High Peak Power VCSELs in Short Range LIDAR Applications

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A technique for short-range LIDAR that monitors high-peak-power pulses rather than uniform square pulses is demonstrated using a commercially available Optek OPV310 VCSEL with a 10µm aperture operating at a wavelength of 850nm for applications in LIDAR-based active defense systems. Using 10ns pulses at a 0.1% duty cycle and 60mW of peak power, a target one meter away exhibiting Lambertian reflectance was detected with a 3:1 minimum signal-to-noise ratio in a narrow-field LIDAR setup using a 28dB amplifier. At 0.75m, using the same target and no signal amplification, a 2:1 minimum signal to noise ratio was achieved in a wide-field setup. These results establish the viability of commercially available low power VCSEL devices for LIDAR.

Many current applications of LIDAR involve simple range-finding for imaging[1]; however, short-range LIDAR systems for countermeasure deployment are not well developed. A system used for detection of fast-moving projectiles, such as those from improvised explosive devices (IEDs) and explosive formed penetrators (EFPs) must be able to detect and track targets at short ranges (about one meter) and successfully deploy countermeasures. By optimizing the electrical circuitry, the output power of a VCSEL can be enhanced[2,3], for use in wide-field LIDAR, which relies on the divergence of light from a point source to detect over a wide area. The wide-field method is preferred over concentrating the light with optics for the narrow-field because the latter method is incapable of detecting any projectiles whose paths do not cross through the beam; thus, a narrow-field LIDAR system is fundamentally flawed for projectile detection. Furthermore, commercially available VCSELs are not typically suitable for short-range detection, as many are low power output devices that are designed for use in fiber optics or other applications with low losses, whereas LIDAR is a high loss application[1]. Since the number of photons that a laser device is able to emit in a short amount of time is limited[4,5], and because only a low percentage of photons that are emitted reflect back to the detector, enhancing the capability of a LIDAR system involves increasing the maximum output of the laser and/or the detector sensitivity and responsiveness.

VCSELs heat up through extended operation if stressed beyond their design capabilities, eventually resulting in lowered conversion efficiency[6]. However, using pulses with pulse widths closer to the thermal time (around ten nanoseconds) can significantly reduce this effect by reducing the accumulation of heat at the device junction level. Furthermore, a lower duty cycle can account for dissipation of any accrued thermal energy[4]. In doing so, it is possible to put much more energy into the device than the design would otherwise allow under CW conditions. By reducing pulse width and duty cycle, the peak output power can be increased (see Fig. 1). Alongside these higher output powers, a larger, focused beam spot was implemented in the LIDAR test to determine the basic parameters required to later optimize a VCSEL for wide-field detection.

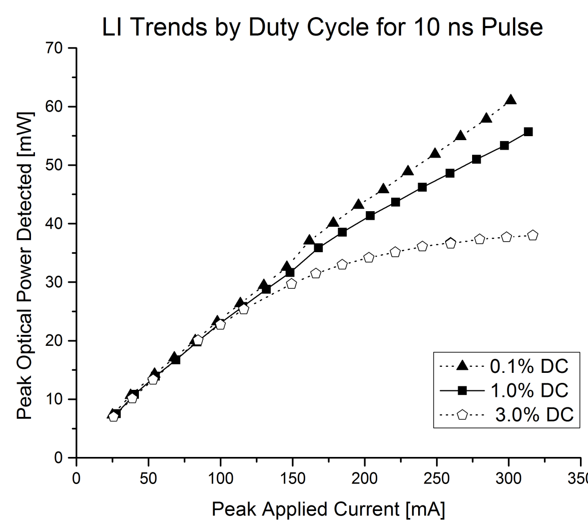

Figure 1. LI chart of OPV310 peak output power vs peak input current.

Parasitics within the electrical circuit network amounted to increased electrical impedance, which distorted the input signals[5]. Additional impedance was introduced by a number of factors including the packaging of the VCSELs, the coaxial connections between devices, and the fact that the impedance of the system varied for different pulse repetition rates[4]. A rectifier diode was employed to limit the negative reflected current pulses from the impedance mismatch before these reflected pulses could sink into the device and cause failure due to high reverse bias. The use of the rectifier diode thereby increased the performance of the VCSEL and alleviated the need for strict impedance matching by preventing pulses with inverted voltage from entering the devices.

An Optek OPV310 VCSEL was used for this procedure with a Thorlabs DET210 photodiode for detection and optical power measurement. The OPV310 VCSEL emits at 850 nm with a 24-degree divergence angle and has a maximum output of 1.5 mW under CW conditions[7]. The DET210 is a 1 GHz, 0.8-mm^2 silicon-PIN photodiode with a spectral response from 200 to 1100 nm [8]. The small aperture of the photodiode required the use of a 6 cm diameter double-convex lens to focus the reflected light into the detector. Before each test, the detector and lens positions were optimized for maximum signal detection. For a pulse width of 10 ns, three different duty cycles were investigated to find the peak performance without thermal rollover. At a duty cycle of 3%, this thermal rollover was noticeable as the output power leveled off with increasing current, while a 0.1% duty cycle showed a nearly linear increase (see Fig. 1). The maximum peak output power attained was 61mW with a duty cycle of 0.1%, while the maximum peak output powers of the 1% and 3% duty cycles were 55mW and 38mW, respectively. It should be noted that higher powers may be possible on this device at the 0.1% duty cycle, but the Agilent 8104AA pulse generator used was limited to a 10.5-volt maximum output.

With the setup configured for wide-field detection and the target distance set at 0.75±0.03 m, the system was able to detect a Lambertian block with a 0.05 m by 0.05 m surface facing the device when the laser was operated at the maximum power output. The property of Lambertian reflectance on the surface of this block ensures isotropic scattering from incident light on the block. The results obtained using the Lambertian target were similar to those from a block of aluminum and from a block of copper when each was oriented to reflect light away from the detector. (see Fig. 2) The signal-to-noise ratios in the configuration with each the Lambertian block and the off-angle copper were approximately 2:1. (see Fig. 2) The DET210 photodiode has a broad spectral response[8], and during testing was shown to respond better to the laser light when room lighting was deactivated. Therefore, the use of a filter to isolate the narrow spectrum of the OPV310 could increase the detected optical power and, in turn, would increase the resolution of the system further. Additionally, currently available Geiger-mode avalanche photodiodes would be more likely to respond to a lower number of photons than what was returned in the 0.75 m test, and thusly, may realize the goal of 1 m detection with the OPV310 at the utilized output power[9]. Therefore, the number of photons incident on the block at this reduced range was sufficient for this LIDAR demonstration. The maximum output power was not great enough to do wide-field LIDAR at a range greater than 0.75 m. However, it was possible to focus the beam spot to approximately 2 cm in diameter on a target area at a one-meter range with a plano-convex lens located at the laser aperture. With the Lambertian block placed at a target range of 1.00±0.03 m, a calculated distance of 0.996±0.047 m was obtained. (see Table 1)

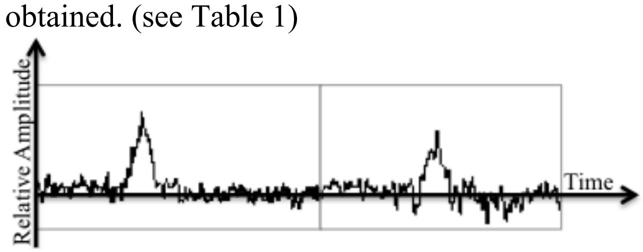

Figure 2. Detector response for wide-field LIDAR at 0.75 m. Left image shows the response from the Lambertian block, the right shows the response for a flat copper block angled 45 degrees from the detector.

Actual Range (cm±3cm)	Calculated Range (cm)
90	90.9 ± 3.6
100	99.6 ± 4.7
110	110.1 ± 5.9
120	119.4 ± 3.4
130	130.5 ± 3.1
140	140.8 ± 4.8

Table 1. LIDAR measurements for select ranges.

A ZFL-1000H 28dB amplifier was used in order to find the minimum output power of the VCSEL necessary to produce a reliable signal for the narrow-field arrangement. The amplifier was applied to the output from the photodetector in conjunction with noise modeling and filtering. The minimum triggering signal was found when the VCSEL output power was reduced to 30mW, with a signal to noise ratio of about 2:1. When using the maximum achieved output of the VCSEL in the narrow-field setup, the signal-to-noise ratio was no less than 3:1. (see Fig. 3) Given the peak output power limitations of commercial VCSELs, even under pulse conditions, detecting projectiles in a wide-field of view at a one-meter distance would require increasing either the output power of the device or the detector sensitivity further.

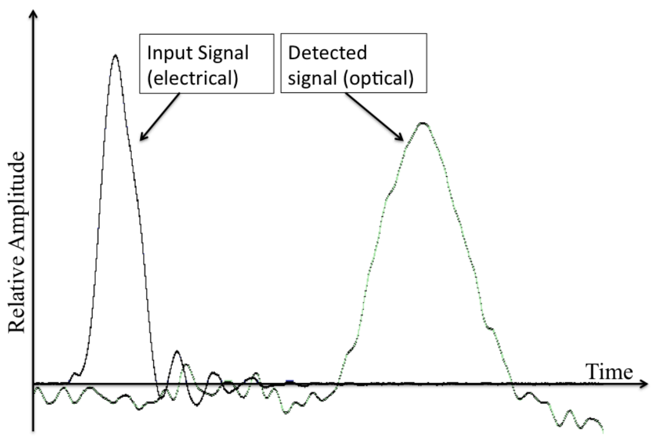

Figure 3. Sample LIDAR capture. The thinner pulse on the left side is the input current pulse to the VCSEL. The wider pulse on the right is the light returned to the detector. This image is from the 1m narrow-field LIDAR test, with the peak-to-peak delay corresponding to the calculated distance. Note that the amplitudes of the two waves are not scaled identically.

Further investigation is necessary to determine whether carrier saturation in the cavity of the VCSEL has been achieved for the 0.1% duty cycle, and also whether the duty cycle could be further refined in the 0.1% to 1% range while maintaining similar output levels. For the application of projectile detection from explosive or shaped charges, a typical speed of 2 km/s [10] would be possible for detection ranges under one meter, as the target would not scale a large distance between pulses. However, for the maximum recorded shaped charge projectile speed on the order of 12 km/s [10], the distance scaled between pulses could be too great for effective detection and velocity measurement of a target at the optimum pulse width and duty cycle of this system. It may be possible to repeat this exercise with multiple devices and a form of time-division multiplexing to enhance the effective pulse repetition frequency (PRF) of the system while maintaining the same output power. With a higher PRF, the time between pulses would be decreased, allowing for accurate measurements to be taken of higher speed projectiles.

While commercial VCSELs are not typically suitable for wide-field LIDAR, it was possible to use one as a demonstration platform for pulse amplitude optimization and LIDAR testing. This VCSEL was able to output a maximum peak power of 61mW at a 10-nanosecond pulse width and 0.1% duty cycle with the use of a rectifier diode. Additionally, this power was sufficient to demonstrate effectiveness for narrow-field LIDAR scenarios, and should be applicable to wide-field LIDAR for capable devices. Efforts are underway to design and produce wavelength beam combining for custom-built large arrays of single mode VCSELs to provide more power under pulse conditions and to cover a wider field of view in short-range LIDAR applications. In addition, more sensitive detectors than the DET210 photodiode could further enhance the signal to noise ratio.

Acknowledgements

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