

***ABSTRACT***

Light Peak is the code name for a new high-speed optical cable technology designed to connect electronic devices to each other. Light Peak delivers high bandwidth starting at 10Gb/s with the potential ability to scale to 100Gb/s over the next decade. At 10Gb/s, we can transfer a full-length Blu-Ray movie in less than 30 seconds. Light peak allows for smaller connectors and longer, thinner, and more flexible cables than currently possible. Light Peak also has the ability to run multiple protocols simultaneously over a single cable, enabling the technology to connect devices such as peripherals, displays, disk drives, docking stations, and more.

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10. **INTRODUCTION**

**Light Peak is Intel's code-name for a new high-speed optical cable technology designed to connect electronic devices to each other in a peripheral bus. Optical networking technologies have been over the last two decades reshaping the entire telecom infrastructure networks around the world. As network bandwidth requirements increase, optical communication and networking technologies have been moving from their telecom origin into the enterprise. For example, today in data centers, all storage area networking is based on fiber interconnects with speeds ranging form 1 Gb/s to 10 Gb/s. As the transmission bandwidth requirements increase and the costs of the emerging optical technologies become more economical, the adoption and acceptance of these optical interconnects within enterprise networks will increase. This report provides the framework for the light peak optical interconnect technology. A brief overview of the light peak interconnects technology and its current application within the enterprise is presented.**

**II. LIGHT PEAK**

**Light Peak** is a new high-speed optical cable technology designed to connect electronic devices to each other in a peripheral bus. It has the capability to deliver high bandwidth, starting at 10 Gbit/s,with the potential ability to scale to 100 Gbit/s. It is intended as a single universal replacement for current buses such as SCSI, SATA, USB, FireWire, PCI Express and HDMI. In comparison to these buses, Light Peak is much faster, longer ranged, smaller, and more flexible in terms of protocol support.

Light Peak was developed as a way to reduce the proliferation of ports on modern computers. Bus systems like USB were intended to do the same, and successfully replaced a number of older technologies like RS232 and Centronics printer ports. However, increasing bandwidth demands have led to the introduction of a new series of high-performance systems like eSATA and Display Port that USB and similar systems can not address. Light Peak provides enough bandwidth to allow all of these systems to be driven over a single type of interface, and in many cases on a single cable using a daisy chain.The Light Peak cable contains a pair of optical fibers that are used for upstream and downstream traffic. This means that Light Peak offers a maximum of 10 Gbit/s in both directions at the same time. The prototype system featured two motherboard controllers that both supported two bidirectional buses at the same time, wired to four external connectors. Each pair of optical cables from the controllers is led to a connector, where power is added through separate wiring. The physical connector used on the prototype system looks similar to the existing USB or FireWire connectors.

Intel has stated that Light Peak is protocol independent, allowing it to support existing standards with a change of the physical medium. Few details on issues like protocol or timing contention have been released. Intel has stated that Light Peak has the performance to drive everything from storage to displays to networking, and it can maintain those speeds over 100 meter runs. As advantages over existing systems, they also note that a system using Light Peak will have fewer and smaller connectors, longer and thinner cables, higher bandwidth, and can run multiple protocols on a single cable.

**One key piece of the device chain that has not been shown is a controller for the device-end of the bus. In the USB case, a single controller can contain the power circuitry, USB device logic, along with off-the-shelf, custom or programmable logic for running devices. A simple USB device can be built by adding a connector, one driver chip, and the hardware the system is meant to drive; a mouse is a good example of a system that is typically implemented using a single off-the-shelf chip. A similar single-chip solution will be in demand for Light Peak as well, but to date Intel has simply suggested it is working with industry partners to provide one. According to Intel, the companies that will produce Light Peak technology include Foxconn, Foxlink, IPtronics, SAE Magnetics FOCI Fiber Optics Communications Inc, Avago, Corning Elaser, Oclaro, Ensphere Solutions, and Enablence.**

**In the next 5-10 years, people will have many reasons for higher bandwidth. Lots of attractive applications that significantly improve user experiences are depending on huge volume of data capturing, transfer, storage, and reconstruction. People will have more and more electrical devices, such as High Definition (HD) video camcorders, HD monitors, Mobile Internet Device (MID) s, laptops and other handheld devices, and they want to be able to share data between these devices, smoothly, quickly and easily. All these user requirements call for higher bandwidth. But existing electrical cable technology**

**in mainstream computing devices is approaching the practical limit for higher bandwidth and longer distance, due to the signal degradation caused by electro-magnetic interference (EMI) and signal integrity issues. Higher bandwidth can be achieved by sending the signals down with more wires, but apparently this approach increases cost, power and difficulty of PCB layout, which explains why serial links such as SATA, SAS, USB are becoming the mainstream. However optical communications do not create EMI by using photonics rather than electrons, thus allowing higher bandwidth and longer distances. Besides, optical technology also allows for small form factors and longer, thinner cables.**

**It’s important to design flexible and effecient protocol to leverage the raw bandwidth enabled by optical fiber. Intel has announced its high speed optical cable technology, Light Peak (LPK) [10], which delivers high bandwidth starting at 10Gbps and has the ability to multiplex multiple protocols simultaneously over a single optical cable.**

**Combining the high bandwidth of optical fiber with Intel’s practice to mulplex multiple protocol over a single fiber, optical technology may change the landscape of IO system design in the future. It’s possible that most of the legacy IO protocols can be tunneled by optical-capable protocols, so some of the legacy IO interfaces can be converged to one single optical interface, significantly simplifying the form factor design of computers. This change in IO system will definitely affect the design of systems. The ultimate goal of system architects is to make a balanced and efficient system, on both power and cost grounds. It makes no sense to have a high throughput IO system with insufficient processing power or overloaded interconnections between IO system and the processor.**

**Mobile and handheld devices are two fast growing market segments which attract interests from processor vendors including Intel and they are our targets for application selection. For mobile and handheld devices, user interface and IO are two important factors besides computing power that affect end users’ purchase decision. Taking power into account, it’s possible that more carefully tuned IO workload offloading engines will be integrated into the IO controller, saving the power to move the data from IO a long way to the system memory.**

**Because we think that the future computing devices, especially low-end and consumer electronics will be more IOcentric, our research philosophy is an IO-oriented one. We try to identify the future IO devices and their usage models first, then we investigate the requirements of the interconnection from the IO’s standpoint, after that we move up to the processor level, trying to figure out the needs of processing power and thus the best architecture for it.**

**With this philosophy in mind, an optical-enabled system model can be illustrated in Fig. 1. There are four main components in this figure, the IO devices, the IO controller which connects to the IO devices through optical fiber, the processing unit and the interconnection between the IO controller and the processing unit, whatever it can be implemented as. We are looking at the system from IO to processor as shown by the arrow.**

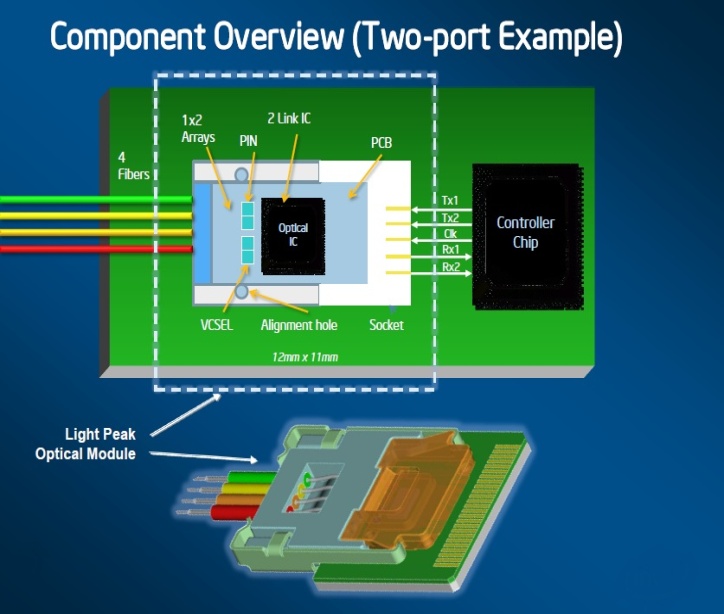


**Fig. 1: Abstract model of the optical-enabled system**

**2.1 Features and key benefit**

* Provide a standard low cost optical-based interconnect
* Support for key existing protocols (USB, HDMI, DP, PCIe, etc)
* Scalable bandwidth, cost, power to support broad base for 10+ years
* Support wide range of devices (handhelds, laptops, PCs, CE, and more)
* Common optical I/O architecture for the next decade and more
* Single, flexible cable that can carry any platform I/O
* Economies of scale from a single optical solution
* 1.Higher bandwidth –10Gbs to 100Gbs over the next decade
* Enables I/O performance for the next generation
* Allows for balanced platform, with external I/O keeping up with most platform interconnects
* 2.Longer, thinner cables and smaller connectors
* Up to 100 meters on an optical-only cable
* Each fiber is only 125 microns wide, the width of a human hair
* .Supports multiple existing I/O protocols over a single cable
* Smooth transition for today’s existing electrical I/O protocols
* Can connect to more devices with the same cable, or to combo devices such as docking stations.

**3. COMPONENTOVERVIEW**



**Light Peak consists of a controller chip and an optical module that would be included in platforms supporting this technology. The optical module performs the conversion from electricity to light and vice versa, using miniature lasers and photo detectors. Intel is planning to supply the controller chip, and is working with other component manufacturers to deliver all the Light Peak components.The main components are fibre optics,optical module,control chip.**

**4. THE FUNDAMENTALS OF OPTICAL COMPONENTS**

**A basic optical communication link consists of three key building blocks: optical fiber, light sources, and light detectors. We discuss each one in turn.**

4.1 Optical Fibers

**In 1966, Charles Kao and George Hockmam predicted that purified glass loss could be reduced to below 20 dB per kilometer, and they set up a world-wide race to beat this prediction. In September 1970, Robert Maurer, Donald Keck, and Peter Schultz of Corning succeeded in developing a glass fiber with attenuation less than 20 dB/km: this was the necessary threshold to make fiber optics a viable transmission technology. The silica-based optical fiber structure consists of a cladding layer with a lower refractive index than the fiber core it surrounds. This refractive index difference causes a total internal reflection, which guides the propagating light through the fiber core. There are many types of optical fibers with different size cores and cladding. Some optical fibers are not even glass-based such as Plastic Optical Fibers (POFs), which are made for short-distance communication. For telecommunications, the fiber is glass based with two main categories: SMF and MMF.**

**SMFs typically have a core diameterof about 9 μm while MMFs typically have a core diameter ranging from 50 to 62.5 μm. Optical fibers have two primary types of impairment, optical attenuation and dispersion. The fiber optical attenuation, which is mainly caused by absorption and the intrinsic Rayleigh scattering, is a wavelengthdependent loss with optical losses as low as 0.2 dB/km around 1550 nm for conventional SMF (i.e., SMF-28∗) [6].**

**The optical fiber is a dispersive waveguide. The dispersion results in Inter Symbol Interference (ISI) at the receiver. There are three primary types of fiber dispersions: modal dispersion, chromatic dispersion, and polarization-mode dispersion. The fiber modal dispersion depends on both the fiber core diameter and transmitted wavelengths. For a single-mode transmission, the stepindex fiber core diameter (*D*) must satisfy the following**

**condition [2]:**



**where λ is the transmitted wavelength and *n*1 and *n*2 are the refractive indices of fiber core and cladding layer, respectively. Consequently, for a single-mode operation at 850 nm wavelength, the fiber must have a core diameter of 5 μm. Since a conventional SMF has typically a core diameter of 9 μm, single-mode operation can be only supported for wavelengths in the 1310 nm wavelength band or longer. The fiber chromatic dispersion is due to the wavelengthdependent refractive index with a zero-dispersion wavelength occurring at 1310 nm in conventional SMF [6]. At 1550 nm, the fiber dispersion is about 17 ps/nm/km for SMF-28. When short duration optical pulses are launched into the fiber, they tend to broaden since different wavelengths propagate at different group velocities, due to the spectral width of the emitter. Optical transmission systems operating at rates of 10 Gb/s or higher and distances above 40 km are sensitive to this phenomenon. There are other types of SMFs such as Dispersion Shifted Fibers (DSFs) where the zero dispersion occurs at 1550 nm.**

**Polarization-Mode Dispersion (PMD) is caused by small amounts of asymmetry and stress in the fiber core due to the manufacturing process and environmental changes such as temperature and strains. This fiber core asymmetry and stress leads to a polarization-dependent index of refraction and propagation constant, thus limiting the transmission distance of high speed (≥ 10 Gb/s) over SMF in optical communication systems. Standard SMF has a PMD value of less than 0.1 ps/√km [6]. Special SMFs were developed to address this issue. Optical fiber is never bare. The fiber is coated with a thin primary coating by the fiber manufacturer; then a cable manufacturer, not necessarily the fiber manufacturer, cables the fiber. There is a wide variety of cable construction. Simplex cable has a single fiber in the center while duplex cables contain two fibers. Composite cable incorporates both single-mode and multimode fiber. Hybrid cables incorporate mixed optical fiber and copper cable. In the enterprise, the MMF is housed in a cable with an orange colored jacket, and the SMF is housed in a yellow jacket cable.**

4.2 Light Sources

**The light source is often the most costly element of an optical communication system. It has the following key characteristics: (a) peak wavelength, at which the source emits most of its optical power, (b) spectral width, (c) output power, (d) threshold current, (e) light vs. Current linearity, (f) and a spectral emission pattern. These characteristics are key to system performance. There are two types of light sources in widespread use: the Laser Diode (LD) and the Light Emitting Diode (LEDs). All light emitters that convert electrical current into light are semiconductor based. They operate with theprinciple of the p-n semiconductor junction found intransistors. Historically, the first achievement of laser action in GaAs p-n junction was reported in 1962 by three groups [1-4]. Both LEDs and LDs use the same key materials: Gallium Aluminum Arsenide (GaAIAs) for short-wavelength devices and Indium Gallium Arsenide Phosphide (InGaAsP) for long-wavelength devices. Semiconductor laser diode structures can be divided into the so-called edge-emitters, such as Fabry Perot (FP) and Distributed Feedback (DFB) lasers and vertical-emitters, such as Vertical Surface Emitting Lasers (VCSELs). When edge-emitters are used in optical fibercommunication systems, they incorporate a rear facet photodiode to provide a means to monitor the laser output, as this output varies with temperature. In today’s optical networks, binary digital modulation is typically used, namely on (i.e., light on) and off (no light) to transmit data. These semiconductor laser devicesgenerate output light intensity which is proportional to the current applied to them, therefore making them suitable for modulation to transmit data. Speed and linearity are therefore two important characteristics.Modulation schemes can be divided into two main categories, namely, a direct and an external modulation. In a direct modulation scheme, modulation of the input current to the semiconductor laser directly modulates its output optical signal since the output optical power is proportional to the drive current. In an external modulation scheme, the semiconductor laser is operating in a Continuous-Wave (CW) mode at a fixed operating point. An electrical drive signal is applied to an optical modulator, which is external to the laser. Consequently, the applied drive signal modulates the laser output light on and off without affecting the laser operation.One important feature of the laser diode is its frequency chirp. The frequency of the output laser light changes dynamically in response to the changes in the modulation current. A typical DFB has a frequency chirp of about 100-MHz/mA. This spread of the wavelength interacts with the fiber dispersion. As previously mentioned, as the data rate is increased, this interaction limits the transmission distance of optical transmission systems due to the additional ISI generated at the receiver [1−4]. Optical back-reflection is one of key issues when coupling the output light from a laser source to a fiber.The optical back-reflection disturbs the standing wave in the laser cavity, increasing its noise floor, and thus making the laser unstable. One practical way to reduce the phenomenon of back-reflection is to place an isolator between the laser cavity and the fiber, which adds a significant additional cost to the laser [1, 4]. Temperature also affects the peak wavelength of the laser; threshold current also increases with temperature as slope efficiency decreases. For DWDM applications, which require very precise operating wavelengths, most of the current laser diode designs need to be cooled to within ± 0.3 °C. As previously explained, the direct modulation of a laser diode has several limitations, including limited propagation distance due to the interaction between the laser frequency chirp and fiber dispersion. This is not an issue for enterprise networks which are short distance, but could be a serious limiting factor for telecommunications applications. To overcome this limitation, the laser diode is operated in a CW mode, and output light is externally modulated by an optical modulator. Intensity modulators can be divided into two main groups: Mach-Zehnder Interferometer (MZI) and Electro-Absorption (EA) modulators. In an MZI modulator, a single input waveguide is split into two optical waveguides by a 3 dB Y junction and then recombined by a second 3 dB Y junction into a single output. A Radio Frequency ( RF) signal, which is applied to a pair of electrodes constructed along the waveguides, modulates the propagating optical beam. The modulator key parameters are its modulation bandwidth, linearity, and the required drive signal voltage for π phase shift. MZI modulators based on LiNbO3 are high-performance modulators with a large form-factor (about 2.5 inches) that are not suitable for optical integration [4, 7]. EA modulators are based on a voltageinduced shift of the semiconductor bandgap so that the modulator becomes absorbing for the lasing wavelength. The advantages of an EA modulator is its low driving voltage, high-speed operation, and suitability for optical integration with InP-based laser diodes [8]. A tunable laser is a new type of laser where its main lasing longitudinal mode can be tuned over a wide range of wavelengths such as the C band (1510−1540 nm) of an Erbium-Doped Fiber Amplifier (EDFA), which is commonly used for DWDM systems [1−4]. The use of tunable lasers is driven by the potential cost savings in DWDM transport networks since a significantly reduced inventory of fixed-wavelength lasers could be maintained for a robust network operation. The technical challenges are to provide both broad wavelength tunability and excellent wavelength accuracy over the laser life. A broadly tunable External Cavity Laser (ECL) employing micromachined, thermally tuned silicon etalons has been designed to achieve these goals.**

4.3 Light Detectors

**Light detectors convert an optical signal to an electrical signal. The most common light detector is a photodiode. It operates on the principle of the p-n junction. There are two main categories of photodetectors: a p-i-n (positive, intrinsic, negative) photodiode and an Avalanche Photodiode (APD), which are typically made of InGaAs or germanium. The key parameters for photodiodes are (a) capacitance, (b) response time, (c) linearity, (d) noise, and (e) responsivity. The theoretical responsivity is 1.05 A/W at a wavelength of 1310 nm. Commercial photodiodes have responsivity around 0.8 to 0.9 A/W at the same wavelength [1-4]. The dark photo-current is a small current that flows through the photo-detector even though no light is present because of the intrinsic resistance of the photo-detector and the applied reverse voltage. It is temperature sensitive and contributes to noise. Since the output electrical current of a photodiodeis typically in the range of μA, a Transimpedance**

**Amplifier (TIA) is needed to amplify the electric current to a few mA [2−4].APDs provide much more gain than the pin photodiodes, but they are much more expensive and require a high voltage power to supply their operation [2]. APDs are also more temperature sensitive than pin photodiodes.**

4.3 Packaging: Optical Sub-assembly (OSA) and Optical Transceivers

**As previously described, laser diodes and photodiodes are semiconductor devices. To enable the reliable operation of these devices, an optical package is required. In general, there are many discrete optical and electronic components, which are based on different technologies that must be optically aligned and integrated within the optical package. Optical packaging of laser diodes and photodiodes is the primary cost driver. These packages are sometimes called Optical Sub-Assemblies (OSAs). The Transmitter OSA package is called a TOSA and the Receiver OSA package is called a ROSA. Figure 1 shows, for example, a three-dimensional schematic view of a DFB laser diode mounted on a Thermo-Electric Cooler (TEC) inside a hermetically sealed 14-pin butterfly package with an SMF pigtail [9]. Most of the telecom-grade laser diodes are available in the so-called TO can or butterfly packages. The standard butterfly package is a stable and high-performance package, but it has a relatively large form-factor and it is costly to manufacture. These packages are typically used for applications where cooling is required using a TEC**



Figure 1: Three-dimensional view of a DFB laser diode configuration with single-mode fiber pigtail

(after Ref. [8] (1990 IEEE))

**The TEC requires a large amount of power to regulate the temperature of a laser inside the package. This type of optical packaging was used for the early 10 Gb/s modules. More recently, tunable 10 Gb/s lasers are using a similar butterfly optical package. The butterfly package design uses a coaxial interface for passing broadband data into the package, which requires the use of a coaxial interface to the host Printed Circuit Board (PCB). Although coaxial cables and connectors have been reduced in size, they still consume valuable real estate in**

**the optical transceiver. The evolution of optical module packages is toward smaller footprint packages. If relatively easy for receivers, the trend toward smaller packages is particularly challenging for laser transmitter modules due to the power and thermal dissipation constraints. Figure 2 shows the evolution of 10 Gb/s optical module packaging technology. To operate with high- performance, uncooled designs must be implemented with more advanced control systems that can adjust the laser and driver parameters over temperature. The smaller packages utilize a coplanar approach to the broadband interface, which more closely resembles a surface-mount component and enables much smaller RF interfaces. TO-can-based designs, which have been used extensively**

**in lower data rate telecom and datacom systems up to 2 Gb/s as well as CD players and other high-volume consumer applications, are now maturing to support highperformance 10 Gb/s optical links. Leveraging the fact that these packages are already produced in high volume will further reduce the cost of the 10 Gb/s optical modules in optical transceiver designs.**

4.4 Optical Transceivers

**For telecommunication applications, the optical transmitter and receiver modules are usually packaged into a single package called an optical transceiver. Figure 3 shows an example of different transceivers and Figure 4 shows an example of the printed circuit board of a transceiver. There are several form factors for this optical transceiver depending on their operating speed and applications. The industry worked on a Multi-Source Agreement (MSA) document to define the properties of the optical transceivers in terms of their mechanical, optical, and electrical specifications. Optical transponders operating at 10 Gb/s, based on MSA, have been in the market since circa 2000, beginning with the 300-pin MSA, followed by XENPAK, XPAK, X2, and XFP.**

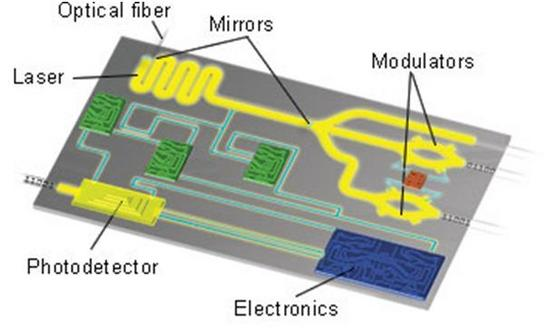


Figure 4: Intel® TXN13220 FR-4 printed circuit board

showing optical modules, Mux/DeMux, and microprocessor

**5. OPTICAL MODULE**

**The optical module does the function o converting optical signals into electrical signals and viceversa.This module contains an array of VCSEL(vertical cavity surface emitting laser)**



**Schematic diagram of Optical module**

**6. VCSEL**

The **vertical-cavity surface-emitting laser**, or **VCSEL** is a type of semiconductor laser diode with laser beam emission perpendicular from the top surface, contrary to conventional edge-emitting semiconductor lasers (also *in-plane* lasers) which emit from surfaces formed by cleaving the individual chip out of a wafer.

There are several advantages to producing VCSELs when compared with the production process of edge-emitting lasers. Edge-emitters cannot be tested until the end of the production process. If the edge-emitter does not work, whether due to bad contacts or poor material growth quality, the production time and the processing materials have been wasted. VCSELs however, can be tested at several stages throughout the process to check for material quality and processing issues. For instance, if the vias have not been completely cleared of dielectric material during the etch, an interim testing process will flag that the top metal layer is not making contact to the initial metal layer. Additionally, because VCSELs emit the beam perpendicular to the active region of the laser as opposed to parallel as with an edge emitter, tens of thousands of VCSELs can be processed simultaneously on a three inch Gallium Arsenide wafer. Furthermore, even though the VCSEL production process is more labor and material intensive, the yield can be controlled to a more predictable outcome.

**The laser resonator consists of two distributed Bragg reflector (DBR) mirrors parallel to the wafer surface with an active region consisting of one or more quantum wells for the laser light generation in between. The planar DBR-mirrors consist of layers with alternating high and low refractive indices. Each layer has a thickness of a quarter of the laser wavelength in the material, yielding intensity reflectivities above 99%. High reflectivity mirrors are required in VCSELs to balance the short axial length of the gain region.**

**In common VCSELs the upper and lower mirrors are doped as p-type and n-type materials, forming a diode junction. In more complex structures, the p-type and n-type regions may be buried between the mirrors, requiring a more complex semiconductor process to make electrical contact to the active region, but eliminating electrical power loss in the DBR structure.**

**In laboratory investigation of VCSELs using new material systems, the active region may be *pumped* by an external light source with a shorter** [**wavelength**](http://en.wikipedia.org/wiki/Wavelength)**, usually another laser. This allows a VCSEL to be demonstrated without the additional problem of achieving good electrical performance; however such devices are not practical for most applications.**

**VCSELs for wavelengths from 650 nm to 1300 nm are typically based on gallium arsenide (GaAs) wafers with DBRs formed from GaAs and aluminium gallium arsenide (Al*x*Ga(1-*x*)As). The GaAs–AlGaAs system is favored for constructing VCSELs because the** [**lattice constant**](http://en.wikipedia.org/wiki/Lattice_constant) **of the material does not vary strongly as the composition is changed, permitting multiple "lattice-matched"** [**epitaxial**](http://en.wikipedia.org/wiki/Epitaxy) **layers to be grown on a GaAs substrate. However, the** [**refractive index**](http://en.wikipedia.org/wiki/Refractive_index) **of AlGaAs does vary relatively strongly as the Al fraction is increased, minimizing the number of layers required to form an efficient Bragg mirror compared to other candidate material systems. Furthermore, at high aluminium concentrations, an oxide can be formed from AlGaAs, and this oxide can be used to restrict the current in a VCSEL, enabling very low threshold currents.**

**Recently the two main methods of restricting the current in a VCSEL were characterized by two types of VCSELs: ion-implanted VCSELs and Oxide VCSELs.**

**In the early 1990s, telecommunications companies tended to favor ion-implanted VCSELs. Ions, (often hydrogen ions, H+), were implanted into the VCSEL structure everywhere except the aperture of the VCSEL, destroying the lattice structure around the aperture, thus inhibiting the current. In the mid to late 1990s, companies moved towards the technology of oxide VCSELs. The current is confined in an oxide VCSEL by oxidizing the material around the aperture of the VCSEL. A high content aluminium layer that is grown within the VCSEL structure is the layer that is oxidized. Oxide VCSELs also often employ the ion implant production step. As a result in the oxide VCSEL, the current path is confined by the ion implant and the oxide aperture.**

**The initial acceptance of oxide VCSELs was plagued with concern about the apertures "popping off" due to the strain and defects of the oxidation layer. However, after much testing, the reliability of the structure has proven to be robust. As stated in one study by Hewlett Packard on oxide VCSELs, "The stress results show that the activation energy and the wearout lifetime of oxide VCSEL are similar to that of implant VCSEL emitting the same amount of output power."**

**A production concern also plagued the industry when moving the oxide VCSELs from research and development to production mode. The oxidation rate of the oxide layer was highly dependent on the aluminium content. Any slight variation in aluminium would change the oxidation rate sometimes resulting in apertures that were either too big or too small to meet the specification standards.**

**Longer wavelength devices, from 1300 nm to 2000 nm, have been demonstrated with at least the active region made of** [**indium phosphide**](http://en.wikipedia.org/wiki/Indium_phosphide)**. VCSELs at even higher wavelengths are experimental and usually optically pumped. 1310 nm VCSELs are desirable as the dispersion of silica-based optical fiber is minimal in this wavelength rang**

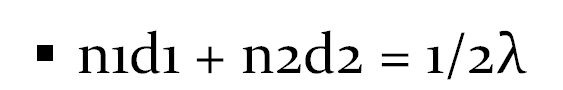


**The advantages of using fiber optics over wiring are the same as the argument for using optics over electronics in computers. Even through totally optical computers are now a reality, computers that combine both electronics and optics, electro-optic hybrids, have been in use for some time. In the present paper, architecture of optical interconnect is built up on the bases of four Vertical-Cavity Surface- Emitting Laser Diodes (VCSELD) and two optical links where thermal effects of both the diodes and the links are included. Nonlinear relations are correlated to investigate the power-current and the voltage-current dependences of the four devices. The good performance (high speed) of the interconnect is deeply and parametrically investigated under wide ranges of the affecting parameters. The high speed performance is processed through three different effects, namely the device 3-dB bandwidth, the link dispersion characteristics, and the transmitted bit rate (soliton). Eight combinations are investigated; each possesses its own characteristics. The best architecture is the one composed of VCSELD that operates at 850 nm and the silica fiber whatever the operating set of causes. This combination possesses the largest device 3-dB bandwidth, the largest link bandwidth and the largest**

**soliton transmitted bit rate. The increase of the ambient temperature reduces the high-speed performance of the interconnect**

* **The axis of the optical cavity is along the direction of current flow versus perpendicular as is the case with conventional laser diodes.**
* **Active region length is very short compared to width therefore radiation is generated from the surface of the cavity as opposed to the edges.**
* **Multiple layers of ¼ wave thick dielectric mirrors with alternating high and low refractive indices serve as reflectors at either end of the cavity.**
* **he geometry of the dielectric mirrors provide wavelength ( ) selective reflectance at the free space wavelength required assuming the thickness of alternating layers and with refractive indices of and if the following equation is satisfied:**



* 
* **Maintaining the relationship of this equation allows constructive interference of partially reflected waves at the interfaces.**
* **The wave is reflected due to a periodic variation of the refractive index ( like a grating). The dielectric mirror can be referenced as a** *distributed Bragg reflector* **(DBR).**
* **Short cavity length (L) (due to nature of geometry for VCSEL) reduces the optical gain of the active layer as seen in the expression: optical gain =exp(gL) where g is the optical gain coefficient.**
* **The semiconductor layers are manufactured using epitaxial growth on a substrate that is transparent to in the emission wavelength.**
* **Example: a 980 nm VCSEL uses InGaAs as the active layer to provide 980 nm emission along with a GaAs crystal substrate that is transparent which is transparent at 980 nm.**
* **Alternating layers of AlGaAs of various compositions developing different bandgaps and refractive indices are used as dielectric mirrors.**
* **This** *microlaser* **has cavity dimensions in the microns making it suitable for arrays or a** *matrix emitter***.**
* **A matrix emitter is a broad area surface emitting laser with applications in optical interconnect and optical computing.**
* **A VCSEL is capable of delivering more power than a conventional laser diode. Up to a few watts with a matrix VCSEL.**
* **The top dielectric mirror is etched after all other layers are epitaxially grown on the GaAs substrate.**
* **The vertical cavity is typically circular in cross section and dictates to the emitted beam having a** *circular cross-section.* **Sometimes emission is from a square area. Beam divergence is from 7 to 10 degrees. The use of microlenses will couple up to 90% of the output flux to the fiber.**
* **The height of the cavity is small (several microns) and only permits one longitudinal mode, however there may be one or more lateral modes.**
* **Usually, in practice there is only one lateral mode in the output spectrum of a cavity with diameters less than 0.8um. Note: there are some VCSELs with several lateral modes. (0.5nm spectral width)**

## 6.1 Characteristics

Because VCSELs emit from the top surface of the chip, they can be tested *on-wafer*, before they are cleaved into individual devices. This reduces the [fabrication](http://en.wikipedia.org/wiki/Semiconductor_fabrication) cost of the devices. It also allows VCSELs to be built not only in one-dimensional, but also in two-dimensional *arrays*.

The larger output aperture of VCSELs, compared to most edge-emitting lasers, produces a lower divergence angle of the output beam, and makes possible high coupling efficiency with optical fibers.

The high reflectivity mirrors, compared to most edge-emitting lasers, reduce the threshold current of VCSELs, resulting in low power consumption. However, as yet, VCSELs have lower emission power compared to edge-emitting lasers. The low threshold current also permits high intrinsic modulation bandwidths in VCSELs[[1]](file:///G:\lightpeak%20details\Vertical-cavity_surface-emitting_laser.htm#cite_note-0).

The wavelength of VCSELs may be tuned, within the gain band of the active region, by adjusting the thickness of the reflector layers.

While early VCSELs emitted in multiple longitudinal modes or in filament modes, single-mode VCSELs are now common.

7. DATA TRANSFER SPEED COMPARISON

### 7.1 Wireless Network

**How does Light Peak compare to the latest technologies? The slowest is wireless. For example, Wireless N (802.11n) can reach 160 Mb/s in the real world. Light Peak is about 60 times faster. Faster wireless standards will come out, but nothing even close to what a good cable can provide.**

7.2 Ethernet

**Moving on to other ethernet type connections, Apple first used Gigabit Ethernet on the "Mystic" Power Mac G4 in 2000. It gives a full 1 Gb/s. The fastest ethernet on the market is 10 Gigabit Ethernet (10GBase-T), and 100 Gigabit Ethernet is under development. You won't find 10G ethernet on many computers. The standard also makes use of fiber optic cable to achieve these transfer rates.**

### 7.3 USB 3.0:The latest USB 3.0 connectors are starting to make an appearance. We see that at best it will be only half the speed of Light Peak. USB 3.0 is rated at 4.8 Gb/s. Of course, theoretical and actual are two different things. In the past USB was unable to deliver more than about two-thirds of theoretical speed.

### 7.4 FireWire :FireWire was an important competitor to USB, but it has been losing popularity. Still, the FireWire standard is still progressing. FireWire S3200 is planned to reach 3.2 Gb/s. That keeps it comparable to USB 3.0, but still much slower than Light Peak. I doubt we'll see many devices that use it.

### 7.5 Hard Drives SATA 6 Gb/s:Hard drives need to be speedy, and a new SATA protocol was recently released, SATA 6 Gb/s. As the name implies, it can go 6 Gb/s. The nice thing with this protocol is it remains compatible with older systems and hard drives. You do need to have the right motherboard to take advantage of the latest speed increase.

### 7.6 HDMI and DisplayPort:The newest video protocols, HDMI and Display Port, are both ready to transfer HD video content or huge blocks of data if all the wires are used together. HDMI version 1.3 and higher will transfer at 10.2 Gb/s, while Display Port can go up to 10.8 Gb/s. These are slightly better than Light Peak, but they are mostly designed for video. No one is pushing the data transfer rates of these protocols.

### 7.8 Light Peak Covers All the Bases:

### The chart shows how Light Peak compares to all of these other protocols. At 10 Gb/s, it can cover a whole range of transfer protocols. The magic of Light Peaks is that it can become the cable of choice for all these protocols with no significant loss in transfer speed.

The folks at Intel are not finished with Light Peak. They plan to push the specification up to 100 Gb/s, with some stops along the way. There is plenty of room for growth - and hopefully backward compatibility - as this latest specification tries to find its way in the world of technology.

7.9 LIGHT PEAK VS USB 3.0

|  |  |
| --- | --- |
| USB 3.0 | LIGHT PEAK |
| 9 Copper Wires | Optical Fibre Cable |
| Speed-3 Gb/sec | Speed-10 Gb/sec |
| Only USB Protocol | Universal |
| Max Cable Length-9m | Max Cable Length-100m |

**8. LIGHT PEAK: THE NEW ERA OF OPTICAL TECHNOLOGY**

**Optical modules traditionally used for telecom and datacom are physically larger than the Light Peak optical module. The Light Peak optical module is only12mm by 12mm and drives two optical ports. 120 Light Peak optical modules could fit in the area of a traditional Telecom module.**

**The Light Peak optical module was designed to be lower cost than Telecom optical modules through clever design and volume manufacturing. Telecom optical modules may cost up to 30 times more than Light Peak.**

**Light Peak can send and receive data at 10 billion bits per second. That is a 1 with ten zeros after it. If you had $10 billion dollars in single dollar bills and piled them on top of each other it would form a stack about 700 miles high.**

**The optical fibers used in Light Peak have a diameter of 125 microns, about the width of a human hair. This thin optical fiber will enable Light Peak to transfer data over very thin, flexible cables.**

**Electrical wires generate electric fields around them when electricity flows through. These electric fields hamper the speed at which signals can be passed down the wires as well as the length of the wires. Photons don’t have this problem, thus with Light Peak one could have thin, flexible optical cables that are up to 100 meters long.**

**The library of Congress contains over 10 terabytes of information (a 1 with 13 zeroes after it). If you used Light Peak technology operating at 10 billion bits per second it would take you only 17 minutes to transfer the complete library of Congress.**

**The lasers used in Light Peak are called VCSELs (Vertical Cavity, Surface Emitting Laser) and are a mere 250 microns by 250 microns in dimension. This is as wide as two human hairs.**

**Light Peak also has the ability to run multiple protocols simultaneously over a single cable, enabling the technology to connect devices such as docking stations, displays, disk drives, and more. A simple analogy is it is like loading up many cars onto a high-speed bullet train.**

**The first laser was invented in 1960 by Dr. Maiman. Some of his contemporaries commented that his invention was a solution looking for a problem. Today, lasers are everywhere including doctor’s offices, internet data centers and in factories for cutting thick sheets of steel. With Light Peak, you will have lasers in your everyday PC.**

**Intel is working with the optical device manufacturers to make Light Peak components ready to ship in 2010, which is 50 years after the first laser was invented.**

**There are over 2100 documents on the internet that constitute a standard. Intel plans to work with the industry to determine the best way to make Light Peak a standard and to accelerate its adoption on a plethora of devices including PCs, handheld devices, workstations, consumer electronic devices and more. Some examples of standards for computers include USB, PCI Express and WiFi.**

**9. CONCLUSION**

**Intel is working with the optical component manufacturers to make Light Peak components ready to ship in 2010, and will work with the industry to determine the best way to make this new technology a standard to accelerate its adoption on a plethora of devices including PCs, handheld devices, workstations, consumer electronic devices and more. Light Peak is complementary to existing I/O technologies, as it enables them to run together on a single cable at higher speeds.**

**At the present time, Intel has conducted three successful public demonstrations of the Light Peak technology and confirmed that the first Light Peak-enabled PCs should begin shipping next year. To say the company is bullish on the technology is an understatement. In his keynote address at the Consumer Electronics Show earlier this year, Intel CEO Paul Otellini called Light Peak “the I/O performance and connection for the next generation,” and confirmed that both Nokia and Sony have publicly announced their support.**

**Victor Krutul, director of Intel’s optical development team and founder of the Light Peak program, is even more effusive, calling Light Peak “the biggest thing to happen to the optical industry ever, or at least since the creation of the laser.”**