VISIT Deliverable Report Cover Sheet

Workpackage:	WP2: Technical Project Coordination and Development of EOM-BR VCSEL
Deliverable number	D2.3a
Deliverable name	Unpackaged 18-32 Gb/s EOM-BR VCSEL
Lead beneficiary:	TUB
Workpackage leader (name):	VIS
Description writer (name):	Alex Mutig
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Deliverable reached ☒ not reached ☐

Deliverable description and summary of achieved results (max. 2400 char.):

The growth, fabrication and characterization of high speed EOM-BR VCSELs have been performed resulting in devices showing high potential for 18 Gb/s operation. Successful growth has been carried out at an industrial epitaxial foundry showing the possibility of scaling the concept to industrial production.

Devices have been fabricated in an high speed geometry using a previously developed sequence of technology steps (e.g. optical lithography, metal evaporation, dry and wet etching, planarization, etc.). Continuous wave (CW) and high speed measurements on the VCSELs have been performed for different aperture sizes.

In a broad range of aperture sizes, current densities, and temperatures, an extinction ratio of 2-to-3 dB was reached. This proves that the device performance is robust across a wide range of device geometries and operating conditions.

A small signal modulation bandwidth of ~17 GHz was measured and large signal modulation experiments indicate a potential of up to 18 Gb/s error free transmission in the RZ format.

Contributors:

TUB, VIS, IQE

VISIT Deliverable Report Technical Annex

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1. Growth and materials characterization studies

The EOM DBR VCSEL structure studied was designed by VI Systems GmbH and grown by IQE Ltd. The structure was processed at the Technical University Berlin to mesas, both in a VCSEL geometry and in a test geometry, and wet oxidation was performed.

To confirm that the structure was properly grown and that the lasing wavelength matches the EOM DBR stop band edge wavelength, optical reflectance mapping was compared with electroluminescence (EL) spectra of the reference structures fabricated from a similar part of the wafer. The results of the study are presented in Fig. 1.

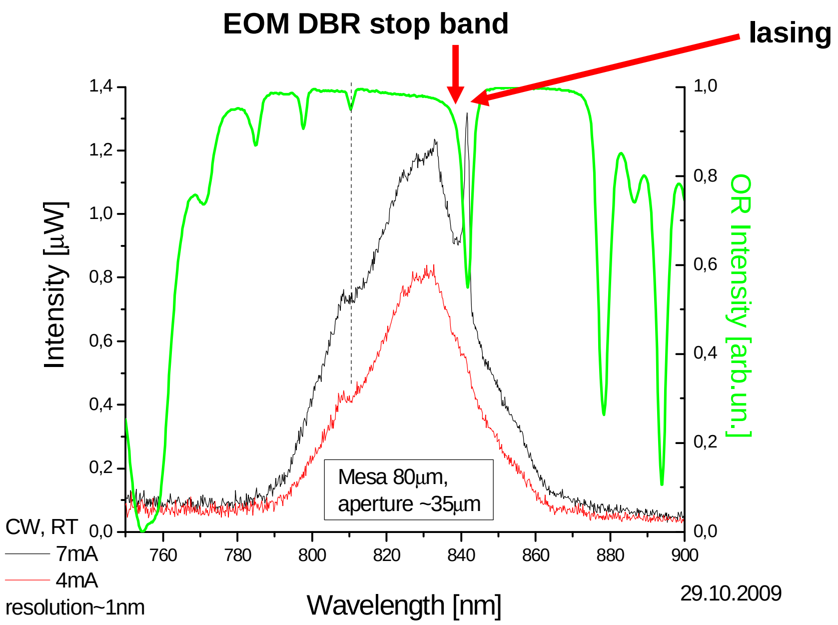


Fig. 1. Optical reflectance and electroluminescence (EL) spectra of the test mesas.

2. Device fabrication

Next EOM DBR VCSELs with different diameters of mesas and oxide apertures were fabricated using standard technology steps (optical lithography, metal evaporation, dry and wet etching, wet oxidation, BCB planarization, etc). Fig. 2 shows a schematic and an optical microscope image of the fabricated EOM DBR VCSELs.

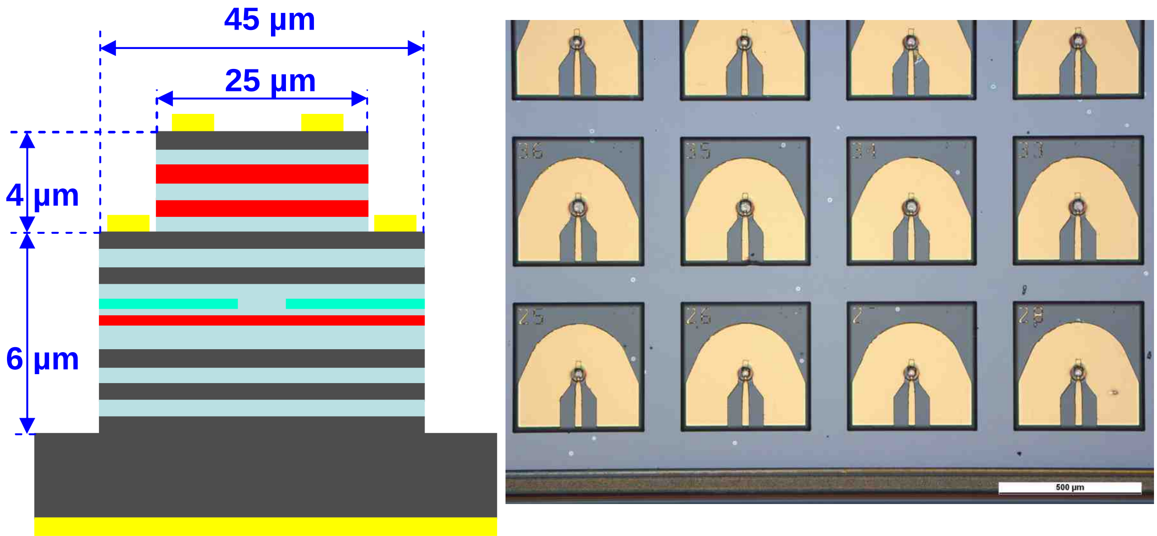
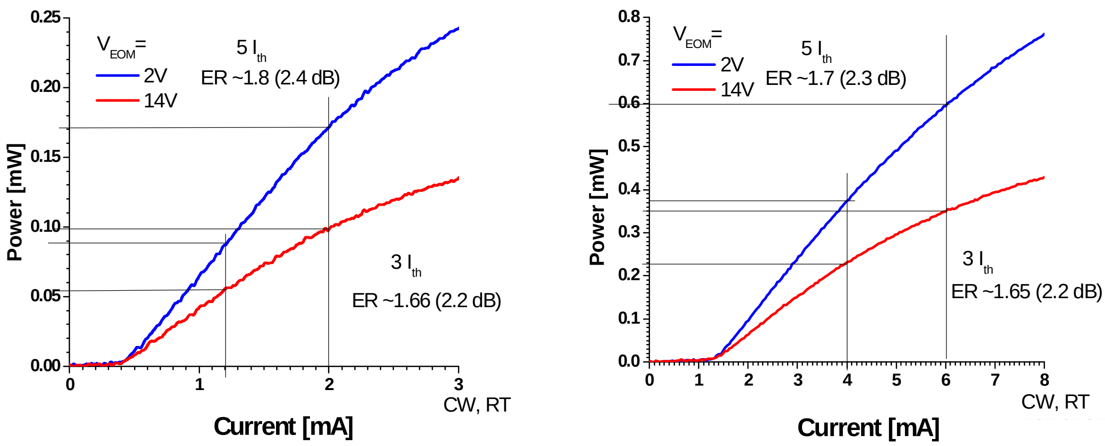


Fig. 2. Schematic picture of an EOM DBR VCSEL (left) and top view of a fabricated EOM DBR VCSEL array.

3. Static properties

The static performance of the EOM DBR VCSELs with different aperture sizes and with two different voltages applied to the modulator section is shown in Fig. 3. Previously large aperture EOM DBR VCSELs have shown only weak if any EO modulation at small currents. By a new cavity design the parasitic effects preventing efficient modulation are dramatically reduced. The modulation efficiency was found to be significant and uniform, irrespective of the mesa size and the current density applied. A significant enhancement of the extinction ratio was observed only at thermal roll-over currents, where the performance is strongly affected by the significant overheating in the “closed” state with lower wall-plug efficiency.



(a) (b)

Fig. 3. L-I curves at two modulator bias voltages for the devices with: (a) a 3 µm-diameter oxide aperture; and (b) an 11 µm-diameter oxide aperture.

The voltages applied to the EO section needed to cause the maximum extinction ratio are rather high (~10-12V). However, at a properly chosen bias point of 4V, peak-to-peak modulation already results in ~1-1.5dB extinction ratio. A moderate increase in the temperature increases the extinction ratio at a given modulation voltage.

Fig. 4 shows EL spectra of a device with a 3 µm-dia. aperture. The device operates in a quasi-single mode up to high current densities and the wavelength chirp with reverse bias is small.

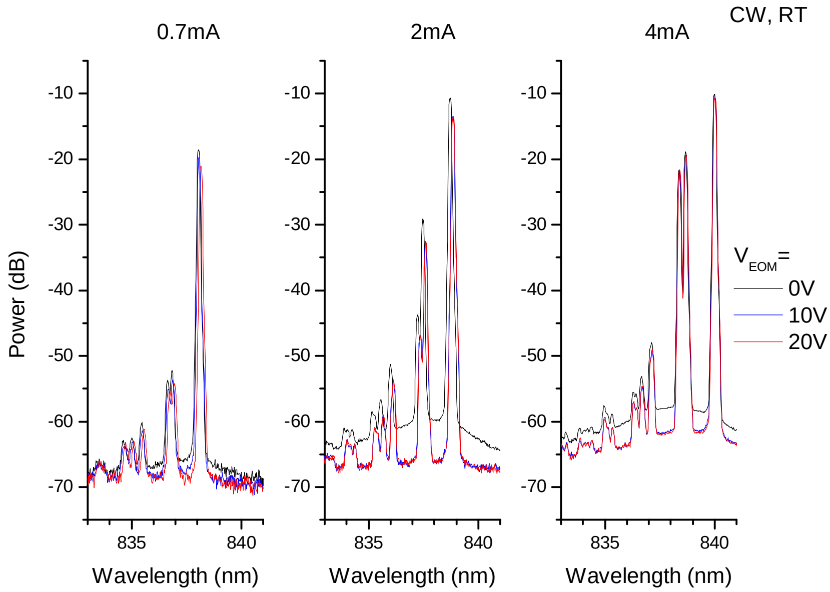


Fig. 4. Lasing spectra in a 27 µm-diameter mesa EOM DBR VCSEL (with a 3 µm-diameter oxide aperture) at different voltages applied to the EO section showing quasi-single mode lasing up to high current densities and with negligible chirp under the EO modulation.

The dependence of the differential efficiency of the structure with a selectively removed EOM DBR part on the inverse temperature is shown in Fig. 5.

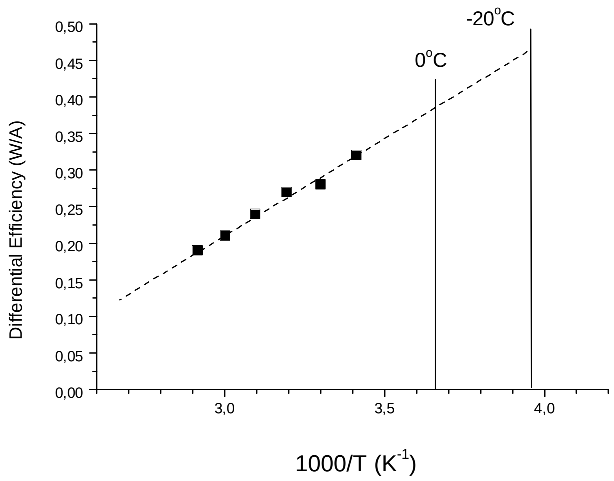


Fig. 5. Temperature dependence of the differential slope efficiency of the device with selectively removed EOM DBR section.

4. Dynamic properties

In Fig. 6 we show a sine-wave modulation amplitude curve of the EOM DBR VCSEL. One can see that the -3dB bandwidth approaches ~17 GHz.

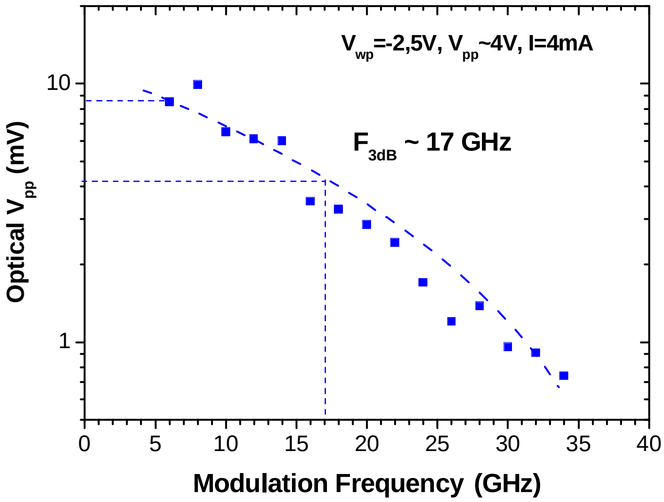
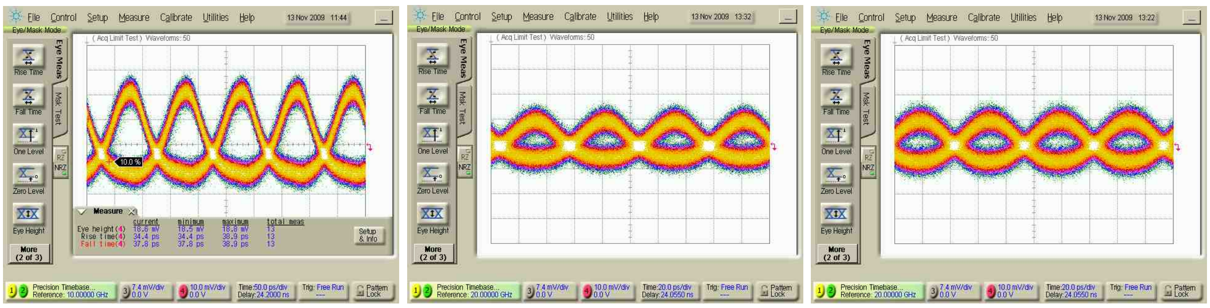


Fig. 6. Sine-wave modulation amplitude of the EOM DBR VCSEL evidencing a high modulation bandwidth.

Large signal modulation experiments have been performed. Truly pulsed operation with a pure sequence of “1” and “0” levels resulted in a clear eye opening at 10 Gb/s as shown in Fig. 7 and thus the device is expected to be suitable for return-to-zero (RZ) modulation at speeds up to ~15-18 Gb/s.



(a) (b) (c)

Fig. 7. Large signal modulation eye diagrams recorded for the EOM DBR VCSEL device at: (a) 10 Gb/s, 8V peak-to-peak modulation voltage; (b) 20 Gb/s, 8V peak-to-peak modulation voltage; and (c) 20 Gb/s 4V peak-to-peak modulation voltage. The EOM DBR VCSEL has a 7 µm-diameter oxide aperture and is operated at a forward current of 8 mA.

5. Conclusion

- The first EOM DBR VCSEL grown at an industrial epi-foundry is proved to operate. Thus the concept can be scaled to industrial production.
- An extinction ratio of 2-3dB is reached in a broad range of aperture sizes, current densities and temperatures. Thus the device performance is robust across a wide range of device geometries and driving conditions.
- Quasi-single mode operation was observed in up to 3 µm-diameter oxide aperture devices, with larger aperture devices operating in a single mode at small current densities.
- A small signal modulation bandwidth of ~17GHz has been measured.
- Large signal modulation experiments indicate presently at least a potential of up to 15-18 Gb/s error free transmission in the RZ format.

Issues to be addressed:

- Those related to the optimization of large scale industrial epitaxial growth.