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Lens-integrated surface-emitting DFB laser arrays for short-reach optical links

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1. Introduction

With the rapid growth in internet data traffic, the performance of information communication technology (ICT) equipments such as edge routers, servers, high-speed switches, and will be limited by the interconnection bandwidth between chassis, racks, boards, and even between chips. Higher power dissipation in circuits to compensate higher dielectric transmission loss becomes a serious bandwidth bottleneck in implication of contemporary electrical interconnects over the bit ratio of 20 Gb/s per lane.

Optical parallel interconnects are very promising for overcoming such short-reach bandwidth problems because they offer higher data density, longer link distance, and lower power dissipation than electrical interconnects thanks to less transmission loss and less susceptibility to inter-channel cross talk.

Vertical-cavity surface-emitting lasers (VCSELs) are a promising light source for such optical parallel interconnects. Their advantageous features are the easy construction of 1D or 2D arrays, narrow circular beams, and low power dissipation. VCSELs are also advantageous in commercial products because they allow wafer-scale manufacturing and testing. Recently, the high-speed and high-temperature performances of VCSELs have significantly advanced in the wavelength range from 0.85 to 1.1 µm (Fig.1) [1] [2].

In contrast, for a wavelength of 1.3 µm, over 20-Gb/s operation at an elevated temperature (> 85°C) is still a challenge. However, choosing this wavelength enables us to use cost-effective single-mode fibers as well as the wavelength-division multiplexing (WDM) technique, which can achieve a drastic increase in the transmission data rate per fiber. Moreover, a 1.3-µm wavelength is preferable in terms of link power budget because a longer wavelength photodiode has higher resonsivity. Therefore high-speed surface-emitting lasers in the 1.3-µm wavelength are of great interest.

We thus developed a new 1.3-µm surface-emitting laser, namely, a lens-integrated surface-emitting laser (LISEL), that enables uncooled 25-Gb/s operation with a 1.3-µm surface emission. It consists of a short InGaAlAs multiple-quantum-well (MQW) distributed-feedback (DFB) active-stripe, a 45° total-reflection mirror, a monolithic lens, and flip-chip bondable electrodes. The laser beam produced in the DFB active stripe is internally reflected at the 45° mirror and emitted through the lens.

The short InGaAlAs-MQW DFB active stripe provides very-high-bit-rate operation at elevated temperatures through to the strong electron confinement in the InGaAlAs MQW. Furthermore, as a result of the monolithic integration of the total-reflection mirror and the aspheric lens, a very narrow circular output beam is obtained in the wafer-normal direction. We demonstrated a very narrow far-field angle of 2° leading to a high-efficiency direct fiber coupling [3] and an uncooled 25-Gb/s direct modulation of LISELs at 100°C [4].

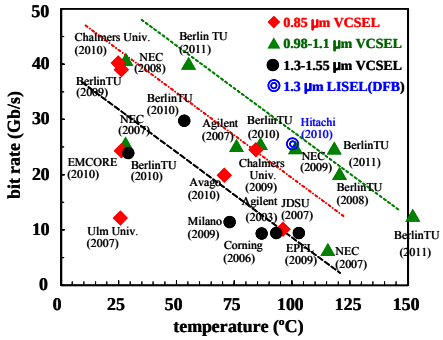

Fig. 1 Recent progress in high-speed VCSELs including our new 1.3-µm lens-integrated surface-emitting laser (LISEL).

In this paper, our recent progress with multi-channel LISEL arrays is described. A four-channel LISEL array for multi-fiber data transmission was fabricated, and it exhibited all-channel 25-Gb/s operation with collimated optical output. Furthermore, a multi-wavelength LISEL array for WDM applications was developed. This laser array emits in wavelengths ranging from 1260 to 1290 nm with a side mode suppression ratio of 42 dB over all nine channels. Clear 25-Gb/s eye openings at 25°C were demonstrated.

2. Device design

A schematic image of the multi-channel LISEL array is shown in Fig. 2. The array consists of InGaAlAs-MQW DFB active stripes, monolithic 45° total-reflection mirrors, monolithic aspheric lenses, and flip-chip bondable electrodes. Short DFB cavity ranges from 100 to 150 µm with a high-index corrugation grating (κ = 200 cm^{-1}) are adopted on the basis of our high-speed design, and the spacing between the DFB stripes is set to 250 µm. The p-type clad-

ding and the active layers are partly removed so that an n-electrode is formed directly on the revealed n-InP surface. This electrode structure has the advantage of low parasitic capacitance and low intra-chip cross talk.

A multiple-wavelength LISEL array for WDM applications, based on the same array design as described before, was also fabricated. The pitch of the corrugation grating was modified by electron-beam lithography to provide precise wavelength emissions from each stripe.

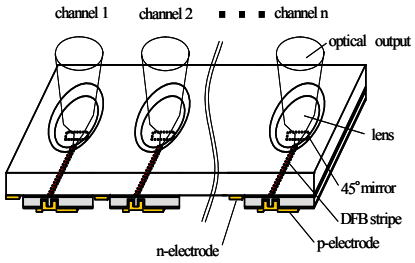

Fig.2 Schematic structure of LISEL array

3. Device characteristics

Four-channel LISEL array

The measured light-current characteristics of the fabricated four-channel laser array with a 100-μm cavity at 25°C are shown in Fig. 3. This array had a low average threshold current of 6.5 mA that ranged from 6.0 to 6.8 mA due to a short cavity and high-index corrugation grating. Single-longitudinal-mode operation with a side-mode suppression ratio of more than 40 dB on each channel was achieved in the 1.3-μm range (see inset of Fig. 3).

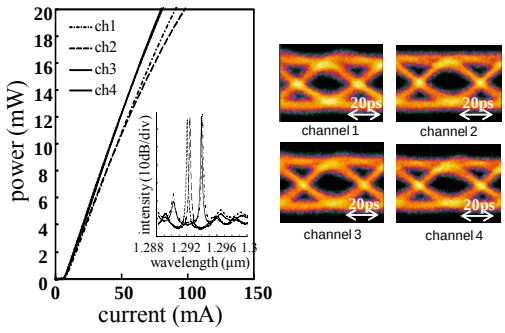

Fig.3 Left: Light-current characteristics of four-channel LISEL array. Inset show the spectrum of each channel. Right: 25-Gb/s eye-diagrams at 50 °C

The measured optical eye diagrams for each channel at a bit rate of 25 Gb/s at 50°C are shown in Fig.3. The center bias current was 45 mA, and the peak-to-peak modulation voltage was 0.7 Vpp for each channel. All eyes were clearly open. The low-current low-voltage performance of each channel was due to the short cavity with high-index grating and the low-impedance flip-chip structure.

Multi-wavelength LISEL array

The lasing spectra of a nine-channel laser array measured at 25°C under continuous-wave (CW) conditions at an output power of 3 mW are shown in Fig. 4. These spectra indicate that the lasers had stable, single-longitudinal-mode characteristics with side-mode suppression ratios of more than 42 dB over all nine channels. The emission wavelengths of the nine lasers at 25°C range from 1260 to 1290 nm at 3.7-nm intervals. We believe this superior single-mode yield was due to the self-phase adjustment at the cleaved facet.

A 25Gb/s eye-diagram at 25°C is also shown in Fig.4 Clear 25-Gb/s eye openings were obtained with the center-bias current and the peak-to-peak modulation current were low at 40 and 30 mA, respectively.

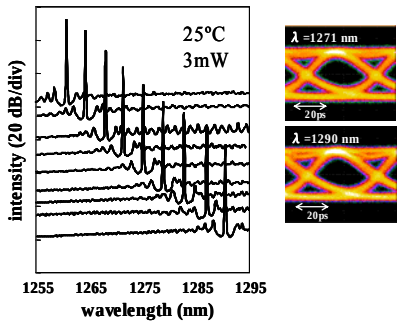

Fig.4 Left: Lasing spectra of nine-channel array under CW operation at 25°C. Right: 25-Gb/s eye diagrams in back-to-back configuration at 25°C.

3. Summery

Recent progress in our multi-channel 1.3-μm lens-integrated surface-emitting laser arrays was reported. A four-channel laser array exhibited low threshold currents (6.5 mA on average), high side-mode suppression ratios (> 40 dB), and clear 25-Gb/s eye openings over all channels. A multiple-wavelength array for WDM applications emitted in wavelength ranges from 1260 to 1290 nm with a side-mode suppression ratio of 42 dB over all nine channels, and it demonstrated clear 25-Gb/s eye openings at 25°C. These multi-channel arrays can provide a compact and low-power-consumption light source for short-reach optical links.

Acknowledgements

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References

[1] P. Westbergh et al., *Proc of International Semiconductor Laser Conf.*, (2010) WC2.

[2] W. Hofmann et al., *Proc. Optical Fiber Communication Conf.*, OTuP2, 2010. (2011) PDPC5.

[3] K. Adachi et al., *Proc. Optical Fiber Communication Conf.*, (2009) JThA31.

[4] K. Adachi et al., *Conf. Lasers and Electro-Optics/Quantum Electron. and Laser Sci. Conf.*, (2010) CME4.