Applications of semiconductor lasers

Abstract- Semiconductor lasers have the potential to meet the demands of next generation high speed optical network applications and also have great impact on various other technology domains. Its low cost, easy wavelength tune ability, low power consumption and pure output make it ideal for optical communication applications. This paper is a review of the merits, demerits, current applications, commercial availability and future directions of semiconductor lasers in optical communication. Comparative analysis of these semiconductor lasers with respect to various parameters also been conducted.

Keywords: Semiconductor lasers, Fabry-Perot laser, Distributed feedback (DFB) laser, External Cavity Diode Lasers (ECDL), Multi Quantum Well (MQW) laser, Vertical Cavity Surface Emitting Lasers (VCSEL)

i. Introduction

The semiconductor lasers were discovered in 1962 by Robert Hall and his team members [1, 2]. With the advent of this technology patents and articles started to publish on this technology but at that time this technology was not mature enough to realize the dreams of the scientists, engineers and physicist. But with advancement in the field and the enabling technologies soon made it possible to produce inexpensive commercially available semiconductor laser. The invention of semiconductor lasers not only revolutionizes the optical communication but it has many applications in other domains also.

Semiconductor lasers are one of the popular optical communication light source for data transmission. They are supposed to be “ the laser of the future", because of their compactness in size, easy integration, more output power, optical pumps for solid-state lasers (primary light source i. e laser diode pumps another solid state lasers) and their rapid improvement.

Semiconductor lasers are essentially diodes which produces coherent light through the process of stimulated emission. They uses semiconductor as a gain medium. The gain medium is pumped by an external source, which is electrical in nature in case of semiconductor lasers [3].

As they are basically p-n junctions, so they are compact and can be fabricated on large scale by the use of advance semiconductor IC technology. Semiconductor lasers are very efficient in converting electrical power into optical power [10].

In section. II basic types of semiconductor lasers are described in terms of their basic working procedure, advantages, disadvantages, commercial availability future directions and applications. Section. III produces the comparison of semiconductor lasers with respect to various parameters and section. IV contains the conclusion.

II. Types of semiconductor lasers

Following are the basic types of semiconductor lasers

Fabry Perot (FP) Lasers

Distributed Feedback (DFB) lasers

Multi Quantum Well (MQW) laser

External Cavity Diode Lasers (ECDL)

Vertical Cavity Surface Emitting Lasers (VCSEL)

A. Fabry-Perot (FP) lasers

In FP lasers, mirrors create the right condition for the lasing to occur. Resonate cavity is formed when two mirrors are put in front of each other. The bouncing of light will take place between these two mirrors, the distance between these two mirrors are adjusted in such a way that this distance is the integral multiple of half wavelength, only is such scenario light will reinforce itself. Wavelengths that are not resonant they undergo destructive interference and deflect. One of the two mirrors is fully reflective and the second mirror allows very small amount of light to pass through [4].

Figure. 1. a: Fabry Perot Laser conceptual structure, Ref: [4]

Figure. 1. b: Fabry Perot Laser structure, Ref: www. scholar. lib. vt. edu

A. 1. Advantages

FP laser gives comb of (Amplified Spontaneous Emission) ASE peak uniform in frequency [5].

FP laser can be used for transmission of data with multimode optical fiber [6].

FP laser also have uniform intensity over Erbium Doped Fiber Amplifier (EDFA) [5].

Perfect for optical links where long term power and wavelength stability is required.

A. 2. Disadvantages

High dispersion in high speed and long transmission system because the spectral width can span as much as 5 nm [6].

At 2. 5Gbps and higher the wavelength center of FP laser goes out of wavelength tolerance.

Not suitable for long distances.

With the improvement in VCSEL's technology, applications of 1310 nm and 1550 nm applications are moving from FP laser to VCSEL.

A. 3. Future directions and Applications

Increase in bandwidth up to 15 GHz (the running value) by reducing low frequency roll off & parasitic effects of bias circuits by injection locking [7].

FP lasers can generate single longitudinal mode laser [8].

FP lasers external optical modulator for optical access network [9].

Spectral width of FP laser allows transmission to distances of 40 Km at 1. 7 Gbps.[5]

FP offers Corse wavelength division multiplexing (CWDM) with channels at 1. 3Î¼m and 1. 5Î¼m simultaneously on a single fiber [5].

FP lasers offer benefits in LAN that use one wavelength per fiber [6].

FP laser can be used as multi wavelength source of Amplified Spontaneous Emission (ASE) for spectrum sliced [5].

The 1550 nm FP laser can support Synchronous Optical Network (SONET) [6].

A. 4. Commercial availability of FP lasers

Multiple Application Platform (MAP) FP laser [9] is FP laser source with key features like single mode or multi mode output, internal modulation, LAN extensions for instrumentation (LXI) compliant etc. This device has weight of almost of half kilo gram & is capable of operating on different optical fibers such as Flexcor™ and SMF-28 [10] with operational temperature range of 10â °C to 40â °C. This product is commercially available.

B. Distributed feedback (DFB) lasers

In FP laser there is feedback of light from the mirrors, this light feedback can be provided in distributed manner by series of closely spaced mirrors/reflectors (means there is a periodic variation in the width of the cavity). There is a corrugated section in the cavity; the incident light passes through section causes series of reflections. If the corrugation period is the integral multiple of half wavelength (Bragg condition) the resulting transmitted wave will add in phase. This mechanism suppresses other longitudinal modes and allow only single longitudinal mode whose wavelength is equal to twice the corrugation period. [11]

Figure. 2. DFB laser structure [4]

B. 1. Advantages

DFB lasers provides better wavelength stability than cleaved end face laser [12]

The line width of DFB is less than that of reflective end face lasers [12].

Low chirp [13]

Better wavelength selectivity.

DFB laser is used in high performance system because of its narrow spectral output width [6].

B. 2. Disadvantages

The amplitude of the standing wave is fixed because of gratings

Emitted wavelength near threshold current cant be controlled [14]

Wavelength chirp is associated with the spatial burning of the carrier holes.

Some values of rare facet phase give unacceptable performance.

B. 3. Future directions and applications of Distributed feedback (DFB) lasers

All optical flip-flop is one of the building block for fast optical packet switching as it temporary stores the header information while the payload is routed to the correct output port. Single distributed feedback (DFB) laser diode based, all optical flip flop can be used to serve this purpose. Experimental results shows that DFB lasers can provide optical memory in an economical way and at the same time shows fast switching of optical packets (as low as 45 ps can be achieved). Using DFB lasers as an all optical flip flop 40 Gbps can be switched. [15]

Used in DWDM system where tune ability of signals are required.

Used in the sensing of extreme narrow line width of the signal.

B. 4. Commercial availability of Distributed Feedback laser

The production of Quantum dot pure Green laser [16] is possible by using DFB laser technology. DFB laser gives high reliability for optical communication to form quantum dot crystal with a wavelength of 1064nm [16]. There is significant amount of reduction in power consumption for converting 1064nm quantum dot laser from electricity to light by the use of DFB laser.

C. Multi Quantum well (MQW) lasers

In Quantum well lasers the active region is very narrow which causes quantum confinement to occur. The wavelength which emits is dependent on the width of the active region rather than the band gap. This feature gives shorter wavelength than conventional lasers [17].

Figure. 3. Cavity structure of MQW laser [4]

C. 1. Advantages

Enhanced gain due to quantum well structure and gain co-efficient is usually 3 times or more than single layer FP laser [13]

Produce shorter oscillation wavelength

Smaller linewidth enhancement factor (Î±), at larger linewidth enhancement factor the laser instability is enhanced [13].

Small optical losses

Better confinement of laser actions because of multiple active regions.

Low threshold current

High modulation speed

Low temperature dependency

C. 2. Disadvantages

The internal structure of MQW laser is designed such that it is more susceptible to back reflections.

C. 3. Future directions and Applications

Modulating retro reflector combines optical retro reflector and optical modulator (MQW lasers).

Strained quantum well technology can become the core technology for high performance semiconductor device by expanding the flexibility of band engineering [18].

Optical repeaters, as it gives saturated output power to about 3dBm.

C. 4. Commercial availability of MQW lasers

SANYO GaAlAs index guided laser diodes with MQW structure, these are infrared powerful lasers source [19] of maximum power up to 200mW and wavelength range of 782nm to 830nm is commercially available.

SONY GaAlAs index guided laser diodes with MQW structure; these are infrared powerful lasers source [19] gives optical power range from 90mW up to 60W. This huge optical output power gives high brightness.

D. External Cavity Diode Lasers (ECDL)

ECDL can also be used to achieve the single longitudinal mode wavelength. ECDL is a semiconductor based laser with one end of the laser diode has anti reflective coating and laser resonator is completed with collimating mirror and external mirror.

As they are tunable lasers so for wavelength selection they use diffraction gratings. End mirror contains collimating lens and diffraction grating. The anti reflective coated end of the diode gets feedback from the diffracted beam. Tuning of the emitted wavelength is done through the rotation of the diffracting grating. There is some more variation for this setup. [11, 20]

Figure. 4. EDCL setup Ref: www. clu-in. org

D. 1. Advantages

Side mode suppression ratio (SMSR) is better than -40 dB and has narrow intrinsic line width

Pulse repetition rate can easily be selected [21]

Filter can be inserted for the fixing of emission wavelength in mode locked diode laser [21] etc.

D. 2. Disadvantages

The direction of output beam changes by rotating the diffraction grating which not suitable for many optical communication applications.

In fixed direction of the output beam, the zero order reflection of the beam bounced by the mirror is lost.

D. 3. Future directions and applications

Tunable continuous wave THz radiation can be generated by the use of dual mode ECDL from 250 MHz to several THz [22]

Without mode hopping wavelength tuning over 40 nm around 1550 nm is expected by new configuration of EDCL with all dielectric thin film Fabry Perot filters. [23]

Atomic clock: ECDL is used in the optical system of the atomic clock; it is used for the cooling and the detection of clock transition. [24]

Mode locked ECDL are mostly used in optical communication (DWDM) for data transmission. [21]

Testing and measurement in optical fiber communication

Non-linear frequency conversion.

D. 4. Commercial availability of ECDL

TEC-100 and TEC-120 [25] External cavity diode Littrow laser system gives optical output power up to 200mW and running range (mod-hop free) up to 30GHz.

DLX-100 [26] External cavity tunable diode gives output power up to 1W and mod-hop free tuning up to 15GHz.

E. Vertical Cavity Surface Emitting Lasers (VCSEL)

VCSEL achieves single longitudinal mode operation in different manner. The active region is placed between two highly reflective surfaces/mirrors. These two reflective surfaces have alternated high and low refractive index. The reflectivity of the surfaces is between 99. 5-99. 9% that is why light oscillates perpendicularly through the layers and emits from the top or the bottom of the device. [27]

E. 1. Advantages

It has high wavelength stability

It is less sensitive to temperature (can operate reliably up to 80 â 🚺 °C)

Less refrigeration is required for VCSEL as it operation do not emit much heat.

It provides high powered per unit area (up to 1200W/cm2)

It emits circular beam as a transmitter which leads to small optical loss.

Figure. 5. VCSEL structure [4]

E. 2. Disadvantages

Because of high mirror reflectivity in the VCSEL internal structure lowers the optical output power.

They emit low output power (in mW) because of their small active medium volume.

InP based VCSEL suffers from having low conduction band offset, low conduction band offset means low confinements of electron which results improper temperature stability of active material gain.

To produce longer wavelength in VCSEL, mechanism of double fusion is used. This mechanism increases the cost as it is complicated procedure [28].

E. 2. Future directions and applications of Vertical External Cavity Surface-Emitting Laser (VECSEL) [20, 32]

There is an issue of optical power supply for Si-photonics transceiver which are being developed for high density optical interconnect on parallel processors can ideally solved by VECSEL as the emits in 1330 nm and 1550 nm. [29]

High speed modulation up to 25 Gb/sec can be achieved by using VCSEL at low current of 7. 4 KA/cm2. [30]

Fast modulation frequency (in GHz) made its use in optical fiber communication as transmitter

Ideal for local and metro area networks as they produce low output power.

Threshold less laser [31] etc…

E. 3. Commercial availability of (VCSEL)

VCSEL technology has flourished and gives wide range of products with ultra low noise, narrow line width, high optical output power (up to 1kW) and high speed modulation (speed > 5GHz) [27].

For high optical output power up to 1KW, a module for cooling of this system is used and fiber is pigtailed for high brightness VCSEL array.

VCSELs are commercially available in blue, green and UV lasers [27].

iii. Comparison of semiconductor lasers

In this section DFB, ECDL, MQW and VCSEL are compared with respect to different parameters and their suitability as optical transmitter in different optical networks.

Parameters

Tuning agent

Output power (in dBm)

Tuning speed

Modulation speed

Lasers

DFB

Temperature

13

Slow (m-sec)

Fast (multi-GHz)

MQW

Quantum confined stark effect

~7

Fast(<1ns)

Fast(multi-GHz)

VCSEL

MEMs

Optically pumped 6

Electrically pumped -3

Fast(Î¼-sec)

Fast (few GHz)

ECDL

Peizo transducer

~13

Slow(m-sec)

Slow (Table. 1: Comparison of semiconductor lasers

Table. 1 shows relative analysis of semiconductor lasers. Each semiconductor laser has got competitive advantage with respect to different parameter.

Table. 2 gives a comprehensive view of the semiconductor lasers and their application in a specific network type as an optical transmitter.

Semiconductor Laser

Network type

FP laser

Short to medium range (Local & Metro) Networks

DFB Laser

Long haul network

MWQ Laser

Short to medium range (Local & Metro) Networks

ECDL

Long haul network

VCSEL

Short to medium range (Local & Metro) Networks

Table. 2: Semiconductor lasers with their network type support

Lasers

Max spectral output width

FP

5 nm

VCSEL

0. 5 nm

DFB

0. 1 nm

Table. 3: Spectral width comparison of short range lasers

Spectral output width measure the range of the wavelengths produce by a laser. From table. 3 it is evident that DFB laser has the narrowest spectral output width, which makes DFB laser the best choice for high performance short range optical transmission systems.

iv. Conclusion

This paper gives a review on the semiconductor lasers, their working, applications, commercial availability and future directions. Relative analysis of these lasers shows that they have competitive advantage in one or other laser parameters and this analysis also shows that which semiconductor laser is appropriate to which type of optical network. Semiconductor lasers have wide applications in optical fiber communication. Lots of exciting research is going on in this field and there is still room of improvements.