16-ch 1060-nm Single-mode Bottom-emitting Metal-aperture VCSEL Array for Co-packaged Optics

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Abstract: We demonstrate 16-ch 1060-nm bottom-emitting metal-aperture VCSEL array for co-packaged optics transceivers. The transverse-control and bandwidth-enhancement is realized thanks to coupled cavity. A record bandwidth and fiber distance product of 250Gbps・km is obtained.

1. Introduction

850nm VCSELs have been widely used in optical interconnects for use in datacenters and HPC [1]. However, global data traffic is increasing due to the development of big data, online video, website reading and could services. Longer optical interconnects are also becoming important in hyper-scale datacenters and inter-datacentre connections. It is hard to increase the link length for 850-nm band multi-mode VCSELs because of the large dispersion and attenuation loss [1].

In addition, for high-speed transmission, signal attenuation caused by the electrical wiring becomes a large issue. Co-packaged optics (CPO) are focusing on the high-integrated electrical-optical connection [2]. Optical devices can be placed much closer to the switch ASICs within the package, which brings low power consumption and small footpring. Thanks to the high-speed and low-power consumption of VCSELs, CPO transceivers based on VCSEL array and multi-core fiber (MCF) are expected to play an important role in future datacenter and edge computing networks because of their ultrahigh data rates density per space [3].

The modulation bandwidth of VCSELs is limited by the limited intrinsic carrier-photon resonance [4]. Recently, we demonstrated intra-cavity metal-aperture (MA) VCSELs for increasing the modulation speed. Thanks to the optical-transverse resonance, MA VCSELs can realize single-mode and high-speed modulation with large oxidation aperture which is good for optical coupling and for reliability. The wavelength of 1060-nm band enables lower dispersion and lower losses of fibers. Benefit from the single-mode, longer wavelength and low chirp operations, >5km single-mode fiber transmission was achieved [5-7]. Also, we demonstrated 1060nm VCSELs with surface relief engineering to provide transverse-resonance in transverse-coupled cavity VCSELs [8].

In this paper, we demonstrate a 16-ch bottom-emitting MA VCSEL array based on a full 3-inch wafer process. It has a good uniformity of single-mode operation and modulation bandwidth. The 50Gbps transmission through 5km-long standard 1,300nm SMF is exhibited.

2. Structure

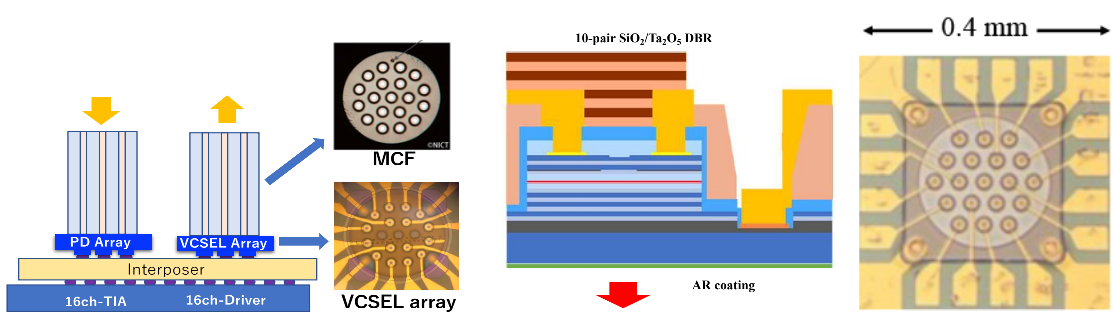

Fig. 1 (a) Schematic of VCSEL CPO transceiver, (b) Schematic of 1060nm bottom emitting metal aperture VCSEL, (c) Photo of 16-ch VCSEL array.

Figure 1 (a) shows the conceptional schematic of 16-ch VCSEL CPO transceiver with 19 core-MCF(Multi Core Fiber). The 1st-gen offers 400Gbps with 25Gbps/per channel. The schematic of bottom-emitting metal-aperture VCSEL is shown in Fig. 1 (b). We used standard 3-inch wafer VCSEL foundry process. Extra 10 pairs SiO_2/Ta_2O_5 DBR provides a 99.96% reflectivity at the top. The reflectivity of the 22 pairs bottom DBR is 99.25%. Through wet-oxidation process, an oxidation aperture is formed with the target diameter of 6 µm. The boundaries between oxidation aperture and metal contact are as small as 1 µm to realize the transverse resonance [5]. The substrate is transparent and is polished with a thickness of below 100 µm for high lens-less coupling to MCF. AR coating is deposited on the back surface to avoid the reflection. The photo of 16-ch bottom-emitting VCSEL array is shown in Fig. 1 (c). The chip size is as small as 0.16 mm^2. Thus, the data rate density per area is as large as 2.5 $Tbps/mm^2$. The distance between each adjacent channels is 40 µm and a multi-core fiber is fabricated with the same hexagonal layout. The fabricated VCSEL array is flip-chip boned with Si-interposer. Flip-chip bonding process enables reducing the electrical connection distance to reduce the signal attenuation. The CPO transceiver packaging is ongoing by our collaborator.

3. Results

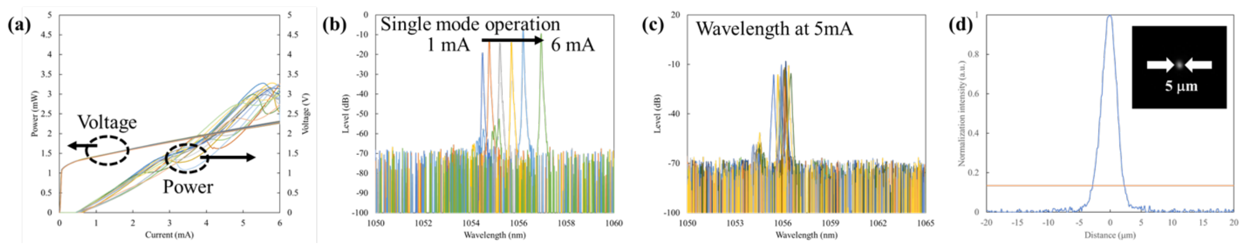

Fig. 2 (a) Superimposed 16-ch I-V-L curves; (b) Spectra at currents from 1 mA to 6mA; (c) Superimposed 16-ch spectra at 5 mA; (d) Near field pattern at 3 mA.

Thanks to the full 3-inch wafer process, all 16 channels in the array show similar performance. The superimposed 16-ch I-V-L curves are shown in Fig. 2 (a). Even expanding an oxidation aperture to 6 µm which is the same as 850nm multi-mode VCSELs, all channels show single-mode operations. The operation voltage at 6mA is as low as 2.2 V. The single-mode output power is typically 3 mW. The threshold current is 0.6 mA.

Single-mode operations are obtained with a high SMSR over 40 dB as shown in Fig. 2 (b). The superimposed spectrum of all 16 channels at 5 mA is shown in Fig. 2 (c). All channels can work at the same wavelength at 1057 nm. The near field pattern (NFP) is 5 µm which is close to the designed value. The expected lens-less coupling loss through a 100um thick substrate is 2 dB.

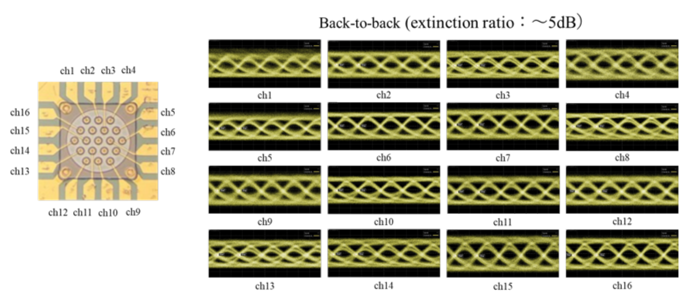

Fig. 3 Eye patterns at 25 Gbps for all 16 channels.

The eye patterns for all 16 channels are shown in Fig. 3. For back-to-back transmission, eye patterns are clearly open at 25 Gbps with the extinction ratio of 5 dB. The total modulation speed of this 16-ch VCSEL is 400 Gbps per module. In previous research, based on the calculation results, bandwidth enhancement was expected after transmission in standard SMF due to the pulse compression [9,10]. Here we show the calculated and measured transfer function of our devices for 5-km SMF transmission and 10-km SMF transmission as shown in Fig. 4 (a). For SMF transmission over 5km, 3dB bandwidth is over 25 GHz and it gives the potential of 50 Gbps (NRZ) and 100 Gbps (PAM4) signal transmission which is suitable to meet the requirement of intra-datacenter.

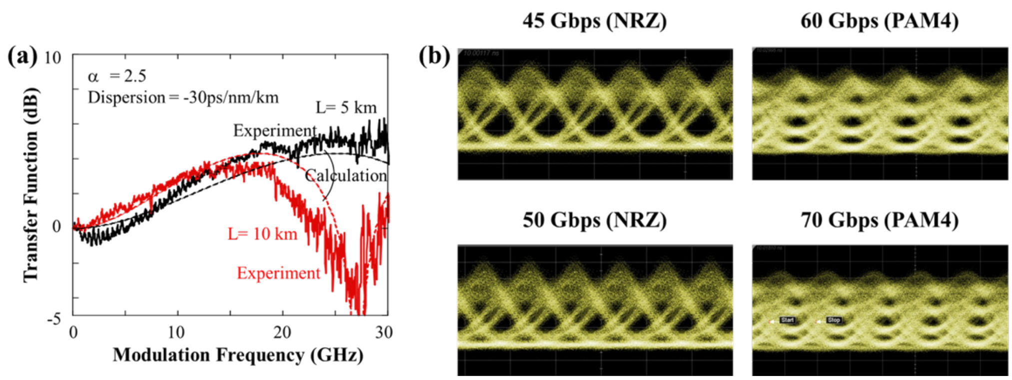

Fig. 4 (a) Calculated and measured transfer function for 5-km and 10-km standard SMF (G652) transmission; (b) Eye patterns after 5-km SMF transmission.

We carried out the eye pattern measurements after 5-km 1,300nm standard SMF(G652) transmission. We observed eye openning at 50 Gbps (NRZ) and 70 Gbps (PAM4) without pre-equalization. The bandwidth and distance product is over 250 Tbps･km which is 25 time larger than 850 nm VCSEL/MMF links.

4. Conclusion

We demonstrate the 16-ch bottom-emitting VCSEL array with metal-aperture structure. This VCSEL array could be fabricated based on the standard VCSEL fabrication platform. Thanks to the transverse resonance, single-mode operations for all 16 channels are obtained even for an oxidation aperture of 6 μm. The total modulation speed is over 400 Gbps per module, resulting in 2.5 Tbps/mm^2. After 5km SMF transmission, we show the 50 Gbps (NRZ) and 70 Gbps (PAM4). The CPO transceiver packaging with 19-core MCF is ongoing by our collaborator. We expect to realize a 100 Gbps (PAM4) transmission per channels and then the total bandwidth will reach at 1.6 Tbps per module. Further scalability up to 3.2 Tbps or 6.4 Tbps could be expected increasing the number of MCFs.

Acknowledgement

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