Multi Aperture High Power 100G Single Mode 850nm VCSEL for Extended Reach 800G Ethernet

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Abstract: The paper presents multi-aperture single mode 850nm VCSEL with optical modulation bandwidth exceeding 30GHz and narrow optical spectrum width enabling long distance high-speed data transmission exceeding 800m over OM4 multi-mode fiber.

1. Introduction

The current development of short wavelength vertical cavity surface emitting lasers (VCSELs) focuses on two main branches: 1) development of the devices meeting IEEE 400G Ethernet standard which are mostly multi-mode devices and transmitters modules based on them [1,2]; 2) single mode short wavelength VCSELs meeting the IEEE 400G standard as well but providing extended reach over multi-mode fiber compared to multi-mode VCSEL devices [3-5]. When, in terms of bandwidth, multi-mode (MM) and single-mode (SM) devices provide very similar performance the main difference is found to be in their optical output power (P) and the optical spectral width (RMS / λrms). The former (P) allows for higher power budget but it is the latter (RMS) which contributes to the limitations in the data transmission distance. Multi-mode devices, while having high output power suffer from having large spectral width that limits the transmission distance due to the dispersion related effects in the optical fibers. On the contrary, the single mode devices have low spectral width and thus can extend the transmission distance, but usually suffer from low output power.

In this paper we present a multi aperture single-mode 850nm VCSEL which combines the advantage of narrow optical spectrum with high output power. The VCSEL bandwidth exceeding 30GHz allows reaching data rates above 100Gbps, high output power exceeding 4mW leaves the room for power budget and narrow spectral width enables long distance data transmission.

2. Multi Aperture Single Mode VCSEL characterization

The 4 aperture 850nm oxide confined VCSEL device is depict in Fig. 1a. The device has GSG electrical interface and the spacing between apertures is of 11um with each of the aperture having an effective diameter of ~2um. Such design guarantees the single mode operation and high output power of the device. In Fig. 1b-c. the LIV characteristic of the VCSEL is presented along with the optical spectrum at various currents. Both the characteristics were taken with a lensed optical fiber (coupling efficiency of 80%). The threshold current is 0.9mA with maximum measured optical power of 4.8mW at 14mA. It has to be noted that such power level is significantly higher comparing with standard single-mode and even multi-mode VCSEL devices [4-6]. The tolerance in the placement of lensed fiber coupling unit to achieve >50% coupling efficiency is ~2x larger for the multi-aperture SM VCSEL compared to single-aperture SM VCSEL. The VCSEL differential resistance is 41Ohms at operating current of 11mA.

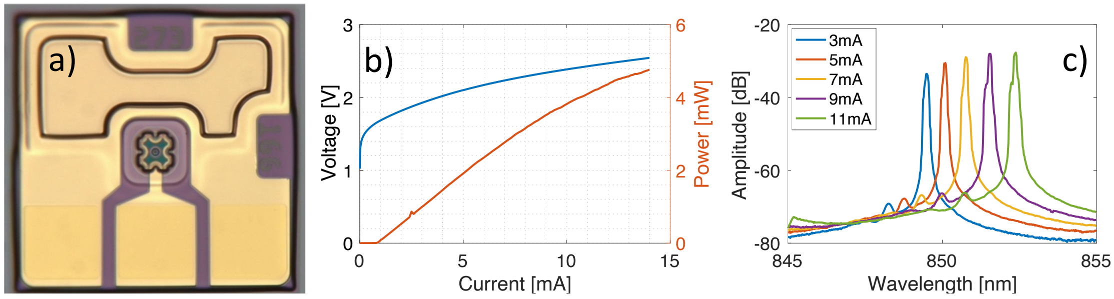

Fig. 1. a) photo, b) LIV and c) optical spectrum of multi aperture single mode 850nm VCSEL

The spectral characteristic of the device shows clear single mode operation (0.18nm RMS width at 11mA) in the whole current range. The wavelength shift with current is of 0.36nm/mA. Fig. 2a shows the S21 characteristic of the device for the currents ranging from 3-13mA (the data is normalized at 1GHz). The optical 3dB bandwidth exceeds 30GHz (31.4GHz at 13mA) and the overshoot (up to 3dB) is only present at low currents.

3. Multi Aperture comparison to Multi Mode VCSEL

The performance of multi aperture SM VCSEL was compared to the multi-mode 850nm VCSEL, 6.5um in aperture diameter. The MM VCSEL device was based on the same epi and was produced in the same processing as the multi-aperture device. The LIV and optical spectrum (taken at operating current of 10mA) is depict in Fig. 2b,c. Both characteristics were taken with lensed optical fiber as for multi-aperture device. The optical power at operating current was 3.5mW, differential resistance was 41.1Ohm and RMS width 0.73nm. The optical bandwidth performance for MM chip is similar to the multi aperture device with 31.3GHz at 10mA (31.2 for multi aperture at 11mA). With the similar high speed performance the multi aperture single mode design provides higher output optical power by 1.3mW and 4 times lower RMS width (0.18nm RMS compared with 0.73nm). More on the MM VCSELs can be found in [6-7]. To compare the multi aperture SM VCSELs with MM the S21 over OM4 fiber ranging in length from 100m to 800m was measured. The results are corrected for the receiver and the whole electrical path so the presented performance is of the VCSELs and fibers only. The VCSELs were biased at 11mA and 10mA for multi aperture and MM devices respectively. The results are presented in Fig. 3a with solid line for multi aperture and dashed for MM VCSEL. The bandwidth reduction for multi aperture chip shows only slight degradation up to 400m (reduction in the bandwidth of 0.9GHz from 31.2GHz in B2B to 30.3GHz after 400m). After 800m of the fiber the bandwidth reduces further to 27.8GHz. The Multimode VCSEL bandwidth reduces to 22.6GHz after 100m, 6.8GHz after 400m and to only 3.3GHz after 800m of OM4 fiber with clearly visible dips at 400m and 800m caused by dispersion related effects. All the measurements were performed on the chip level.

The performance of the single aperture SM VCSEL was further tested in data transmission experiment. The VCSEL die was driven with 56Gbit/s 500mV$_{\text{peak-to-peak}}$ electrical PRBS11 signal from a bit pattern generator (SHF) through 300mm high frequency cable and 65GHz bias-tee (SHF). As previously, the light was coupled with lensed fiber and via optical attenuator either received directly by a 32GHz optical module of a sampling oscilloscope (Tektronix) or transmitted through the OM4 fiber and then received with the sampling scope. No signal processing was applied at the transmitter nor at the receiver end of the system. Fig. 3b,c and d show the eye diagrams at B2B (received power 4.8mW), after 400m OM4 fiber (received power 4mW) and after 400m OM4 fiber with additional 6dB attenuation (received power 1mW). The eyes are clearly open with no signs of inter-symbol interferences and for all the cases error free data transmission was achieved. The multi aperture device fulfils requirements for the encircled flux in the fiber.

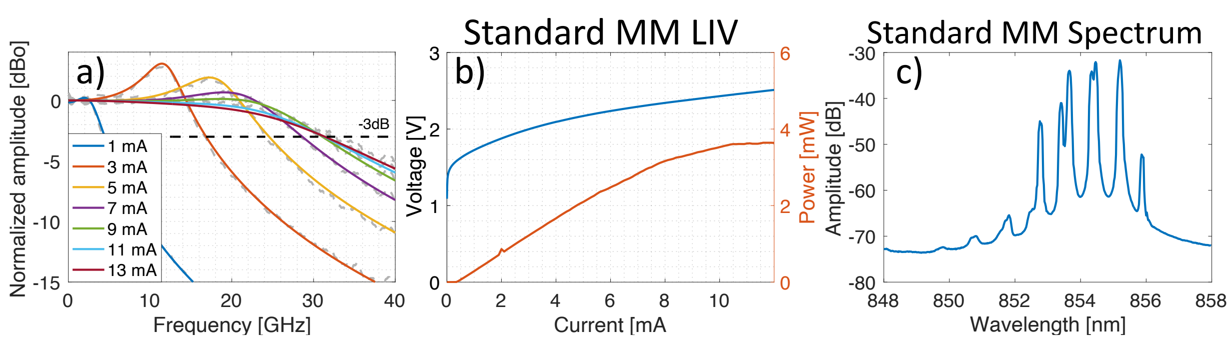

Fig. 2. S) S21 of multi aperture SM VCSEL, b) and c) LIV and optical spectrum of 6.5um multimode VCSEL

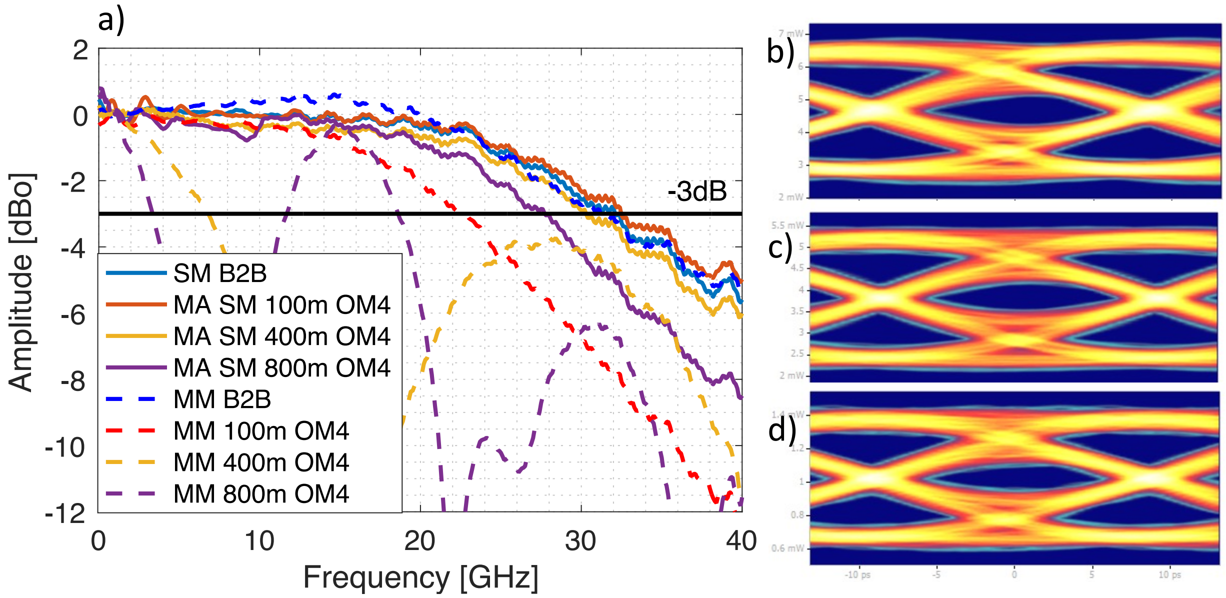

Fig. 3. A) bandwidth at the end of OM4 fiber with VCSEL transmission for multi aperture SM chip (solid line) and MM VSCEL (dashed line); b), c) and d) 56Gbit/s eye diagrams at B2B, after 400m OM4 and after 400m OM4 and 6dB attenuation for multi aperture single mode VCSEL respectively.

4. Summary

In the paper we showed novel approach to the SM VCSEL design using multi aperture concept and proved that such a device can be utilized for the optical data transmission. The multi aperture device has significantly reduced RMS width compared to a regular MM device while still providing high output power and very good high frequency performance. The modulation bandwidth of the device itself is above 30GHz and after 800m of OM4 fiber reduces to 27.8GHz allowing 56Gbit/s NRZ error free data transmission with 6dB margin and should allow reaching 100Gbit/s PAM-4 with ease. Applying equalizers (like feed forward equalization) should increase the transmission distance even further where the high output power leaves additional power margin e.g., for SWDM couplers or other link impairments.

5. Acknowledgement

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6. References

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