Google data centers can have a million lasers working in them. What kind of laser and why?

Introduction

Data Centers are used by large enterprises to back-up information by storing it in remote servers. Since Google is the most widely used search engine, it needs the largest data centers to meet the needs of its ever growing web traffic. Google Data Centers can be analogous to a giant warehouse-scale computer. [2] The data center spans a large space including multiple buildings in which all servers are connected by routers and switches. The connections are centered at one hub using fiber optics.

The performance of servers is drastically increasing over time. In return, the performance of inter-connected servers increases proportionally. Networking does not have a straightforward scalability solution, although increasing the bandwidth size along with servers is easy, increasing bisection bandwidth requires a more complex solution. Data center network topologies physically connect switches and servers using effective scaling, cost, latency, and power consumption solutions. [7] Google uses a system that cascades switch chips using a fat tree topology network. [2] Data center topology networks use wavelength-division multiplexing technologies to reduce power consumption while maintaining and improving scalability and full bisection bandwidth.

Requirements of a Google Data Center

In current Information and Communication Technology (ICT) environments, data centers play a significant role in facilitating the continuous flow of information through online services from distant parts of the world. There are strict requirements for the high reliability and availability of data centers in order to deminish any failures or system outages. There must be a specific architecture that ensures reconfigurability of data centers when connecting physical servers in the network. The demand for inter-server (bisection) bandwidth is rapidly increasing; in fact over the past decade, the bisection bandwidth of Google data centers has increased by a factor of a thousand. [6] As band width requirements are increased, fiber optics solutions are needed for interconnection of servers in order to scale out the data center. Fibre optics need to carry over 1 petabit bandwidth allowing reliable storage access and computing resources with low latency and high throughput. [4] A large number of interconnection links are needed to fufill this high bisection bandwidth requirement, and some important criteria is considered when creating the interconnections; specifically around cost efficiency, power consumption and adaptability.

To minimize costs and ensure reconfigurability, different optic fibre technologies are used depending on the different sections of the network. The large-scale size of the data centers means the data must travel through fibers that are to the order of 10^3m in length. In order to keep the losses to a minimum, these fibers must have high tolerances. Single mode fiber optic cables are used by Google to meet these long-distance requirements. On the other hand, for shorter link distances of 100m or less, a vertical cavity surface emitting laser (VCSEL) would be used. VCSELs are proven to have lower costs, as discussed below. Google also uses multimode-fiber-based small form-factor pluggable (SFP) transceivers. Pluggable optics are used to ensure that they can be easily removed and replaced when necessary.

Lasers used in Google Data Centers

Since the distances between the servers and hub can be over 4km, the fibers used are single mode rather than multi-mode. A single mode fiber only allows a particular mode of light to pass through, reducing the number of reflections. The diameter of the core and the cladding is approximately 9μm and 125μm respectively.

The light source for the optical signal sent through the fibers is produced by a VCSEL. This is a semiconductor laser from which light is emitted perpendicular to the cavity. A closer look at the cavity of a VCSEL is shown in Figure 1.

Principles of Semiconductor Lasers

Laser diodes are created by combining p and n-type semiconductor wafers. The top layer is engineered to have many holes (positive charge carries characterised by the absence of an electron), making it a p-type semiconductor and the bottom layer has extra electrons, making it an n-type semiconductor. A common example is Gallium Arsenide p-type and doped Gallium Arsenide and Selenium n-type wafers. Between these wafers is the diode junction. When a current is applied, both holes and electrons flow towards the junction. Electrons from the n-type are in an excited state and may spontaneously combine with a hole to lower their energy. A photon is emitted into the cavity junction upon combination and is reflected by distributed Bragg reflectors. The cavity is incredibly thin, forming a single mode Fabry-Pérot resonator. These spontaneously emitted photons may stimulate further combination events, producing coherent light with photons of identical phase and wavelength. Where this amplification exceeds the absorption losses, lasing occurs. A small fraction of the laser light exits the cavity and is detected by the photodiode, which regulates the applied

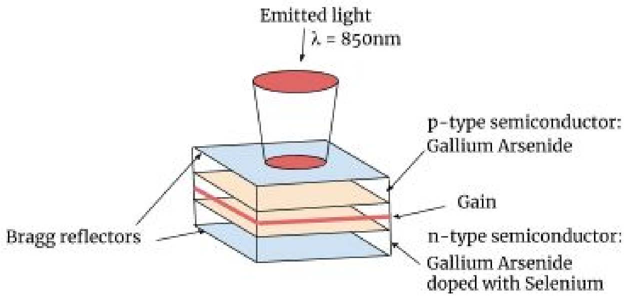

Figure 1: A diagram of cavity of a VCSEL laser used in the Google data center fiber optic cables.

current to maintain a steady intensity of laser light. For conventional laser diodes, the emitted laser light suffers large diffraction effects, and a collimating lens must be used to create the beam. Without this lens, it is difficult to couple the emitted light to optical fibers.

VCSEL Theory

The structure of a VCSEL is similar to conventional diode lasers, with a few key differences. [5] The semiconductor wafers are comprised of p and n-type doped Gallium Arsenide and Aluminium Gallium Arsenide. [3] The wafers themselves are layered to create Bragg dielectric mirrors with very high reflectivity (99.9% for the bottom mirror and 99.0% for the output coupler). The laser beam is emitted in a direction perpendicular to the wafers as a cylindrical beam, leading to lesser diffraction effects. This leads to higher coupling efficiencies with optical fibers, and the beam may be collimated with a single lens, leading to clear advantages over conventional diode lasers. Typically, about twenty layers of quarter wavelength thickness are required for each mirror. The refractive index of the wafers varies largely with Aluminium content and by careful preparation of wafer compositions, very thin Bragg mirrors may be constructed. Additionally, the lattice constants of AlGaAs and GaAs are effectively identical, but AlGaAs has a significantly higher bandgap (energy difference between conductance and valence bands). This leads to quantum confinement, via multiple quantum wells, of electrons and holes in the active medium, increasing the lasing efficiency. The band gap structure confines electrons and holes in closer proximity, increasing the number of combination events and thus the number of photons emitted.

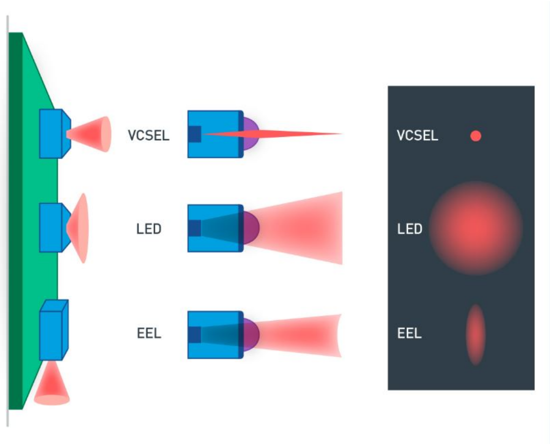

Figure 2: A visual comparison of the output of various light sources: VCSELs, LEDs, and EELs. From: FINISAR. MyVCSEL at: https://www.myvcsel.com/

Properties of the lasers

The use of single mode fiber allows for the signal to travel a greater distance with higher bandwidth. This is a consequence of lower attenuation due to the number of reflections being reduced by its structure of having a much smaller core. However, the single mode fiber is costly, so for economic reasons it is only used when necessary for long distance connections (i.e. over 4km).

Advantages of VCSELs

The VCSELs are arranged in a 2D array to increase the output power by coupling the beams of multiple VCSEL elements to produce a single beam focused using lenses. The structure of an array provides more reliability which is vital for the application of continuously running data centers. The reliability of the array comes from the intrinsic back-up provided by all other elements of the array if one fails. As represented in Figure 2, the VCSELs provide a higher intensity compared to EELs (Edge Emitting Lasers) and LEDs (Light Emitting Diodes). They are also capable of higher efficiencies due to the following reasons: EELs suffer greater edge diffraction effects, therefore require a system of collimating lenses. Also, due to the lack of quantum confinement, EEls need a greater input current. EELs and LEDs are at risk of catastrophic optical damage due to mirror heating effects which VCSELs are immune to, hence have a long wear-out life.

Conclusion

With ever growing demand for data storage, Google must engage in a continuous process of upgrades to ensure it maintains its ability to meet demand. The bottleneck for performance is the bisection connections between servers within the data centres, and it is here that the field of laser physics makes a significant impact. Vertical Cavity Surface Emitting Lasers are a novel form of semiconductor lasers, providing the immediate ability to increase data transfer rates through the bisections. Additional advantages of low cost, low power consumption, resistance to catastrophic optical failure and easier optical fiber coupling make VCSELs a common solution to bisection bottlenecks.

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