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1060nm Single-mode Bottom Emitting VCSEL Array with Intra-cavity Metal-aperture for Multi-core Fiber Co-packaged Optics Transceivers

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Abstract

We demonstrate 1060nm 16 channels bottom emitting VCSEL arrays with intra-cavity metal-aperture. The metal-aperture enables the single mode operation with large oxidation apertures and the bandwidth enhancement. Thanks to the transverse response, the 3dB small signal response reaches over 20 GHz.

1. Introduction

With the fast development of 5G, cloud computing, streaming and social networking, the Internet traffic keeps a high growth rate. According to some reports, more than 99% network traffic is related to datacenters [1] and nearly 75% of data center traffic is inside data centers [2]. Multi-mode 850 nm vertical cavity surface emitting lasers (VCSEL) and multi-mode fibers (MMF) are the main choice in the present short-reach optical interconnection inside data center. However, the transmission distance in hyper-scale data centers is needed to be over 1km and 850 nm VCSELs are no longer acceptable because of large dispersion and attenuation loss [3]. In addition, Co-packaged optics (CPO) has been attracting much attention in data centers and edge computing networks since CPO brings optics much closer to switch ASICs in a single package, so that power consumption could be saved by reducing the reach [4]. A VCSEL gives us high-speed and low-power consumption [5], which will meet requirements in CPO. The NICT project toward high-speed and low-power consumption CPO transceivers based on VCSEL array and multi-core fiber (MCF) was started [6], which could deliver advantages on power consumptions and capacity density per module.

A flip-chip and bottom-emitting VCSEL platform shown in Fig. 1 [6] enables reducing the electrical connection to a VCSEL driver array. On the other hand, the modulation bandwidth of VCSELs is typically restricted to typically less than ~ 20 GHz because of the limited intrinsic carrier-photon resonance [5]. We demonstrated a coupled-cavity VCSEL for pushing the modulation bandwidth [7]. However, a common difficulty in coupled cavity lasers is a stability and reproducibility. Very recently, we demonstrated intra-cavity metal-aperture (MA) VCSELs for single-mode and high-speed operations, including >5km single-mode fiber transmission thanks to their single-mode and low chirp operations [8-10].

In this paper, we demonstrate 16-ch bottom emitting VCSEL arrays with intra-cavity metal-aperture structure based on a full 3-inch wafer process, exhibiting the single-mode operation with a large mode filed diameter for the low loss direct lens-less coupling to MMF.

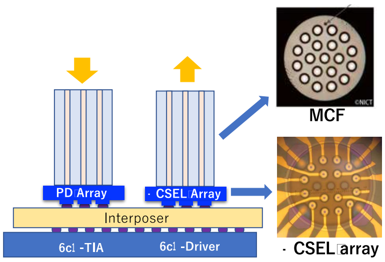

Fig. 1 CPO transceiver based on VCSEL array and MCF [6].

2. Structure

The photo of the 16-ch bottom emitting VCSEL array chip is shown in Fig. 2(a). The VCSEL array is fabricated by a full 3-inch wafer foundry process. The total chip size is as small as 1x1 mm^2. The 16-ch VCSELs are arranged under the hexagonal layout with spacing of 40 μm as matched to the core layout of MCF. The schematic of bottom emitting MA-VCSEL is shown in Fig. 2(b). The active region consists of three $In_{0.25}Ga_{0.75}As$/GaAs quantum wells and the emitting wavelength is adjusted at 1060 nm. The reflectivity of the 10-pair SiO_2/Ta_2O_5 DBR is as high as 99.96%. The reflectivity of the 22-pairs bottom DBR is 99.25%. The GaAs substrate was polished with a thickness of below 100 μm. Then, AR coating was carried out on the substrate back surface to reduce the reflection for direct coupling to MMF.

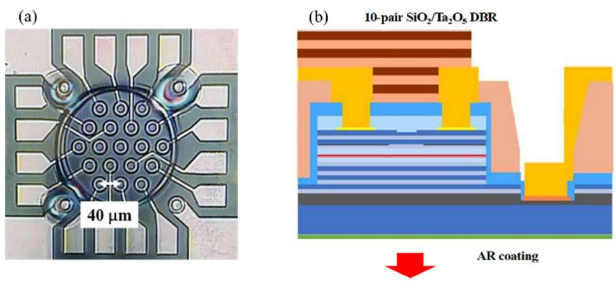

Fig. 2 (a) Photo of 16-ch bottom emitting VCSEL array and (b) schematic of bottom emitting VCSEL with intra-cavity metal aperture.

3. Results

The superimposed IL characteristics of all 16-ch VCSELs are shown in Fig. 3. The series resistance is as small as 80 Ω thanks to a large oxide aperture of around 7 μm, which is comparable to 850nm multi-mode VCSELs. The threshold current is as low as 0.7 mA. The typical output power at the current of 6 mA is 1.8 mW and the slope efficiency is approximately 0.3 W/A which could be improved by adjusting the pairs of DBR.

The lasing spectra of the 16-ch VCSEL array are shown in Fig. 4. The devices show single mode operations for the entire current range from 2 mA to 10 mA, thanks to the transverse resonance in the intra-cavity metal-aperture structure. The side mode suppression ratio is over 30 dB.

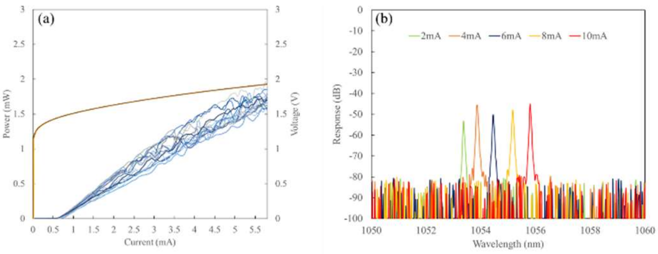

Fig. 3. (a) Superimposed IL characteristics of 16-ch array and (b) Lasing spectra at different currents.

Figure 4 shows the measured near field pattern (NFP) at 6 mA, exhibiting a single-lobe profile with a mode field diameter of 5.6 μm. Based on our previous calculation, the lensless low coupling loss of below 1dB with SM-MCF is expected when a substrate thickness of below 100 μm.

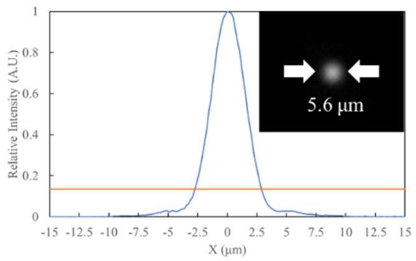

Fig. 4. Near field pattern.

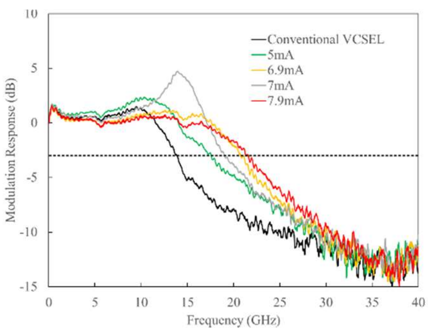

Fig. 5. Small signal modulation response of bottom emitting MA-VCSEL array in comparison with conventional multimode VCSEL.

We also realized the bandwidth enhancement of single mode VCSEL array with intra-cavity metal-aperture by the modification of a DBR layer structure to enhance the transverse resonance. The small signal modulation response of the bottom emitting MA-VCSEL array is shown in Fig. 5 in comparison with conventional multi-mode 1060 nm VCSEL. The modulation bandwidth is increased from 14 GHz to 22 GHz thanks to the transverse coupled cavity effect.

4. Conclusion

We demonstrated 16-ch bottom emitting MA-VCSEL based on full 3-inch wafer process, enabling flip-chip bonding for use in compact CPO transceivers. The spacing between each adjacent VCSELs is 40 μm and the total size of chip is as small as 1 mm^2. With the intra-cavity metal-aperture, single mode operations were obtained with large oxidation apertures of 7 μm, which is important for high reliability. Also, the bandwidth enhancement was observed thanks to the coupled cavity effect. The surface relief engineering provides higher data rates of over 50 Gbps we recently demonstrated [11]. We could expect an overall data rate of 800 Gbps and 1.6 Tbps in our VCSEL-based CPO transceivers, increasing a channel bit rate up to 50 Gbps NRZ and 100Gbps PAM4, respectively.

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