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# Polarization-stabilized single-mode vertical-cavity surface-emitting lasers

Ki Soo Chang, Young Min Song, and Yong Tak Lee
Gwangju Institute of Science and Technology, 1, Oryong-dong, Buk-gu, Gwangju , Korea, 500-712
Tel: +82-62-970-2206, Fax: +82-62-970-3128, Email: ytlee@gist.ac.kr

**Abstract**

We developed polarization-stabilized single-mode vertical-cavity surface-emitting lasers (VCSELs) with a side mode suppression ratio of over 35dB and orthogonal polarization suppression ratio of over 14dB for the entire drive current range by introducing a mode selective aperture (MSA) and asymmetric current injection (ACI).

## 1 Introduction

Vertical-cavity surface-emitting lasers (VCSELs) have become a vital optical component in short distance optical data communication applications, such as local area networks (LANs), storage area networks (SANs), and parallel optical interconnects [1]. In recent years, VCSELs extend their application area to various non-communication fields, such as bio-sensors, gas sensors, atomic clocks, laser mouse sensors, and proximity sensors [2]. May of these applications require single-mode and stable linearly polarized output beam. However, the standard oxide-confined VCSEL designs typically lead to lase in multiple transverse modes due to the large effective index step induced by the low refractive index of the Al-oxide layer. Furthermore, the light from VCSELs do not has a well-defined linear polarization state due to the isotropic material gain and symmetric device geometry.

In this presentation, we report a simple and robust technique for obtaining a single-transverse-mode and polarization-stabilized operation of an oxide-confined VCSEL by introducing a combination of a mode selective aperture (MSA) and asymmetric current injection (ACI).

## 2 Device structure and fabrication

For experimental confirmation of the proposed idea, we fabricated oxide-confined ACI VCSELs with an MSA as shown in Fig. 1 and Fig. 2. Asymmetric current injection (ACI) structure by restricting p- and n-contacts to the opposite side of the mesa provides an asymmetric gain for two orthogonal polarization states. For conduction and heavy hole band transition, the transition probability becomes a maximum when the angle between the momentum vector of electron and the electric field polarization of emitted photon is $90^o$ [3]. Therefore, perpendicular polarization to the current path is preferred in ACI VCSELs. For the suppression of high-order modes, we introduced MSA in the top DBR mirror. The MSA, formed naturally in the top DBR during the selective oxidation step for the current aperture (CA) formation, provides a large optical loss in the outer region of the top mirror. If the MSA diameter is larger than the fundamental mode width and smaller than the high-order mode width, only the lasing threshold for the high-order mode becomes high. Thus, a VCSEL with an MSA can maintain a stable fundamental mode operation.

We measured the near-field profile to investigate the spatial intensity distribution of the transverse modes in the VCSEL. The full width at half maximum (FWHM) of the fundamental mode and lowest high-order mode are 4.3 and 8.4 μm, respectively, for VCSEL with CA of 5μm. In order to experimentally confirm the validity of the proposed concept, VCSELs with MSA of 7μm and CA of 5μm in diameter were fabricated and characterized.

The epitaxial layer is a typical structure for 980nm intracavity-contacted oxide-confined VCSELs. However, the epitaxial layer structure is not optimized yet for high-power single-mode operation because 45nm-thick oxidation layers for current aperture are located in the middle of the node and antinode of standing wave pattern [4]. The CA and MSA were formed simultaneously in the wet thermal oxidation furnace at a temperature of 400 °C. Standard intracavity-contacted VCSEL processing was used to fabricate ACI VCSELs with MSA without additional process steps due to the simultaneous formation of MSA and CA via single step oxidation by properly controlling the mesa diameters.

## 3 Results

Fig. 3 shows CW lasing spectra and light output characteristics of fabricated ACI VCSEL with MSA at room temperature. Completely stable single-mode operation was achieved with side mode suppression ratio (SMSR) of over 35dB for entire drive current range. Relatively high threshold current and low slope efficiency can be attributed to the increase of optical loss not only for high-order transverse mode but also for fundamental mode. Single-mode operation for entire current range and small slope efficiency indicate that the maximum single-mode output power can be increased by optimizing the MSA diameter relative to the CA diameter. Fig. 4 shows polarization resolved output power and orthogonal polarization suppression ratio (OPSR) versus current. The ACI VCSEL with an MSA clearly exhibits a dominant polarization perpendicular to the current path as expected. The maximum OPSR is 17dB at 7mA. The difference between the total output power and the sum of the powers in both polarizations is due to the loss by collimation optics and polarizer.

The most obvious advantage of fabricating polarization-stabilized single-mode VCSELs using this method is that standard VCSEL processes can be used without any additional process steps.

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## 4 References

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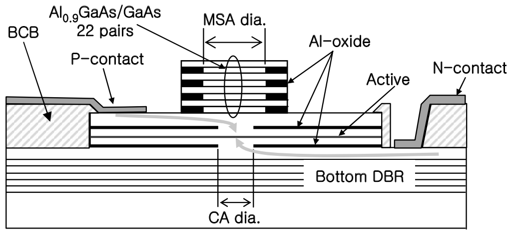


Fig. 1. Schematic diagram of the asymmetric current injected (ACI) VCSEL with a mode selective aperture (MSA).

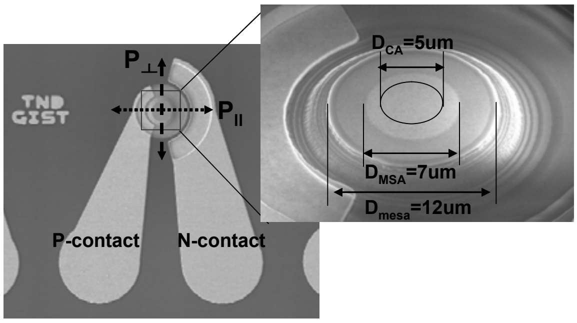


Fig. 2. SEM images of the fabricated ACI VCSEL with MSA.

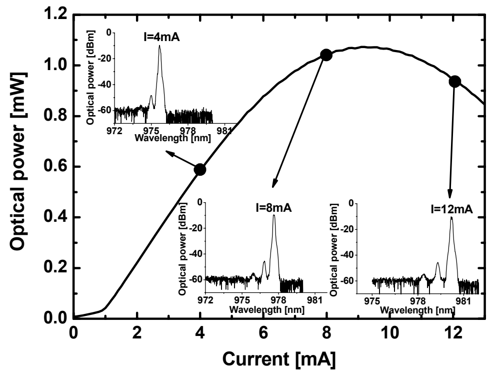


Fig. 3. LI characteristic for the ACI VCSEL with CA and MSA of 5 and 7μm in diameter, respectively. Inset: Current dependent emission spectra.

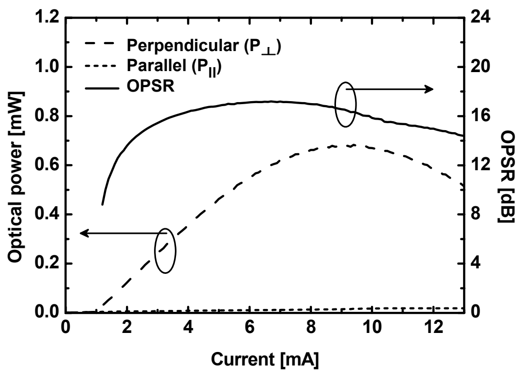


Fig. 4. Polarization resolved output power and OPSR versus current.