Electro-thermally Tunable 850nm VCSELs with metal/semiconductor Thermally Actuated Mirror

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Abstract

We report on an electro-thermally tunable 850nm VCSEL, exhibiting a large negative wavelength drift of 2.0nm/K. Continuous and linear wavelength tuning of 25 nm was obtained with heating power of 9.4 mW.

I. INTRODUCTION

A tunable vertical cavity surface emitting laser (VCSEL) is a good candidate for light source for use in short-distance wavelength division multiplexing (WDM) networks and bio-imaging applications[1]. There have been different wavelength tuning schemes such as micro-machined VCSELs [1] and electro-thermal tuning VCSELs [2]. We demonstrated a possibility of increasing the temperature dependence of wavelength by introducing a SiO2/AlGaAs monolithic cantilever structure [3]. In this paper, we demonstrate a VCSEL with a metal/semiconductor cantilever structure for efficient electro-thermal wavelength tuning.

II. MEMS VCSEL WITH METAL/SEMICONDUCTOR BIMORPH MIROMACHINE MIRROR

The schematic cross-section of a VCSEL with a thermally actuated metal/semiconductor cantilever mirror is shown in Fig. 1. It consists of 18.5 pair AlGaAs top DBR, 9/4 λ-thick air gap, Al2O3 anti-reflection layer, λ- cavity including GaAs/AlGaAs five quantum wells, oxide confinement layer and 40 pair AlGaAs bottom DBR. The top mirror is supported by a cantilever beam which is composed of semiconductor DBR (AlGaAs) and metal (gold) film. Since the coefficient of thermal expansion (CTE) of gold is around three times larger than that of AlGaAs DBR, a slight change in temperature of the cantilever induces its deflection, resulting in change in cavity length of the VCSEL. A metal heater is integrated into the cantilever for electro-thermal wavelength tuning.

We formed a T-shaped air-bridge structure [4] right under the micro-heater to avoid heat spreading to a substrate.

The tip deflection of the cantilever per temperature change depends on its structural parameters, i.e., length, thickness ratio of metal and semiconductor, and difference of their CTEs. Thus, we are able to increase the temperature dependence of thermal actuation for efficient electro-thermal wavelength tuning.

Wavelength shift Δλ due to change in cavity length Δd can be approximated as Δλ = λL_{eff} × Δd, where Δd is change in air gap thickness and L_{eff} is the effective cavity length that includes the penetration of optical field into DBRs. Figure 2 shows the calculated wavelength shift of the MEMS VCSEL as a function of temperature. We can expect a tunable range of 35 nm caused by temperature changes of 20 K in a cantilever having a 150 μm-long cantilever. The tuning range is limited by free spectral range (FSR) of the cavity that can be expanded with a shorter cavity design for future work.

III. ELECTRO-THERMAL TUNING

We fabricated MEMS VCSELs that have various cantilever lengths from 60 to 160 μm with a 170 nm-thick Au strain control layer. The scanning electron microscope image of a device is shown in Fig. 3. The measured temperature dependence Δλ/ΔT is shown in Fig.4 as a function of cantilever lengths. It is successfully controlled from -0.24 to -2.0 nm/K by changing the cantilever length. It is noted that the temperature dependence is proportional to the square of the cantilever length as shown in Fig. 5. While the measured result is two times larger than calculated values, it might be due to uncertainty of the thickness of deposited metal or its material constants.

We carried out electro-thermal tuning of wavelength by heating the cantilever using integrated micro-heater. The electro-thermal tuning characteristic of a MEMS VCSEL having a 100 μm-long cantilever with a 170 nm-
thick strain control layer is shown in Fig. 6. Thanks to large temperature dependence $\Delta \lambda / \Delta T$, continuous and linear wavelength tuning of 25 nm was obtained with heating power as low as 9.4 mW. The tuning efficiency, which is defined as wavelength shift per heating power, also can be controlled by changing the cantilever length as shown in Fig. 7. For example, a tuning efficiency of -4.7 nm/mW was obtained with a 120 µm-long cantilever.

**IV. CONCLUSION**

We demonstrated a giant wavelength-temperature dependence of a tunable VCSEL employing a thermally actuated and monolithically-integrated cantilever for efficient electro-thermal tuning. We experimentally demonstrated temperature dependence of -0.24 to -2.0 nm/K, which is $3 \sim 28$ times larger than that of conventional VCSELs. As a result, the tuning efficiency could be increased to 4.7 nm/mW. The tuning efficiency can be further improved by making the heating element smaller, which enables low power consumption tunable lasers.

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**REFERENCES**


