Vixar Application Note

VCSEL EOS/ESD Considerations and Lifetime Optimization

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1.0 Introduction

Electrostatic Discharge (ESD) is the release of static electricity when two objects come into contact. It is a known, well documented and constant threat to the life of most semiconductor devices. Electrical Overstress (EOS) is a term/acronym used to describe the thermal damage that may occur when an electronic device is subjected to a current or voltage that is beyond the specification limits of the device. ESD and EOS are related types of over stress events but at opposite ends of a continuum of current/voltage/time stress conditions. ESD is typically a high power/voltage and moderate energy/current event that occurs in a short time frame (generally <1 us), whereas, EOS is a lower power/voltage and higher energy/current event that occurs over a longer duration of time (generally >1 ms). ESD is often considered a subset of EOS and it can be difficult or impossible to differentiate between these two types of events. The same features that give Vertical Cavity Surfaced Emitting Laser (VCSEL) devices their unique properties, such as inherent fast response time and small size, also make them susceptible to ESD and EOS.

2.0 VCSEL ESD Susceptibility and Protection

Depending upon device design VCSEL devices can be susceptible to ESD damage at threshold voltages ranging from 1000V (typically for larger devices) to less than 100 V (for very small devices) Human Body Model (HBM). This voltage is much less than many other semiconductor and optical products and puts some VCSELs in the most ESD sensitive classes for electronics. The active area a VCSEL is much smaller than that of an edge-emitting laser, for example, so the ESD susceptibility is greater for the VCSEL [1]. An ESD voltage of 100 V is also far below the 2000 V minimum that is perceived by a person, so a device could be damaged without the event ever being seen or felt. Industry research has shown that independent of the manufacturer or design, the main variable that affects the susceptibility of VCSELs to ESD is the aperture size. As the aperture diameter decreases, the current density or localized energy of an EOS/ESD event becomes greater. Figure 1 displays ESD susceptibility/voltage vs. aperture size for VCSEL devices from Honeywell and Agilent [2]. Also included in the figure is where Vixar devices fall along this curve.

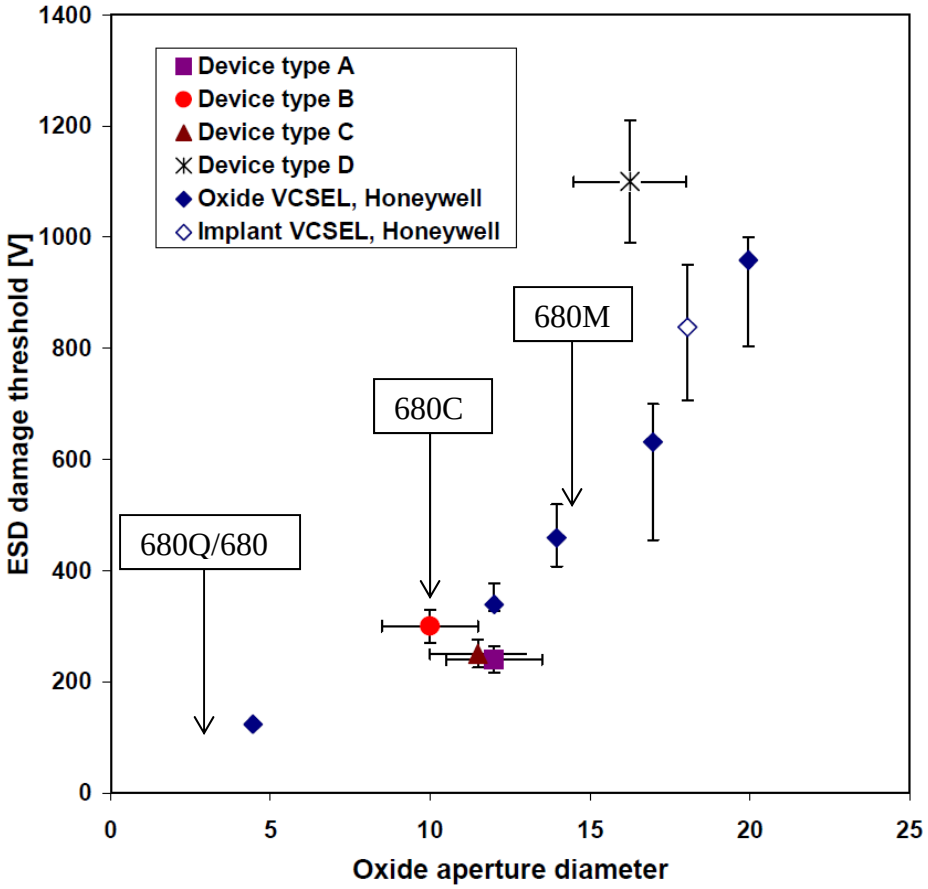

Figure 1: ESD voltage thresholds for oxide VCSELS (Human Body Model, reverse bias) [2]

As can be seen from the graph, Vixar's 680Q and 680S devices are very susceptible to ESD damage and that is why we recommend an ESD protection diode be added to the packaged component, depending on the application and usage. Vixar has tested small aperture single mode VCSELs that include the ESD protection diode using three strikes at 1000 V, in both the forward and reverse direction without any evidence of ESD damage (Human Body Model, per IEC 61000-4-2, 150 pF / 330 Ohm network). Since the ESD protection diode has a capacitance of approximately 80 pF, it can limit the modulation frequency to 35 MHz or less, so it cannot be used for all applications.

3.0 ESD Control

ESD events can be avoided by following industry standard guidelines such as ANSI/ESD S20.20. The guideline explains how grounding, safe package handling, air ionizers, and many other precautions can be put into place to minimize ESD events. This procedure only applies to the Human Body Model (HBM) events larger than 100 V. For VCSEL products, further precautions such as floor grounding, widespread ionizer usage, and more stringent ESD technical requirements and more frequent verification may be required.

4.0 EOS Control and Precautions

EOS precautions also need to be taken when working with VCSELS. The following is a list of examples of how EOS events can inadvertently occur. It is not a complete list.

- Connecting the VCSEL device to a power supply that is already on.
- Intermittent connects from the VCSEL to the power source. This can be caused by pins that are too short for a socket or pins that are too different in length to all fit well into a socket.
- Turning on a power supply that is already set to a voltage or current using the AC main switch. A large voltage/current spike can be propagated to the device when the instrument is first turned on. Vixar recommends setting the power supply to 0 V, then turning it on, and finally slowly adjusting it to the desired current, voltage, mode, amplitude, etc.
- Current in the reverse bias direction to the VCSEL should be minimized and avoided. Current in the reverse bias direction of greater than 0.1 μA could possibly cause damage. So accidently setting the current source instrument to the wrong polarity could damage the device. Also a voltage of 5 V or more reverse bias can cause damage, depending on the current compliance/limit setting of the sourcing instrument being used.
- Setting the sourcing unit connected to the VCSEL to force voltage instead of current. If the voltage is too high, even in the forward bias direction, it will generate a large current which will damage the device. The current limit or current compliance limit should be set just above the desired operating current when using a voltage source.

In general, to avoid EOS damage to a VCSEL device avoid reverse bias currents of any kind and whenever possible use a soft, gradual turn on of the VCSEL in the forward bias direction using a current source.

5.0 Identifying EOS/ESD damage

Sufficiently large ESD/EOS events may cause immediate symptoms such as lowered output power, dark areas within the emission aperture, and large reverse leakage. Lower level EOS/ESD events by contrast may cause no immediate effects, but can introduce one or more crystal dislocations that can grow into dark line defects over time. The device may not fail for minutes, hours, days, weeks, or longer after the stress event, but the device's reliability will have been compromised. Because of this, it can be very difficult to determine the root cause or exactly when and where the stress event occurred. A sufficiently large EOS/ESD event can usually be easily identified because of physical damage observed at the surface of the VCSEL. The physical damage can be identified by melted pad or bonding metal, discoloration at the surface, or other changes to the VCSEL structure. Damage can also sometimes be observed by biasing the device with current below the lasing threshold, and observing the emission from the aperture. Dark regions in the emission pattern, especially around the outside of the device aperture, can indicate EOS/ESD. An example emission pattern of an ESD damaged VCSEL can be seen in Figure 2. The dark areas on the outside left and right sides of the aperture in Figure 2 are typical signs of ESD damage.

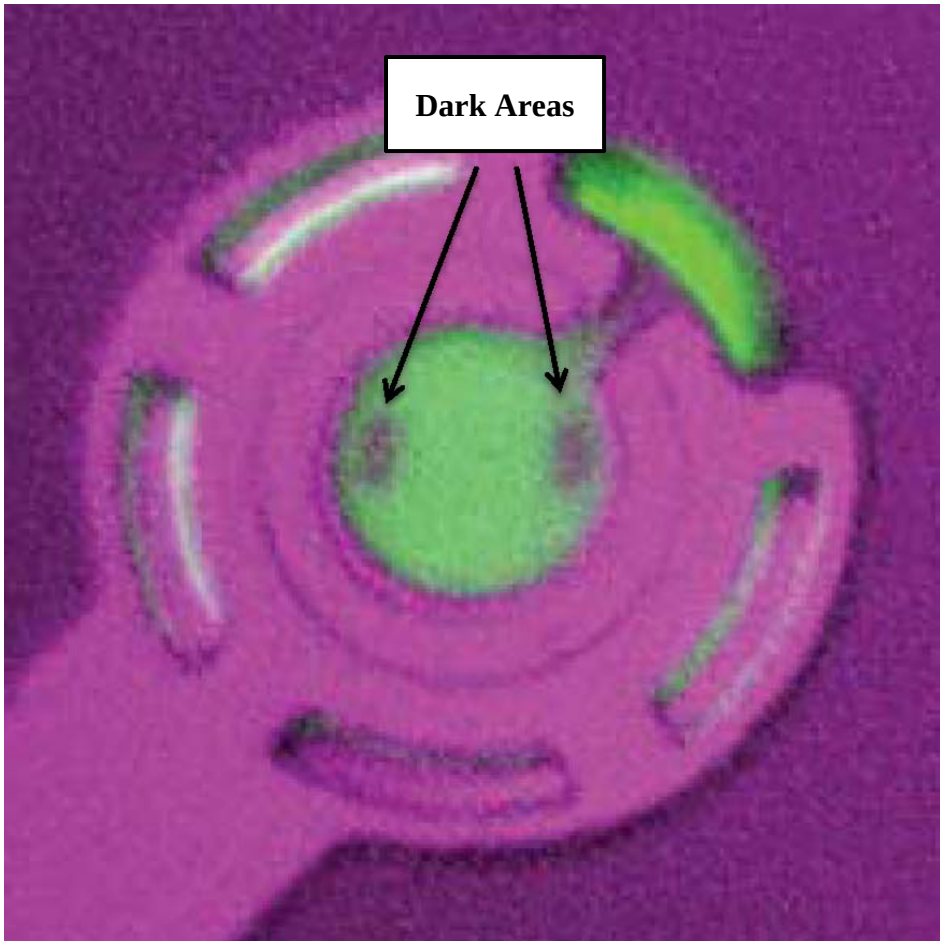

Figure 2: VCSEL emission of an ESD damaged device [4]

Many times EOS/ESD damage cannot be visibly observed at the surface of the VCSEL, but there are electrical signatures that do indicate EOS/ESD damage. Electrically, ESD and EOS are detected via a reverse bias leakage test. For a damaged part, the current is much higher for a given reverse voltage. Figure 3 shows the before and after reverse leakage of a part damaged by ESD.

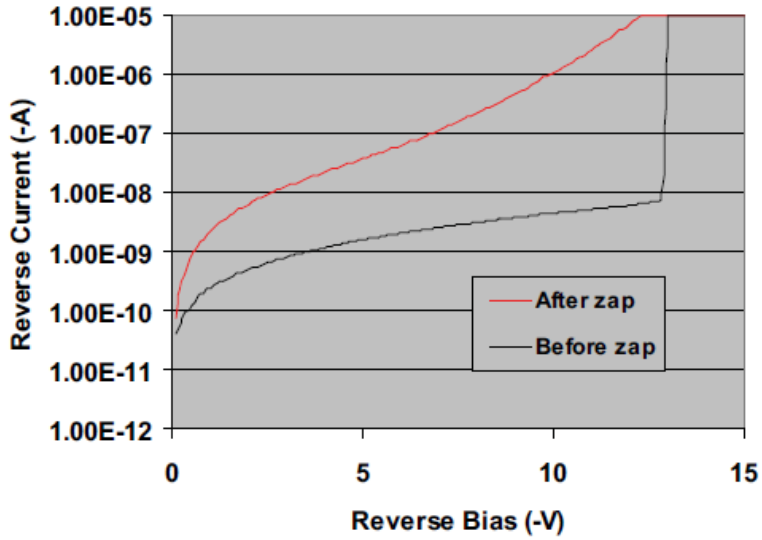

Figure 3: Typical reverse bias characteristics of an ESD damaged VCSEL [4]

The reverse bias leakage test can also indicate other types of defects, but it is not usually an indicator for intrinsic VCSEL wear out. **Vixar recommends that customers do not attempt reverse leakage measurements.** Great care needs to be taken when performing a reverse leakage measurement. The act of doing the measurement can damage the device if proper instrumentation precautions are not taken. For instance, when forcing voltage in the reverse direction, the current compliance/limit should be set to a value of 0.1 uA or lower on the instrument being used. The forward voltage output power (L), Current (I), Voltage (V) curves (i.e., LIV curves) for a VCSEL are not typically good indicators of EOS/ESD damage. For moderate to high levels of EOS/ESD damage, the slope efficiency and threshold current may be measurably affected. However, for low levels of EOS/ESD, latent damage can occur which may not be immediately observed in the forward bias measurements, but may appear after 10s to 1000s of hours of operation. Therefore Vixar finds the reverse bias measurements to be a more sensitive measure of whether EOS/ESD damage has occurred.

6.0 EOS/ESD Screening

At Vixar screening techniques are used at multiple levels of assembly to identify defective VCSELs, including those possibly damaged by EOS/ESD, and eliminate them from the population. The tests include but are not limited to:

- A minimum of 24 hours of burn-in, excluding unpackaged, bare die sent directly to the customer
- Electrical characterization both in the forward and reverse biased direction.
- Optical power characterization.
- Optical microscopy inspection for physical defects.

7.0 Enhancing VCSEL Lifetime

Even a perfectly fabricated, packaged, and operated VCSEL containing no EOS/ESD damage or defects will eventually wear out. The lifetime of a VCSEL is very dependent on the operating temperature and current used. The lifetime can vary greatly, even by many years, for the same design using even slightly different operating conditions. As an example for a small aperture device, such as a single-mode VCSEL, decreasing the operating temperature from 40° C to 30° C can double the lifetime. For the same design decreasing the operating current from 2 mA to 1 mA can increase the lifetime by over six times. The current applied to the VCSEL can also cause a secondary effect on the lifetime of the VCSEL by increasing the junction temperature internal to VCSEL. If the VCSEL is used in a pulsed application, where the VCSEL is only on for a short portion of the cycle, then this junction heating affect can be reduced or eliminated. Also, since the VCSEL is only on for a percentage of the cycle, its actual usage time will be diminished by that same percentage.

8.0 Conclusions

Vixar highly recommends using stringent ESD and EOS safe procedures when handling VCSEL devices due to their inherent sensitivity. Vixar also recommends that an added ESD protection diode be considered for our most sensitive small aperture 680Q and 680S devices. For applications where the added ESD diode protection is not feasible, such as modulation above 35 MHz, extra ESD precautions should be taken. ESD precautions help to improve the relatively shorter term reliability of VCSEL devices. The long term reliability of the VCSELs on the other hand is affected mainly by the operating conditions under which the devices are used. The temperature and current, if possible, should be minimized to increase the life of the devices.

References

[1] T. Kim et al, “Degradation Behavior of 850 nm AlGaAs/GaAs Oxide VCSELs Suffered from Electrostatic Discharge,” *ETRI Journal*, Volume 30, Number 6, December 2008

[2] J. Krueger et al, “Studies of ESD-related failure patterns of Agilent oxide VCSELs,” Proc. SPIE, Volume 4994, 2003, pp. 162-172

[3] ANSI/ESD S20.20-2007

[4] Finisar Advanced Optical Components Division, ”An Atlas of ESD Failure Signatures in Vertical Cavity Surface Emitting Lasers,” *Application Note* 2004