Survical probability plot for 11 diode lasers from fig. 12 operated in repetitive cw mode with EOL criterion of 7% power decrease.

6. A GLANCE AT POWERS BEYOND 200 W

The thermal resistance of passively cooled diode lasers can be reduced by employing a thermal bypass to the substrate side of the laser diode element. This method has successfully been applied by Murata et al. 15 years ago [5]. Such a package has now been realized with standard 50% filling factor 940nm high-power laser diode bars of 2 mm cavity length from JENOPTIK Diode Lab GmbH, Berlin, Germany. Double-side indium soldering and double-side gold-tin soldering have been employed to bond submount and bypass to the epitaxial p-side and the substrate n-side of the laser bar and to both sides of an aluminum nitride ceramic plate placed behind the rear facet of the laser bar. The measured thermal resistance was R_{th} = 0,35 K/W. LI curves are shown in fig. 15. A maximum output power of 238W has been achieved at 300A with the AuSn packaged diode laser. Maximum and TRO efficiency for both solders were 57 and 42%.

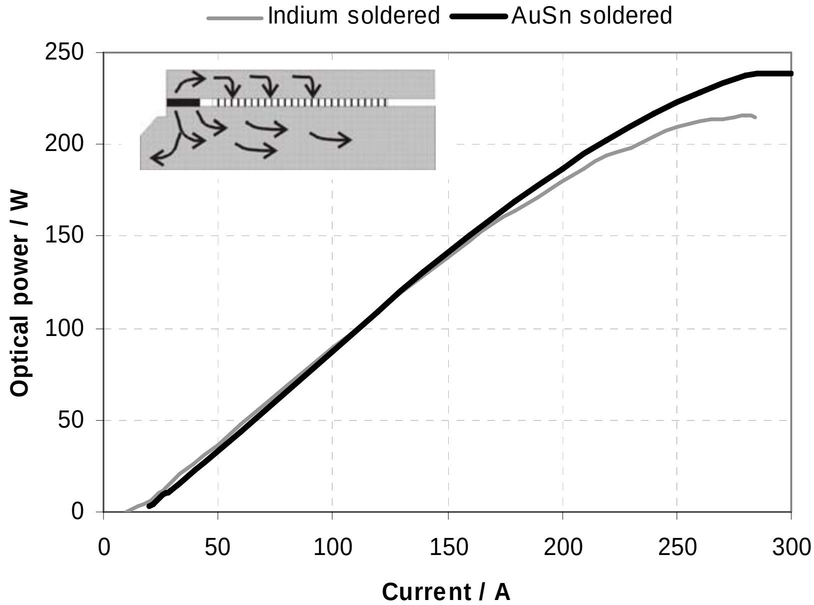


Fig. 15: LI curves of passively cooled diode lasers with thermal bypass. The arrows in the insert represent the heat flow.

7. CONCLUSION AND ACKNOWLEDGEMENTS

Technological improvements, notably that of gold-tin soldering have lead to increased powers and increased reliability of passively cooled 940nm diode lasers. Lifetime tests promise reliable operations of 120 Watt cw in hard pulse mode for at least 15,000 hours and of 150 Watt cw for nearly 5,000 hours. Tests will go on to confirm these estimations.

Additionnally, a thermal bypass could improve the cooling and increase the optical output power up to nearly 240W.

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