

Electro-thermal tuning of MEMS VCSEL with giant wavelength-temperature dependence

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Abstract: We demonstrate the electro-thermal tuning of a MEMS VCSEL with a thermally actuated SiO_2 /semiconductor cantilever. The wavelength-temperature dependence of the MEMS VCSEL could be increased as large as 0.46 nm/K, which is 6 times larger than that of conventional single-mode lasers. A micro-heater is integrated nearby the cantilever structure. A continuous wavelength tuning range of 4.7 nm is obtained with heating power of 29 mW.

Keywords: vertical cavity surface emitting laser (VCSEL), tunable laser, micro-machine, thermal stress, cantilever

Classification: Optoelectronics, Lasers and quantum electronics, Ultrafast optics, Silicon photonics, Planar lightwave circuits

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1 Introduction

A tunable vertical cavity surface emitting laser (tunable VCSEL) [1, 2] is a good candidate as a light source for use in wavelength division multiplexing optical interconnects, gas sensing [3] and optical coherence tomography (OCT) [4]. Since a VCSEL has a very short cavity, a slight change of a cavity length gives us continuous and wide wavelength tuning. There have been different wavelength tuning schemes such as MEMS VCSELs [1] and electro-thermal tuning VCSELs [5]. We demonstrated the giant temperature dependence of wavelength for a VCSEL with a thermally actuated cantilever [8, 9]. If we use such a highly temperature-dependent VCSEL for electro-thermal tuning, the power consumption for wide wavelength tuning can be decreased. In this paper, we present the electro-thermal tuning of a VCSEL with a thermally actuated mirror exhibiting a large temperature dependence of 0.46 nm/K.

2 Fabrication of an electro-thermally actuated MEMS VCSEL

Figure 1 (a) shows the cross sectional structure of a VCSEL having a cantilever-shaped mirror. The structure is the same as a micromachined tunable VCSEL except the structure of the cantilever. It consists of a SiO₂ loaded semiconductor cantilever, an air gap, an Al_xO_y anti-reflection layer, GaAs/AlGaAs quantum wells, an oxide confinement layer, and a bottom DBR. The role of an Al_xO_y anti-reflection layer is to improve the tuning efficiency of wavelengths associated by the displacement of a cantilever structure [10, 11]. Since the coefficient of thermal expansion of SiO₂ is about ten times smaller than that of AlGaAs DBR, the thermal stress is induced by the temperature change of the cantilever, which leads to the deflection of the cantilever and hence the change of the cavity length. Therefore, we can change the lasing wavelength by heating the cantilever. The temperature





dependence of the lasing wavelength is determined by structure parameters of the cantilever: the cantilever length and the ratio of SiO_2 thickness and semiconductor DBR thickness [6].



Fig. 1. (a) Cross sectional structure of a tunable VCSEL having an electro-thermally actuated cantilevershaped mirror. An n-doped layer is inserted between SiO2 layer and AlGaAs DBR so that only the cantilever can be heated by Joule heat generated by applying an voltage between the electrodes. (b) Scanning electron microscope of the VCSEL with 70 μ m-long SiO2 loaded cantilever structure. A 2 λ -thick air-gap is formed between the top mirror and active region by selective chemical etching of a sacrificial layer.

Figure 1 (b) shows the scanning electron microscope image of a fabricated micromachined VCSEL. An n-type doped layer shown as "heating layer" in Fig. 1 (a) is inserted between SiO₂ layer and DBR so that we can heat only the cantilever with Joule heat that is generated by applying a voltage between the two electrodes, which are shown as "heating layer contact" in Fig. 1 (b). The Joule heat has no influence on lasing characteristics since there is sufficient distance between the active region and the heating region (~100 μ m). The thermal isolation between the active region and the heating part is large enough. The cantilever length ranges from 60 μ m to 120 μ m. It is monolithically fabricated. The fabrication process is in the following: a SiO₂ strain control layer is deposited on a VCSEL wafer by RF sputtering at the first step of the process. Next, cantilevers and mesas are defined with a standard photolithography followed by inductive coupled plasma etching with Cl₂ gas. Then, an Al_{0.98}Ga_{0.02}As layer is selectively oxidized under H₂O





vapor to form oxide confinement structures. Electrodes for current injection into an active region and a heating layer are formed at the same time. Finally, a GaAs sacrificial layer under the cantilever is selectively etched and the cantilever is released.

3 Measurement

An experimental setup for wavelength tuning is shown in Fig. 2 (a). The device was placed on a $3 \text{ cm} \times 3 \text{ cm}$ copper plate, and the temperature of the device is fixed at 20°C by a Peltier device. Figure 2 (b) shows the I-L-V characteristic of the fabricated device. The threshold current is 4 mA and the maximum output power is 1.4 mW at the bias current of 11 mA. The high threshold current is partly due to the large diameter of an oxide aperture (>6 μ m), which can be reduced. Its slope efficiency can also be improved by optimizing the top mirror reflectivity. Two independent voltage sources are used for injecting current in an active region and for heating the cantilever, respectively. Figure 2 (c) shows the lasing spectra of the fabricated device with a 100 μ m-long cantilever. Several transverse modes can be seen due to its large oxide-confinement aperture (>6 μ m), but quasi-single mode operation was obtained.

We measured the temperature dependence of lasing wavelengths as shown in Fig. 3 (a). Laser operating current was fixed at 8 mA. Large wavelength shift of 10 nm was observed for temperature changes of 22 K thanks to the thermal actuation of the MEMS mirror. The measured temperature dependence is as large as 0.46 nm/K, which is 6 times time larger than that of conventional VCSELs. The solid line of Figure 3 (a) shows the calculated temperature dependence of the resonant wavelength with a thermally actuation of the cantilever structure. The displacement of a cantilever is calculated under the assumption that the thermal expansion coefficient of SiO₂ and Al_{0.85}Ga_{0.15}As/Al_{0.2}Ga_{0.8}As DBR are 0.5 ppm/K and 5.7 ppm/K, respectively. The measured result is in good agreement with the calculation.

We carried the electro-thermal tuning experiment. Laser operating current was also fixed at 8 mA. Figure 3 (b) shows the lasing spectra for different heating powers in the heating element. Figure 3 (c) shows the lasing wavelength as a function of heating power. Lasing wavelength red-shifted with increasing the heating power and continuous wavelength tuning of 4.7 nm was obtained with heating power of 29 mW. Assuming the mirror is uniformly heated up, the temperature change is estimated to be 10 K. In the current device structure, most of heat is spread into a substrate, and thus the heating of the cantilever is not efficient. The present electrical power consumption can be reduced by optimizing the path of heating current. In addition, we are able to increase the temperature dependence of wavelength by increasing the stress control layer and increasing the cantilever length since we predicted a giant temperature dependence of over 3 nm/K [9]. The device measured in Fig. 3 (a) is different from the device in Figs.3 (b) and (c). Those lasing wavelengths are different. This would be due to on-wafer variation in cantilever







Fig. 2. (a) Measurement setup, (b) I-L-V characteristic of the device and (c) lasing spectrum.

lengths and layer thicknesses.

4 Conclusion

We experimentally demonstrated a tunable VCSEL with an electro-thermally actuated mirror. A large temperature dependence of 0.46 was obtained, which is 6 times larger than that of conventional VCSELs. Continuous wavelength tuning range of 4.7 nm was demonstrated with heating power of 29 mW. Further optimizations on our thermally-actuated cantilever VCSEL having higher temperature dependences and efficient heating structure would enable lower power consumption and widely tunable operations for ultra-high capacity WDM optical links and for high resolution real time OCT imaging.







Fig. 3. (a) Lasing wavelength shift due to thermal actuation of the MEMS mirror. 0.46 nm/K and $\sim 10 \text{ nm}$ of wavelength shift was obtained, (b) lasing spectra under various conditions of heating power and (c) lasing wavelength as a function of heating power.

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