A comprehensive reliability study of high-power 808 nm laser diodes mounted with AuSn and indium

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ABSTRACT

In the scope of the project TRUST, more than 20 aging tests have been performed on about 300 high-power laser diode bars with a variation of the mounting technology, current load, operation temperature, and operation mode. Our main goals were the improvement of the reliability and the determination of acceleration parameters for aging tests. We present selected results of long-time aging tests, acceleration factors, and thermal activation energies for high-power 808 nm laser diodes. Due to the increasing demand for higher output powers, we focus mainly on gold-tin mounted laser bars and show their great potential in comparison to the standard indium packaging technology.

Keywords: 808 nm, high-power diode lasers, reliability, accelerated lifetime tests

1. INTRODUCTION

The broad industrial application of high-power laser diodes (HPLDs) started more than 10 years ago. HPLDs are used directly in materials processing, medicine, display, or printing systems, but also as pump sources for various rod, disk, and fiber lasers. In the last few years we see an increasing demand in HPLDs and a constant development towards higher optical output powers per laser bar. For industrial applications, the reliability is rated as the key parameter deciding about the more or less extensive use of HPDLs in future. Its importance is even higher than the achievement of new records in the optical output power of laser bars. Customers today expect device lifetimes of more than 20,000 hours or 25 MShots, respectively. In view of the fast development in diode laser technology within the last few years, the development and implementation of accelerated aging tests becomes more and more important to ensure a high reliability at reasonable investment costs.

Within the framework of the project “TRUST - Reliability Analysis of Brilliant High-Power Diode Lasers in Industrially Relevant Operation Regimes” we have carried out a comprehensive study on more than 300 diode laser bars mounted with gold-tin and indium solder on actively cooled heat sinks. An increase of the optical output power on the one hand and of the heat sink temperature on the other hand was used to accelerate the device aging. For both mounting technologies, thermal activation energies as well as acceleration factors for an increase of the optical output power in aging tests were determined.

Our comprehensive study was accompanied by an extended pre-characterization of the laser bars and diodes using optical inspection of the facets, thermal imaging, packaging-induced strain analysis, defect-related electroluminescence etc., to identify correlations of initial failures or distinctive features with reduced lifetime.

In this paper, we present selected results of long-time aging tests, acceleration factors, and thermal activation energies for high-power 808 nm laser diodes with one type of laser bar. First we describe the investigated 808 nm laser bars and the test matrix. Then we explain the methodology of lifetime data processing and analysis as well as the determination of acceleration factors and thermal activation energies. The emphasis in our presentation lies on aging results under various operation conditions of gold-tin mounted laser bars. A comparison between continuous wave (cw) and long pulse operation (i.e. pulse lengths of 0.1-1 s, 50% duty cycle), but also with the well-known indium solder technology is carried out. Finally, acceleration factors and thermal activation energies are given.

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2. EXPERIMENTAL

2.1 Samples and test equipment

The devices explored in this study were grown on 3” n-type (001) GaAs substrates by metal-organic vapor phase epitaxy on the basis of a quaternary InAlGaAs single quantum well embedded off-centered into Al_{0.4}Ga_{0.6}As waveguide layers. A more detailed description is given in Ref. 3.

The aging tests described in this report were carried out on the same type of 808 nm laser diode bars from OSRAM Opto Semiconductors GmbH (OSRAM) with a cavity length of 1200 µm. These so-called ‘cm-bars’ consists of 25 laser stripes with an emitter width of 200 µm and a pitch of 400 µm corresponding to a filling factor of 50%. Typical values of the threshold current and the maximum wall-plug efficiency are 13 A and 57%, respectively. All laser bars for our tests were produced in the beginning of 2005 using the standard epitaxial structure and processes from that time. OSRAM recommended a nominal optical output power of $P_{\text{nom}} = 50$ W for actively cooled laser bars of this type implying a thermal resistance of $R_{\text{th}} < 0.5$ K/W. Note, that newer types of 808 nm laser diode bars with a higher wall-plug efficiency developed at the same time within the project BRILASI were not used in this study.

All laser diode bars were mounted on the same type of an actively cooled heat sink. For a direct comparison of soft and hard soldering technologies, we used very similar HPLD packages. As shown in Fig. 1 there were only two changes in the standard indium solder assembly: A gold-tin solder layer deposited on an expansion-match copper-tungsten (CuW) submount was inserted between the laser bar and the indium soft solder. Furthermore, the contact-lid on the n-side of the laser bar was replaced by wire bonds.

Before we started the aging tests, all laser bars and diodes were extensively pre-characterized using optical inspection of the anti-reflection (AR) coated facets, thermal imaging, packaging-induced strain analysis, defect-related electroluminescence, near field imaging etc., to identify correlations of initial failures with reduced lifetime for each HPLD.

The aging tests at a constant driving current are performed in specially designed HPLD aging setup within a cleanroom to avoid any contamination. Our test stages are capable to take up 16 laser diodes mounted on actively cooled heat sinks. The temperature of the cooling water circuit can be chosen between 20 and 50°C with a stability of ±0.5°C. Each laser diode is connected to an individual current source. The emitted radiation of each laser diode is detected by a photodiode. Its signal, the operating current and voltage as well as the cooling water temperature and flow rate are monitored and recorded by a computer. Investigations of our micro-channel heat sinks have shown that all aging results presented in section 4 are not influenced by corrosion usually leading to a decrease of the cooling efficiency.

2.2 Test matrix

Besides the improvement of the reliability, our main goals within the project TRUST were the investigation of the aging behavior under various operation conditions and the determination of acceleration parameters for aging tests. In our comprehensive reliability study on 300 high-power laser diode bars we have chosen the test matrix given in Table 1 for gold-tin mounted laser diode bars. The term long-pulse mode means hard-pulse operation at 1.5 Hz with 50% duty cycle. Additionally, three aging experiments at different frequencies (2.5, 5 and 10 Hz, 50% duty cycle) with an optical output power of $P_{\text{aging}} = 60$ W and a heat sink temperature of $T_{hs} = 20\degree C$ were carried out to detect a possible frequency
dependence of the degradation rate in the industrially relevant pulsed operation regimes. In order to achieve statistically reasonable data, each aging experiment was run with 16 diodes apart from the cw tests at 80 W/20°C and 80 W/50°C. The latter two cw tests were run only with 8 diodes.

Table 1. Test matrix for aging experiments on gold-tin mounted laser diode bars driven at various operation modes, optical output powers, and heat sink temperatures.

<table>
<thead>
<tr>
<th>Optical output power</th>
<th>Heat sink temperature $T_{hs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{aging}$</td>
<td>$P_{aging}/P_{nom}$</td>
</tr>
<tr>
<td>60 W</td>
<td>1.2</td>
</tr>
<tr>
<td>70 W</td>
<td>1.4</td>
</tr>
<tr>
<td>80 W</td>
<td>1.6</td>
</tr>
</tbody>
</table>

The same set of aging experiments was carried out on indium mounted laser bars with optical output powers of 10 W lower than given in Table 1 for hard soldered devices.

### 3. DATA ANALYSIS

#### 3.1 Lifetime evaluation and extrapolation

All aging experiments in this report are carried out in the automatic current control (ACC) mode. At the beginning of aging tests in the ACC mode, lasers often show a small increase or decrease of the optical output power at the driving current before the degradation rate $\Delta P/\Delta t$ stabilizes to a nearly constant value. This initial test period is not considered for extrapolations.

Fig. 2. Determination of HPLD lifetime from an aging test in the automatic current control mode.

The principle of lifetime determination from an aging test in the ACC mode is shown in Fig. 2. The end-of-life criterion is defined as the time $\tau_{EOL}$ after which the optical output power of a laser falls below the value of $0.8 \cdot P_0$ for the first time. Aging tests are not always carried out until this end-of-life criterion is fulfilled. In this case the lifetime is evaluated by a linear extrapolation of the recorded degradation curve as shown in Fig. 2. Especially for short test times the extrapolation can result in unrealistic large lifetime values. Depending on the number of test lasers and the standard deviation of the degradation rates, extrapolation is allowed only up to $n$-times of the performed test duration, which is considered to follow linear degradation of the optical output power (see Table 2). For details see ISO/FDIS 17526.
Table 2. Permitted extend of extrapolation to achieved lifetime data.7

<table>
<thead>
<tr>
<th>Number of test lasers</th>
<th>Standard deviation of the degradation rate</th>
<th>Permitted extrapolation extend n</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 10</td>
<td>5% to 10%</td>
<td>3</td>
</tr>
<tr>
<td>5 to 10</td>
<td>&lt; 5%</td>
<td>5</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>5% to 10%</td>
<td>5</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>&lt; 5%</td>
<td>7</td>
</tr>
</tbody>
</table>

**Lifetime statistics**

In lifetime analysis, the Weibull distribution is most commonly used due to its flexibility – it can also express the behavior of other statistical distributions such as normal and exponential. The failure probability, i.e. the cumulative Weibull distribution function, $H(t)$, is described by

$$H(t) = 1 - \exp\left(-\left(\frac{t}{T_{63}}\right)^b\right).$$

(1)

Here $b$ is the Weibull exponent (slope parameter), $t$ is the operation time of a device, and $T_{63}$ is the characteristic time at a failure probability of 63.2%. Accordingly, the survival probability is given by $1-H(t)$. A decreasing failure probability over time ($b < 1$) suggests “infant mortality”, i.e. defective items fail early and the failure rate decreases over time as they fall out of the population. A constant failure probability suggests that items are failing from random events ($b = 1$). In this case, the Weibull distribution reduces to the exponential distribution. Finally, an increasing failure probability ($b > 1$) suggests “wear out”. When $b = 3.4$, then the Weibull distribution appears similar to the normal distribution.

In aging experiments on laser diode bars we distinguish between sudden, soft, and pseudo failures. Sudden failures occur spontaneously during the test time. Soft failures are events when the optical output power of a laser diode falls below the value of $0.8 \cdot P_{0}$. Pseudo failures describe possible soft failures after a linear extrapolation of the degradation curve as shown in Fig. 2.

Fig. 3. (a) Aging test in cw mode on 16 indium mounted laser bars with $P_{\text{aging}} = 1.4 \cdot P_{\text{nom}}$ at $T_{hs} = 50^\circ$C. (b) Survival probability of the diode lasers vs. time. Full symbols mark sudden and soft failures, open symbols stay for so-called pseudo failures. The solid line depicts a fit to $1-H(t)$ with $T_{63} = 4.975 \text{ h}$ and $b = 1.5$.

The potential of the Weibull statistics to lifetime analysis is shown in Fig. 3 for the example of an aging test in cw mode on 16 indium mounted laser bars with 140% of the nominal optical output power at an elevated heat sink temperature of 50°C. The sudden and soft failures [full symbols in Fig. 3(b)] as well as the pseudo failures [open symbols in Fig. 3(b)] could be described with one set of Weibull parameters. For this particular aging test, the best fit of the failure times to
the cumulative Weibull distribution function [solid line in Fig. 3(b)] gives values of $b = 1.5$ for the Weibull exponent and $T_{63} = 4.975\ h$ for the characteristic time at a failure probability of 63.2%.

3.2 Acceleration factors

In view of the fast development in diode laser technology within the last few years, the development and implementation of accelerated aging tests becomes more and more important to ensure a high reliability at reasonable investment costs. Lifetime tests of HPLDs can be accelerating by an increase of the heat sink temperature, the optical output power, the driving current or a combination of these operating parameters.

The failure rate $\lambda$ can be described by eq. (2). The indices $\text{aging}$ and $\text{nom}$ stands for the aging test conditions and the nominal operating conditions, respectively.

$$\lambda_{\text{aging}} = \lambda_{\text{nom}} \cdot \pi_T \cdot \pi_P \cdot \pi_I$$  \hspace{1cm} (2)

The parameters $\pi_T$, $\pi_P$, and $\pi_I$ are the acceleration factors describing an increase of the test temperature, the optical output power, and the driving current, respectively. Here the temperature acceleration factor $\pi_T$ is given by

$$\pi_T = \exp \left[ -\frac{E_A}{k_B} \left( \frac{1}{T_{\text{aging}}} - \frac{1}{T_{\text{nom}}} \right) \right],$$ \hspace{1cm} (3)

where $E_A$ is the thermal activation energy and $k_B$ is the Boltzmann’s constant. There is a wide spread of published data for the thermal activation energy of usual failure mechanisms in the range from 0.2 to 0.7 eV. The acceleration factor $\pi_P$ for the optical output power $P$ can be determined using expression (4):

$$\pi_P = \left( \frac{P_{\text{aging}}}{P_{\text{nom}}} \right)^\beta,$$ \hspace{1cm} (4)

where $\beta$ is the so-called derating exponent with typical values between 2 and 4 for indium packaged laser bars. Finally, the acceleration factor $\pi_I$ for the driving current $I$ is given by

$$\pi_I = \left( \frac{I_{\text{aging}}}{I_{\text{nom}}} \right)^x.$$ \hspace{1cm} (5)

As the driving current for diode lasers is directly correlated with the optical output power and the operating temperature, it is usually set to $x = 0$, i.e. the acceleration factor $\pi_P$ becomes equal to 1.

All acceleration factors given in this report were determined using expression (2)-(5).

4. AGING TEST RESULTS

4.1 Aging at elevated optical output power

One possible way to shorten the duration of aging tests is the acceleration by an increase of the optical output power. Figures 4(a) and (b) as well as Fig. 6(a) show aging tests (each with 16 HPLDs) on gold-tin mounted laser bars in long-pulse mode at a heat sink temperature of 20°C with three different optical output power levels: $1.2\ P_{\text{nom}}$, $1.4\ P_{\text{nom}}$, and $1.6\ P_{\text{nom}}$. Although these tests run under a significant overstress, we did not observe any sudden or soft failures during the test time. We find the expected increase of the degradation rates from $-5.6 \times 10^{-5}\ W/h$ at $1.2\ P_{\text{nom}}$ to $-4.5 \times 10^{-4}\ W/h$ at $1.6\ P_{\text{nom}}$. Figure 4(c) illustrates the acceleration of aging with increasing optical output power. All data points represent pseudo failures estimated by a linear extrapolation of the recorded degradation curves. For an increase of the optical output power from $1.2\ P_{\text{nom}}$ to $1.6\ P_{\text{nom}}$ we could determine an acceleration factor $\pi_P$ of $8.1 \pm 0.4$.

Similar aging tests on indium mounted laser bars (each with 16 HPLDs) were carried out in long-pulse mode at a heat sink temperature of 20°C with optical output powers of $1.2\ P_{\text{nom}}$ and $1.4\ P_{\text{nom}}$. The result of an aging test with 120% of
the nominal optical output power is depicted in Fig. 5(a) showing sudden failures within a shorter test time compared to the gold-tin mounted laser bars [see Fig. 6(a)]. As we used the same type of laser bar and heat sink for both mounting technologies, we can state that the aging of the investigated HPLDs with indium packaging is determined by a strong degradation of the indium solder interface in long-pulse operation under overstress. In this mode the laser bars are exposed to a full thermal cycle between heat sink temperature and maximum junction temperature at the given output power during each pulse. The different thermal expansion coefficients $\alpha$ of the copper heat sink ($\alpha_{\text{Cu}} = 17 \times 10^{-6} \text{K}^{-1}$) and the semiconductor laser bar ($\alpha_{\text{GaAs}} = 6.5 \times 10^{-6} \text{K}^{-1}$) cause extremely hard thermo-mechanical stress to the laser bar leading to a fatigue of the soft solder interface accelerated by electro- and thermomigration of the indium. Finally, the laser bars fail due to a local overheating and melting of the semiconductor materials. Forthcoming failures of indium mounted laser bars are announced by an increased nonlinear degradation as one can see in Fig. 5(a).

Fig. 4. Aging tests in long-pulse mode at $T_{\text{hs}} = 20^\circ\text{C}$: (a) with $1.4 \times P_{\text{nom}}$ and (b) with $1.6 \times P_{\text{nom}}$ – both on gold-tin mounted laser bars; see Fig. 6(a) for the test with $1.2 \times P_{\text{nom}}$. (c) Failure probability of the gold-tin mounted diode lasers bars vs. time: Open symbols stay for so-called pseudo failures. The solid lines depict fits to the cumulative Weibull distribution function.

In our long-pulsed aging tests under overstress, the reliability of the HPLD packages was mainly affected by a degradation of the solder interface for indium mounted laser bars whereas the gold-tin mounted devices showed a real degradation of the semiconductor material. The long-pulse lifetime of the gold-tin mounted laser bars driven with $1.6 \times P_{\text{nom}}$ is expected to exceed 20,000 hours. There have been other evidences for a long-time hard-pulse reliability of hard-soldered laser bars.$^{11}$ In view of the increasing demand on higher optical output powers per laser bar one should account for the power and temperature threshold limiting the long-time stability of the indium solder interface. Recent experiments performed at DILAS outside the project TRUST with the same type of laser bars mounted with an improved indium soldering process on a more efficient micro-channel heat sink show a significant shift of this threshold towards stronger operation conditions allowing now reliable operation in long-pulse mode up to $1.3 \times P_{\text{nom}}$ [see e.g. Fig. 5(b)].

Fig. 5. Aging tests in long-pulse mode on indium mounted laser bars stemming from the same epitaxial run with $1.2 \times P_{\text{nom}}$ at $T_{\text{hs}} = 20^\circ\text{C}$: (a) test within the project TRUST and (b) recent experiments on laser diodes with an improved indium soldering process mounted on a new type of micro-channel heat sinks with improved cooling properties.
4.2 Aging at elevated operation temperature

Another way to accelerate aging tests on HPLDs is the increase of heat sink temperature. Figures 6(a) and (b) show aging tests (each with 16 HPLDs) on gold-tin mounted laser bars in long-pulse mode with 120% of the nominal optical output power at two different heat sink temperatures: 20°C and 50°C, respectively. Figures 6(d) and (e) depict the degradation curves of indium mounted laser bars driven in cw operation with $1.4P_{nom}$ at heat sink temperatures of 20°C and 50°C, too.

Fig. 6. Aging tests in long-pulse mode with $1.2P_{nom}$ on gold-tin mounted laser bars at $T_{hs} = 20°C$ (a) and 50°C (b). Aging tests in cw mode with $1.4P_{nom}$ on indium mounted laser bars at $T_{hs} = 20°C$ (d) and 50°C (e). Failure probability of the gold-tin (c) and indium (f) mounted diode lasers bars vs. time: Full symbols stay for sudden and soft failures, whereas open symbols mark so-called pseudo failures. The solid lines depict fits to the cumulative Weibull distribution function.

For both mounting technologies we observe an acceleration of the degradation rate with increasing heat sink temperatures illustrated in Figs. 6(c) and 6(f) for hard and soft solder packaged laser bars, respectively. The full symbols in the Weibull plots [Figs. 6(c) and 6(f)] represent sudden and soft failures, whereas open symbols mark pseudo failures estimated by a linear extrapolation of the recorded degradation curves.

We did not observe any sudden or soft failures in the long-pulse aging experiments with $1.2P_{nom}$ on gold-tin mounted laser bars during the test time. For an increase of the heat sink temperature from 20°C to 50°C we have determined an acceleration factor $\pi$ of $13.1 \pm 1.2$ resulting in a thermal activation energy of $E_A = (700 \pm 25) \text{ meV}$ according to eq. (3).

In order to receive a temperature acceleration factor for indium mounted laser bars we had to consider aging tests with $1.4P_{nom}$ in cw operation that were not influenced by a degradation of the indium solder interface within the test duration.
The aging tests shown in Figs. 6(d) and (e) show a temperature acceleration by a factor $\pi_T$ of $6.3 \pm 0.7$ resulting in a thermal activation energy of $E_A = (500 \pm 30)$ meV according to eq. (3).

Different values of thermal activation energies determined for the same type of laser bar are usually explained with different degradation mechanisms occurring under different operation conditions. Cathodoluminescence and photoluminescence microscopy studies on degraded laser diodes from our four aging tests discussed in this paragraph show the same type of bulk degradation in the quaternary InAlGaAs single quantum well. We assume that the main reason for different values of thermal activation energies determined for indium and gold-tin mounted laser bars is the lower packaging-induced strain in hard-soldered devices due to the expansion-matched CuW submounts in comparison with soft-soldered bars. Photocurrent measurements on our HPLDs prove a strong reduction of packaging-induced strain in gold-tin mounted laser bars. So we have to bring simply more energy into the crystal lattice before the accumulation of the same type of defects can be activated.

4.3 Comparison of aging at cw and pulsed operation

In the past, several reliability studies on indium-mounted laser bars reported on a much stronger degradation of HPLDs in long-pulsed operation in comparison with cw operation (see e.g. Ref. 14). The aging tests in our recent study support these previous results. At a heat sink temperature of 20°C, fifteen indium soldered laser bars failed within 2,000 hours of long-pulsed operation with $1.2 P_{\text{nom}}$ [see Fig. 5(a)], whereas all HPLDs operated with $1.4 P_{\text{nom}}$ in cw mode remained unaffected over more than 6,000 hours [see Fig. 6(d)]. The constant thermo-mechanical stress in cw operation leads to a higher stability of the soft solder interface compared to the hard-pulse mode. Furthermore the packaging-induced strain relaxes strongly; after 500 hours of cw operation at $1.4 P_{\text{nom}}$ the strain is reduced by about 50%. Nevertheless, the stability of the indium interface is limited by a power and temperature threshold.

![Fig. 7. Results of comparative aging tests on gold-tin mounted laser bars with $1.6 P_{\text{nom}}$ at $T_{\text{hs}} = 20°C$ operated (a) in long-pulse and (b) in cw mode.](image)

In contrast to soft soldered laser bars, we observe an increase of the degradation rate for cw operation compared with the test in long-pulse mode as shown in Fig. 7. This behavior is primarily caused by two factors: First, the small packaging-induced strain in hard soldered laser bars cannot relax at all during cw or pulsed operation. Compared to indium, the gold-tin solder interface is stable. Second, the CuW submount in the gold-tin package inserts an additional thermal resistance between the laser bar and the heat sink leading to an increased junction temperature in comparison with an indium mounted device operating with the same optical output power. As shown in section 4.2, an elevated junction temperature effects an accelerated aging of HPLDs. For these reason we also observe a higher degradation rate for gold-tin mounted laser bars than for indium soldered devices under the same test parameters in cw operation.

5. SUMMARY

There is an essential need for the development and application of accelerated lifetime tests due to the high costs for aging equipment and experiments as well as due to the fast development in diode laser technology within the last few years. We presented selected results of a comprehensive reliability study on 808nm laser diode bars from OSRAM obtained within the project TRUST. The laser bars were mounted with indium and gold-tin on the same actively cooled heat sinks. More than 20 aging tests under various operating conditions were carried out leading to a deeper insight into the aging behavior of HPLDs. Table 3 summarizes the results on gold-tin mounted laser bars with $T_{50}$ as the characteristic time at a failure probability of 50%. Please note, that an extrapolation of degradation curves is allowed only up to a maximum of 7-times of the performed test duration $t_{\text{test}}$, although we neglect this demand here for a better comparability.
We have observed a significant acceleration of device aging by an increase of the heat sink temperature, the optical output power, the driving current and a combination of these operating parameters. For both mounting technologies, thermal activation energies as well as acceleration factors were determined.

In our long-pulsed aging tests under overstress, the reliability of the HPLD packages was mainly affected by a degradation of the solder interface for indium mounted laser bars whereas the gold-tin mounted devices showed a real degradation of the semiconductor material. In contrast to soft soldered laser bars, we observe an increased degradation rate for cw operation compared with the test in long-pulse mode for gold-tin mounted devices. We have determined two different values of the thermal activation energy for indium and gold-tin mounted laser bars of $E_A = (500 \pm 30)$ meV and $E_A = (700 \pm 25)$ meV, respectively, mainly due to the reduced packing-induced strain in hard soldered devices.

<table>
<thead>
<tr>
<th>$T_{hs}$ (°C)</th>
<th>$P_{aging}$ (W)</th>
<th>$P_{aging}/P_{nom}$</th>
<th>Test mode</th>
<th>$t_{test}$ (h)</th>
<th>Test mode</th>
<th>$T_{50}$ (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>60</td>
<td>1.2</td>
<td>long-pulse</td>
<td>4.000</td>
<td>long-pulse</td>
<td>175.000</td>
</tr>
<tr>
<td>20</td>
<td>70</td>
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<td>long-pulse</td>
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<td>82.000</td>
</tr>
<tr>
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<td>80</td>
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<td>cw</td>
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</tr>
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</table>

Table 3. Results of aging tests on gold-tin mounted laser bars.

Our study demonstrated the large potential of gold-tin mounted laser diode bars especially in the industrially relevant pulsed operating mode at high optical output powers.

6. ACKNOWLEDGEMENTS

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