Eye safety with ams OSRAM IR VCSELs: safe limits, measurements & use of integrated safety features

Application Note

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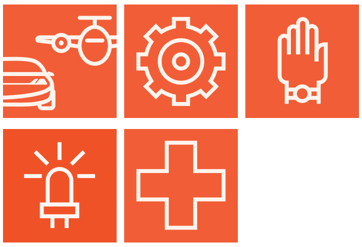

Valid for:
BIDOS P2433 Q, EGA2000, TARA2000-AUT-SAFE, BELAGO

Abstract

Eye safety is a critical design aspect in illuminated visualization applications, especially those with non-visible (IR) illuminators, and particularly for lasers. This application note, a co-operative effort between ams OSRAM and Chronoptics, includes a survey of the hazards of IR illuminators, the relevant safety standards and categorizations. It focuses further on IR VCSEL illuminators, considers fault modes and detection mechanisms, and discusses the safety features integrated into ams OSRAM's VCSELs. Detailed analysis is done on a selection of ams OSRAM's VCSELs, including measurement results to compute safe operating conditions and enable classification of the illumination system in the safest, Class 1, category.

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1 Introduction

Eye safety is a critical design aspect in all illuminated visualization applications, especially those with non-visible (IR) illuminators, whether lasers or LEDs. This application note addressing various aspects of this topic including a survey of the hazards is the result of a co-operative effort between ams OSRAM and our partner Chronoptics who have deployed our laser illuminators in their end applications, namely iToF 3D camera systems.
(check: https://ams-osram.com/support/partner-network/partner-search/chronoptics for more detail).

This application note provides a general overview to the users on different hazards that can occur from infrared radiation (780 nm – 1400 nm) and a general guideline for safe operating conditions. Only the main aspects of the situation are explained, and simplifications are made.

ams OSRAM provides assistance to the best of its knowledge but does not guarantee that every hazard of any possible application is described by the information given in this application note. The laser safety certification of the final product, using infrared illuminator modules, is the responsibility of the final system manufacturer.

In case users need help with the design of eye-safety compliant circuit designs and control algorithms or safety certification of end-products for their final application according to the latest standards, our partner Chronoptics as well as other test houses or certification agencies could offer such consulting services.

2 General information

The field of laser-based sensing solutions is rapidly growing; lasers and especially pre-integrated VCSEL modules are an integral part of the indirect time-of-flight (iToF) cameras and stereovision 3D cameras that utilize active flood illumination of the scene. They are also at the heart of LiDAR systems and proximity or ranging sensors which can be found in many applications such as robotics or automotive in-cabin sensing. ams OSRAM provides market leading laser solutions to its customers, covering different technologies, spectra and integration options. This application note focuses on packaged infrared VCSEL modules which serve as illuminators in the 850nm or 940nm spectrum. These VCSEL illuminator modules are integrated by the manufacturers into their target systems, and the system integrator is responsible for the overall safety of the system.

Nevertheless, some of the ams OSRAM packaged VCSEL products provide inbuilt functionality to simplify the design of the final safety architecture and reduce the overall design burden.

All products that emit light radiation – whether ultraviolet, visible, or infrared – must comply with the international standards and guidelines that specify the emission limits or exposure limits for human skin or eye. This requirement is independent of the physical principle of optical radiation generated, be it incandescent, LED or laser.

2.1 Description of the hazards and applicable standards

Optical radiation transports energy and when the power of the light is concentrated onto a small area it can lead to damage. An example is the magnifying glass that focuses sunlight to heat up and ignite paper. Similarly, infrared (artificial optical) radiation can lead to damage if the irradiance is high enough.

Special care must be taken at the exposure of biological tissues to light radiation, especially in the case of human skin or the tissues of the human eye, namely the cornea and retina.

International commissions define exposure limits for optical radiation onto the human body. The EU “Radio Equipments / Low Voltage Directive” includes high level safety directives and further references to harmonized standards which are defining emission limits and classes or risk groups. Energy sources fall within the IEC-62368 safety standard, which further refers to IEC-60825:1-2014 “Safety of laser products” for laser emission. LEDs and non-laser lamps are covered by IEC-62471 “Photobiological safety of lamps and lamp systems”.

The ams OSRAM infrared laser illuminators for visualization applications are of the VCSEL (Vertical Cavity Surface Emitting Laser) type and therefore the laser systems built with these fall, among other, under the IEC-60825 standards.

This application note refers to and follows the recommendations of the IEC-60825 standards, which is adapted, with some modifications, as national standard in many countries and regions, for example as EN 60825 in Europe and as DIN 60825 in Germany. Also the U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health) accepts classification based on IEC 60825-1:2014 based on laser notice 56.

2.2 Categorization of lasers in classes

Standards on laser safety often categorize lasers into different classes with the purpose of providing the user with an aid in evaluating the hazard associated with a specific laser device such that he can determine the necessary control measures. Laser classification relates to the potential hazard of accessible laser radiation in respect to skin and eye damage.

Table 1: U laser classification according to IEC 60825-1 standard (Annex C.2, incomplete extract)

Laser class	Laser product definitions
1	Laser products that are safe during use, including long-term direct intra-beam viewing, even when exposure occurs while using telescopic optics. Class 1 also includes high power lasers that are fully enclosed so that no potentially hazardous radiation is accessible during use.
1M	Laser products that are safe, including long—term direct intra-beam viewing for the naked eye (unaided eye). The maximum permissible exposure (MPE) can be exceeded, and eye injury may occur following exposure with telescopic optics such as binoculars for a collimated beam with a diameter larger than the standard specified measurement diameter.
1C	Laser products that are intended for direct application of laser radiation to the skin or internal body tissues for medical, diagnostic, therapeutic or cosmetic procedures. Although the emitted laser radiation may be at Class 3R, 3B or 4 levels, ocular exposures are prevented by one or more engineering means.
2	Laser products that emit visible radiation in the wavelength range from 400nm to 700nm that are safe for momentary exposures but can be hazardous for deliberate staring into the beam. The time base of 0.25s is inherent in the definition of the class (…). Comment: The natural aversion behavior for exposure to bright light sets the 0.25s time base.
2M	Laser products that emit visible laser beams and are safe for short time exposure only for the naked (unaided) eye. The maximum permissible exposure (MPE) can be exceeded, and eye injury may occur following exposure with telescopic optics such as binoculars for a collimated beam with a diameter larger than the specified measurement diameter (…)
3R	Laser products that emit radiation that can exceed the maximum permissible exposure (MPE) under direct intra-beam viewing, but the risk of injury in most cases is relatively low. The accessible emission limit (AEL) for Class 3R is limited to 5 times the AEL of Class 2 (visible laser radiation) or 5 times the AEL of Class 1 (for non-visible laser radiation). Because of the lower risk, fewer manufacturing requirements and control measures for the user (depending on national regulations) apply than for Class 3B. Class 3R laser have limited risk (…) but products are not considered intrinsically safe.
3B	Laser products that are normally hazardous when intra-beam ocular exposure occurs including accidental short time exposure. Viewing diffuse reflections is normally safe. Class 3B lasers which approach the accessible emission limit (AEL) for Class 3B may produce minor skin injuries or even pose a risk of igniting flammable materials. However, this is only likely if the beam has a small diameter or is focused.
4	Laser products for which intra-beam viewing and skin exposure is hazardous and for which the viewing of diffuse reflections may be hazardous. These lasers also often represent a fire hazard.

It is important to understand that the laser classification may differ between different standards, in the naming as well as in the classification. An important example is ANSI Z136.1(now obsolete), which defined the laser classes I, II, III, and IV. As stated before, this application note follows the widely recognized IEC-60825.

The IEC-60825 defines eight laser classes (see Table 1). The higher the class number, greater the hazard associated with the laser device. Laser products certified as Class 1 are safe during use, including long-term direct intra-beam viewing, even when exposure occurs while using magnifying optics. The term “eye-safe” may only be used for Class 1 laser products.

2.3 Exposure limits for the human eye

The IEC standards define emission limits for light that hits the human eye. These limits depend on several parameters, including the wavelength of the light, the duration of the light pulse and the light modulation scheme. In addition, they depend on the divergence of the light, the minimal distance of the eye to the light source, source size, and the spacing between multiple sources. Please refer to the applicable standards for more details.

The exposure limit for a person is called the Maximum Permissible Exposure (MPE) which is defined as the highest power or energy density (in W/cm^2 or J/cm^2) of a light source that is permitted, as measured at the cornea of the human eye or at the skin, for a given wavelength and exposure time.

2.4 Exposure limits to human skin

As stated in the IEC-60825 standards, the skin can, in general terms, tolerate a great deal more exposure to laser beam energy than can the eye. According to the IEC-60825, only lasers of Class 3B or higher pose a risk to skin injuries.

2.5 Reasonably foreseeable single-fault condition

The IEC standard 60825:1-2014 requires the supplier of a laser product to analyze whether the product can fail in a way that the emitted laser radiation exceeds the limits that the product is classified for. The standard requires consideration of reasonably foreseeable single-fault conditions that can occur to the product. The classification requires that the emission is not exceeding the limits of a certain class even in this failure mode. The standard proposes conducting a risk analysis to determine if a specific failure is reasonably foreseeable. This risk analysis may be performed in the form of a FMEA (failure mode and effect analysis) with the procedures described in IEC 61508.

The reasonably foreseeable single-fault conditions need to be addressed with technical measures to limit the light radiation that is emitted after the fault occurs.

2.6 Accessible emission limit (AEL)

Accessible Emission Limit is defined as the limiting value of the energy that can reach the eye's pupil opening (or accessible emission, AE), based on the IEC 60825-1:2014. A laser product can be classified as Class 1 if the accessible emission is less than or equal to the Accessible Emission Limit of test condition 1 and condition 3.

For long exposure times this limit is based on the equation:

Equation 1:

$$AEL = 7 \bullet 10^{-4} \bullet C_4 \bullet C_6 \bullet T_2^{-0.25} W$$

- C_4: A correction factor of the wavelength
- C_6: A correction factor of the source apparent size.
- T_2: The time value from which the AEL is independent of the exposure time. Function of the angular size of the source.

For pulsed radiation, the corresponding limits need to be considered. The calculations consider the radiation in the near infrared wavelength region. The evaluation and the formulae are explained in a simplified way. For details, please refer to IEC 60825-1:2014. Final products are subject to IEC 60825-1:2014.

3 Fault modes

As described in section 2.5, the supplier must prevent single fault conditions that can result in a risk to eye safety. There are several potential failure modes which could result in high emission levels, for example:

- Laser over-current/over-voltage: Applying excessive current (or voltage) to the VCSEL can lead to an increase in the laser output power, potentially exceeding safe exposure limits. This could be caused by faulty or malfunctioning laser driver circuits, voltage regulators, or a short circuit, and can lead to uncontrolled power delivery to the VCSEL.
- Pulse width: In pulsed or modulated applications, the maximum duration and duty cycle of the pulses must be maintained to avoid emitting high levels of laser radiation.
- Mechanical damage: Physical damage to the VCSEL or optics can affect its output emission profile and introduce eye safety concerns.
- Overheating: VCSELs generate heat during operation, and if the heat dissipation is insufficient or cooling mechanisms fail, it can result in increased temperature at the chip surface.
- Cold temperature: Operating the VCSELs in low temperature environments could increase the optical output power above exposure limits.
- Power supply failure or incorrect power supply turn-on or turn-off sequencing. If separate power supplies are used for the VCSEL and laser driver, then laser emission must not occur when the laser driver power supply is not enabled.

3.1 Fault detection and shutdown mechanisms

To prevent hazardous emission from the VCSEL due to a potential fault, such as those provided above, the manufacturer should generate a FMEA to identify possible conditions and implement corresponding shutdown mechanisms into the circuit design. Example fault detection mechanism include:

- Laser anode voltage monitoring
- Laser cathode short circuit detection to ground monitoring
- Laser driver supply voltage and current monitoring
- Optical power detection (e.g. by photo diode)
- Pulse width and duty cycle monitoring of the control signal, driver, or optical output.
- Diffuser integrity monitoring (e.g. with ITO conductive layer on cover window, or monitoring reflected optical signal to a photodiode)
- Laser external temperature monitoring (high or low temperature limit)
- Driver internal temperature monitoring

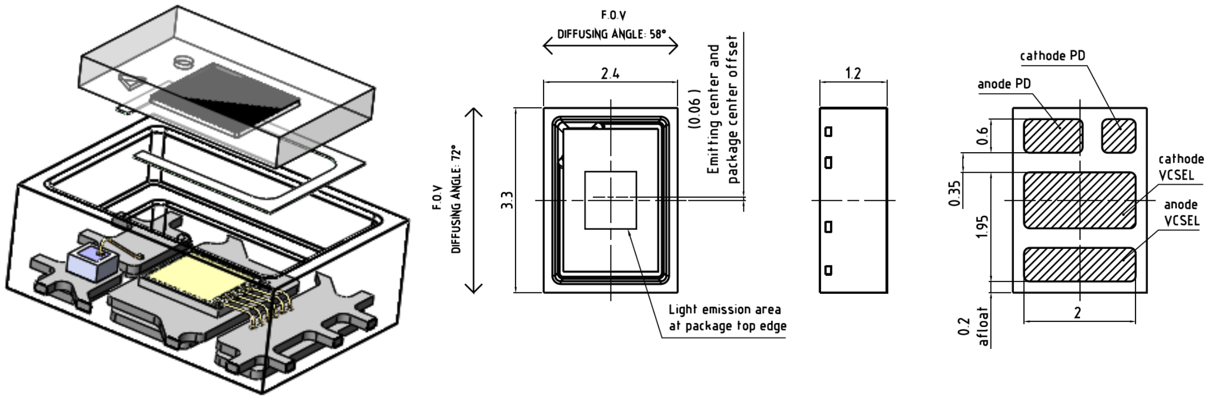
The selection of which fault detection mechanisms are required will differ for each application and should be determined based on the system design and FMEA outcomes.

4 VCSEL module design

4.1 Package

The QFN packages from ams OSRAM are designed for high power applications. The package can also incorporate a dedicated monitor photodiode (MPD) for monitoring the performance of VCSEL and diffuser, which is especially helpful in reliable designs for eye safety circuitry. QFN packages with diffusers have a moisture sensitivity level of 3 and are reflow solderable (max 260°C for 30 sec.) and compatible with surface mount technology (SMT) equipment. The design forms a package with a venting hole that minimizes the risk of condensation within the module.

Figure 1: BIDOS module(1)



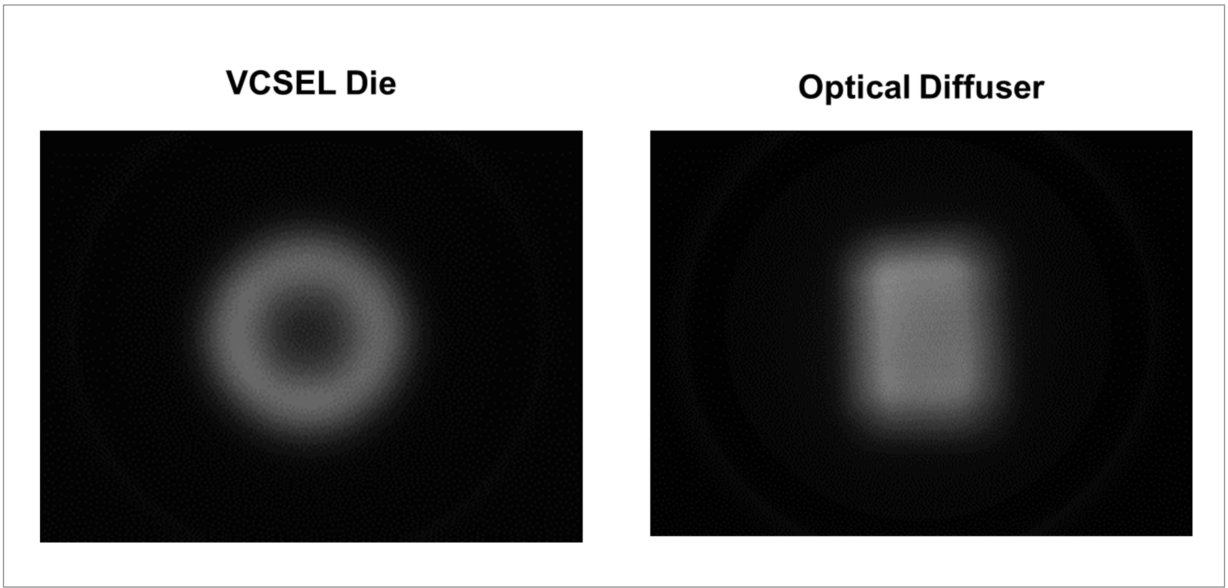
(1) ams OSRAM's BIDOS module consists of a lead-frame substrate with spacer structure, and diffuser assembled to form a package around the VCSEL die and monitoring photodiode.

4.2 Optical diffuser

ams OSRAM NIR illuminators are often applied in a 2D imaging or a Time of Flight (ToF) measurement system. A pulsed or shaped optical signal is sent into the environment, reflects off nearby objects, and is detected by a photodiode (camera) array that may consist of PINs, APDs, or SPADs. Regardless of the detector design, the illumination source must deliver a uniform light signal over the specified region of interest that matches the detector array's field of view. Traditional diffuser materials cannot deliver the required shape and uniformity required for this application, so advanced optical diffusers must be used.

The diffuser optics used in ams OSRAM's QFN packages are designed to shape and project a rectangular field of illumination (FOI) when projected onto a flat surface. The optical diffuser consists of a proprietary pattern imprinted into a thin polymer film coating on glass. The pattern creates the rectangular FOI through refraction. Diffuser performance is observed to be independent of NIR wavelength, VCSEL die layout, and package alignment. These optical diffusers are also designed to break up the spatial coherence from the VCSEL die to eliminate any potential interference fringes and reduce speckle in the projected illumination.

Figure 2: Optical diffuser are efficient at converting the VCSELs narrow, ring-shaped beam profile (left) into a wide, rectangular illumination source with high uniformity (right)



ams OSRAM has developed a portfolio of products that incorporate optical diffusers into the QFN package to generate various rectangular fields of illumination, including 102° x 85°, 78° x 65°, and 63° x 50° FOI. The diffuser film is protected underneath the glass cover and inside the package. The module design supports sufficient ventilation of the modules and prevents condensation on the diffuser pattern, which would negate the diffuser and may result in an eye safety hazard.

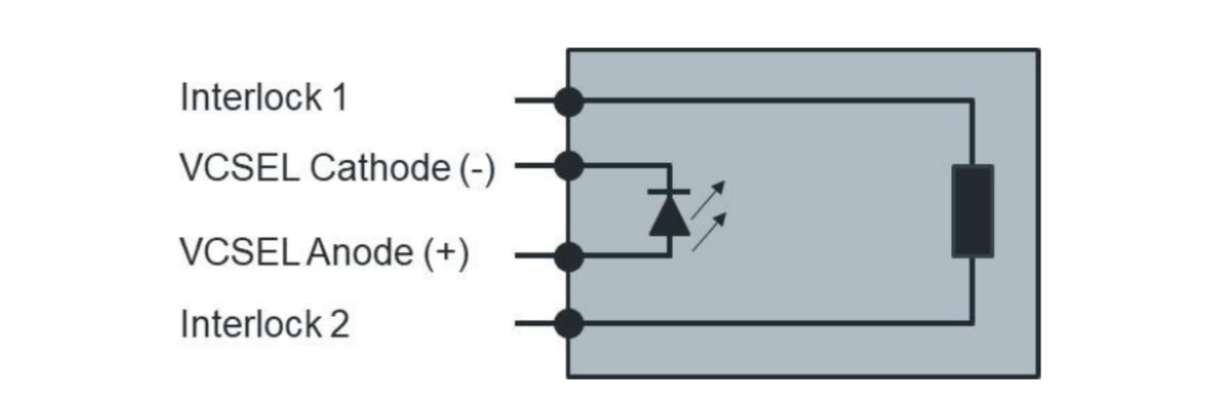
5 Integrated eye safety features

5.1 Diffuser monitoring with a resistive interlock

The first line of eye safety defense implemented in VCSEL packages is the diffuser. The diffuser expands the VCSELs' beam divergence over a wide FOI and allows VCSELs to be eye safe while in close proximity to end users. While the diffuser is extremely robust, it can still be damaged. Therefore, detecting when a diffuser is damaged and disabling the VCSEL can avoid harm to the eye.

The resistive interlock consists of an electrical trace between two pads of the module and it spans the optical diffuser. The module datasheet provides an upper and a lower spec for the resistance value of the interlock circuit. The electrical circuit diagram of a module having an interlock is shown in the figure below.

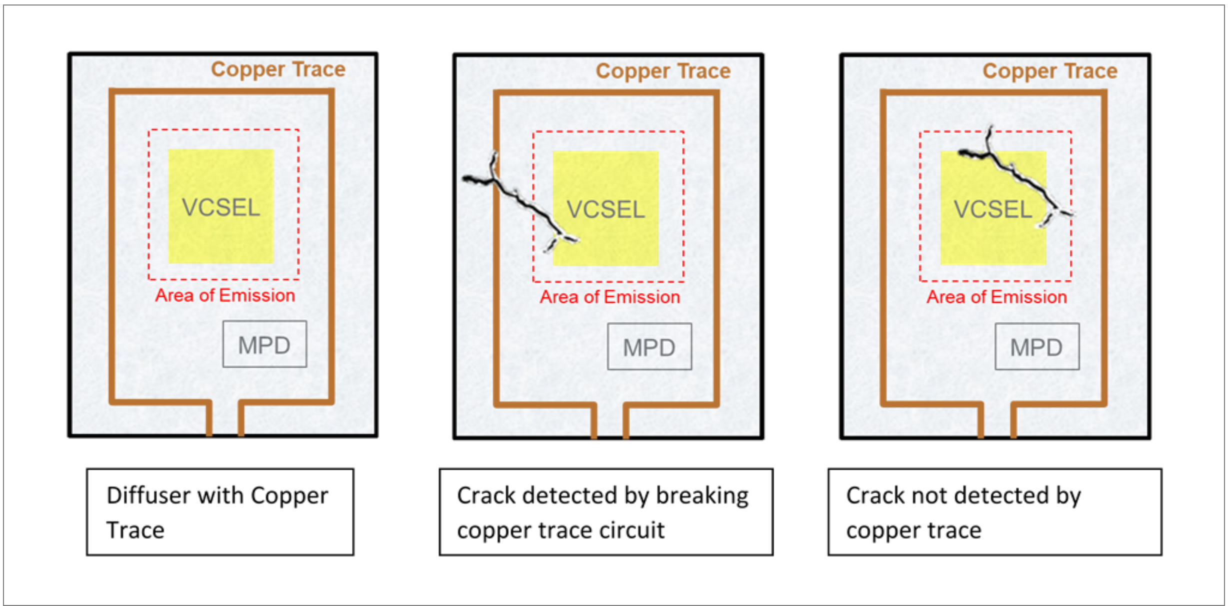
Figure 3: The electronic circuit schematic of the resistive interlock



The interlock can detect fault situations where the diffuser comes loose from the module or where there is a crack deep enough to attack the trace and allow a change in the resistance. Other faults like minor holes or cracks may be missed.

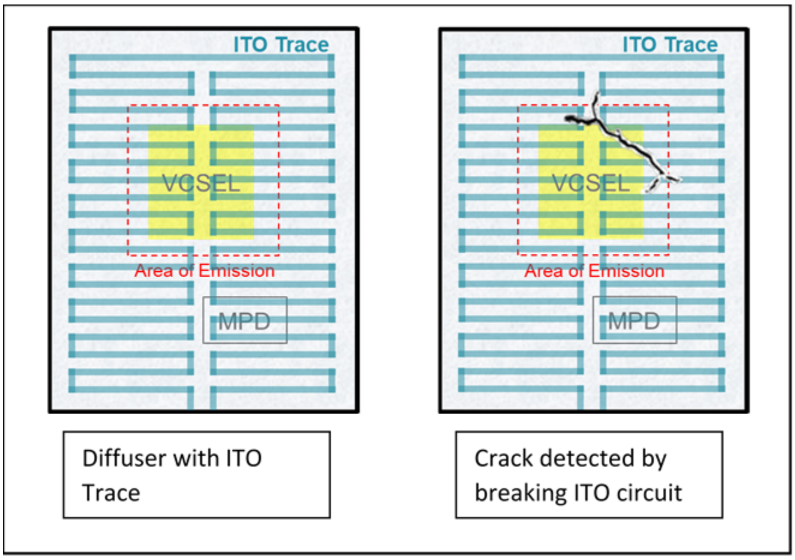
One type of interlock implementation (used in ams OSRAM's TARA2000-SAFE variant) has a metallic trace along the outside perimeter of the diffuser. This trace completes a circuit that, when broken, can be used to signal to turn off the VCSEL. Since the metal trace would block the laser if it ran over the area of emission, it is implemented on the perimeter and could miss localized minor cracks on the diffuser.

Figure 4: A metallic trace can detect diffuser damage spanning beyond the emission area



An alternative (used by ams OSRAM VCSELs BIDOS BELAGO dot projectors) is an indium tin oxide (ITO) trace patterned on the glass cover and spanning the diffuser. ITO is conductive and operates similarly to the metallic trace. The ITO trace is highly transparent at NIR wavelengths and can be traced within the emission area of the diffuser. This ensures most glass cracks will be detected. Regardless, an ITO trace in the path of the VCSEL beam may have some impact on the optical power and beam divergence.

Figure 5: An ITO trace can detect diffuser damage inside the emission area

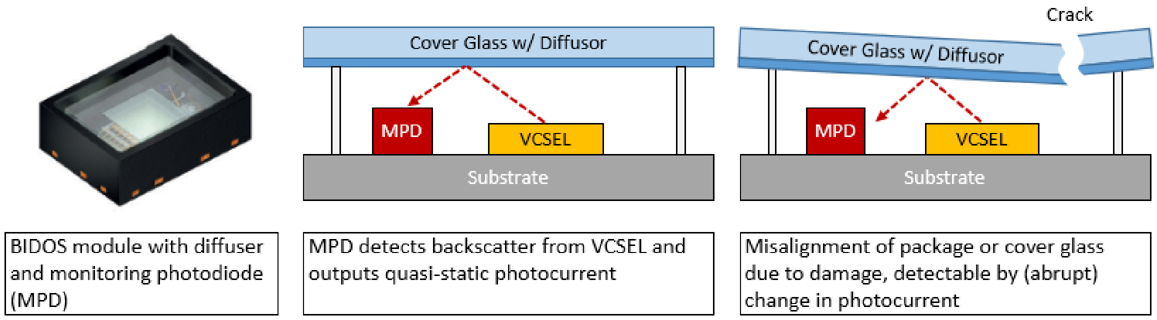


5.2 Monitor photodiode

An alternate method (used in many VCSELs from the ams OSRAM BIDOS family) in identifying a critical fault is to use a monitor photodiode (MPD) to detect the backscatter from the diffuser. The efficiency of the diffuser directly correlates to how much backscatter is detected by the MPD. This method can directly measure the severity of a damaged optical diffuser. By tracking the current of the MPD, one can detect cracks in the diffuser module and take necessary precautions in real-time.

In addition, the MPD can detect when the diffuser is impacted from indirect damage to the module: Damage of the package’s substrate or sidewall as well as beam focusing condensation on the diffuser optics. The condensate degrades the package’s ability to diffuse the light source and preserve the original eye safety requirements. Unlike the metallic or ITO trace methods, the MPD can detect this failure mechanism as a drop in measured optical backscatter inside the package.

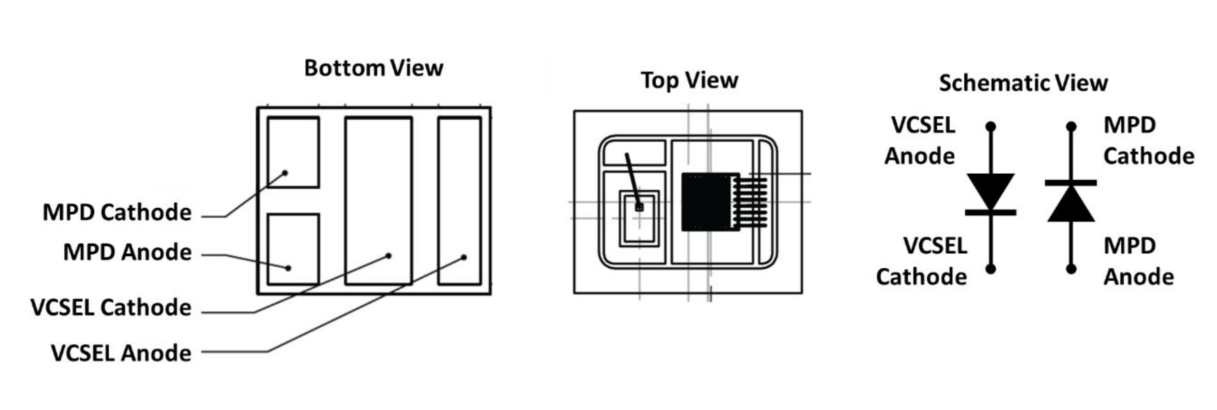
Figure 6: A monitor photodiode can directly detect for both diffuser damage and moisture condensation inside the package



Inside the VCSEL package, the VCSEL is electrically isolated from the MPD. Each component has an anode and cathode connection on the QFN package footprint. This is essential, as sharing a common connection between both components will degrade the measurement sensitivity due to electrical crosstalk. The VCSEL driving current is significantly higher than the MPD measurement current. Any shared electrical lines will create a voltage drop due to the cumulative high current load and impact the MPD current reading. If the MPD is not required for prototype or similar product builds, the MPD anode and cathode connections can be left open on the PCB.

Production parts of the QFN package can have observable differences in MPD responsivity. Variations during manufacturing, including but not limited to component deviations, diffuser alignment, and die positioning, will result in a measurable range in MPD currents in production parts under similar operating conditions. The MPD is also more sensitive to shorter NIR wavelengths, so the 850nm VCSEL products will exhibit higher MPD currents compared to their 940nm counterparts. For high-sensitivity applications, ams OSRAM recommends calibrating each illumination source after production. Production lines can code software with initial MPD measurement readings, under which higher accuracy levels of diffuser monitoring can be utilized.

Figure 7: The VCSEL and MPD die are electrically isolated inside the package



In addition to manufacturing variations, the photodiode output will also be somewhat dependent on the operating environment due to effects from temperature, ambient lighting, and reflectivity of objects placed in front of the VSCEL.

While the MPD sensitivity is independent of temperature, the VCSEL optical power will decrease at higher temperatures and reduce the amount of scattered light into the MPD. Options to avoid false triggering a low MPD threshold include using Automatic Power Control (APC), where the laser current is dynamically adjusted to compensate for changes in temperature; measuring the laser temperature with an external PCB temperature sensor and dynamically adjusting the MPD threshold; or simply characterizing the expected VCSEL optical power levels over the application ambient temperature range and selecting an appropriate threshold level that avoids false triggering due to low VCSEL optical power but still allows for detection of diffuser damage due to low backscattered light.

In environments with high levels of ambient light, such as sunlight, the photodiode output will consist of both the response from the internal VCSEL reflection from the diffuser as well as the level from the external light source. This can be reduced by using a secondary optical window in front of the VCSEL package that allows the laser IR wavelength to pass through, while blocking visible wavelengths from the ambient light source. In applications where the VCSEL is pulsed or modulated in bursts, it is possible to measure the photodiode output while the laser is in the off state and subtract this value from the measurement when the laser is in the on state, allowing the contribution from the ambient light to be isolated from the diffuser back-reflection level.

In some applications highly reflective objects may be placed directly in front of the VCSEL illumination source. In these cases, the MPD output will consist of both the reflection from the internal diffuser as well as light reflected from the external object back into the VCSEL package and onto the MPD. While the MPD output is higher than expected in this scenario, similar to the case for high ambient light scenarios, the mitigation options mentioned above for high ambient light cannot be used here. In practice, the backscattered light from external objects is only a concern when the object is extremely close to the VCSEL output window, which is often not a practical operating scenario. For example, an iToF camera will typically have a minimum operating distance of 10cm where the lens remains in focus and the image sensor provides sufficient dynamic range to avoid pixel saturation. Detection of a MPD current above an upper threshold may therefore indicate a problem with the diffuser, or a problem where the application is unable to produce meaningful data from the iToF camera due to an object being too close. The end-use application can therefore respond by stopping the camera before re-starting it to determine if the detected condition remains.

6 Types of damage on the diffuser

While there are many ways to classify component damage, there can be three simplified categories with increasing severity of diffuser damage: scratches, cracks, and breaks. The level of impact will have a different effect on the MPD current reading, which can better determine the severity and potential impact the damage to the user.

The outer glass can be scratched from excessive contact or abrasive forces. If the diffuser is scratched from the outside, the diffractive polymer layer will not be affected and won't become an eye safety hazard. Regardless, the additional scattering from scratching will increase the MPD current, which can enable early detection of current and future damage to the package.

If damage penetrates the entire depth of the glass window, the diffuser will be cracked. This damage results in significant internal scattering, and the glass will backscatter more optical power and significantly increase the MPD current. If all glass pieces remain connected to the package, the VCSEL will typically emit a nonuniform, broader FoI with undesired hotspots.

Excessive force will break the module, resulting in glass shard removal and possibly entire diffuser separation from the VCSEL package. This results in an unsafe scenario where the laser beam emerges from the VCSEL package without undergoing any diffusion. Without any backscattering from the diffuser, the MPD current will drastically decrease.

Figure 8: Images of diffusers mounted on ceramic packages that are (from left to right) new, scratched, cracked, and broken

While the MPD is useful for evaluating diffuser performance in real-time, it is not a failproof method to ensure eye safety standards. Each VCSEL application will have its own specific driving conditions and operating environments that need to be considered. The laser product integrator is responsible for testing the final product performance and reliability to meet eye safety standards through the assistance of a certified laser safety consulting firm.

7 Design for monitoring circuits

7.1 Interlock monitoring circuits

Two options could be considered:

- Circuit based on a hardware lock (eg. MOSFET based)
- Circuit based on a software lock (eg. GPIO triggered)

A software control that is less reliable from a safety point of view than the hardware lock.

Two examples of hardware lock implementations are shown below. The first is a low cost, low power solution using a MOSFET to turn off the VCSEL current when the interlock resistance increases significantly. It can only really distinguish between an open or close circuit on the interlock.

The second example uses one or more comparators, giving more granularity in detecting both open and short faults on the interlock.

Figure 9: Interlock monitoring with a MOSFET

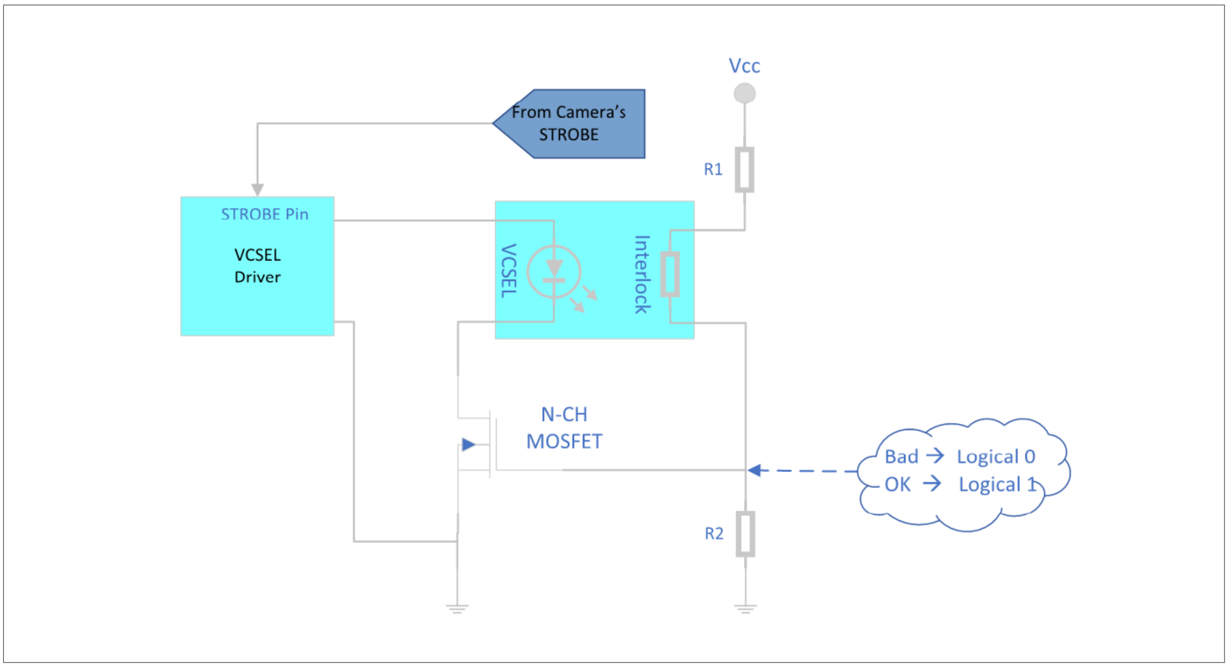
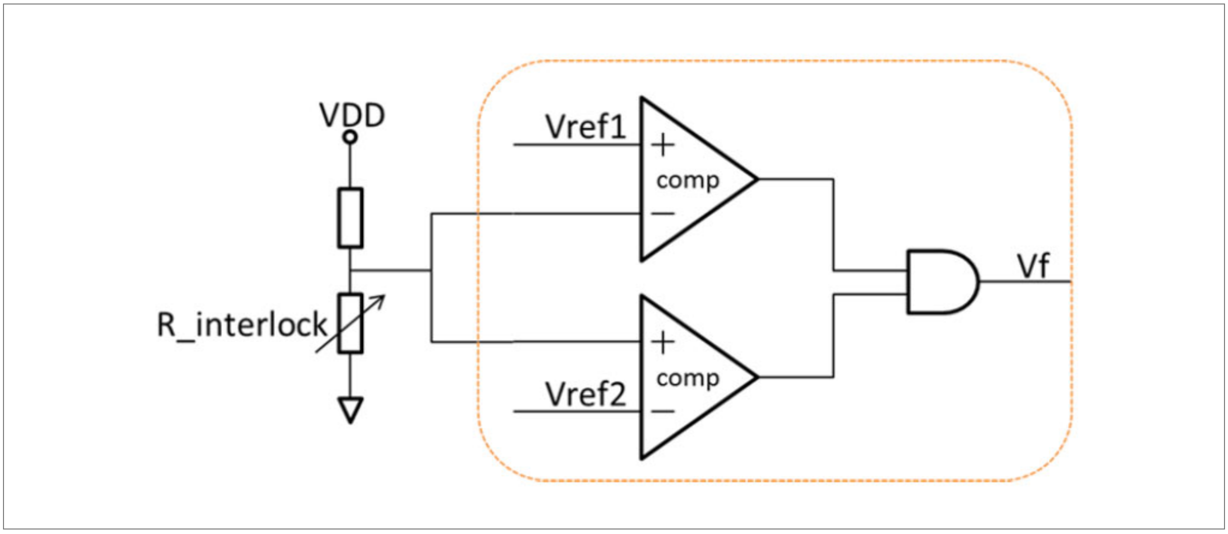


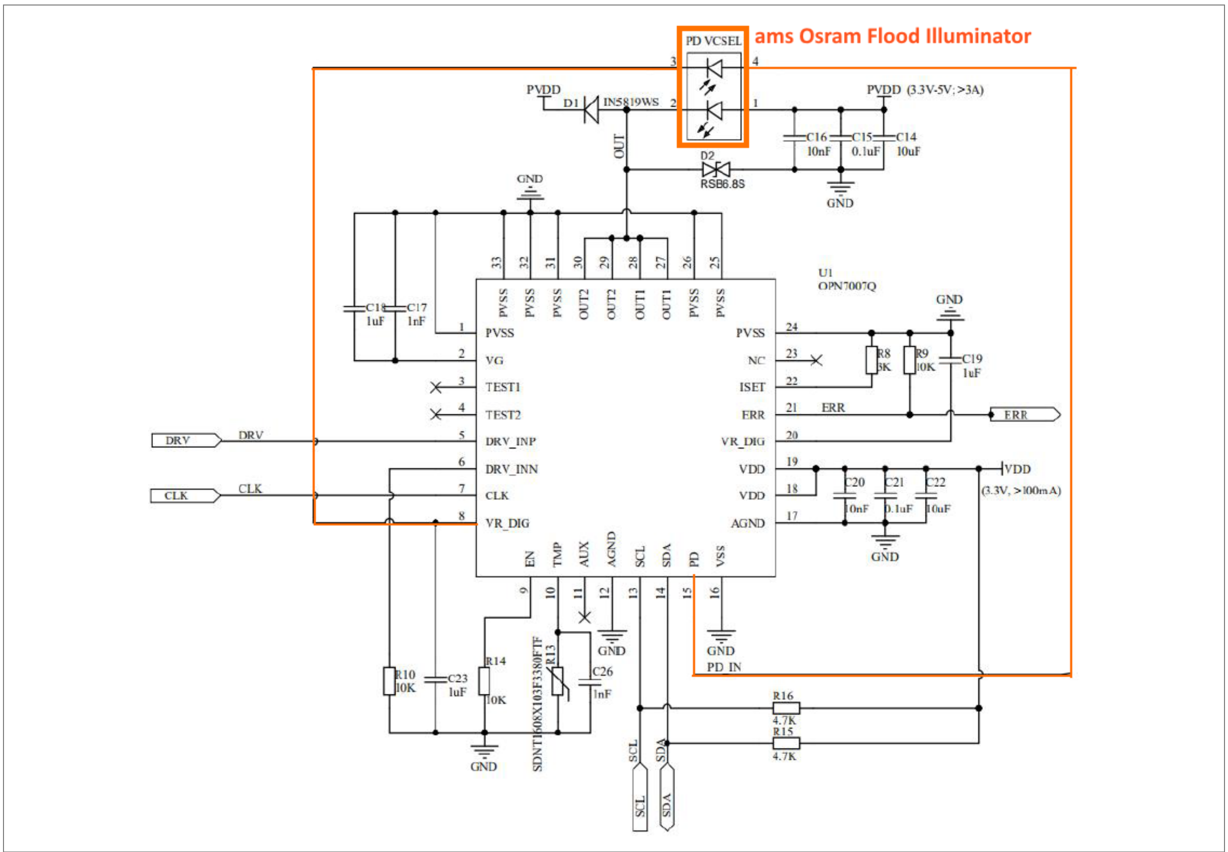
Figure 10: Interlock monitoring with comparators



7.2 Circuit design for monitoring photodiode

Shown here is an example of a circuit design including fault detection using the monitoring photodiode for eye protection. The schematic below, from a third party application note, uses a VCSEL driver with integrated current sensing pins to connect the monitoring photodiode. This is the simplest way of using the MPD in an application, as the VCSEL driver integrates an ADC and shutdown logic. If the VCSEL driver does not integrate the MPD monitoring feature, it can be implemented using additional components in between the monitoring photodiode and the VCSEL driver. However, such components must be selected to comply with the fast switch-off time requirements. As a rough guideline, switch-off time should be faster than 1 µs after the diffuser´s function is impaired.

Figure 11: VCSEL driver example showing connection of monitoring photodiode (source: OPNOUS OPN70xx)



7.3 Monitoring other faults & mechanical protection

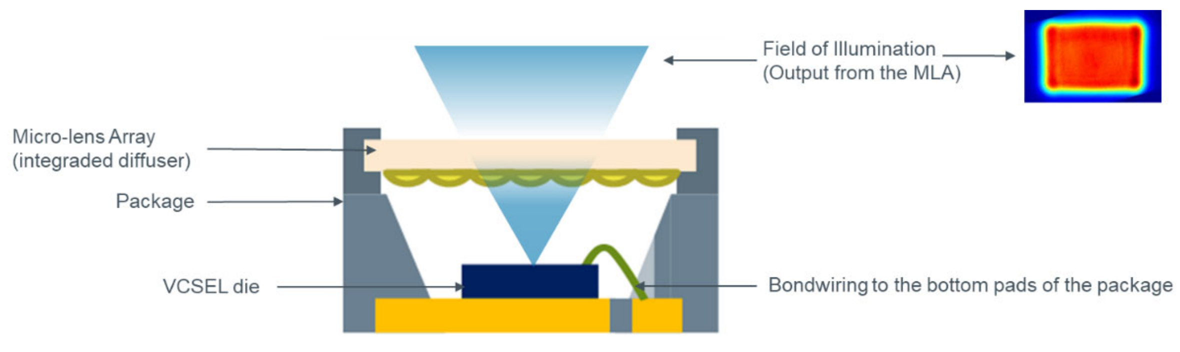
In addition to monitoring a photodiode for diffuser failure, there are multiple other fault detection mechanisms that should also be considered as described in section 3. Some iToF sensors have built-in laser safety features and are designed to interface with intelligent laser drivers that contain proprietary safety monitoring features, such as over current and overvoltage protection, duty cycle limits, temperature sensing, ITO and MPD monitoring. To provide these robust safety features without the use of an intelligent driver would require many external discrete components, often increasing system size and cost. These drivers also help ensure that the VCSEL is turned off with a fast response time when a fault is detected, ensuring that the output never exceeds the accessible emission limits for a Class 1 laser product under any of these fault conditions.

The VCSEL driver itself could fail as also the power supplies to the driver. These should also be externally monitored to detect failures and cut the power. In addition to circuit-level protection, the manufacturer should also include mechanical protection of the VCSEL and diffuser, such as adding a secondary acrylic shield in front of the VCSEL's diffuser windows.

8 Safe operating and measurement conditions

The ams OSRAM NIR VCSEL (vertical cavity surface emitting laser) illuminators emit laser radiation at a peak wavelength of about either 850nm or 940nm. Above the VCSEL, a micro-lens array (MLA) is placed to act as a diffuser, which diffuses the light emitted by the VCSEL within a certain angle called field of illumination as shown in the figure below.

Figure 12: Illustration of a VCSEL based illuminator



An evaluation for laser safety must be done by the system designer to ensure that the product operates as a class 1 laser. We performed a calculation for laser safety classification, according to IEC 60825-1, Edition 3.0 (2014), condition 3, (described in the next section) based on measurement data for a selection out of the ams OSRAM VCSEL portfolio. Extrapolation can introduce uncertainty in the results and the classification. Single fault conditions are not considered. For classification, condition 1 (telescope condition) was not considered, since the radiation is emitted into a large solid angle (beam not collimated) (reference: 5.4.1 of IEC 60825-1, Edition 3.0).

8.1 Measurement condition 3 ("unaided eye")

For a complete safety analysis, each position of the eye should be considered. In addition, an accommodation of the eye is to be evaluated as well. According to the IEC laser safety standard IEC 60825-1, the range from 10 cm to infinity should be considered.

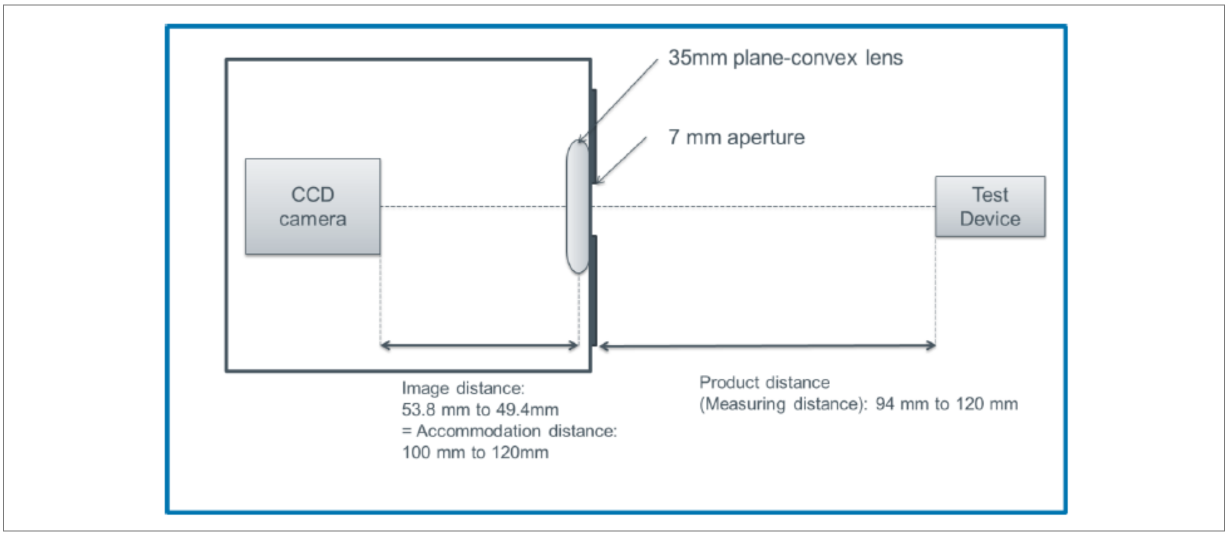
The measurements were done with a method referred to as "artificial eye" setup for measurement condition 3 ("unaided eye"). This condition is described in IEC 60825-1, Edition 3.0. The measurement setup consists of a lens, an aperture with 7 mm diameter (corresponding to the pupil) and a CCD-camera as shown in the figure below.

The device under test was placed in front of the artificial eye. The distance between the device and the 7 mm aperture of the lens was referred to as "product distance". The product distance can be varied up to 120 mm. For each product distance, the accommodation distance is varied by increments of the image distance. The image distance is the distance between the CCD-camera and the principal surface of the lens.

All the images taken with the CCD-camera are analyzed by means of computer software according to the prescriptions given in IEC 60825-1 for irregular extended sources. The computations were performed with rectangular integration areas. To calibrate the pixel values of the images in terms of power, the power through 7 mm aperture was measured at various product distances. The power levels were then assigned to the sum of pixel values measured with the CCD-camera at the corresponding distances.

Apparent source size (mrad) and the power behind a 7 mm aperture (mW) were used to derive a classification of a module under the operating condition. These values were also used for extrapolation of the data and classification of additional, not directly tested, operating conditions.

Figure 13: Measurement setup considered for the extended evaluation (Condition 3)



8.2 Calculating eye safety limits

For pulsed sources, the IEC60825-1, Edition 3.0 standard defines “Accessible Emission Limit” (AEL) for single and multi-pulses, for pulse durations of 5µs < t ≤ T2:

Equation 2: Single pulse criterion AELs

$$AELs = 7 \bullet 10^{-4} \bullet C_4 \bullet C_6 \bullet t^{0.75} J$$

Where

- C_4: A correction factor of the Wavelength.
- C_6: A correction factor of the source apparent size.

- T_2: The time value beyond which the eye damage is independent of the exposure time. Function of the angular size of the source.

For a single pulse, the energy per pulse is compared to the limit above.

Reduced pulse criterion (multi pulse) AELs:

Equation 3: Reduced pulse criterion (multi pulse) AELs

$$AELs = 7 \bullet 10^{-4} \bullet C_4 \bullet C_6 \bullet t^{0.75} \bullet C_5 J$$

Where

- C_5: Correction factor for multi-pulse; depends on the pulse duration and the number of pulses within the evaluation time

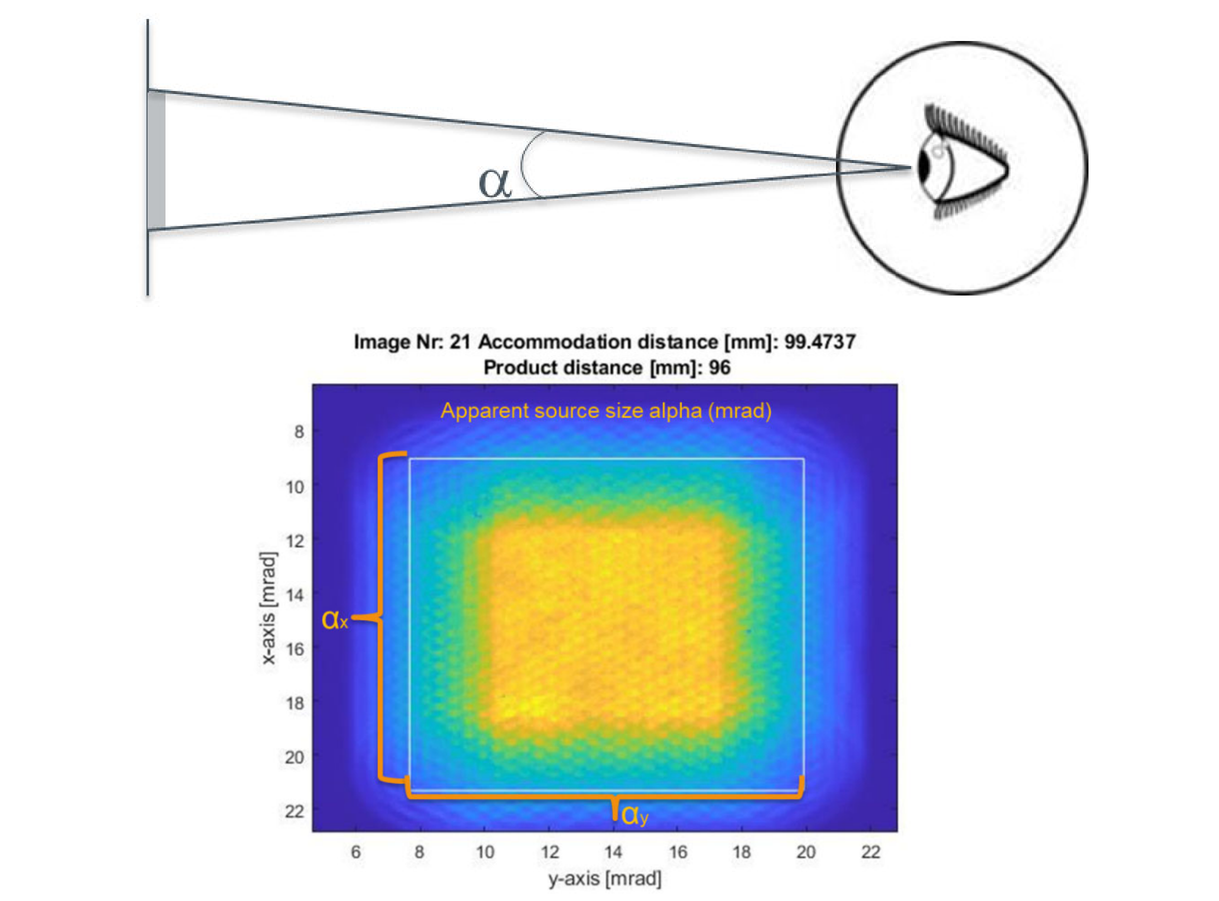
The average pulse energy from pulses within a pulse train shall not exceed the AEL for a single pulse multiplied by the correction factor C5.

For other exposure time domains, the corresponding limits should be considered. The most restrictive condition - single pulse, multiple pulse or averaged power criterion shall be the focus.

8.2.1 Eye safety limits parameters

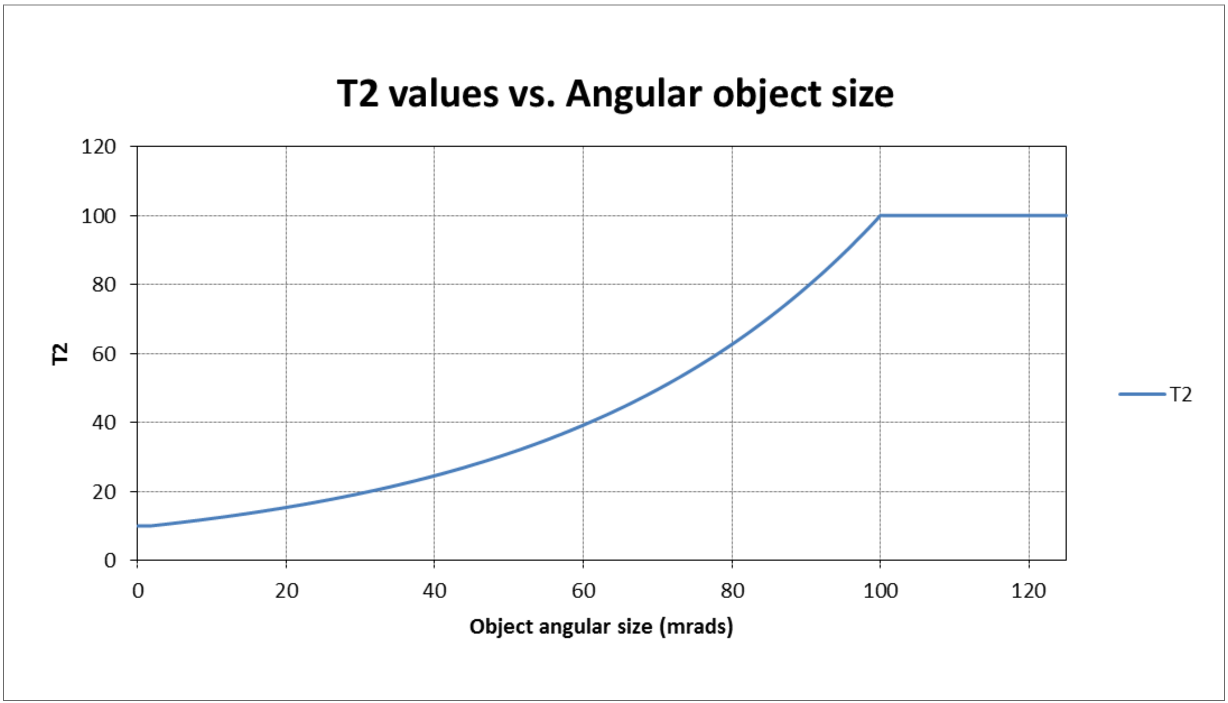
The accessible emission should be below the emission limit to meet the criterion of a Laser Class 1. α is the apparent source size or angular size (in radians) of the source with respect to the eye. It can be determined by means of image post processing of the image of the light source on the eye for different focus positions taken with a CCD detector. The images are scanned with sliding windows in a range defined by the IEC 60825-1, Edition 3.0 (2014). The most restrictive image and results are considered for the classification.

Figure 14: Definition of apparent source size α



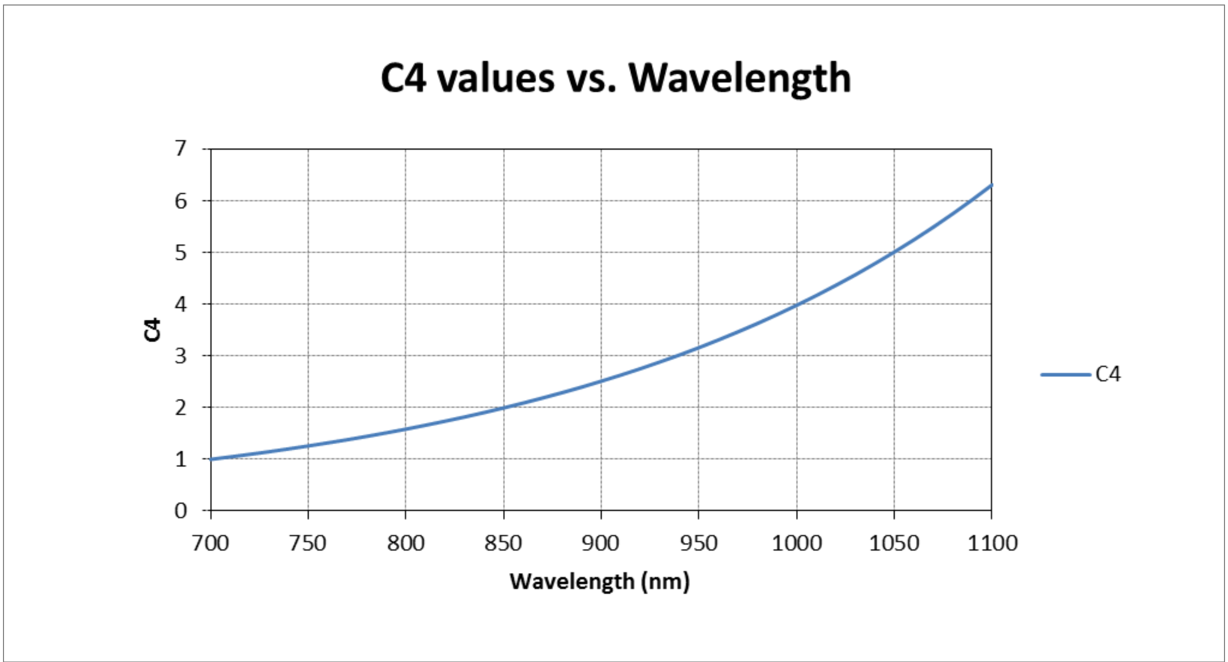
- α_{min} minimal angular size that the eye can resolve. Below this value we consider the source to be point source. α_{min} = 1.5 mrads
- α_{max} maximal angular size that the eye can see meaning that bigger objects will not be fully imaged. This depends on the exposure time:
  – For t < 625µs => α_{max} = 5 mrad
  – For 625µs < t < 0.25s => α_{max} = 200 * $t^{0.5}$ mrad
  – For t > 0.25s => α_{max} = 100 mrad
- T_2: Time value which is related to the eye movement. It is function of the angular size of the source:
  – $T_2 = 10*10^{[(\alpha-\alpha min)/98.5]}$ seconds
  – If $\alpha < \alpha_{min}$ T_2 = 10 seconds
  – If $\alpha > \alpha_{max}$ T_2 = 100 seconds

Figure 15: T_2



- C_4 is a correction factor which depends on the wavelength and is related to the absorbance in the Melanin layer of the eye. $C_4 = 10^{0.002(\lambda-700)}$ with λ wavelength in nm.

Figure 16: C_4



- C_5 depends on the pulse duration and the amount of pulsed within the evaluation time. It is used for the multiple pulsed limits. The correction factor is applied to pulses with an emission time smaller than 0.25s.
- C_6 correction factor is for an extended source evaluation and increases the emission limits. It is alpha dependent and defined as:

Equation 4:

$$C_6 = \begin{cases} 1 & if\ \alpha < \alpha_{min} \\ \alpha/\alpha_{min} & if\ \alpha_{min} < \alpha < \alpha_{max} \\ \alpha_{max}/\alpha_{min} & if\ \alpha_{max} < \alpha \end{cases}$$

For the EGA2000 & BIDOS modules, extrapolation is applied without any system level considerations. Thermal management is critical as well as the operating condition to reach the desired power conversion efficiency or the emitted power. Therefore, for the analysis results in this document, the data does not consider the temperature effect on the emitted power. In addition, the emitted power versus the operating current was assumed to behave linearly.

To determine the max operating current, the most restrictive criterion was used.

8.3 Regarding skin hazard

To assess the risk to the skin, the total average power is required.

The skin limit is 0.5W which is the limit of Class 3B. This AEL does not prevent any kind of skin injuries, it is set to prevent significant skin injuries.

9 Analysis results

This chapter shows analysis results of examples of safe operating conditions with typical current ratings. If the value AE/AEL is larger than 1, the system can't be considered as a laser Class 1 product. Most of the driving conditions shown in the following tables are below an AE/AEL of 1 and should give an indication about the ratio of the accesible emission and the corresponding limit. Approaching an AE/AEL ratio of 1, measurement uncertainties and variations of the electrical driver must be taken into account. In any case the final system needs to be evaluated and classified.

9.1 BIDOS V105Q121A-940

The apparent source size α for this product is 8.0 mrad. The following table shows examples of safe operating condition for V105Q121A-940 with maximum current ratings:

Table 2: Evaluation results BIDOS V105Q121A-940 – for reference only

Pulse duration (µs)	Duty cycle	AE/AEL (-) most restrictive, class 1, if < 1
0.1	5%	0.15
0.5	5%	0.15
100	5%	0.63
200	5%	0.75
300	5%	0.83

Forward current for all tested driving conditions = 4A.

9.2 BIDOS V105Q131A-940

The apparent source size α for this product is 8.0 mrad. The following table shows examples of safe operating condition for V105Q131A-940 with maximum current ratings:

Table 3: Evaluation results BIDOS V105Q131A-940 – for reference only

Pulse duration (µs)	Duty cycle	AE/AEL (-) most restrictive, class 1, if < 1
0.1	5%	0.16
0.5	5%	0.16
100	5%	0.53
200	5%	0.63
300	5%	0.70

Forward current for all tested driving conditions = 4A.

9.3 BIDOS V205Q121A-940

The apparent source size α for this product is 7.5 mrad. The following table shows examples of safe operating condition for V205Q121A-940 with maximum current ratings:

Table 4: Evaluation results BIDOS V205Q121A-940 – for reference only

Pulse duration (µs)	Duty cycle	AE/AEL (-) most restrictive, class 1, if < 1
0.1	5%	0.35
0.5	5%	0.35

Forward current for all tested driving conditions = 4A.

9.4 BIDOS V205Q131A-940

The apparent source size α for this product is 7.5 mrad. The following table shows examples of safe operating condition for V205Q131A-940 with maximum current ratings:

Table 5: Evaluation results BIDOS V205Q131A-940 – for reference only

Pulse duration (µs)	Duty cycle	AE/AEL (-) most restrictive, class 1, if < 1
0.1	5%	0.26
0.5	5%	0.26
100	5%	0.98
200	0.5%	0.95
300		

Forward current for all tested driving conditions = 4A.

9.5 EGA2000-940-N

The apparent source size α for this product is 9.1 mrad. The following table shows examples of safe operating condition for EGA2000-940-N with maximum current ratings:

Table 6: Evaluation results EGA2000-940-N – for reference only

Pulse duration (µs)	Duty cycle	AE/AEL (-) most restrictive, class, if <1
0.1	5%	0.38
1	3%	0.75
1.5	4.5%	1.0
0.1	2%	0.38

Forward current for all tested driving conditions = 4A.

For all the above pulsing scenarios with the max operating current listed the skin limit is not exceeded. Similar data expected for BIDOS V105Q121A-940, but not tested.

10 Summary

The application note explores various aspects around eye safety for designs using ams OSRAM's VCSEL based IR illuminators, in particular the BIDOS and EGA2000 product families, including regulations on and categorization of lasers, integrated safety features, designing monitoring circuits and measurement data related to safe operating conditions.

The importance of defining proper driving conditions such as pulse width, pulse period and operating current is shown, to fulfil the safe operating conditions and meet the requirements for classification as a Class 1 device (according to IEC 60825-1:2014, Edition 3.0).

11 Literature

- Laser Products - Conformance with IEC 60825-1 Ed. 3 and IEC 60601-2-22 Ed. 3.1 (Laser Notice No. 56) IEC 60825-1:2014.
- Classification and Requirements for Laser Illuminated Projectors (LIPs) (Laser Notice No. 57).
- Safety of laser products - Part 1: Equipment classification and requirements.

12 Revision information

Changes to current revision v1-00	Page
Initial production version	

- Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
- Correction of typographical errors is not explicitly mentioned.

ABOUT ams OSRAM Group (SIX: AMS)

The ams OSRAM Group (SIX: AMS) is a global leader in intelligent sensors and emitters. By adding intelligence to light and passion to innovation, we enrich people's lives. 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 20,000 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 EUR 3.6 billion revenues in 2023. Find out more about us on https://ams-osram.com.

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