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Invited

Widely Tunable VCSEL Using Micromechanical Structures

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1. Introduction

Semiconductor diode lasers have become by far the most widely available and most important lasers. In addition to transforming the consumer electronics industry, the advances in diode lasers have enabled the communications industry to expand their service capabilities to meet the escalating bandwidth demand triggered by recent explosive growth of internet applications.

In this talk, we will review a new type of laser which provides wavelength tunability through the use of an integrated micromechanical tunable structure. The novel fabrication technique enables record performance in lasers with wavelength engineerablity, which makes them well-suited for wavelength-division-multiplexing (WDM) ultrahigh bandwidth optical communication applications.

2. Vertical Cavity Surface Emitting Lasers

A vertical-cavity surface-emitting laser (VCSEL) is a particular type of a semiconductor diode laser which is becoming increasingly more important. A VCSEL's cavity is perpendicular to the wafer plane, which thus guides its optical beam in the vertical direction. This is in contrast with the conventional diode lasers, which have a horizontal cavity and emit beams in the direction parallel to the wafer plane.

A VCSEL typically has its two mirrors and active region (sandwiched in-between) all grown by a single-step epitaxy on a 2-3" diameter substrate. The typical size of a VCSEL can be 10 μm in diameter and 6 μm in thickness, and the chip size is larger for handling purposes. Once the wafer is grown, the lasers can be fabricated via processing steps similar to those for IC (integrated circuits) fabrication. The processing and testing are all performed in a wafer scale, completely eliminating the labor-intensive steps required for edge-emitting lasers. This property makes VCSELs highly attractive for low-cost manufacturing and promising for achieving new functionalities via integration with other devices. For many, VCSEL is a dream come true; it is the MOSFET [1] of diode lasers.

3. Wavelength Engineering of VCSEL

A VCSEL array with 140 uniformly-spaced distinct wavelengths was demonstrated [2] in 1990, marking the beginning of wavelength-engineering of VCSEL and VCSEL for wavelength division multiplexed (WDM) systems [3]. Such a monolithic array emitting distinct, designed wavelengths is referred to as a multi-wavelength laser array.

WDM is one of the most expedient methods to increase the transmission capacity of a given transmission medium, such as an optical fiber. By transmitting signals in N channels (wavelengths) through one single fiber, the aggregate bandwidth can be increased by a factor of N without the need of physically increasing the number of fibers. WDM systems are now being rapidly deployed in telecommunication systems at 1.55 μm wavelength regime.

The VCSEL structure is ideal for wavelength engineering. The VCSEL has an ultrashort cavity length, more than two orders of magnitude shorter than an edge-emitting laser, and thus typically has only one Fabry-Perot (longitudinal) mode (within the laser gain bandwidth), which determines the lasing wavelength. Thus, by varying the cavity length slightly, the lasing wavelength can be varied accordingly. This presents an excellent and unique opportunity for engineering wavelength-tunable lasers.

4. Wavelength-Tunable VCSEL

Wavelength-tunable VCSEL were first made using the well-known effects such as carrier plasma effect, thermal effect, etc. However, it was clear that none can vary wavelength as effectively and over as large a range as physical change of the cavity length itself, which can be accomplished by moving the VCSEL's top mirror via a micromechanical structure. Shown in Figure 1 is a schematic of a micromechanical tunable VCSEL, with its entire mechanical structure made of GaAs/AlGaAs epitaxial material with very high thickness precision.

An air-gap was made in the VCSEL cavity by selective removal of some of the epitaxy material. Thus, most of the VCSEL's top DBR is suspended above the rest of the heterostructure and is supported by a cantilever. A voltage is applied to the two contacts surrounding the air-gap, which makes the cantilever move up and down to vary the gap size and thus the VCSEL cavity length. A third contact is used to inject current into the active region beneath the air-gap. A very wide, nearly continuous tuning range of 32 nm was achieved, as shown in Fig. 2. The VCSEL also exhibits excellent and uniform light-current characteristics over the entire tuning range with ~1 mA threshold current and 1 mW output power under CW room temperature operation. [5]

Figure 3 Scanning electron micrograph picture of a micromechanical tunable VCSEL. The VCSEL cavity includes an airgap and a DBR, which is suspended above the rest of the heterostructure and is supported by a cantilever. The airgap is created by selective removal of GaAs sacrificial layer.

5. Conclusion

Tunable VCSEL with nearly continuous tuning of 32 nm was demonstrated with uniform tuning characteristics. We believe this structure will create a major impact in the design of tunable lasers.

References

1. MOSFET stands for metal-oxide-semiconductor field effect transistor. This transistor structure facilitated a large scale integration and high tolerance manufacturing, two key factors that triggered the integrated circuits revolution.
2. C. J. Chang-Hasnain *et. al.* , IEEE J. Quantum Electron, vol. 27, No. 6, pp. 1368-1376, 1991.
3. C. J. Chang-Hasnain, *et. al.*, Electronics Lett., vol. 26, No. 13, pp. 940-1, 1990.
4. W. Yuen, G. S. Li, and C. J. Chang-Hasnain, IEEE Journal of Selected Topics in Quantum Electronics on Semiconductor Lasers, vol. 3, 2, pp 422-8, 1997.
5. M. Y. Li *et. al.*, IEEE Photonics Technology Letters, vol. 10, 1, pp. 18-20, 1998.

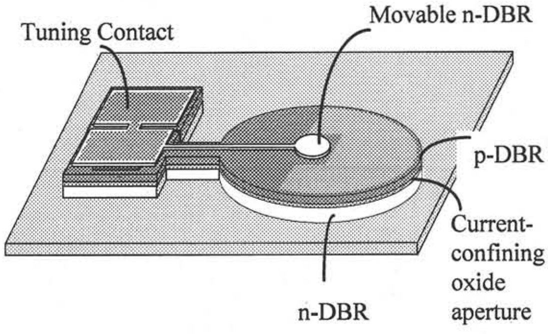

Fig. 1 Tunable VCSEL schematic

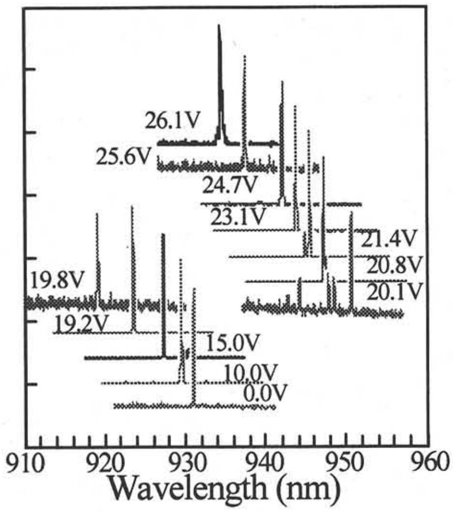

Fig. 2 Tuning spectra: widest tuning range was achieved for a VCSEL.

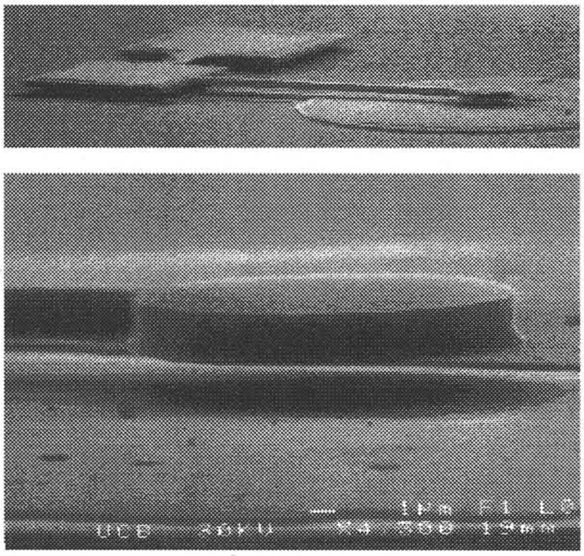

Fig. 3 Scanning Electron Micrograph of the tunable VCSEL (top) and close-up picture of the cantilever head (bottom)