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1 Introduction

Vertical Cavity Surface Emitting Laser (VCSEL) arrays have emerged as an important technology for applications within the consumer, industrial, automotive, and medical industries. Vixar has developed a family of high-power arrays targeting these applications. This paper introduces the application requirements for this technology, the relevant benefits of VCSEL technology, and the performance that has been demonstrated with VCSEL arrays.

VCSELs have recently made significant inroads in the consumer market (Figure 1). They have found application as proximity and ranging sensors, face identification, and 3D cameras in cell phones. 3D cameras can also enable gesture recognition in gaming systems and situational awareness for augmented and virtual reality systems. Potential future consumer applications can include home automation involving biometric identification for security or gesture recognition for controlling appliances and electronics.

In the industrial market (Figure 2), VCSEL arrays play an important role in providing 3D vision for safety sensors, motion control, and robotic applications for factory and warehouse automation. Industrial applications also consist of IR illumination for night vision in security systems. Drones for surveillance or delivery applications benefit from 3D imaging and sensing, and 3D imaging can help build CAD models beneficial for large-scale design and construction.

The benefits of 3D imaging and sensing are also recognized within the automotive market (Figure 3). The initial application of VCSELs in this market will be in the automobile interior, such as gesture recognition and driver monitoring. Exterior applications include 3D monitoring over shorter distance to avoid side collisions with other automobiles and detect the presence of pedestrians or bicyclists.
Applications are also emerging in the medical market. Visible or IR 3D imaging provides complementary information to more traditional x-ray or MRI imaging methods by revealing differences in tissue oxygenation that can reveal important information about disease states. High power arrays can also be applied in low light laser therapy applications.

The characteristics of VCSELs have enabled the transformation of 3D sensing and imaging by providing a cost-effective optical source with unique characteristics. Two main imaging mechanisms are used for 3D imaging (Figure 4). In structured lighting, a pattern is imposed upon the light source (dots, lines, etc.), and a camera is used to detect distortions in imaged pattern to estimate object depth. A time of flight scheme can also be used to resolve the third dimension by using a time gated camera to measure the roundtrip flight time of a light pulse. A variation on this approach is to modulate a light beam and measure the phase shift of the reflected light signal to estimate distance travelled.
VCSEL Technology Overview

There are 3 main types of semiconductor based light sources (Figure 5). They all require the growth of single crystal layers on a semiconductor substrate. Individual devices are created by photolithographically patterning the wafer. Light Emitting Diodes (LEDs) emit light from the top surface of the wafer and can be tested at the wafer level. Lasers require an active material that emits light and a cavity to provide feedback to achieve stimulated emission. The cavity for edge-emitting lasers (EELs) is formed by cleaving the wafer. Due to this design, light is emitted from the cleaved edge of the chip, and the laser cannot be tested before packaging. In contrast, the cavity for a VCSEL is built by growing mirrors formed by alternating layers of two different refractive indices, creating a Bragg reflector. With the light generating layers between two Bragg reflectors, a cavity is formed to produce stimulated emission that radiates from the surface of the wafer. Therefore, VCSELs can also be tested on the wafer. This reduces production costs by sorting nonfunctional die before device packaging. Furthermore, the vertical emission of the VCSEL allows the use of any kind of package available to LEDs.
The optical output of each optoelectronic device is different from one another due to these design characteristics. The spontaneous emission from the LED is Lambertian, filling a wide hemisphere with light. The stimulated emission from the VCSEL beam is circular with a much narrower emission angle. The beam angle from the edge emitting laser is elliptical due to the asymmetric nature of the optical cavity, where the angle of emission is wider in the direction normal to the die surface. While LEDs have 30-50nm spectral widths, VCSELs and EELs emit light with narrower spectral widths (1-2nm). VCSELs and EELs can also be modulated at higher speeds, typically >100X faster than LEDs. Therefore, VCSELs combine the manufacturing advantages of LEDs with the performance advantages of lasers.

The VCSEL geometry limits the amount of optical power a single VCSEL can provide. The mirrors grown on either side of the active region (Figure 6) create a laser cavity for optical confinement in the vertical direction. However, efficient operation of the device also requires current confinement in the lateral direction. This is achieved with an electrically insulating oxidation layer to force current flow through the center of the VCSEL. A metal contact on the top surface of the VCSEL provides current injection into the VCSEL. For top emitting VCSELs, the metal must have a transparent aperture to allow the light to leave the device. There is a limit to how efficiently the current can be spread across this aperture. Thus, the maximum power that can be emitted from a single aperture is limited. For applications requiring more power, multiple VCSELs are created on a single die and operate together in parallel (Figure 7). An important advantage of this solution is that the array of mutually incoherent lasers provides a low speckle illumination source that also has a narrow linewidth. The characteristics of these optoelectronic light sources are highlighted in Table 1.
**Table 1. Comparison of performance attributes of optoelectronic sources.**

<table>
<thead>
<tr>
<th></th>
<th>IRED</th>
<th>VCSEL</th>
<th>EEL (FP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optical Power</strong></td>
<td>Up to 4.5 W</td>
<td>0.1 W up to 6 W</td>
<td>Up to 120 W</td>
</tr>
<tr>
<td><strong>Beam quality</strong></td>
<td>Lambertian</td>
<td>Symmetric</td>
<td>Asymmetric</td>
</tr>
<tr>
<td></td>
<td>Very wide divergence</td>
<td>Low divergence</td>
<td>Medium Divergence</td>
</tr>
<tr>
<td><strong>Temperature stability</strong></td>
<td>0.25 nm/K</td>
<td>0.06 nm/K @ 850 nm</td>
<td>0.25 nm/K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.07 nm/K @ 940 nm</td>
<td></td>
</tr>
<tr>
<td><strong>Spectral width</strong></td>
<td>20-30 nm</td>
<td>1-2 nm</td>
<td>1.2 nm</td>
</tr>
<tr>
<td><strong>Specie</strong></td>
<td>Low</td>
<td>Low in an array</td>
<td>High</td>
</tr>
<tr>
<td><strong>Switching time</strong></td>
<td>Low speed</td>
<td>High speed</td>
<td>High speed</td>
</tr>
<tr>
<td><strong>Packaging</strong></td>
<td>Simple</td>
<td>Simple</td>
<td>Complex</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Best</td>
<td>Good</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**Figure 6. Illustration of the structure of a VCSEL.**
Figure 7. Photos of VCSEL arrays. (a) A 281 element VCSEL array with both common anode and common cathode. Wire bonds to a package are visible on the bottom side of the chip. (b) A pseudo-random array used for structured lighting. (c) An 8x8 VCSEL array where each VCSEL can be modulated independently.

3 Sensing Requirements and VCSEL Performance Attributes

3.1 Design Requirements
Some of the important requirements of the optical light source for sensing applications, including 3D sensing and imaging, include the following:

**Optical output power:** Sufficient power is required to illuminate the area of interest. The optical power can range from milliwatts for short range sensing to watts for interior imaging. Exterior vehicle applications require solutions with over 10 watts for short distance collision-avoidance systems and kilowatts for LIDAR in self-driving cars.

**Power efficiency:** A high efficiency in converting electrical to optical power is advantageous for many applications. This is particularly true for mobile consumer devices, where battery lifetime is strongly dependent on environmental sensing and illumination solutions.

**Wavelength:** For most human-interfacing applications, it is preferable that the illumination is in the infrared region, so it is unobtrusive to the human eye. On the other hand, low cost silicon photodetectors or cameras cannot efficiently detect IR wavelengths beyond 1000nm. Therefore, the most desirable wavelength range is between 800nm and 1000nm. 940nm is advantageous for outdoor applications, since H\textsubscript{2}O absorption in the atmosphere reduces solar radiation noise at this wavelength. However, some industrial applications prefer a visible (650-700nm) source for sensor alignment. Medical applications may rely on the absorption spectra of tissue at specific wavelengths.
**Spectral width and stability:** The presence of background radiation, including sunlight, can degrade the signal-to-noise ratio of a sensor or camera. This can be compensated with a spectral filter on the detector or camera. A notch filter can be implemented without a loss of efficiency when an illumination source with a narrow and stable spectrum is used.

**Modulation rate or pulse width:** For sensors based upon time of flight or a modulation phase shift, the pulse rise time of the optical source determines the spatial resolution in the third dimension. Shorter pulses are required to improve the resolution of depth sensing in time of flight applications.

**Beam divergence:** A wide variety of beam divergences or patterns might be specified, depending upon whether the sensor is targeting a focused spot or a broad area.

**Packaging:** The package provides the electrical and optical interface to the VCSEL die. It may incorporate an optical element that helps to control the beam profile or generates a structured light pattern. Particularly for mobile devices, the overall packaging should be as compact as possible.

### 3.2 VCSEL Performance Attributes and Advantages

VCSEL technology addresses the attributes required by 3D sensing and imaging, including power efficiency, a low speckle illumination source with a narrow spectral width, narrow beam divergence, and flexibility in packaging solutions.

Power conversion efficiencies (PCE) in the range of 40-50% can be achieved at wavelengths in the 800-1000nm range. VCSEL arrays have a spectral width of approximately 1-2 nm. In addition, the wavelength shift is of a VCSEL is less sensitive to temperature, increasing only 0.06nm/°C. This shift with temperature is four times less than the wavelength shift in an LED or a Fabry-Perot EEL. This allows the use of filters in photodetectors or cameras to reduce the noise associated with background solar radiation.

The angular beam divergence of a VCSEL is typically 10-25 degrees full width half maximum. The VCSEL light can be efficiently collected using optical elements including lenses for a focused beam profile, diffusers for a wide beam, or a diffractive optical element for pattern generation. Additionally, the individual VCSELs in an array are incoherent and produce a laser beam with low speckle content in comparison to a conventional high-power laser. This is a unique combination: a low speckle optical source that also has a narrow spectral width.

The vertically emitting nature of the VCSEL gives it more packaging flexibility and allows for the use of the packages available for LEDs. One can integrate multiple VCSELs on a single chip to form a high-power array and package them with photodetectors or optical elements. Plastic lead frames, ceramic surface mounts, or chips-on-board options are available to VCSELs.
4 Performance Details of OSRAM VCSEL Arrays

High power VCSEL arrays are available from OSRAM at multiple wavelengths, including 940nm, 850nm and 680nm. The key performance results are summarized below.

4.1 IR VCSELs and VCSEL Arrays

Individual VCSEL performance provides an evaluation of the fundamental VCSEL design, unaffected by thermal cross-talk with other VCSELs in an array. Figure 8 illustrates the performance of an individual VCSEL at 940nm over a solder temperature range from 20-100°C. The maximum room temperature efficiency exceeds 50% and remains above 35% over the typical operation range of 6-10mA drive current, even up to 100°C.

![Figure 8. (a) Output power and voltage plotted vs current (L-I-V plot) and over temperature, (b) Corresponding power conversion efficiency plotted vs current and over temperature.](image)

A challenge in designing a VCSEL array is to manage the thermal cross-talk between VCSELs that can reduce the device efficiency. While one can maintain the efficiency of the individual VCSELs by choosing a sufficiently large pitch, die size should be minimal while providing sufficient power in a small form factor that is cost effective. Figure 9 illustrates performance results for an optimized 3W die. The power label designation is chosen to reflect power levels at near peak efficiency over a wide temperature range. The 3W power can be achieved with approximately a 40% efficiency up to 60°C. Multiple die have been designed to achieve optimal power output ranging from 0.5W to 4W.
The performance of VCSELs and VCSEL arrays at 850nm is very similar to the performance of 940nm VCSELs. Both the output power and the power conversion efficiency are plotted as a function of current in Figure 10. The peak efficiency of 46-47% occurs in the current range of 5-10mA. Figure 11 illustrates the performance of a 2W 850nm VCSEL array operated with 100µsec pulse width and 1% duty cycle over temperature. A power conversion efficiency of 40% is achieved, and the VCSEL array is operational up to 125°C under pulsed conditions.
Another aspect of VCSEL performance is the beam profile of the light emitted from the VCSEL. Figure 12 illustrates the beam profile for two different sized VCSELS. 3D imaging for structured light applications benefit from beams that have a Gaussian-shaped profile. Figure 12 (a) shows examples of the beam intensity versus angle for a small aperture device which have a Gaussian or near-Gaussian profile. Time of Flight applications are less sensitive to the beam profile shape, though a narrow profile can improve the transmission efficiency with integrated optics. Figure 12(b) illustrates the beam profile of a larger VCSEL with a donut-shaped profile. This larger aperture VCSEL is more powerful and efficient, but the increased size excites higher transverse modes that result in a non-gaussian beam profile.

![Figure 12](image)

**Figure 12.** VCSEL beam profile (a) Beam intensity vs angle for a small aperture VCSEL, suitable for a structured lighting application, (b) Beam profile of a larger aperture VCSEL with a better efficiency for Time of Flight applications.

The spectrum also changes as the VCSEL’s aperture size increases. Figure 13(a) shows the spectrum of a small aperture device. Two spectral modes are visible, but one is more than 10X more intense than the second mode. Larger aperture VCSELS, as shown in Figure 13(b), exhibit multiple modes, with some modes having comparable intensity levels. Nevertheless, the spectral width of the device is still on the order of 1 nm. VCSELS will undergo a spectral shift with changes in temperature. 850nm VCSELS shift 0.06nm/°C, and 940 nm VCSELS will shift 0.07nm/°C. For comparison, LEDs or EELs at the same wavelength shift 0.25nm/°C. This is a major benefit for coupling light to a photodetector with a narrow filter that absorbs unwanted sunlight radiation.

For time of flight applications, the modulation speed is one of the key performance attributes of a VCSEL array. Figure 14 illustrates the pulse shape of a 940nm 2W VCSEL array pulsed with a peak current of 3A using an IC Haus HG20M driver. The measured rise time is 380psec, and the fall time is 430psec. The performance is a function of the integration between the VCSEL and driver, so results may vary with a different laser driver solution.
4.2 Red VCSELs and VCSEL Arrays

Red VCSELs (660-680nm) have a slightly different materials structure than infrared devices, and the material selection affects the performance attributes. Figure 15 is a schematic illustration of the red VCSEL structure. Both IR and red VCSELs are grown on a GaAs substrate, and the mirrors consist of different compositions of AlGaAs. The key difference is in the material composition making up the quantum well layers. Instead of AlGaAs/InGaAs, the active region for red VCSELs consists of AlGaInP. This compound is more temperature sensitive, so red VCSELs have a reduced operating temperature range. This temperature sensitivity also increases with shorter wavelengths. Thus, VCSELs with a wavelength less than 660nm are very limited in power and temperature range.
Figure 15. Schematic illustration of the structure of VCSELs in the wavelength range 660-680nm.

Figure 16 illustrates the L-I-V over temperature performance of small aperture devices ranging in wavelength from 658nm to 681nm. As the wavelength increases, the maximum power increases and is less sensitive with shifts in operating temperature.

The beam shape for small aperture VCSELs has a Gaussian-shaped profile, as shown in Figure 17(a). The angular beam divergence slightly increases as the current is increased. In Figure 17(b), the spectral characteristics of these devices show multiple modes, but the total spectral width less than 1nm.

Figure 18 illustrates the performance of 680nm VCSELs as a function of the aperture size at room temperature. Figure 18 (a) is the L-I-V of VCSELs of multiple aperture sizes, and the maximum output power increases with size. Figure 18(b) shows the power conversion efficiency for 680nm VCSELs with various aperture sizes. The peak efficiency is around 33% for aperture sizes between 6 and 14µm diameter, and the current at peak efficiency increases with larger aperture size.
Figure 17. (a) Beam divergence of a small aperture 670nm VCSEL in two orthogonal directions, and as a function of current. (b) Spectral characteristics of a small aperture VCSEL emitting light at 670nm

Figure 18. (a) L-I-V of 680nm VCSELs at room temperature as a function of aperture diameter. (b) Power conversion efficiency of the different sized VCSEL apertures at room temperature.

As for IR VCSELs, high power can also be generated from an array of red VCSELs. Figure 19(a) is a near field photo of a red VCSEL array with 110 VCSEL apertures. Figure 19(b) illustrates the performance of a larger red VCSEL array under various driving conditions. The design emits around 2.5W when driven under direct current (DC) operation and reaches 10W output power when pulsed with a 1% duty cycle and 100µsec pulse width. The power reaches 9W with 100µsec pulse widths at a 10% duty cycle. The thermal sensitivity of red VCSELs is visible when comparing wafer level test data, not optimized for heat sinking, to the data taken after die packaging, with both measured at 100µsec pulse width and 1% duty cycle. The power is noticeably higher in the packaged case due to better thermal management, demonstrating the significant impact thermal heat sinking has on VCSEL die performance.
Similar to IR VCSELs, the beam shape transforms from Gaussian to a donut-shaped profile as the red VCSEL aperture size increases. This can be seen in Figure 20(a). The beam intensity is somewhat lower in the normal direction, and the overall 1/e² full width beam divergence is approximately 20 degrees.

The polarization of red VCSELs differs from IR VCSELs. Without special measures, the polarization of an IR VCSEL is random due to the symmetric design of the circular aperture and will fluctuate over changes in operating conditions. In contrast, the polarization of red VCSEL tends to be linearly polarized and aligned with one of the cleave planes of the crystal. Figure 20(b) shows the power measured from a multi-mode red VCSEL in two orthogonal directions and the polarization stability as a function of operating current.
5 VCSEL Packaging and Integration

The packaging of higher power VCSEL arrays is also very important in delivering the desired performance for an application. Considerations include providing mechanical robustness, high thermal conductivity, and beam shaping optics. The package can also provide additional functionality, including output power monitoring or the integration of a laser driver or integrated circuit.

5.1 Package options

The vertically emitting nature of the VCSEL can take advantage of surface mount packaging that has been developed for LEDs. Figure 21 illustrates some options that have been developed for VCSEL array packaging. A photo of an array packaged in a Plastic Leaded Chip Carrier (PLCC) package is shown in Figure 21(a). After die attach and wire bonding, the die is protected with an optically clear encapsulant. A thick lead frame pad of copper is used for electrical contacts and thermal heat sinking. Figure 21(b) illustrates a custom plastic QFN package with a thick metal pad. However, an optical window is attached to a top surface of the package. This window may consist of a micro-lens array (MLA) or a diffuser for beam shaping. Figure 21(c) illustrates a ceramic package solution with an engineered diffuser. An AlN submount with patterned two-sided metal and metallized vias forms the base for superior thermal performance. A ceramic frame forms the side walls and allows the attachment of integrated optics.

![Figure 21. Array packaging approaches for illumination and Time of Flight imaging. (a) PLCC, (b) QFN incorporating an optical element, (c) AlN ceramic submount with ceramic frame and engineered diffuser.](image)

Additional solutions for VCSEL array packaging are illustrated in Figure 22. Figure 22(a) contains a circuit board incorporating a linear array of VCSEL die mounted directly on the PCB with the circuitry for controlling individual VCSEL die. This is a solution for a solid-state laser scanner with no moving parts. Figure 22(b) shows a package developed for an 8x8 VCSEL array with individual addressability control for each aperture. The VCSEL die is mounted on an AlN submount, placed and wire bonded to a ceramic lead frame package, and protected with a glass window. Figure 22(c) is an image of a ceramic package developed for an array of VCSEL die, providing >100W of total peak power.
5.2 Incorporation of Optics into a VCSEL Array Package

The ability to incorporate optics to control the output beam profile is an important aspects of packaging VCSELs. Optics allow the user to focus the beam using a lens, expand and homogenize the beam with a diffuser, or create an array of spots from a holographic grating. Figure 23 shows how the VCSEL beam can be shaped with a diffuser. Figure 23(a) contains a plot of beam intensity versus angle without an additional optics. The donut-shaped beam profile with multi-mode VCSELs is clearly observed. In Figure 23(b), the VCSEL output beam is transformed into a homogenized, wide beam using a diffuser.

Diffusers can be engineered to provide a very specific field of view. Figure 24 illustrates the beam profile that results after transmission through a diffuser designed to achieve a rectangular field of view that is 45° in one direction and 60° in the perpendicular direction. The divergence angle is defined as the full width half max angle where the intensity has dropped by 50% from the normal intensity. Far-field intensity profiles in Figure 24 (a) are projected onto a flat surface to measure flat field illumination. Figure 24(b) is a projection photo showing how the profile has been transformed from the circular, donut-shaped VCSEL profile to a rectangular field of view.
5.3 Adding Additional Functionality to the VCSEL Array Packaging

Packages can incorporate additional functionality such as a laser driver or a photodetector. OSRAM has incorporated photodetectors into both ceramic and QFN packages. The photodetector can be used to monitor the output power of the VCSEL array to help keep it within specified operating parameters. It can also be used to detect diffuser damage or loss. Figure 25 (a) illustrates the incorporation of a photodiode inside a ceramic package. Figure 25(b) is a plot of the measured photodiode current vs. the VCSEL operating current under 3 different conditions. The purple line is the measured photodiode current with the diffuser attached to the package. While most of the light from the VCSELs is transmitted through the diffuser, a small percentage is scattered back into the package. Some of that scattered light is detected by the photodiode. The green line is the low signal power detected with no diffuser on the package due to the presence of ambient light. The orange light shows the impact of a melted or absent diffuser layer on a glass window. The VCSEL light scattered from a glass window is reduced, and the signal reaching the photodiode is significantly lower compared to the condition with a functional diffuser. One can therefore improve eye safety conditions by monitoring the signal of the photodetector and looking for significant changes in output power. If an anomaly is detected, the device can be programmed to disable the VCSEL and prevent direct eye exposure to the laser beam.
Figure 25. (a) A picture of the inside of the package shown in Figure 21(c). Both the VCSEL die and photodiode are visible. (b) The photodiode signal as a function of VCSEL drive current for the normal case with the diffuser in place, for the case with no diffuser, and for glass only, simulating the melting or removal of the diffuser layer.

It is important for the monitor photodiode signal to be consistent over various environmental conditions to ensure eye safety. Figure 26 illustrates the characterization of the photodiode in the package with the diffuser at various temperatures. The photodetector current increases linearly with VCSEL output power. The signal is also consistent over operating temperature.

Figure 26. (a) Photodiode signal vs. VCSEL power over temperature. (b) Effective photodiode responsivity as a function of temperature.
6 Overview of Products and Sample Availability

This paper has described many of the performance attributes of VCSEL arrays as well as different packaging solutions. OSRAM has a portfolio of standard VCSEL array products but has the capability to develop custom products.

OSRAM offers standard VCSEL die at various power ranges. IR VCSELs (850nm and 940nm) die are available at power levels varying from 0.5W to 4W, with die details shown in Figure 27. In addition, standard 3 aperture die (0.22 x 0.22 x 0.1 mm) are available at 680nm, 850nm, and 940 nm for applications requiring a compact VCSEL illumination source.

Standard packaging for VCSEL power arrays at OSRAM includes PLCC and ceramic packages. Both can be filled with a transparent encapsulant to protect the die and wire bonds. Alternatively, the ceramic package can be covered with a glass window patterned with an optical diffuser designed to disperse the laser beam at specific field of views. Ceramic packages with 4 leads are also available to incorporate a photodiode for VCSEL monitoring. A summary of standard VCSEL packaging options is shown in Table 2.

Table 2. Standard packaging options for OSRAM’s VCSEL power array die.

<table>
<thead>
<tr>
<th>Package Size</th>
<th>VCSEL Power Arrays</th>
<th>Package Options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5W</td>
<td>1W</td>
</tr>
<tr>
<td>PLCC2 2835</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PLCC2 5052</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>C 2023 2L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>C 2034 4L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>C 2835 2L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>C 2835 4L</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 27. Die characteristics for OSRAM’s standard VCSEL Power Array
OSRAM can supply samples of both VCSEL die and packaged solutions on a test PCB for device evaluation. Test boards are copper based insulated metal substrates designed with pillar technology to maximize the thermal heat flow from the VCSEL die or package. Test boards can be connected to thermoelectric controllers to accurately determine device performance over operating temperatures. Test boards will add to the parasitic capacitance to the system and are not recommended in evaluating VCSEL performance at short (<10 μs) pulse widths. An example test PCB is shown in Figure 28.

Detailed data sheets for standard products can be found online at www.vixarinc.com. Please contact sales@vixarinc.com for more details on sample orders, pricing, and availability.