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# Highly Stable Operations of High Speed Transverse Coupled Cavity VCSELS

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## Paper Summary

We report the highly temperature stable operation of 980nm transverse coupled cavity VCSELS for optical interconnects. The device shows the bandwidth enhancement at 25 Gbps from 0°C to 60°C without adjustment of the driving conditions.

## Introduction

Recently, a high-speed and highly-energy efficient light source has been a key of optical interconnects in data centers and supercomputers and so on. VCSELS have been playing as a major role for these giant data center networking. The modulation speed of VCSELS is essentially limited by their relaxation oscillation frequencies (ROF) and their parasitics [1]. In order to boost the modulation speed far beyond the ROF, we proposed and demonstrated a VCSEL using a transverse coupled cavity (TCC) [2-4], which exhibited the record 3-dB bandwidth of over 29 GHz and 27 GHz for multi-mode (MM) and quasi-single mode (QSM), respectively. We also observed large signal modulation up to 36 Gbps which was mainly limited by the measurement set-up, while the eye was completely closed for VCSEL without feedback even at 30 Gbps. The basic concept of the bandwidth enhancement is based on the photon-photon resonance in the coupled cavity [5,6]. However, a major concern is the stability on operating conditions such as changes in ambient temperature and driving currents.

In this paper we demonstrate the highly temperature stable operation of high-speed 980 nm transverse coupled cavity VCSELS with the enhancement of modulation bandwidth. The device shows the stable operation at 25 Gbps from 0°C to 60°C without adjustment of the driving conditions.

## Structure

Figures 1 (a) and (b) show the schematic structure and SEM image of a fabricated TCC-QSM VCSEL, respectively. The base epitaxial structure is the same as that of conventional 980 nm InGaAs/GaAs QWs VCSELS. The bottom mirror consists of a 41.5-period Si-doped  $\text{Al}_{0.92}\text{Ga}_{0.08}\text{As}/\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}$  DBR. The active region has three  $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}/\text{GaAs}$  quantum wells embedded in one- $\lambda$  cavity. The top mirror consists of a 26-period carbon-doped  $\text{Al}_{0.92}\text{Ga}_{0.08}\text{As}/\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}$  DBR. Lateral optical confinement is formed using an oxide layer and the lateral bow-tie connection of two cavities leads to a leaky travelling wave in the lateral direction from the VCSEL into the feedback cavity. A

small bow-tie shape oxide-aperture illustrated in Fig. 1(b) enables a quasi-single mode operation [4].

## Results

Figure 2 (a) shows the high-speed measurement set-up with temperature elevation. A deriving current is injected only in the laser cavity side, while the electrical leakage is suppressed below 1  $\mu\text{A}$  thanks to the proton implantation at the center region of the joint connection between the two cavities. Lateral optical coupling takes place to the feedback cavity and makes the feedback to the VCSEL cavity, Figure 2(b) shows 25 Gbps non-return-to-zero (NRZ) eye patterns for VCSELS with and without optical feedback with a word length of  $2^{31}-1$  while an injected currents into a VCSEL cavity was fixed at 5.5 mA for the both cases (with and without optical feedback). The voltage swing was fixed at 400 mVpp. As shown in Fig. 3(a) we measured the spatially-resolved intensity from the VCSEL side with various temperatures from 0°C to 60°C. Figure 3 (b) shows the NRZ eye patterns for the VCSEL with feedback from 0°C to 60°C with data rates of 25 Gbps and voltage swing of 600 mVpp. The NRZ eye was completely closed for the VCSEL without feedback at 25 Gbps, we could see clear eye opening for the VCSEL with feedback up to 60 °C. Figure 4 shows the measured eye patterns with various VCSEL injected currents from 4 mA to 10 mA with a step of 0.5 mA. The results indicate that the bandwidth enhancement of the transverse coupled cavity VCSEL is less dependent on injected currents and temperatures.

## Conclusions

We demonstrated a high speed 980 nm TCC-QSM VCSEL with highly temperature stable modulation characteristics, operating at bit rates of 25 Gbps in a wide temperature range from 0°C to 60°C without adjustment of the driving conditions. The results show that the bandwidth enhancement is not sensitive to the driving conditions of the TCC VCSEL.

## References

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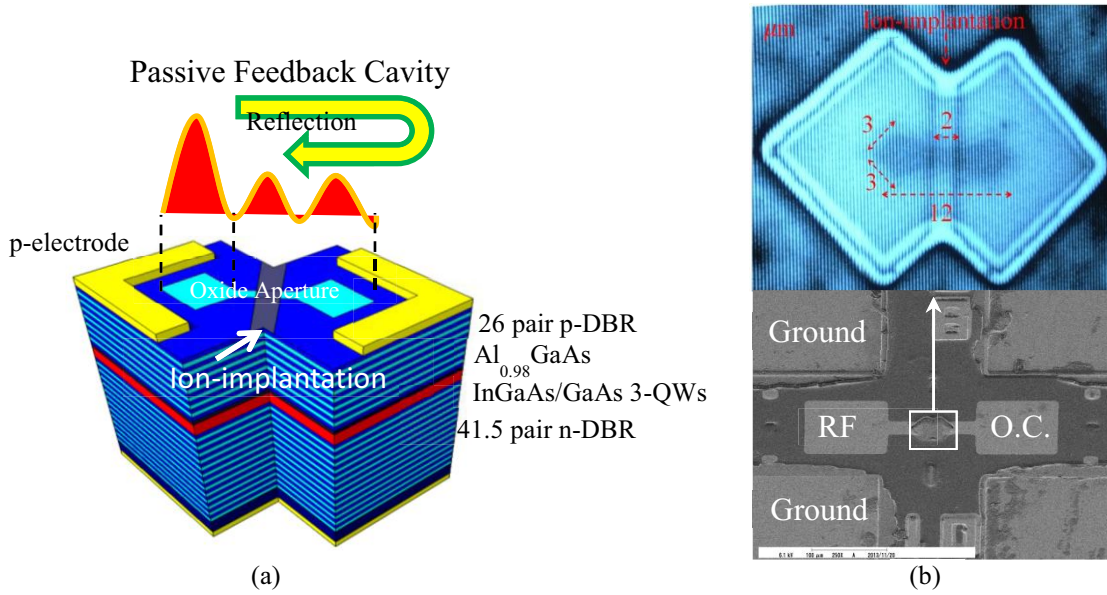


Fig. 1 (a) Schematic cross-section and (b) the top view SEM image of the transverse coupled-cavity VCSEL with oxidation formation shape.

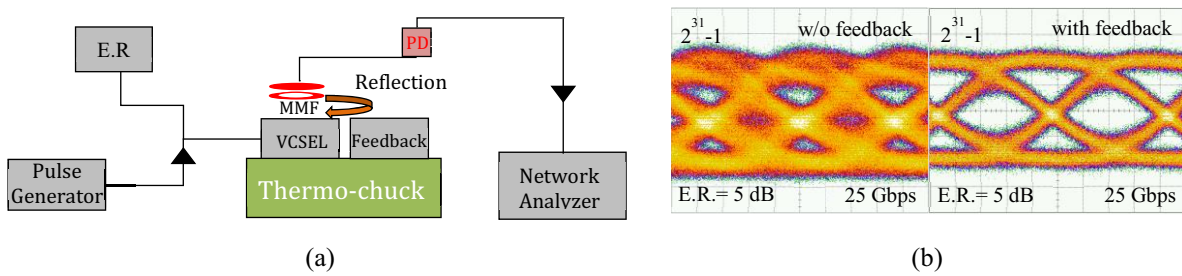


Fig. 2 (a) Measurement set-up (b) 25 Gbps eye patterns with an extinction ratio of 5 dB, PRBS of  $2^{31}-1$  and bias current of 5.5 mA for the both cases with and without optical feedback.

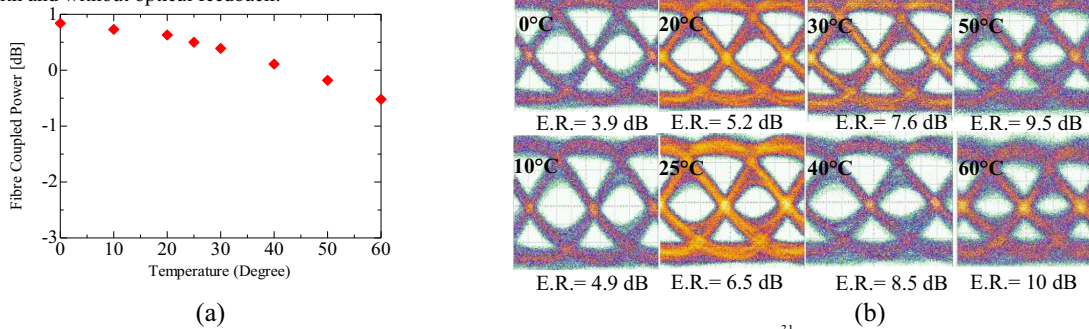


Fig. 3 (a) Spatially resolved fiber coupled power, and (b) NRZ, 25 Gbps eye pattern with PRBS of  $2^{31}-1$  and bias current of 7.8 mA, while the temperature is altered from 0 to 60°C.

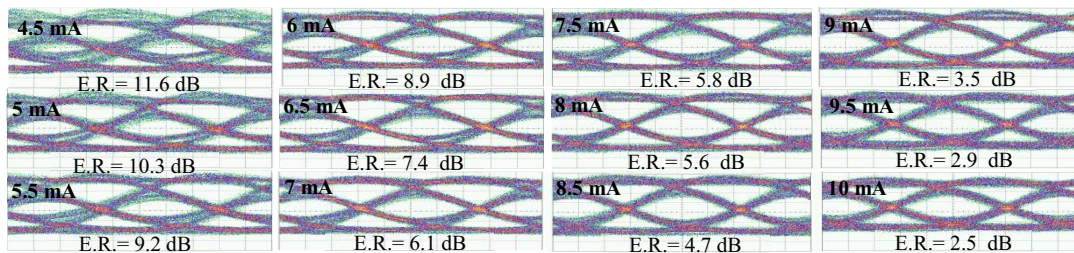


Fig. 4 NRZ eye pattern at 25 Gbps with a PRBS of  $2^{31}-1$  and bias current of VCSEL from 4.5-10 mA with step of 0.5 mA at RT.