

Array of MEMS Tunable VCSEL for Multiple Wavelengths

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Abstract: We design vertical cavity surface emitting laser (VCSEL) arrays emitting multiple wavelength. We present optical techniques based on a fully integrated sensor as a building block for bio-sensing and bio-imaging. VCSEL device basic properties and nearly all applicable cavity design rules are introduced. VCSELS emit a circular and uniform beam, perpendicular to the top surface which can greatly reduce the complexity and cost. Other advantages include a narrow and stable emission of light spectrum and good reliability. We can design the sensor to operate at a desired wavelength within the near infrared (IR) to provide low tissue absorption and low bio-molecular auto fluorescence. Consequently, we can achieve deep tissue penetration and low background emission levels for improved sensitivity.

Keywords: Micro electro-mechanical system, vertical cavity surface emitting laser (VCSEL), PIN diode, laser diode, VCSEL array, laser simulation.

I. Introduction

VCSEL stands for vertical cavity surface emitting laser. VCSEL technology has historically provided the most cost effective optical link solution for high bandwidth applications and proven in recent years by their rapid adoption over edge-emitting lasers in the data communications market. The significant cost reduction afforded by the 1.3 micron VCSELS will make increased bandwidth more accessible and cost effective for the telecommunications and Internet infrastructure. Vertical cavity surface emitting lasers are being developed towards higher speed; higher operating temperature and higher efficiency to satisfy demands for higher interconnect capacity, higher interconnect density, and reduced power consumption in e.g. data centers and high performance computing systems. Optical injection locking is proposed as a solution to these problems. It enhances the intrinsic component bandwidth and reduces frequency chirp considerably.

Optical techniques are widely used in clinical and biomedical laboratories. All these techniques include the study of fluorescence, bioluminescence, absorption, and scattering to determine changes in bio-molecular interactions. Optical techniques have been useful in exploring many phenomena in biological tissues, ranging from nm-scale molecular interactions to whole body studies in small animals and in vivo diagnostics in humans. The ability to observe biological changes over many orders of magnitude in time and space has led many researchers to seek new techniques and uses for optical sensing and imaging in biomedicine. Advances in microelectronics and optoelectronics fabrication techniques allow miniaturization of optical imaging and scanning systems and tailored light sources and detectors. Robust fabrication techniques in Silicon and Gallium Arsenide devices are increasingly used to create many semiconductor based lasers, detectors, and waveguides optimized for biomedical applications. Solutions for optical biomedical systems featuring two or more of the components integrated into a functional sub unit enjoy several advantages over bulk optical systems. This gives us the tremendous reduction in size, power, and cost of an integrated system.

It is possible to have embedded optical sources in MEMS technology. Optical sensor will have direct access to biomedical appliances, by the way of the structure like VCSEL Semiconductor Laser. In our project, we wish to use VCSELS to release the optical signal in the band of 600nm to 1100nm for the prediction of parameters in biomedical field and other as well.

The first VCSEL was proposed in 1979 by Soda, Iga, Kitahara and Suematsu, but practically devices for CW operation at room temperature were not reported until 1988. The first semiconductor VCSEL was invented by Axel Scherer and Jack Jewell, two scientists at the AT and T Bell Laboratories. Today, VCSELS have replaced edge-emitting lasers in applications for short-range fiber optic communication such as Gigabit Ethernet and Fiber Channel.

Micro-Electro-Mechanical System is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro fabrication technology. Micro-electromechanical systems (MEMS) are a process technology used to create tiny integrated devices or systems that combine

mechanical and electrical components. Simple VCSEL consumes more power as compared to MEMS VCSEL. We required smaller wavelength in the range of nm which a very less hence we used MEMS VCSEL.

This paper is intended to provide the basic knowledge necessary to understand VCSELs' benefits and limitations and at the same time to give an overview of some state-of-the-art performance data obtained experimentally. We start with basic studies of the laser cavity, such as active region and reflector properties, where essential differences to edge-emitting laser operation are underlined.

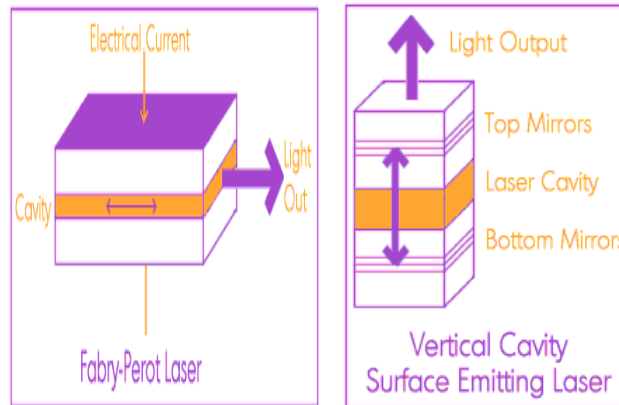


Figure 1: Edge Emitting Diode Vs VCSEL

VCSEL: Lasers that emit light from top surface In contrast with regular 'edge emitters'

Early laser diodes are called edge emitting lasers. The emission of edge emitting lasers is parallel to the boundary of the semiconductor. The edge emitting lasers emit light beam from cleaved edge of the laser. On the other hand, vertical cavity surface emitting laser emits beam perpendicular to the top surface. Emission is carried out from the vertical cavity of the semiconductor laser in case of vertical cavity Surface emitting laser. It is very difficult to integrate edge emitting lasers in large numbers. As compared to edge emitting lasers vertical cavity surface emitting lasers are easily integrated in large numbers on the same substrate.

II. Device Methods And Materials

1. Device Structure

A typical VCSEL consists of two oppositely doped distributed Bragg reflectors with a cavity layer between. DBR is the distributed Bragg reflector used because of their high reflectivity. To design VCSEL structure we require high reflectivity material hence we used distributed Bragg reflectors In the VCSEL stack of the materials are placed in between upper and lower DBRs. Upper and lower distributed Bragg reflectors are oppositely doped which forms an active region in between them. Current is injected into the active region of the structure. As the entire cavity can be grown with one step epitaxial, these lasers can be manufactured after that test on a wafer scale. This presents a significant manufacturing advantage in various fields. The position of the layers and the thickness variation with respect to the center of the cavity is crucial for the resulting wavelength variation; the closer they are to the cavity center, the larger is the wavelength change. This property lends to designs of wavelength-tunable VCSEL and multiple wavelengths VCSEL arrays.

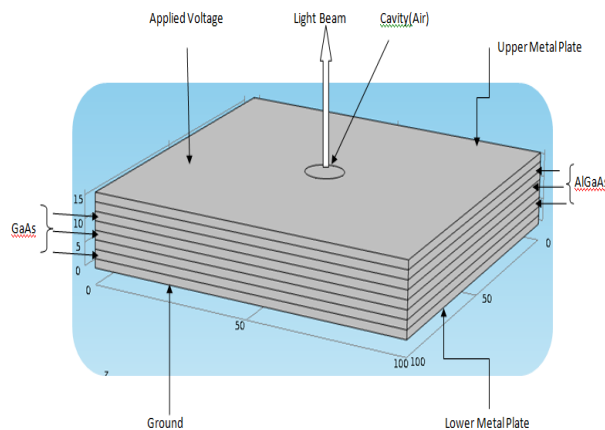


Figure 2: Structure of VCSEL

The project structure is exactly alike above diagram. Total eight blocks are placed over one another out of which first and eighth block are the upper and lower metal, middle six blocks are stack of GaAs and AlGaAs material. In the upper metal the cavity is formed at the center. The voltage is applied to the upper metal and ground is connected to the lower metal. Complete action is formed with epitaxial layers and light beam is emitted from the top surface. The device works like a conventional diode.

2. Materials

To demonstrate VCSEL we use the materials like GaAs, Al_{0.3}Ga_{0.7}As, Al_{0.1}Ga_{0.9}As and AlAs. These materials having different thickness, width and height for building a VCSEL structure. All these materials having different refractive index. According to thickness and refractive index of the particular material tens of thousands of VCSELs can be processed simultaneously on a three inch Gallium Arsenide wafer. We have to keep alternate layers of GaAs and AlGaAs to form a proper stack through which current can be injected. Once voltage is applied to the upper plate of the laser it acts like a semiconductor diode whose working principle is similar to that of the photodiode. Which forms a capacitive effect of charged and discharged plates of the capacitors. By applying supply to the upper plate it get charged very soon until and unless other plate will be charged (bottom plate). This action is same as the charged store capacitor. Means we can say that at a certain condition our VCSEL behaves like capacitor.

Material	Thickness(um)	Refractive Index
GaAs	0.2	3.6
Al _{0.3} Ga _{0.7} As	0.3	3.5
Al _{0.1} Ga _{0.9} As	0.3	3.5
AlAs	0.25	3.2

Figure 3: Table shows Refractive Index and Thickness of the Materials

3. Working Operation

The working operation of the VCSEL device is very similar to the PIN diode. Basically PIN diode is formed by sandwiching intrinsic semiconductor material in between p-type and n-type semiconductor. In original Structure of VCSEL two oppositely doped distributed Bragg reflectors mounted on top and bottom of the device structure. The oppositely charged particles are attracted towards each other which forms photon current. Once by giving activation to the conductive plate of the device, it forms an active region.

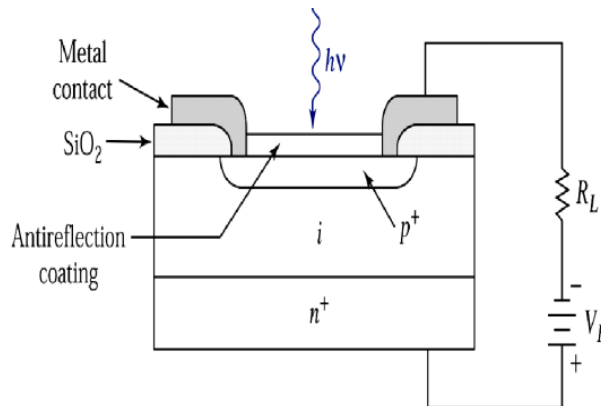


Figure 4: VCSEL circuit diagram

A PIN diode obeys the standard diode equation for low frequency signals. At higher frequencies, the diode looks like an almost perfect (very linear, even for large signals) resistor. There is a lot of stored charge in the intrinsic region. At low frequencies, the charge can be removed and the diode turns off. At higher frequencies, there is not enough time to remove the charge, so the diode never turns off. The PIN diode has a poor reverse recovery time.

The high-frequency resistance is inversely proportional to the DC bias current through the diode. A PIN diode, suitably biased, therefore acts as a variable resistor. This high-frequency resistance may vary over a wide range (from 0.1 ohm to 10 KΩ in some cases, the useful range is smaller, though).

The wide intrinsic region also means the diode will have a low capacitance when reverse biased.

In a PIN diode, the depletion region exists almost completely within the intrinsic region. This depletion region is much larger than in a PN diode, and almost constant-size, independent of the reverse bias applied to the diode. This increases the volume where electron-hole pairs can be generated by an incident photon. Some photo detector devices, such as PIN photodiodes and phototransistors (in which the base-collector junction is a PIN diode), use a PIN junction in their construction.

The diode design has some design tradeoffs. Increasing the dimensions of the intrinsic region (and its stored charge) allows the diode to look like a resistor at lower frequencies. It adversely affects the time needed to turn off the diode and its shunt capacitance. PIN diodes will be tailored for a particular use.

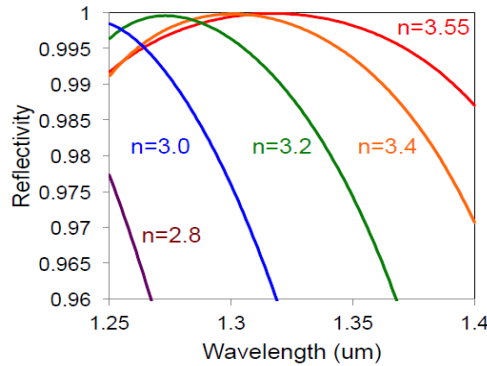


Figure 5: Wavelength Vs Reflectivity Graph

Figure-3 shows the graphical relationship between wavelength and reflectivity in accordance with the refractive index of the materials.

III. Result Analysis

The analysis were obtained from VCSEL model with different cavity size to form an array. When we applied 10V to the upper conductive plate of the VCSEL then we obtained following simulation results. The voltage is dropped into the centre of the cavity due to which power is dissipated. The dissipated power shows that emission is spread.

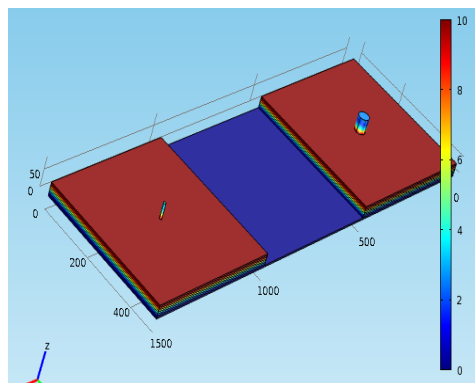


Figure 6: Voltage Analysis of VCSEL Array

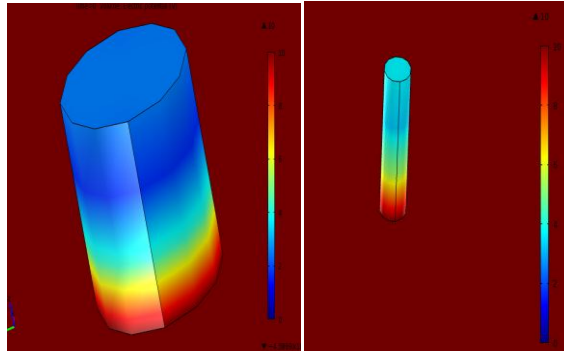


Figure 7: Comparison of Voltage among the Cavities

Figure-4 shows that the Voltage is 4.5391 V in the cavity as we applied 5V to the circuit. Similarly, Figure-5 shows that the voltage is 4.4463 V inside the cavity. From the simulation results, it is observed that by increasing the size of the cavity voltage drop is increased. Hence we have to keep the narrow cavity to achieve the better emission of beam.

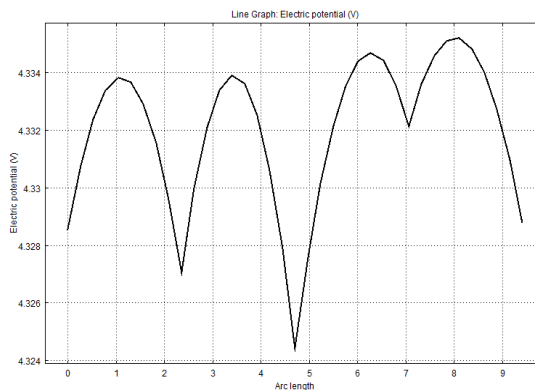


Figure 8: Arc Length Vs Electrical potential

In accordance with the applied electric potential to the conductive metal plate. Charge is distributed throughout the area of the cavity. The above graph (Figure 7) shows that how the potential is spread along the whole cavity. Our cavity is of a circular shape having very small radius. Therefore the arc length of the cavity shows variation in electric potential.

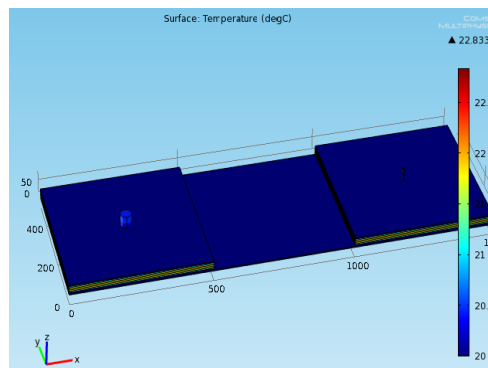


Figure 9: Temperature Analysis of VCSEL Array

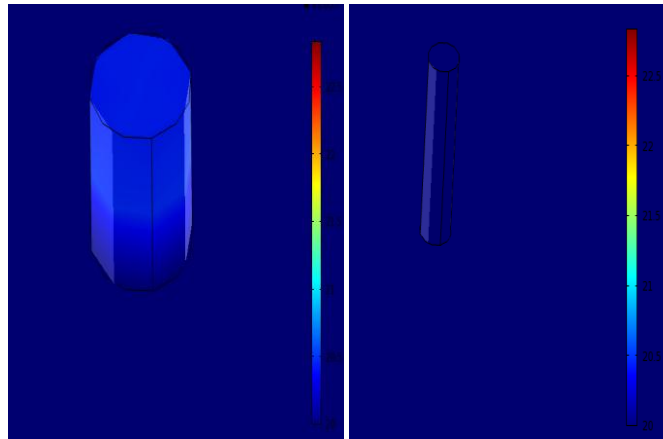


Figure 10: Comparison of Temperature among the cavities

As we have seen earlier results of voltage analysis the power dissipation is more with respect to the area of the cavity. Figure-8 and Figure-9 shows that temperature analysis of same model. We have made this analysis only to observe the boundary conditions of our VCSEL. In Figure-9 it is clearly shown that how the temperature is spread along the cavities. In case of large cavity temperature decreases from bottom to top of the cavity as we apply normal room temperature. Similarly, the temperature is throughout constant along the narrow cavity.

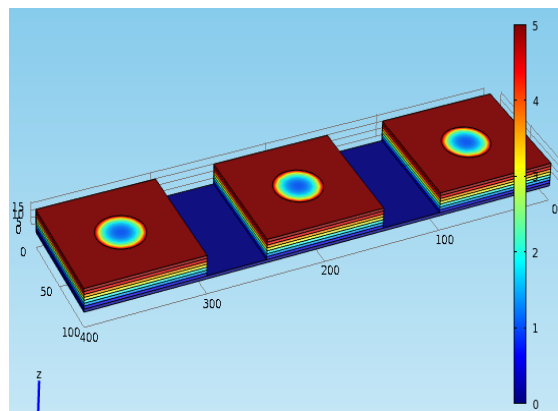


Figure 11: Structure of Three VCSEL Array

Power Dissipation is with respect to area of the cavity. If greater the dimensions, Propagation is more, thereby increasing the amount of losses hence lesser is the reflectivity. Emission is not continuous because it is spontaneous emission and only at a certain instant it emits. Similarly if Aperture size is increased voltage drop is more as the temperature is spread along the cavity. Hence we have to keep a small cavity to achieve the better emission of beam.

IV. Conclusion

The analyses were obtained by using COMSOL Multiphysics. If cavity is large, it implies emission is spread and observation is difficult. Hence we require small Cavity size for getting large wavelength. Temperature analysis for the same device was obtained which shows that VCSELs structural parameters are independent of the temperature.

V. Future Scope

Multiple wavelength communication demands one laser with varying wavelength. We will be able to generate multiple wavelengths on the same substrate using VCSEL. VCSEL Arrays are natural which provides degree of freedom in design. Multiple wavelengths can be obtained from a single device which would be very economical. The device will be used to switch wavelengths in Metro area networks; it regulates traffic throughout the network. Multiple wavelengths will be obtained from a single device by making more than one cavity on that device only.

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