Wavelength control of MEMS VCSELs

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Abstract

Our recent research activities on the wavelength control of MEMS VCSELs will be reviewed. This talk explores the potential and challenges for new functions of VCSELs, including the wavelength athermalization and tuning with a micromachined structure.

Introduction

The temperature dependence of single-mode semiconductor lasers, which is typically 0.1nm/K, is a remaining problem to be solved. The elimination of costly thermoelectric controllers is desirable for use in low cost WDM networks. If it is realized, we expect low power consumption as well as small packages. We proposed an athermal VCSEL with a fixed wavelength even under temperature changes using the self-compensation based on a thermally actuated cantilever structure[1]. The structure is based on micromachined tunable VCSELs[2]. We have demonstrated small temperature dependence in micromachined vertical cavity optical filters and light emitters of GaAs/GaAlAs materials [3, 4]. It is a challenge to realize an athermal and tunable VCSEL based on the proposed concept.

In this paper, we present the athermal and tunable operation of semiconductor lasers using a micromachined VCSEL structure. In addition, we will describe "gain-matched" VCSELs for ultra-wide temperature operations.

Device Structure

Figure 1 shows the principle of athermal operations and the schematic structure of a micromachined VCSEL[5]. The base structure of the devices was grown in Corning Incorporated, and is similar to that of InP-based VCSELs with tunnel junction[6]. The cantilever is a 5.5-pair GaInAsP/InP DBR which was grown on a GaInAs sacrificial spacer layer above the active region. A 3-pair Si/SiO$_2$ dielectric mirror was deposited on the head of the cantilever. To realize athermal operations, a λ/2-thick InP and a λ-thick InP thermal strain control layers are added on the top and the bottom of the cantilever, respectively, to produce an asymmetric cantilever structure. Because GaInAsP has a larger thermal expansion coefficient than InP, we are able to obtain the thermal actuation of the cantilever for compensating the temperature dependence of wavelength.

The SEM view of a micromachined InP-based VCSEL is shown in Fig. 2. The mesa formation of the dielectric top mirrors was carried out by reactive ion etching (RIE). After patterning the cantilever structure using inductively coupled plasma dry etching, the GaInAs sacrificial layer was etched-off to release freely suspended InP/GaInAsP cantilevers.

We also fabricated an athermal and tunable 850 nm VCSEL[7]. The device consists of a top GaAlAs MEMS mirror, an active region including GaAs three quantum wells and an AlGaAs bottom p-DBR including an oxide aperture, which provides optical and electrical confinement. The top MEMS mirror is a freely suspended cantilever-shaped AlGaAs n-DBR including Al$_{0.85}$Ga$_{0.15}$As thermal stress control layer at the bottom.

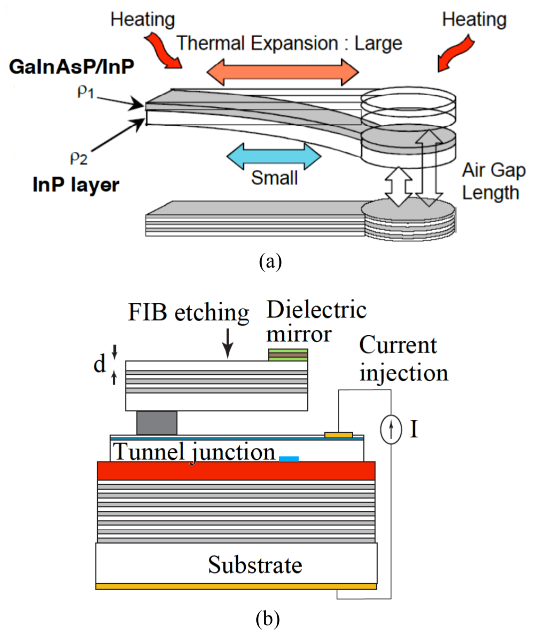

Fig.1 (a) Principle and (b) schematic structure of athermal VCSEL with a micromachined cantilever structure [5].

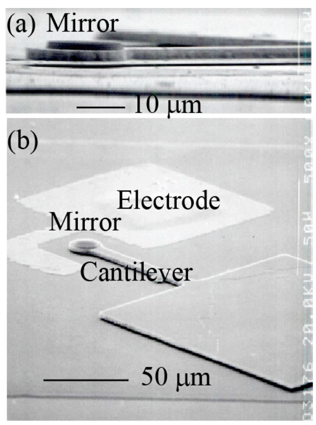

Fig. 2 SEM image of athermal InP-based VCSEL with a thermally-actuated cantilever structure [5].

Athermal and Tunable Operations

Figure 3 shows the measured lasing spectra at different temperatures for a 1550nm athermal VCSEL[5]. The lasing wavelength could be locked within 0.03 nm for temperature changes of 19K with a cantilever length of 95 μm and the lowest temperature dependence we achieved is as low as 0.0016nm/K. We also realized the athermal operation for 850 nm VCSELs[7]. The wavelength of the transverse-mode could be locked for temperature changes of 17K and the temperature dependence is as low as 0.002nm/K, which is 40 times smaller than that of conventional VCSELs. The active region and the cantilever structure are almost thermally isolated, which enables us to realize the wavelength tuning by changing the injection current in the active region. We obtained continuous wavelength tuning of 1 nm using an electro-thermal tuning scheme. The result shows a possibility of athermal VCSELs with wavelength tuning.

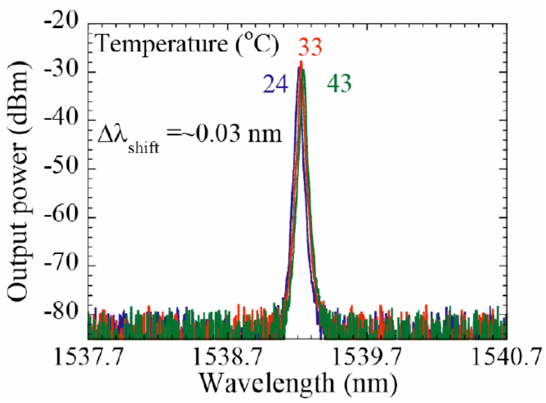

Fig. 3 Temperature dependences of lasing spectra [5].

Gain-matched VCSELs

We proposed a novel gain-matched VCSEL[8] with a thermally actuated cantilever structure, which enables the lasing wavelength to be matched with a gain peak wavelength even under wide temperature changes. We are able to increase the temperature dependences of lasing wavelengths by designing the cantilever structure. In the case of conventional VCSELs their temperature dependence of lasing wavelength (typically 0.07 nm/K) is much smaller than that of a gain-peak wavelength (typically 0.3 nm/K for 1.1 μm VCSELs). Thus large detuning among them deteriorates the modal gain with temperature changes. If the lasing wavelength can be matched with a gain-peak wavelength even under temperature changes, this deterioration can be avoided. Thus, the temperature dependence is similar to that of Fabry-Perot edge emitting lasers. Various laser performances such as thresholds and modulation bandwidths can be improved in our gain-matched VCSELs. The modeling result shows a potential of wide temperature operations of over 200K as shown in Fig. 4.

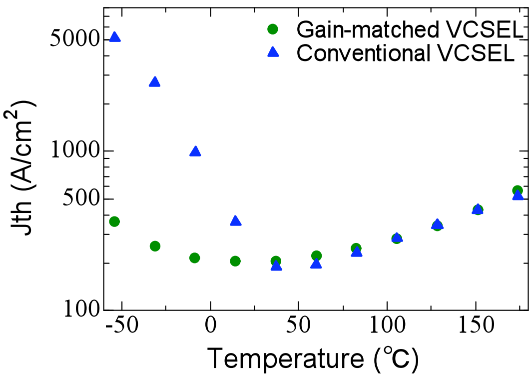

Fig. 4 The calculated temperature dependence of threshold current density with gain-matched VCSEL and conventional VCSEL [8].

Conclusions

We presented the design and the experiment on athermal and tunable MEMS VCSELs. The temperature dependence is 40 times smaller than that of conventional single-mode VCSELs. In addition, wavelength tuning of 1 nm was obtained with changing drive current at the same time. By making temperature controllers unnecessary, our athermal and tunable VCSEL may enable low power consumption and size reduction of transceivers for WDM applications. In addition, we proposed a novel concept of "gain-matched" VCSELs which allow the lasing wavelength to be perfectly matched with a gain-peak wavelength even under wide temperature ranges.

Acknowledgment

This work was partly supported by National Institute of Information and Communications Technology.

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