VCSEL Swept Source

USING FAST WAVELENGTH TUNABLE LASERS IT IS POSSIBLE TO DO 3D OPTICAL IMAGING WITH DOWN TO MICROMETER ACCURACY AND UP TO HUNDREDS OF METERS RANGE AT KHZ-MHZ LINE-SCAN RATES. THIS IS ESPECIALLY USEFUL FOR NON-INVASIVE MEDICAL IMAGING, BUT EXPANDS TO SEVERAL OTHER APPLICATION SUCH AS INDUSTRIAL IMAGING AND LIDAR

Lasers are becoming ubiquitous in our daily lives from optical communications to laser material processing. Compared to most lasers a wavelength tunable laser differs in that the tuneability of the wavelength is a desired and controlled effect.

OCTLIGHT specializes in VCSEL Swept Sources based on patented wavelength tunable laser technology[1].

- Our VCSEL laser technology enables full 3D imaging, surface and subsurface, in real time
- Our products are used as OCT Swept Sources for ophthalmology applications

Optical Coherence Tomography (OCT) is a non-invasive imaging technique that provides a view inside objects and tissue. The basic principle and advantages of coherent detection behind OCT finds applications in several application areas besides ophthalmic imaging such as Metrology and 3D Vision for autonomous systems. Coherent detection is also the principle behind from Optical Frequency Domain Reflectometry (OFDR) and Frequency Modulated Continuous Wave (FMCW) see Figure 1.

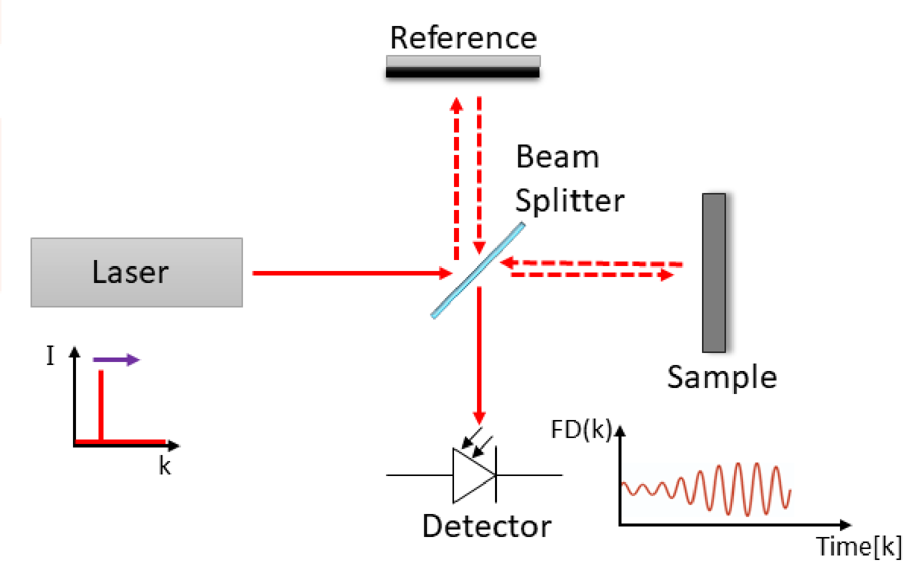

Figure 1 Sketch of coherent detection. A wavelength tunable laser is split to a reference and the sample/scene which combines again and its detected with a photodetector, acquired by a digitizer and by Fast Fourier Transform gives the distances (+ velocity)

TYPES OF WAVELENGTH TUNABLE LIGHT SOURCES

The technology of swept sources can be implemented by mainly four types of wavelength tunable lasers[2]:

- External Cavity Lasers (ECL)
- Fourier Domain Mode-Locked (FDML)
- Segmented-Grating Distributed Bragg Reflector (SG-DBR)
- Vertical Cavity Surface-Emitting Laser (VCSEL)

ECLs is a well-established technology based on an optical gain chip and external mirror. ECLS has an inherent limitation on the scan rate due to the long cavity length. Lasing is built from spontaneous emission as the wavelength is swept which cause a decrease in the imaging range (coherence length) as the scan rates increases limiting the sweep rate to around 400 kHz. Short-cavity ECLs can also exhibit periodic pulse trains that generates ghost images from surfaces such as focusing lenses through coherence revival.

FDML technology is a highly versatile technology where a wavelength tunable filter is synchronized to the round-trip time of a laser ring cavity. The dynamics of the FDML is very complex and require advanced polarization control, chromatics dispersion and active stabilization of the center wavelength. With this up to 3.2 MHz SS-OCT imaging has been demonstrated ant the FMDL is a very versatile and high-performance device for R&D.

SG-DBR was originally developed for static tuning in telecommunication. This semiconductor technology has no moving parts and instead the speed is limited by thermal effects. Delicate control of carrier-injection allow wavelength sweep to be programmed and continuous micro-sweep of 0.5 nm can be stitched to achieve high resolution up to 400 kHz. Post-process OCT data analysis is needed to address the non-continuous wavelength sweep inherent to this technology.

VCSEL is a semiconductor technology which is unique in its short optical cavity which results in a narrow linewidth and long coherence length. Together with the MEMS system this enables very rapid adiabatic wavelength tuning up to several tens MHz. Hence to increase the imaging range and rate in 3D imaging the VCSEL technology is in many cases an advantageous choice.

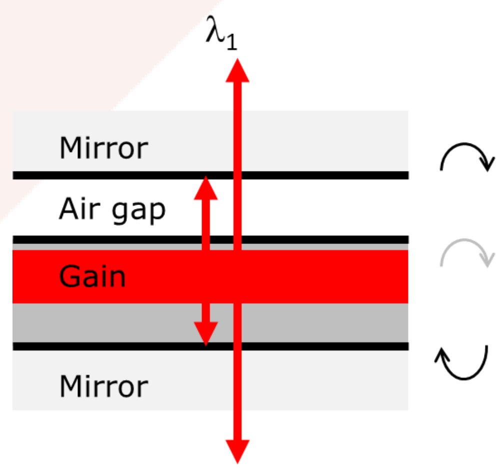

Figure 2 Sketch of MEMS-VCSEL with substrate mirror, gain region, air gap and top mirror.

ADVANTAGES OF VCSEL TECHNOLOGY

- The superior optical coherence length of VCSEL technology permits a disruptive increase in imaging range
- The VCSEL enable rapid tuning range (MHz) due to a smaller beam waist and smaller mechanical mirror size.
- The electrically pumped VCSEL allow easier wafer-scale testing and a simpler, smaller form-factor component.

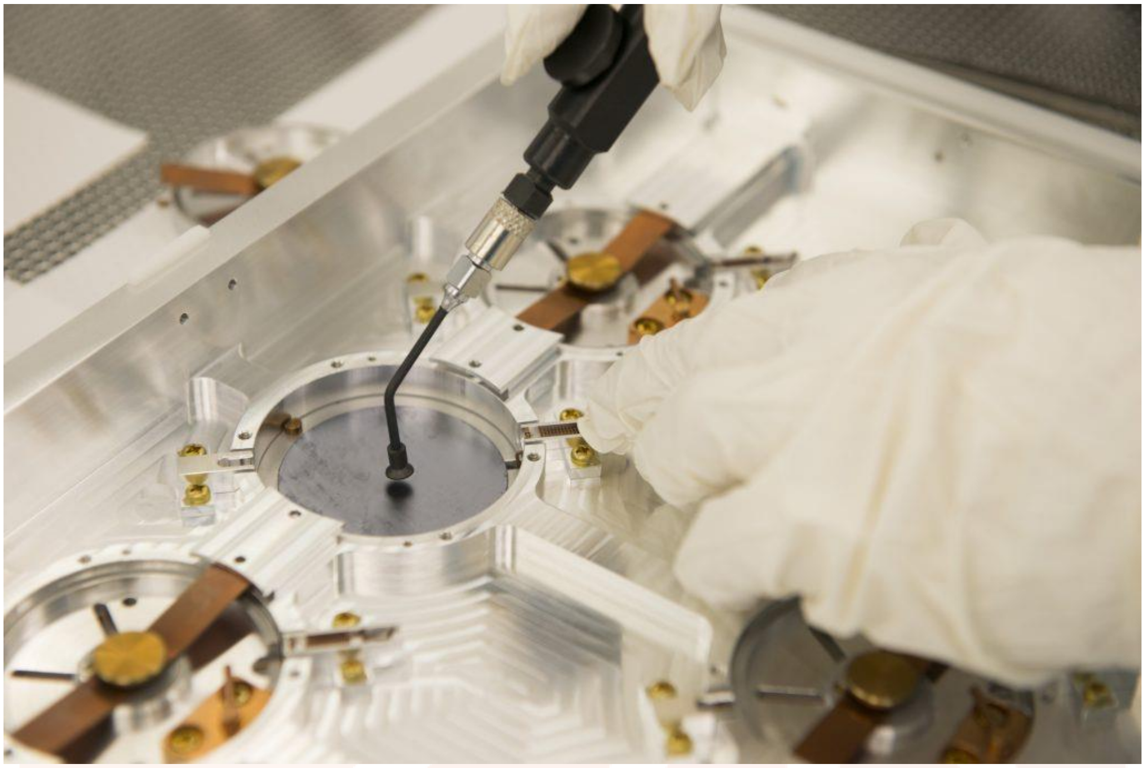

Figure 3 MEMS-VCSEL are fabricated using seminconductor technology which achieves very high precision and scalability through batch processing and wafer-level testing

UNIQUE FEATURE AND BENEFIT OF OCTLIGHT TECHNOLOGY

The OCTLIGHT VCSEL Swept Source is unique in using monolithic MEMS-VCSELs like 9xx nm datacom VCSELs and a single material MEMS system like proven MEMS timing solutions. The Caliper VCSEL Swept Source is a complete subsystem which includes efficient optical coupling and amplification of the VCSEL together with wavelength sweeping of the MEMS using low voltages.

For applications where a flexible scan rate is desired, such as to switch between several scan modes, we offer the Swept Source Caliper-FLEX.

For applications where a fixed scan rate is needed, we offer the Swept Source Caliper-HERO. The patented Highly Efficient Resonant Oscillator (HERO™) technology achieves fast scan rates into the MHz range by operating the MEMS in vacuum with a simple and low-voltage drive signal. This provides several benefits including:

- High phase stability
- Long-term stable wavelength sweep
- Symmetric bi-directional sweep
- High reliability due to the absence of MEMS catastrophic failure

The long-term stability makes efficient high throughput data acquisition possible using a single-channel DAQ with pre-calibrated FFT linearization.

MEMS VCSEL

What Is a MEMS VCSEL and How Does It Work?

The OCTLIGHT VCSEL Swept Source is based on a semiconductor laser diode with an integrated wavelength sweeping mechanism (moving the top mirror of Figure 2). The laser diode is a Vertical-Cavity Surface-Emitting Laser (VCSEL) that has single-mode light emission and long coherence length. The wavelength sweep is implemented using a Micro-Electro-Mechanical System (MEMS) to change the length of the laser cavity by which a stable and rapid wavelength sweep results.

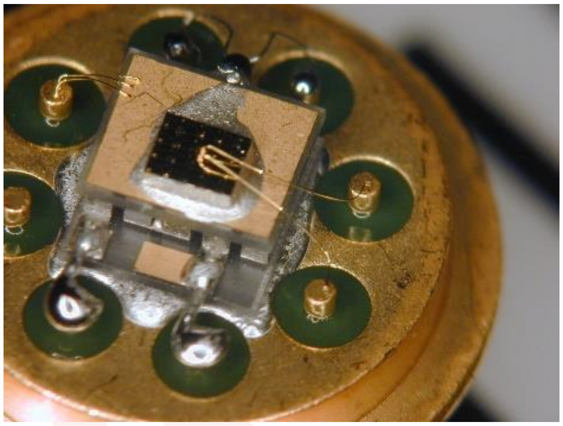

Figure 4 VCSELs are packaged on standard transistor outlines headers (TO) as in the picture or integrated with other optical components in butterfly (BTF) packages or Photonics Integrated Circuits (PICs)

Due to their high reliability and unique Gaussian beam profile 8xx-9xx nm VCSELs have become a cornerstone in datacom using active optical cables (AOC) for cloud computing and now also in 3D imaging using time-of-flight (ToF) and VCSEL arrays for smartphones and automotive. LiDAR is the latest application area where VCSELs are being deployed for both ToF and Frequency-Modulated Continuous Wave (FMCW).

What Is the Reliability of a MEMS VCSEL?

Before the introduction of Texas Instruments Digital Micromirror Devices (DMD) MEMS was seen as a technology with potential reliability issues due to the micro-mechanical moving element, but since then the often-superior reliability has been proven in numerous applications from the DMD to MEMS timing solutions where billions of units have been shipped with failure rates less than 1 defective parts per million (DPPM). MEMS has been widely commercialized within both automotive and consumer applications especially driven by pressure sensors and inertial measurement units (IMUs).

Reliability of VCSEL and MEMS has been extensively investigated and operating lifetime of 10,000 to 100,000 hours have been demonstrated for commercial products. The VCSEL technology further has the advantages of wafer-scale testing which reduces packaging cost while ensuring high quality.

What Form Factors of VCSEL Technology Are Required?

Depending on the final application different form factors may be required. The VCSEL is uniquely positioned to be integrated from highly miniaturized Photonic Integrated Circuits (PIC) to sophisticated optical fiber or free-space instruments.

Optical systems can be made with free-space optics or fiber optics for devices for small to medium volume applications where size constraints are relaxed. The VCSEL can easily be packed in a TO package for free space and pigtailed for fiber delivery which forms the basis of the optical integration in the VCSEL Swept Source. Light sources with fiber output are easy to work with and integrate in any optical system. The VCSEL Swept Source from OCTLIGHT comes with a single-mode fiber and interface to contact to any optical imaging system.

Recently there has been a rapid development in Photonics Integrated Circuits which offers the possibility to integrate optical functionality known from optical fiber and free-space system into a single chip. This is advantageous for large volume applications where size is a constraint. The small VCSEL chip area of 250x250 um and surface-emission makes it possible to integrate using direct transfer technology to PICs with efficient optical coupling to surface gratings.

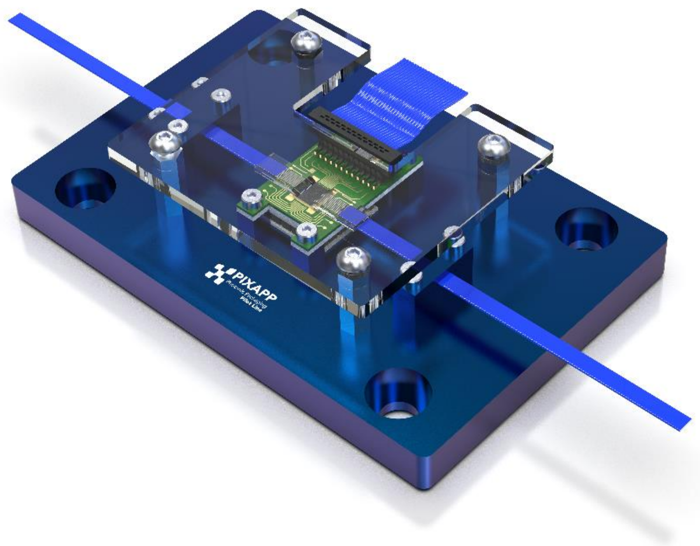

Figure 5 Photonic Integrated Circuits (PIC) allow miniturization of optical system and VCSELs can be integrated directly with PICs

PHOTONIC INTEGRATED CIRCUITS (PICS)

PIC is an emerging photonics technology that allows for extreme miniaturization of optical systems. The technology has recently matured to a level where it is a key part in the rapid increase of the internet bandwidth.
The matured ecosystems makes available multi-wafer-projects for prototyping new designs and foundries are ready to take over the commercialization of design.
Initiatives such as the Photonic Packaging Pilot Line (PIXAPP) and the Pilot Line in Photonics (PIX4life) offer services to get your R&D started
https://pixapp.eu/packaging-solutions/
https://pix4life.eu/

FURTHER INFORMATION

In this whitepaper on VCSEL Swept Source technology key concept within coherent detection, wavelength tunable light sources and optical integration has been introduced.

VCSELs is a key enabling technology that has driven significant advances in applications such as datacom, consumer electronics (optical mice) and LiDAR due to their scalability and high performance. MEMS-VCSEL enable new applications using coherent detections to achieve high resolution and long range imaging.

We hope you have found this whitepaper useful. . For additional questions, quote on the VCSEL Swept Source or support in your application you can contact us at sales@octlight.com or +45 53862737.

REFERENCES

[1] T. Ansbæk, I. Chung, E. Semenova, O. Hansen, and K. Yvind, “Resonant MEMS Tunable VCSEL,” *Sel. Top. Quantum Electron. IEEE*, 2013.

[2] T. Klein and R. Huber, “High-speed OCT light sources and systems [Invited],” *Biomed. Opt. Express*, vol. 8, no. 2, p. 828, Feb. 2017.