# Vixar Application Note
# VCSEL Ceramic Packages


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# 1 Introduction

Vertical cavity surface emitting lasers (VCSELs) are an important technology for application in a variety of markets, including consumer, industrial, automotive, and medical industries. Three-dimensional (3D) cameras using flash LiDAR technology utilize the many benefits of a VCSEL to produce a narrow spectral width signal with very short (< 10 ns) pulse widths. The narrow beam divergence (< 30°) allows efficient light collection by optical diffusers to uniformly illuminate a target field.

The top-emitting property of a VCSEL enables flexible packaging options for VCSEL die. Vixar's ceramic modules enable the cost-efficient integration of VCSEL die and diffusers into a small, robust package [Figure 1]. In addition, monitor photodiodes (MPDs) can be integrated inside the package to measure the diffuser's performance and improve eye safety considerations.

This application note reviews the VCSEL ceramic module products offered by Vixar. The package is described in detail in performance and reliability. This document also covers the diffuser robustness, performance, and monitoring using integrated MPDs.

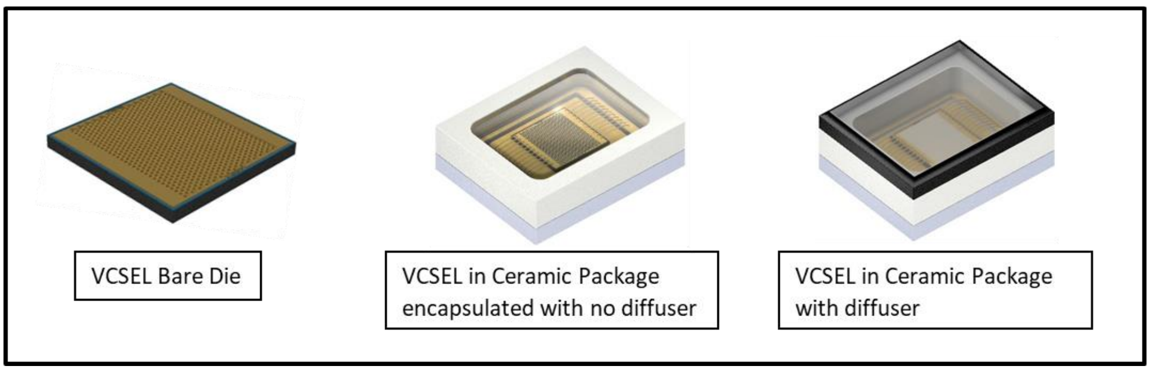


**Figure 1**: Vixar's portfolio consists of VCSEL die (left), ceramic packages with encapsulant (center), and ceramic packages with optical diffuser (right).

# 2 Ceramic Package

## *2.1 Module Design*

The ceramic packages from Vixar are designed for high power applications. The package can also incorporate an MPD for monitoring the performance of the VCSEL and diffuser. The ceramic substrate is constructed with thermally conductive AlN ceramic with gold-plated solder pads and are 2.8mm x 3.5mm in dimensions [Figure 2]. A ceramic spacer and a diffuser are attached to the substrate. Ceramic packages with diffusers have a moisture sensitivity level of 2 and are reflow solderable (max 260°C for 30 sec.) and compatible with surface mount technology (SMT) equipment. The design forms a sealed package that is resistant to both liquids and gases and allowing cleaning of the circuit board after solder reflow.

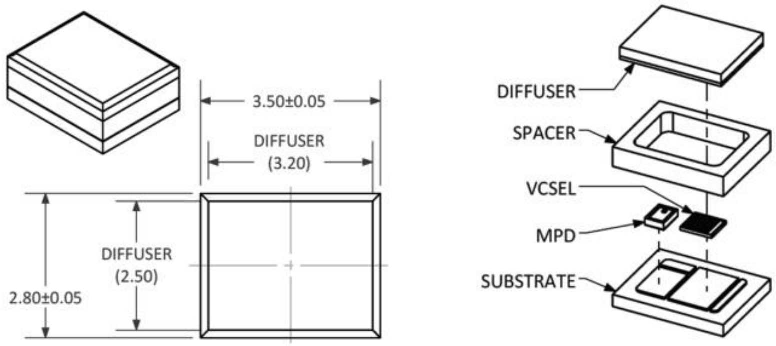


**Figure 2**: Vixar's ceramic module consists of a substrate, spacer, and diffuser assembled to form a fully sealed package around the VCSEL die and MPD.

## *2.2 Thermal Resistance*

VCSELs are very sensitive to thermal build-up at the junction inside the die. Many flash LIDAR applications drive VCSELs under high current, high duty cycle (DC) applications in pulse trains for indirect time of flight (iTOF) measurements. Thermal buildup can occur during a single pulse train, and power droop may be observed if thermal paths are not properly managed. Decreasing the thermal resistance of the VCSEL package enables more power to be dissipated in the die without impacting the laser's performance or lifetime.

The ceramic package has superior thermal properties due to its design and material selection. AlN-based ceramic packages ensure adequate thermal flow through the entire submount while ensuring electrical isolation between anode and cathode solder pads. Unlike most plastic-based packaging, both bond pads are thermally active due to the thermal flow through the ceramic substrate.

Mounting the VCSEL on a metal core PCB is recommended. PCBs with Cu pillar or Cu coin technology is best to remove heat from the package. Standard FR-4 PCBs are not recommended for high power applications, but they may be acceptable for lower power applications if properly designed with sufficient thermal vias.

## *2.3 Environmental Robustness*

The ceramic package is also designed for most industrial applications that expose the product to adverse thermal environments [Figure 3]. Ceramic modules have been tested at low (-40°C) and high (105°C) temperature storage conditions for >1,000 hours. High Temperature Operating Lifetime was used to test parts at 85°C for >1000 hours. Ceramic packages have been evaluated for thermal shock (-40°C to 85°C) for >300 cycles. Moisture susceptibility was also evaluated with Moisture Resistance (65°C / 93%RH) and High Temperature High Humidity (85°C / 85%RH) tests. All tests have shown no failures during each test, with a failure labeled as a >20% degradation in emission at the operating VCSEL current.

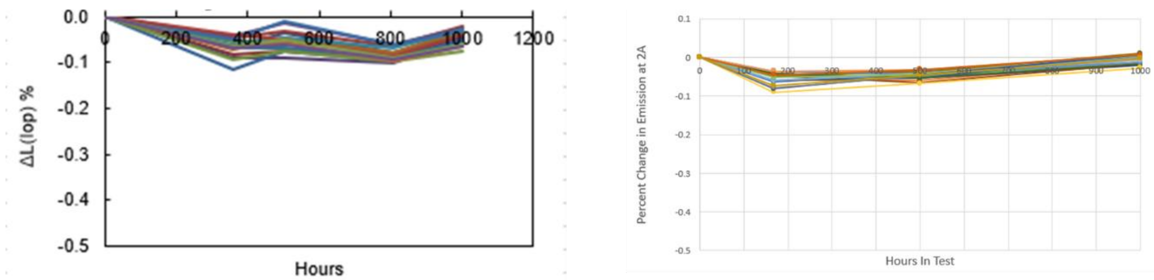


**Figure 3**: Reliability test results for High Temperature Operating Lifetime (left) and High Temperature High Humidity (right) testing results show no failures.

## *2.4 Mechanical Robustness*

The ceramic package utilizes multiple adhesion components to optimally assemble the various material components into a single robust solution. With the package being an assembly of multiple components, mechanical testing was conducted to determine the overall robustness of the package and verify sufficient material adhesion and assembly procedures. Ceramic packages were tested with lateral (shear) and vertical (pull) tests to determine minimum force requirements before catastrophic failure of the module [Figure 4]. Mechanical forces were placed on the diffuser to impact all components between the pressure point and the ceramic substrates. The materials used to adhere the diffusers and frames to the ceramic package were shown to withstand high shear and pull forces. Mechanical robustness did not change after product exposure to extreme storage temperatures or thermal cycling.

# 3 Optical Diffuser

For most designs, flash LiDAR utilizes a time of flight (ToF) measurement method. A pulsed optical signal is sent into the environment, reflects off nearby objects, and is detected by a photodiode array that may consist of PINs, APDs, or SPADs. Regardless of the detector design utilized, 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 can't deliver the required shape and uniformity required for this application, so advanced optical diffusers must be used.

The diffuser optics used in Vixar's ceramic packages are designed to shape and project a rectangular field of illumination (FOI) when projected onto a flat surface [Figure 5]. 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.

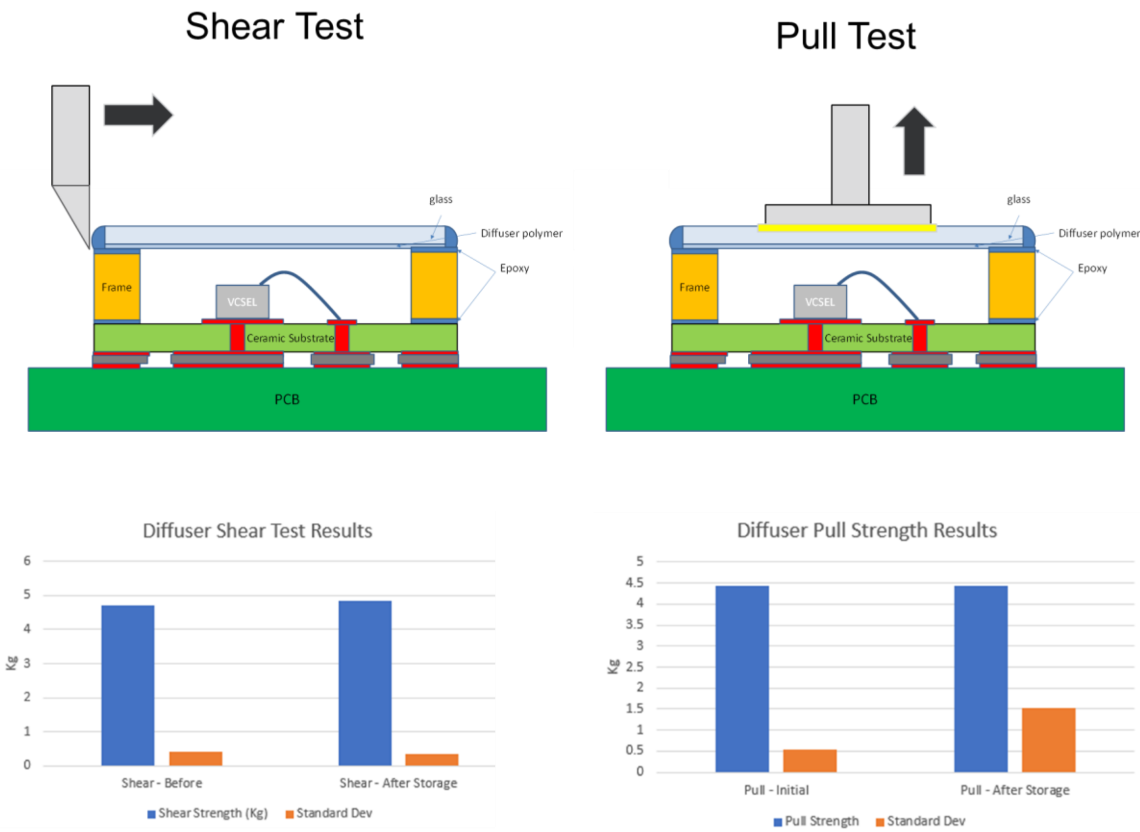


**Figure 4**: Vixar's ceramic modules are developed with high mechanical strength, as demonstrated by lateral shear (left) and vertical pull (right) tests.

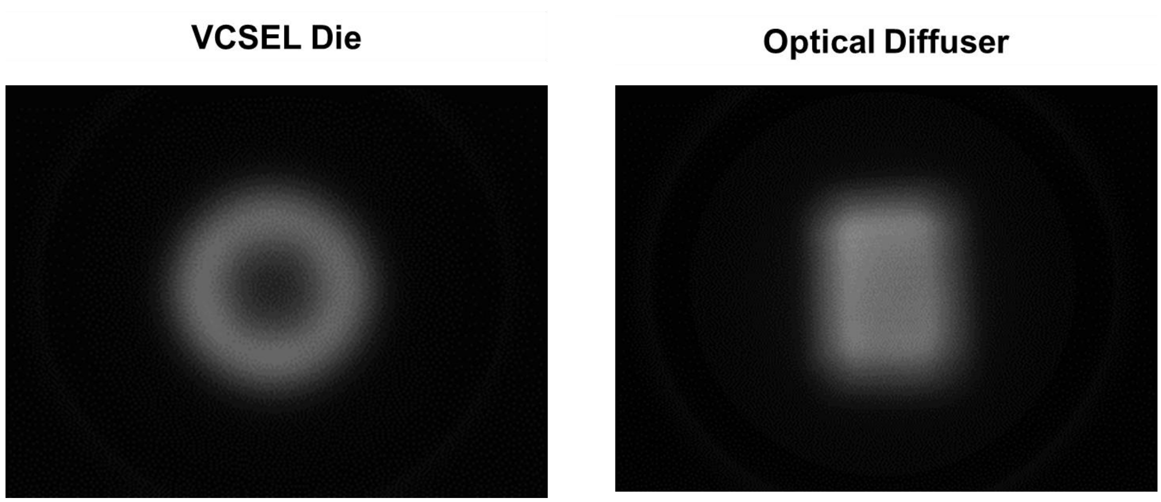


**Figure 5**: Optical diffuser are efficient at converting the VCSELs narrow, ring-shaped beam profile (left) into a wide, rectangular illumination source with high uniformity (right).

Vixar has developed a portfolio of products that incorporate optical diffusers into the ceramic package to generate various rectangular fields of illumination, including 60° x 45°, 72° x 58°, and 110° x 80° FOI. The diffuser film is protected underneath the glass cover and sealed inside the package. While the device is not hermetically sealed, the proprietary assembly process drastically reduces the rate at which moisture penetrates the package. Unlike similar packages on the market, Vixar's ceramic products do not require vent holes to pass thermal cycling reliability tests. The fully sealed package allows standard post reflow circuit board cleaning processes such as an ultrasonic scrubber in solvent. The module design prevents moisture from entering and condensing on the diffuser pattern, which would negate the diffuser and may result in an eye safety hazard.

# 4 Diffuser Monitoring

As the vertical-cavity surface-emitting laser (VCSEL) consumer market continues to grow, VCSEL suppliers have invested in safety measures to protect the end user. One of the major consumer concerns is the eye safety of VCSELs. The first line of defense implemented in VCSEL packages is a 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. A fear for consumer applications is that a damaged diffuser will allow undiffused light through and cause permanent eye damage to their customers. Therefore, there is a need to detect when a diffuser is damaged so the VCSEL can be disabled to avoid any harm.

One method is to have a metallic trace along the outside perimeter of the diffuser [Figure 6]. The metal trace will complete a circuit that will signal to turn off the VCSEL when the trace is broken. The metal trace cannot detect cracks that do not occur along the trace. Since the metal trace would block the laser if it ran over the area of emission, it is not able to detect some cracks that could allow undiffused light through.

Alternatively, an indium tin oxide (ITO) trace can be patterned on the glass cover to detect a damaged diffuser [Figure 7]. ITO is conductive and operates similarly to the metallic trace. The ITO trace is mostly transparent at the VCSEL wavelength 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 impact the optical power, beam divergence, and efficiency.

The preferred method in identifying damage to the product is to use a monitor photodiode (MPD) to detect the backscatter from the diffuser [Figure 8]. The effectiveness of the diffuser directly correlates how much backscatter the MPD can detect. This method can directly measure the severity of the 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. If the substrate or sidewall of the package is damaged, this can allow moisture into the package that can condense on the diffuser polymer film. The condensate degrades the package's ability to diffuse the light source and preserve 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.

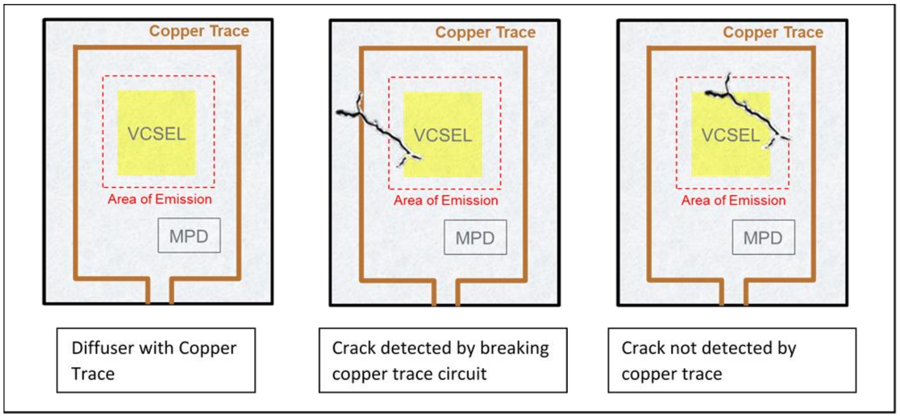


**Figure 6**: A metallic trace can only detect diffuser damage outside the emission area.

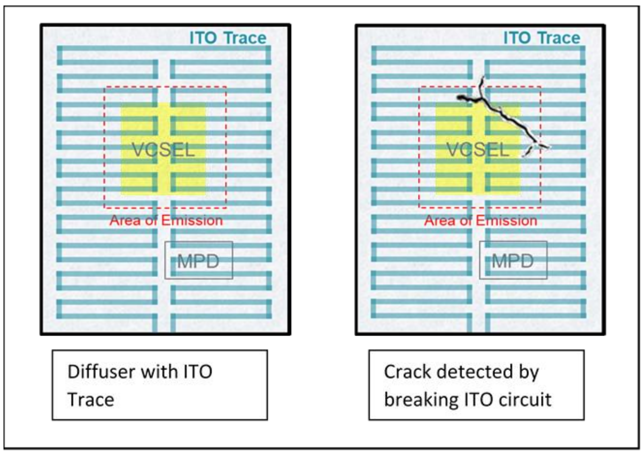


**Figure 7**: An ITO trace can detect diffuser damage inside the emission area.

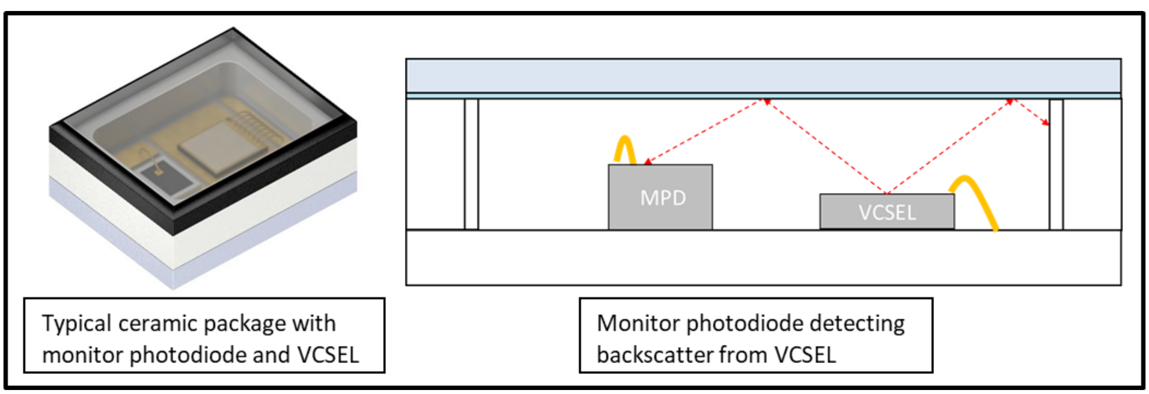


**Figure 8**: A monitor photodiode can directly detect for both diffuser damage and moisture condensation inside the package.

# 5 Monitor Photodiode

Inside the VCSEL package, the VCSEL is electrically isolated from the MPD [Figure 9]. Each component has an anode and cathode connection on the ceramic package footprint. This is essential, as sharing a common connection between both components will degrade the measurement sensitivity. The VCSEL driving current is over 1000x 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 ceramic package will cause observable differences in MPD responsivity [Figure 10]. 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. For high-sensitivity applications, Vixar 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.

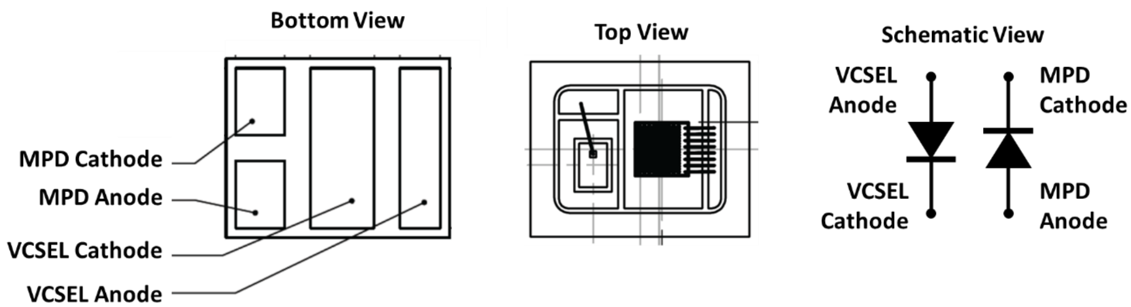


**Figure 9**: The VCSEL and MPD die are electrically isolated inside the ceramic package.

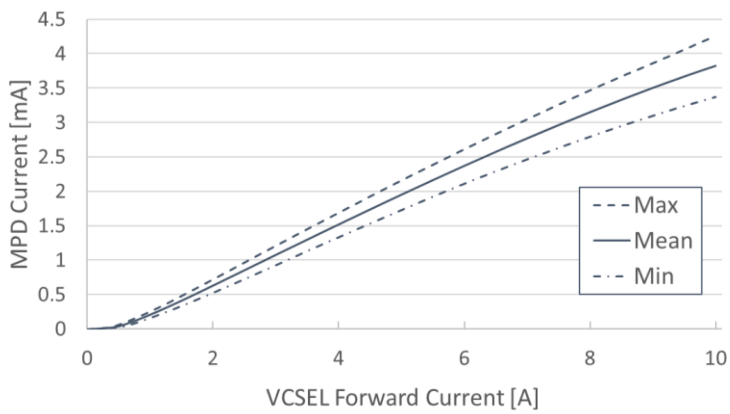


**Figure 20**: Measurable tolerance in MPD current in a lot size of 125 samples in a ceramic package with a 940nm 550 aperture die and a 72 x 58 FoI Diffuser.

Algorithms can be programed to better detect fast changes in MPD current due to a crack while ignoring slow changes that occur over product lifetime. While the MPD sensitivity is independent of temperature, VCSEL power will decrease at higher temperatures and reduce the amount of scattered light into the MPD. The MPD is also more sensitive to shorter NIR wavelengths. 850nm VCSEL products will exhibit higher MPD currents compared to their 940nm counterparts. Some applications will present highly-reflective objects directly in front of the VCSEL illumination source, resulting in a sudden increase in MPD current. Algorithms will need to consider the various end-use applications and operate accordingly to minimize false alarms.

# 6 Diffuser Damage

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 [Figure 11]. 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 [Figure 12].

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 shattering, 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 11**: Images of diffusers mounted on ceramic packages that are (from left to right) new, scratched, cracked, and broken.

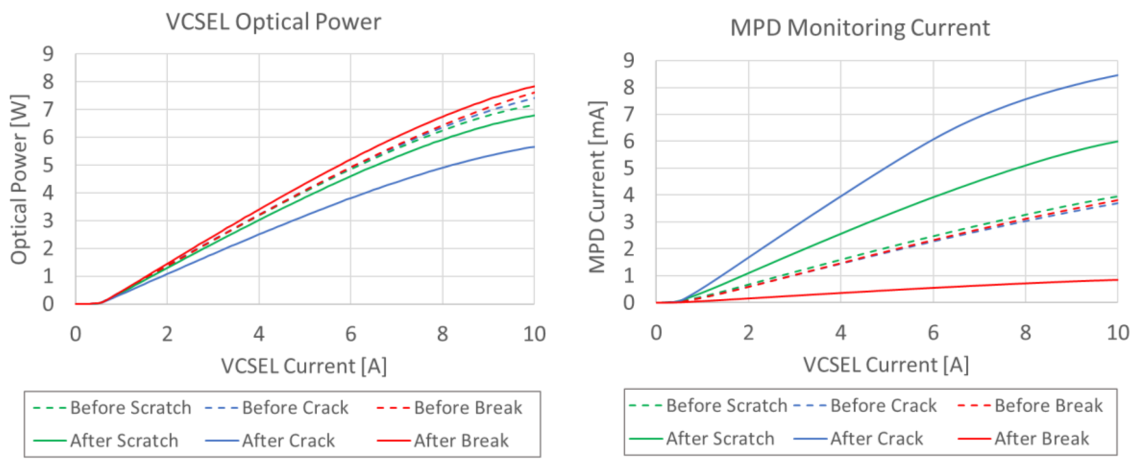


**Figure 32**: Measurement results showing how damage to the package diffuser won't impact the VCSEL optical power output (left), but it will significantly impact in the MPD current (right).

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 Conclusion

Vixar had developed a portfolio of ceramic product that protect the VCSEL die and enable SMT processing for many consumer and industrial applications. Vixar's ceramic packages are robust under harsh thermal, mechanical, and environmental conditions. The package enables a variety of optical diffuser with different FOIs to match the system's detector array.

Ceramic packages are available with the integration of monitor photodiodes to ensure diffuser health monitoring. Damage to the diffuser is important to ensure eye safety for end users in high-power TOF applications. Diffuser damage mechanisms are evaluated to demonstrate how the MPD can determine the effectiveness of product performance and health under different destructive scenarios.