Using visible InGaN laser diodes

Application Note

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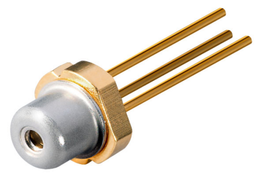
Valid for:
InGaN visible laser diodes

Abstract

ams-OSRAM AG offers visible, InGaN-based laser diodes that are well suited for automotive and industry applications, as well as for projection. This application note provides a guideline for the proper use of visible InGaN laser diodes from ams-OSRAM AG and describes their technical details as well as the operation of the laser diodes.



Further information:

For more detailed information and the latest product update visit the ams-OSRAM product website or contact your local sales office to get technical assistance during the design-in phase.

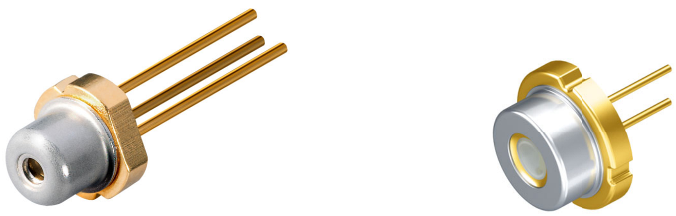
Table of contents

1 Basic information on handling and assembly

1.1 Safety instructions

Depending on the mode of operation, laser diodes (refer to Figure 1) emit highly concentrated visible light which can be hazardous to the human eye. Products which incorporate these devices must follow the safety precautions specified in IEC 60825-1 “Safety of laser products”.

Figure 1: Product pictures of a green single-mode laser (PL 520 in a TO38icut package) and a blue multi-mode laser (PLPT9 450LB_E in a TO90 package)



PL 520 PLPT9 450LB_E

Testing and maintenance of these products shall be only performed by personnel trained in laser safety. For more details please refer to the relevant local safety regulations and the requirements for manufacturers specified in IEC 60825-1.

The manufacturer of the final product must determine the laser class based on the driving conditions and the optical design, such as focusing lenses.

1.2 Storage and shipping

Storage and shipping should be done in a clean and dry atmosphere in a certain temperature range. Please refer to the “Storage Temperature” range in the data sheet.

1.3 Unpacking and handling

The visible InGaN diode lasers are shipped in a conductive plastic shipping container that is packed in a sealed conductive plastic bag.

Before opening the plastic bag, diode lasers should be kept at room temperature (in the room where the bag will be opened) for at least 4 hours to achieve thermal equilibrium. The protective bag may be opened only in a clean environment and non-humid atmosphere.

Solvents, non-conductive plastics and glues are not allowed near the diode lasers, because solvents could emerge and deposit on the window. Especially, the blue multi-mode power laser light can bake the contamination on the window, reducing its transparency.

Dust on the window can be removed by cleaning with oil-free compressed air. Mechanical stress to the window should be avoided in order to prevent the breaking of the hermetic seal.

Please also avoid scratches to the bottom surface of the TO package. These can increase the thermal resistance of the device mounted to the heat sink, which might result in reduced efficiency and thermal overload of the diode laser.

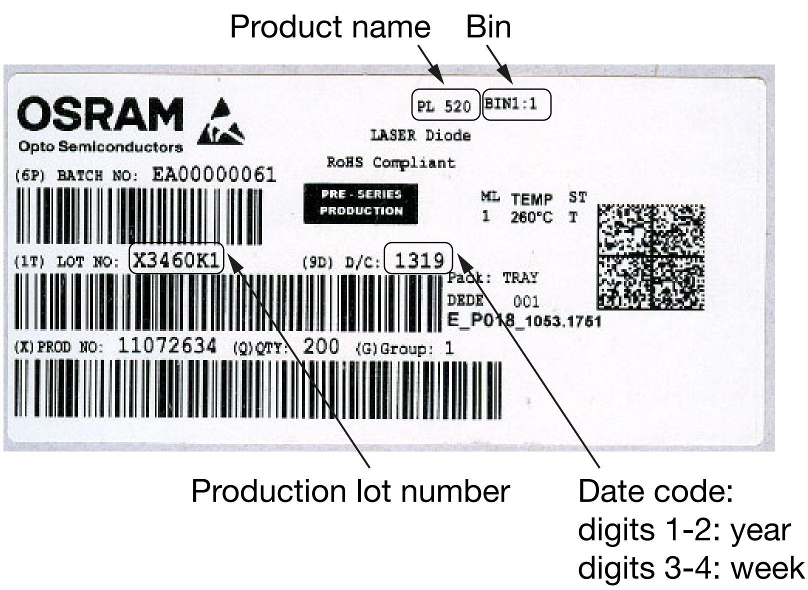
Operation in a particle-free and sealed environment is recommended as due to the high luminance particles, on the window of the TO package can lead to local heating of and damage to the window. Moreover, a sealed environment can prevent the steel cap of the TO package from aggressive impacts such as corrosion through interaction with salt.

Mechanical stress on the pins or bending of the pins can lead to damage to the hermetic seal and has a negative effect on long-term stability.

1.4 Label information

Figure 2 shows the label for visible laser diodes is which is placed on the sealed conductive plastic bag. The date code reflecting the Backend production date is printed on the label in addition to the product name, binning information and the production lot number.

Figure 2: Standard label for visible laser diodes



1.5 ESD handling

Since, InGaN diode lasers are electrostatic sensitive devices, their handling requires strict precautions against electrostatic charges. Every person and each tool that might get into contact with the diode laser must be continuously ESD-protected. Therefore, the devices should only be handled in ESD-protected areas (EN 100 015 former CECC 000 15).

InGaN laser diodes without an ESD protection diode have an ESD class 0 according to the Human Body Model. ESD pulses in reverse voltage in particular can cause damage to the laser diodes. Operating the laser afterwards may result in a strong reduction of output power.

The blue PLPT9 450LB_E multi-mode laser has an ESD protection diode inside the package and is protected for voltages of up to 8 kV (HBM model). For polarity please refer to the data sheet.

1.5.1 Recommendations for ESD control

To enhance the protection grade in the laser module we recommend implementing an ESD protection diode (e.g. Zener Diode) in the circuit design, if there is no ESD diode in the laser package already. The following points must be considered in order to ensure the proper protection of the diode:

- Breakdown voltage: The breakdown voltage of the ESD protection diode must be higher than the total forward voltage of the laser diode in order to ensure the correct functioning of the circuitry under normal circumstances.
- Response time: The response time of the ESD protection diode must be faster than that of the laser diode. Thereby, the protection mechanism can work effectively before a pulse may cause any damage to the laser diodes. Due to the fast switching times of the laser diodes, the response time of the protection diode is supposed to be in the range of 1 ns or less.

Basics for protection against static:

Grounding

Grounding systems shall be used to ensure that devices, personnel and any other conductors are at the same electrical potential.

Protection

To avoid exposure to static charges, keep components and modules separated during storage and transit. Through protection against statically charged objects and electric fields potential damage to laser components is minimized.

As statically charged insulators cannot be discharged by grounding, it is advisable to eliminate non-conductive plastic materials and other types of insulators from the working place, transit and storage areas.

Neutralization

Neutralization is the process to discharge insulators. This happens naturally through the process of ionization. Ions are charged particles that are always present in the atmosphere in the form of atoms, molecules or groups of molecules such as drops of water. The use of an ionizer generates billions of ions in the air and enables the static charge on an insulator to leak away.

Prevention

Prevention can be the most effective and important personal contribution to eliminate damage caused by ESD. Please find a set of guidelines below:

- Always keep working areas clean and tidy. Remove unwanted objects, especially those made of non-conductive plastic materials.
- When transferring components from one person to another, both persons should be grounded or at the same voltage potential.
- Avoid laser components or modules coming into contact with any insulating material.
- Never enter a static-proof working area without taking the necessary precautions.
- Always be aware of these rules when working with devices that can be damaged by electrostatic discharges.

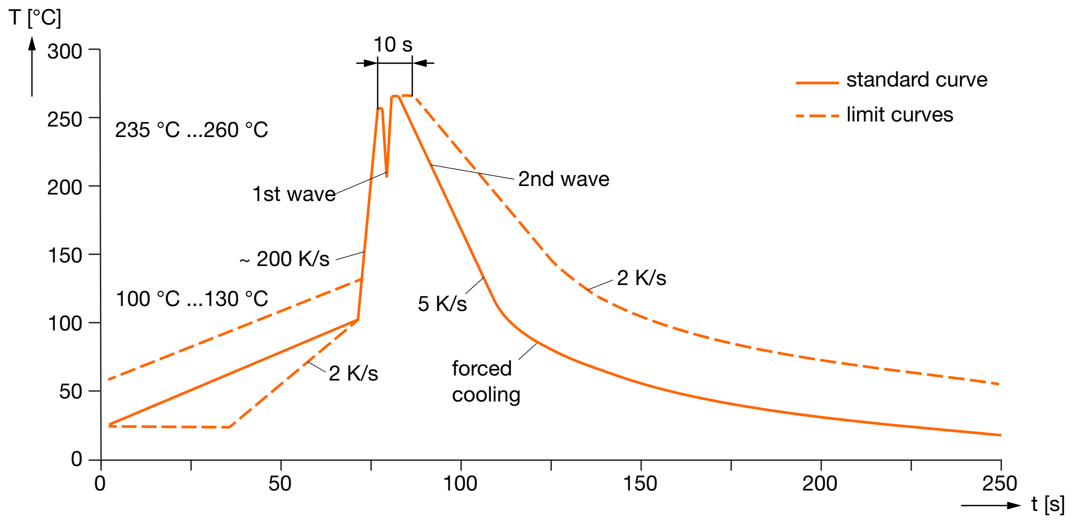
For further information on ESD handling please refer to the application note “ESD Protection while Handling LEDs“ which also applies to InGaN laser diodes.

1.6 Soldering

ams-OSRAM AG uses TTW (through the wave) soldering for their qualification process. Figure 3 shows a TTW soldering profile for the PLPT9 450LB_E. A minimum distance of 1.5 mm from the solder point to the baseplate of the TO90 package is recommended. To be RoHS-compliant, use lead-free soldering. The maximum rating for the soldering temperature should not exceed 10 sec at a maximum of 260 °C.

ams-OSRAM AG recommendation: The lifetime of the laser diode should be validated in an appropriate lifetime test at customer side for each soldering profile defined.

Figure 3: TTW soldering profile used by ams-OSRAM AG for the PLPT9 450LB_E



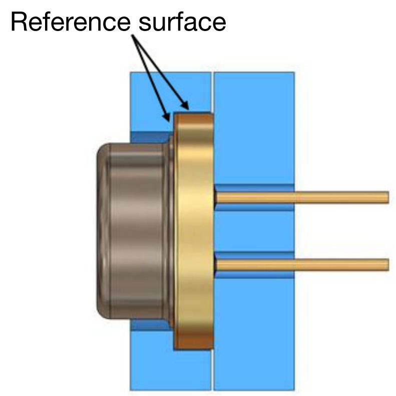
2 Mounting and thermal management

2.1 Mounting

A laser diode should only be mounted at the baseplate of the TO package. The cap should not be exposed to mechanical stress.

The reference surface for positioning the laser diode is the front side and the circumference of the baseplate, see Figure 4.

Figure 4: Reference surfaces of a TO90 package



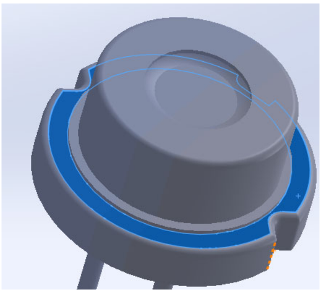
To prevent breakage of the hermetic seal of the pins, the laser diode's pins and baseplate must not be exposed to mechanical stress during mounting. Deformation of the baseplate must be avoided.

For the PLPT9 450LB_E TO90 device, the downward force on the area marked in Figure 5 shall not exceed 2,500 N in order to avoid mechanical stress on the package when mounting. On limited sample size tests were performed with press down forces on the marked area of up to 3,000 N – 5,000 N without negative impact on the hermetic sealing of the package.

ams-OSRAM AG recommendation: The reliability of the laser diode should be validated in appropriate qualification tests at customer side on system level with the integrated laser diode.

For the TO90 package, the mechanical robustness of the pins is tested according to the MIL-STD-883 2004.5.B2 and 2004.5A standards. With these tests, the maximum bending and the pulling strength of the pins are tested.

Figure 5: Area on the baseplate around the cap of the TO90 package



2.2 Thermal management

Appropriate cooling is required in order to obtain the specified output power and a long lifetime of the laser diode. The maximum rating for the junction temperature $T_{Junction}$ for GaN lasers is stated in the respective data sheet. Operation at this value will significantly reduce the lifetime of the diode.

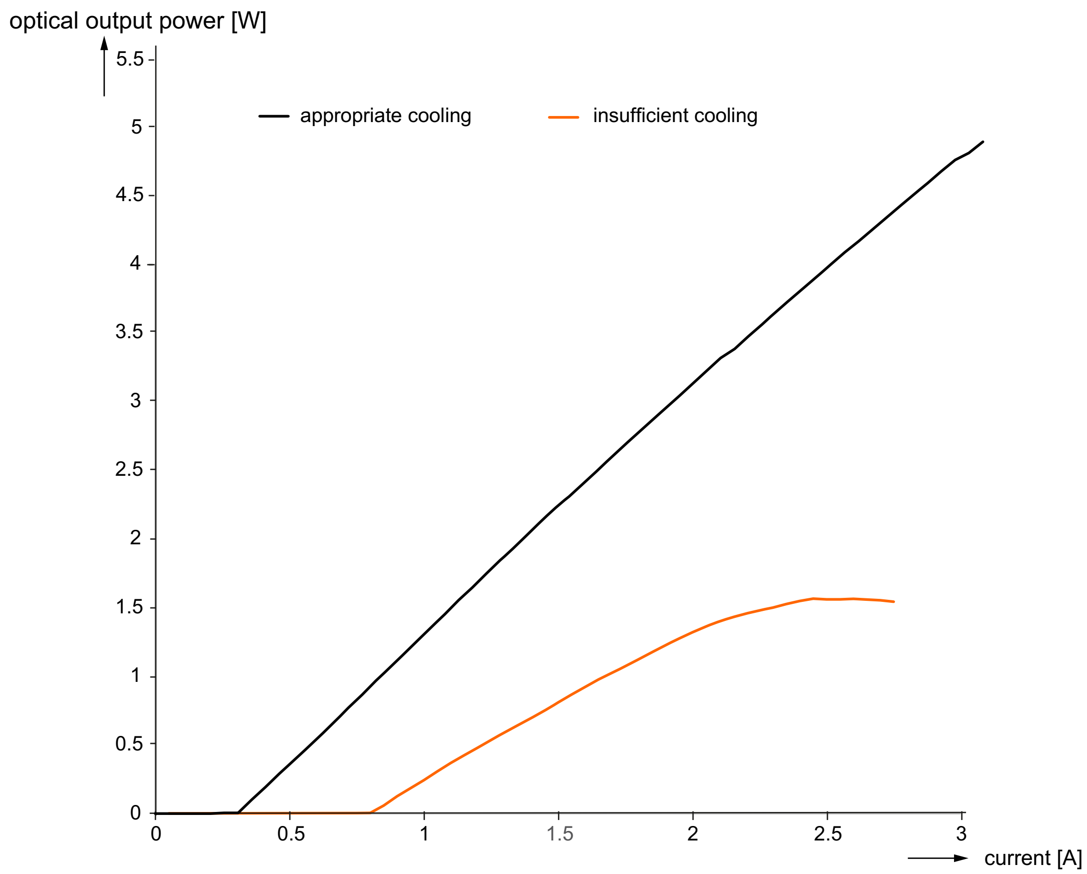
The junction temperature can be calculated using the following equation:

$$T_{Junction} = (U \cdot I - P_{opt}) \cdot R_{th} + T_{Case}$$

,where P_{opt} is the optical output power, U the operating voltage, I the operating current, T_{Case} the temperature of the package and R_{th} the thermal resistance (junction to case).

Insufficient cooling can also result in a significant reduction of the output power, especially at high power levels or temperatures. Figure 6 shows the influence of the cooling on the output power of the blue PLPT9 450LB_E multi-mode laser. In the worst case the output power can even drop to zero within the specified operating range.

Figure 6: Dependency of the optical output power of the PLPT9 450LB_E on the cooling



If a laser diode does not reach the specified optical output power at the specified maximum operating current, please review your cooling system.

2.3 Influence of thermal connection (junction to heat sink) $R_{th,JH}$

Figure 7 shows various thermal connection configurations of a TO90 package of the PLPT9 450LB_E to a highly thermally conductive heat sink, such as copper. The thermally connected surfaces are indicated as blue areas. The thermal connection only via the 2 pins is not shown as the 2 pins are not thermally connected to the TO90 housing. Using just a low conductive heat sink material, such as a PCB board, will increase the thermal resistance.

Figure 7: Various thermal connections of a TO90 laser diode package to a highly thermal conductive heat sink

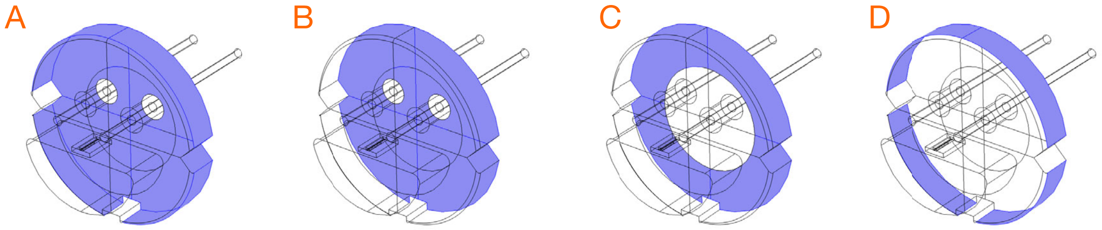
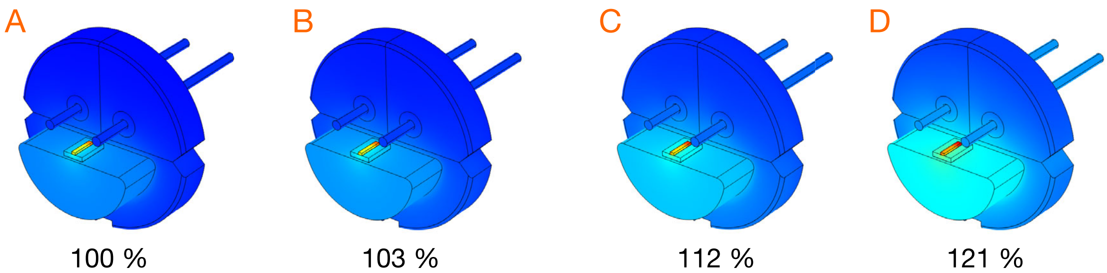


Figure 8 shows the corresponding simulation results performed for the blue PLPT9 450LB_E multi-mode laser in a TO90 package. Here, dark bluish colors indicate low temperatures, whereas light bluish to red colors indicate increased to high temperatures.

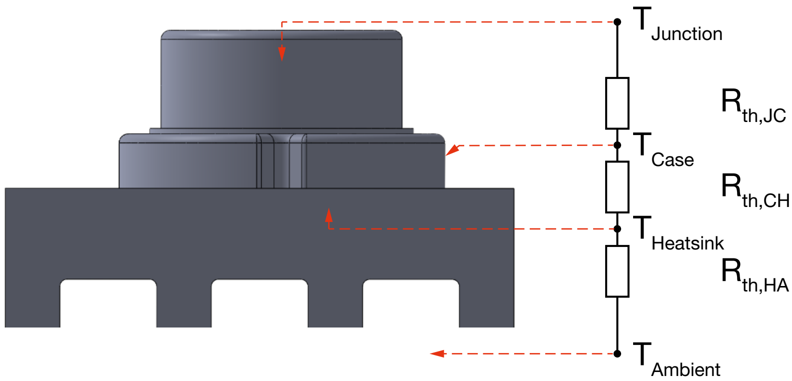
Figure 8: Simulation results for the cooling configurations shown in Figure 7. The thermal resistances junction to heat sink $R_{th,JH}$ relatively for the PLPT9 450LB_E



A complete thermal baseplate contact of the package results in the lowest thermal resistance $R_{th,JH}$ of 100 % relative reference (Figure 8A). For an absolute value of the thermal resistance of the bare TO-package $R_{th,JC}$ see the respective data sheet. Decreasing the connected area to only the bottom of the baseplate will increase the thermal resistance $R_{th,JH}$ slightly to 103 % (Figure 8B). A further reduction of the connected area at the bottom of the baseplate leads to a thermal resistance $R_{th,JH}$ of 112 % (Figure 8C). A thermal connection only via the lateral surface increases the $R_{th,JH}$ to 121 % (Figure 8D). Without a suitable fixture, the thermal connection is reduced to the pins, which is not recommended as the pins are not thermally connected to the TO90 housing, so they cannot dissipate the heat power.

Figure 9 shows a schematic of a TO90 laser diode package on a heat sink with the main absolute temperature points and thermal resistances of a system.

Figure 9: Schematic of a TO90 laser diode package on a heat sink with the main absolute temperature points and thermal resistances of a system



The total thermal resistance of the system is defined as the sum of the single R_{th}:

$$R_{th_{system}} = \sum R_{th_i}$$

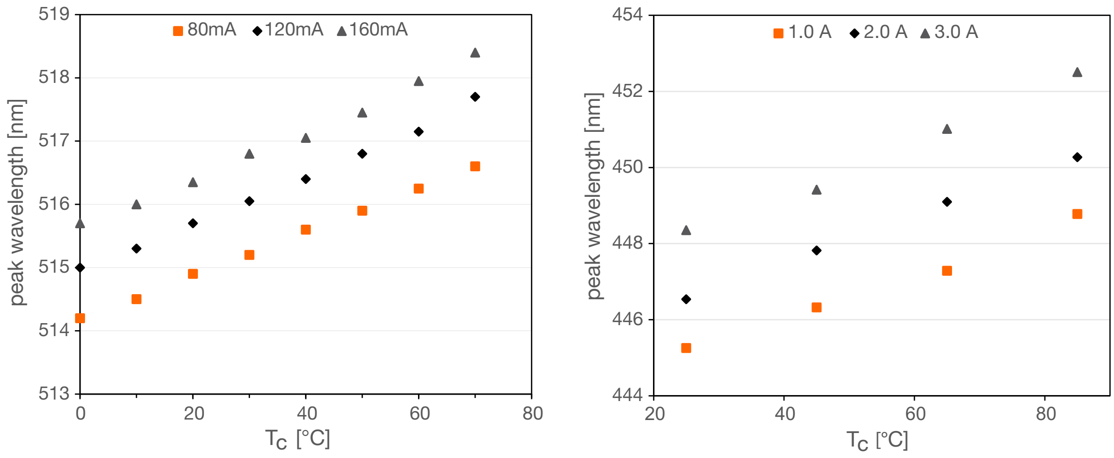
,where $R_{th,JC}$ is the thermal resistance from the junction to the case gas indicated in the respective data sheet. The heat sink is classified by the thermal resistance from heat sink to ambient, so $R_{th,HA}$. As even flat metal surfaces still have a certain surface roughness (see Figure 9), there is contact resistance between the base plate of the TO package and the heat sink, described as $R_{th,CH}$ in Figure 9.

The contact resistance $R_{th,CH}$ can be reduced by ~ 50 % compared to a pure clamping connection by soldering the bottom of the baseplate of the TO90 package to the heat sink. With this method, a short circuit must be avoided.

2.4 Wavelength shift versus temperature and current

The shift of the emission wavelength with temperature for GaN laser diodes is in the 0.04 to 0.06 nm/K range. Figure 10 shows the wavelength shift for the PL_520 and PLPT9 450LB_E at various currents and case temperatures.

Figure 10: Influence of the cooling on the peak wavelength of the PL_520 and the PLPT9 450LB_E.

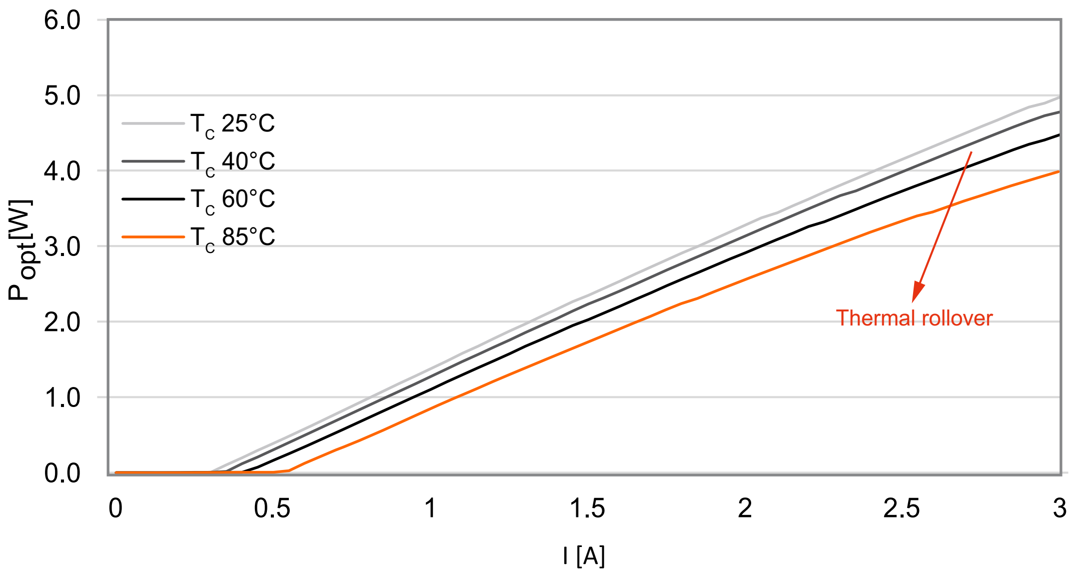


2.5 Thermal rollover

A so called thermal rollover in continuous wave (cw) operation is observed mainly for the visible multi-mode lasers which have the highest thermal load at the operating point (Figure 11). This effect is caused by self-heating of the laser diodes. The rollover starts at lower currents with increasing temperature due to lower efficiencies at higher temperature.

If a laser diode is operated in overstress, which means at too high power levels or temperatures and therefore, driven close to or at this thermal rollover the lifetime of the laser diode will be reduced.

Figure 11: Temperature dependence of the thermal rollover for a PLPT9 450LB_E with typical performance



Therefore, we recommend that you operate the blue PLPT9 450LB_E multi-mode laser only up to the maximum permissible optical output power depending on the case temperature, as stated in the data sheet.

3 Electrical and optical considerations

Visible InGaN laser diodes from ams-OSRAM AG are developed for cw operation. To obtain the full lifetime it is strongly recommended not to exceed the nominal output power and the nominal operating conditions (operating current, case temperature) for a longer period of time. Operation above nominal conditions may reduce the lifetime of the laser diode and operation above the maximum ratings specified in the data sheet even for a short time may irreversibly damage the device.

Visible InGaN laser diodes from ams-OSRAM AG may also be operated in pulsed mode at any pulse width between a few ns and cw operation and at any duty cycle. However, the maximum ratings specified for cw operation also apply to the pulsed operation.

Furthermore, please note that the output power of the laser diode depends on the temperature. Thus, for applications that require constant output power over a broad range of temperatures, an automated power control (APC) is required. A photodiode (PD) is usually adopted to optically monitor the output power of the laser diode. ams-OSRAM AG provides a series of photo detectors with compact size and high sensitivity which are suitable for APC (refer to the Appendix, Table 1).

3.1 Operating conditions

As a semiconductor laser is inherently a current-driven device, a true current source is recommended for driving laser diodes.

Laser diodes must not be driven by a voltage source. Similar to LEDs, the forward voltage depends on the junction temperature and differs from device to device.

An ideal power supply for a laser diode has the following characteristics:

- Current source
- Transient suppression (also low noise)
- Independent clamping current limit
- Slow start / ramping the current signal during switch-on
- Output overvoltage protection
- Input undervoltage detection
- Output short-circuit / interruption detection
- Shorting output during driver off status for ESD protection
- No undershooting of the output voltage at switch-off of the laser, so that a negative voltage over the laser diode cannot occur.

As a laser diode has a very short rise time and the mirrors of the resonator are the most sensitive parts of the design, even short current peaks beyond the maximum data sheet conditions may lead to a catastrophic optical mirror damage (COMD) resulting in a significant reduction of optical output power. Especially when switching the laser diode on and off, transient currents beyond the maximum conditions can occur which must be blocked.

For this reason, the maximum conditions for current and optical output power given in the data sheet must not be exceeded, not even in pulse mode.

Mains supply circuits should be designed to block external noise sources such as inductive loads. Battery-driven designs are more relaxed in this regard. External in-coupling of noise can be reduced by a circuit design with short connection paths between the laser driver and laser diode.

Laser diodes shall be driven with a regulated driver, so either in constant current mode (ACC Automatic Current Control) or constant optical power mode (APC Automatic Power Control). For APC control a photo diode is used to feed back the optical output power detected in order to control the laser diode current to maintain constant optical output power.

To protect against turn-on transients, a laser diode driver should feature a slow-start circuit at switch on. The slope of the turn on ramp should be applied according to the application needs. Moreover, there is a need to limit the output current. Otherwise damage to the mirror facet may result.

A separate overvoltage protection of the power supply ensures that the output voltage is limited in terms of changes of impedance of the load, e.g. interruption of the load connection. An input undervoltage detection ensures the proper control of the constant current regulator to start working after the full input voltage is applied.

Ideal laser diode drivers offer a shorting feature to maintain the output leads at the same electrical potential when the laser is not being operated. This shorting output feature offers ideal ESD protection during off status.

When switching off the laser diode an undershooting of the output voltage is not allowed as the laser diode is not designed for application of reverse voltages. Most integrated driver solutions provide the above-mentioned safety features and only require a few additional external parts. Especially for a cold start, the temperature dependency of the forward voltage of the laser diode has an influence on the switch-on behavior of the laser diode driver.

For example, with proper thermal connection of the PLPT9 450LB_E the major part of the heat-up of the laser diode — not of the system — takes place within ~100 ms, which means that most of the thermally caused changes of the forward voltage at one operating point are within this period of time.

ams-OSRAM AG recommendation: The lifetime of the laser diode should be validated in an appropriate lifetime test at customer side for the driver design used.

ams-OSRAM AG cannot be held liable for the completeness of the recommendations. The customer must perform his own tests to verify the design.

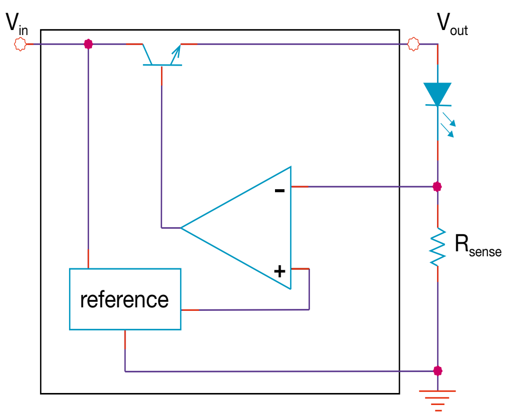
There are 2 main driver topologies for constant current drivers:

- Linear regulator
- Switching regulator

3.2 Linear regulator

Described simply, a linear regulator consists of 3 parts as shown in Figure 12: a reference voltage, a transistor/MOSFET and an amplifier for feedback control of the sense signal. A linear regulator controls a pre-defined output voltage or current.

Figure 12: Simple schematic of a linear regulator with an NPN-transistor and a sense resistor for feedback to control constant current



With a linear regulator, the input voltage must be higher than the output voltage plus a minimum voltage for the transistor/MOSFET in order to be able to regulate the target output current. The dropout voltage is defined as the difference between input and output voltage, where a further reduction of the input voltage would result in not being able to control the target current on the output. This voltage, which is needed at minimum, is specified in the respective data sheet of the laser diode driver.

The power loss P_d of a linear regulator is mainly given by:

$$P_d = (V_{in} - V_{out}) \cdot I_{out} + V_{in} \cdot I_q$$

,where V_{in} is the input voltage, V_{out} the output voltage, I_{out} the output current and I_q the quiescent current.

Due to production-based variations and the temperature dependency of the forward voltage of the laser diode, the V_{in} for the laser driver must be set with a certain safety margin above the V_{out} required.

3.3 Switching regulator

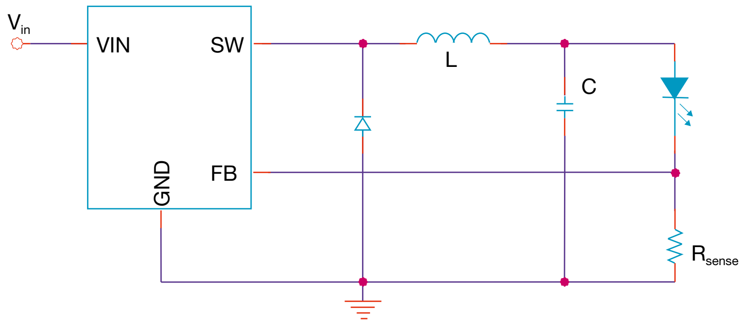
With a switching regulator, the electrical power from the input side is converted to the output side at a different voltage/current level. The input voltage can also be lower than the output voltage.

Examples of different topologies:

- Buck (set down converter, output voltage lower than input voltage)
- Boost (set up converter, output voltage greater than input voltage)
- …

Figure 13 shows a simple schematic of a buck topology with controller, internal MOSFET and sense resistor for current control feedback.

Figure 13: Simple schematic of a buck topology with controller and a sense resistor for feedback to control constant current



The buck controller switches the input voltage V_{in} with a certain duty cycle to the output pin SW. The inductor current results as integral of the inductor voltage $u_L(t)$ according to

$$u_L(t) = L \cdot \frac{di_L(t)}{dt}$$

thus resulting in a triangle-shaped current form.

The diode acts as a recovery diode during switch-off status on output pin SW. The capacitor acts as a voltage source during switch-off status on output pin SW and smoothens the current signal on the load side. The signal on the sense resistor is used to control the duty cycle of the buck controller to a target output current.

The power losses of a switching regulator are mainly given by:

- Conduction losses during switch on phase:

  $$P_{on} = R_{DS_{on}} \cdot I_{out}^2 \cdot D$$

  , where $R_{DS,on}$ is the drain-source on-state resistance, I_{out} the output current and D the duty cycle.

- Switching losses:

  $$P_{SW} = V_{in} \cdot I_{out} \cdot (T_{rise} + T_{fall}) \cdot \frac{1}{2} \cdot f_{SW}$$

  , where V_{in} is the input voltage, I_{out} the output current, T_{rise} the rise time, T_{fall} the fall time of the MOSFET and f_{SW} the switching frequency of the MOSFET.

- Quiescent power losses:

  $$P_q = V_{in} \cdot I_q$$

  , where V_{in} is the input voltage and I_q the quiescent current.

If a pure switching regulator is to be used for a constant current source, the design must be performed to ensure all the requirements for a laser driver mentioned under chapter "3.1 Operating conditions". There are many integrated circuit (IC) manufacturers who provide e.g. buck or boost controller.

3.4 Low power driver solutions

For low power applications, the most common driver topology is the linear regulator, as the absolute power losses are relatively low and the requirements for a laser diode driver as mentioned in the “Operating conditions” chapter are easier to fulfill compared to a pure switching regulator.

For example, the laser diode driver iC-NZN (www.ichaus.de/ic-nzn) from the manufacturer iC-Haus GmbH allows CW operation and switching with defined current pulses up to 155 MHz in controlled burst mode with currents up to 300 mA. “Controlled” means that a pre-set operating point is maintained during the burst phase via the LVDS/TTL switching input. The driver enables both APC and ACC mode with the setting of an external resistor. It features a laser current limitation, a fast soft-start function and strong transient suppression with small external capacitors.

3.5 High power driver solutions

Especially with high current loads, the drop-out voltage of a linear regulator must be kept as low as possible to minimize power dissipation.

For the PLPT9 450LB_E, high power laser diode the CW power laser diode driver iC-HTG (www.ichaus.de/htg) from the manufacturer iC-Haus GmbH offers precise constant current control with minimal external component count. An external power transistor and a shunt resistor (R_{sense}) are used to set up a closed-loop current driver either in ACC or APC mode. The external power transistor (P-channel or N-channel) can be driven by connecting the gate of the transistor to the pin VRP or VPN, respectively. All the parameters, including the internal reference voltages, can be set via serial communication (I^2C or SPI).

In APC mode, an internal programmable logarithmic monitor resistor (PLR) or an external monitor resistor can be selected to close the control loop.

In ACC mode, the laser diode current can be measured by the use of a low impedance shunt resistor to minimize the power losses.

The output power can be analog modulated with a frequency of up to 50 kHz.

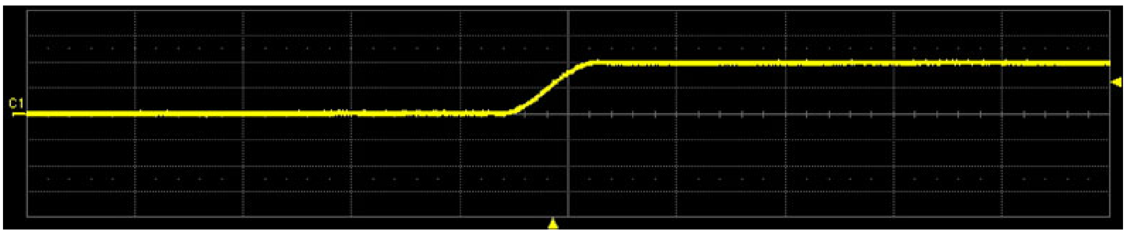
The iC-HTG allows the laser channel to be disabled when an overcurrent threshold has been exceeded. This overcurrent threshold is programmable using an 8-bit linear D/A converter.

For efficiency enhancement, the iC-HTG offers the feature via a DCO output pin to control the output voltage of an external DC/DC converter as supply voltage of the laser diode in order to allow the linear regulator to work at the lowest possible supply voltage close to the dropout voltage. This reduces power losses while maintaining the preset current for the laser.

Figure 14 shows an example of the soft-start current feature after switch-on of the iC-HTG laser diode driver for the PLPT9 450LB_E to ramp up to 2000 mA without any transients beyond maximum conditions.

Please check the manufacturer's web site (www.ichaus.de) and their support contact for further documentation or technical support on their range of laser drivers.

Figure 14: Example of a soft-start feature of a laser diode driver to an output current of 2000 mA without transients upon switch-on



3.6 Optical

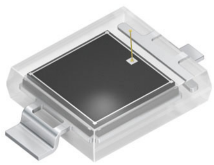
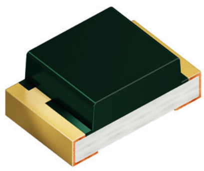
In case of optic design or simulation needs, ray files of laser diodes for various software versions (e.g. Lighttools, Zemax, ASAP, Tracepro, Speos) can be downloaded from the ams-OSRAM AG web site (Application Support)

For latest updates regarding available secondary lenses, please contact your local ams-OSRAM AG sales office.

4 Appendix

Selected photo detectors available for APC (www.osram.com/os/)

Table 1: Series of compact-size and high sensitivity photo detectors from ams-OSRAM AG, which are suitable for APC feature

Part number	Picture	Spectrum range	Package size
SFH 2430		400~900 nm	4.4 * 3.85 * 1.15 mm^3
SFH 3711		440~690 nm	2 * 1.28 * 0.8 mm^3
SFH 3204		420~1100 nm	1.1 * 3.0 * 1.2 mm^3
SFH 2201		300~1100 nm enhanced blue/green sensitivity	4.0 * 5.1 * 0.85 mm^3

ABOUT ams OSRAM Group (SIX: AMS)

The ams OSRAM Group (SIX: AMS) is a global leader in optical solutions. By adding intelligence to light and passion to innovation, we enrich people's lives. This is what we mean by Sensing is Life. With over 110 years of combined history, our core is defined by imagination, deep engineering expertise and the ability to provide global industrial capacity in sensor and light technologies. Our around 24,000 employees worldwide focus on innovation across sensing, illumination and visualization to make journeys safer, medical diagnosis more accurate and daily moments in communication a richer experience. Headquartered in Premstaetten/Graz (Austria) with a co-headquarters in Munich (Germany), the group achieved over EUR 5 billion revenues in 2021. Find out more about us on https://ams-osram.com

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