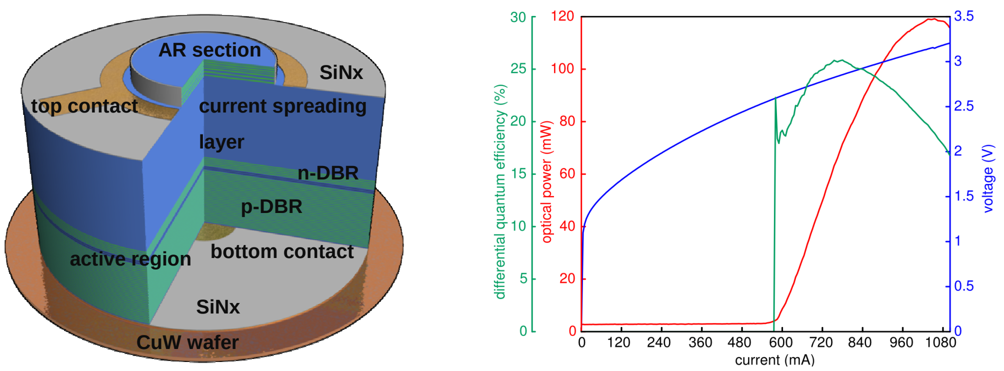
WP3 Highlights

Electrically pumped mode locked VECSELs

The FAST-DOT consortium have realized electrically pumped vertical external cavity surface emitting lasers (EP-VECSELs) in the 100 mW range. These devices, being driven electrically rather than optically, are compact and potentially extremely low cost. For the first time, we have demonstrated sub 10 ps pulse width in mode locked operation of these devices. The ability of an EP-VECSEL to emit short pulses, have the potential to be scaled to high powers and still be compact enough to simply fit in a handheld device are the unique features of this type of device. An example of the compactness of electrical pumping, showing the gain chip fitting comfortably in the O of the Euro can be seen in the picture opposite.

Design of high power electrically pumped VECSEL

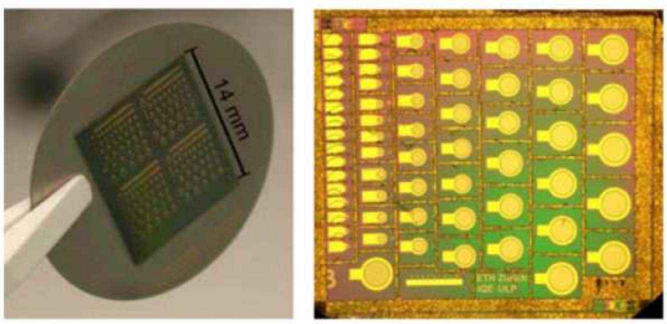
One of the key activities of the project is the development of electrically pumped vertical-external-cavity surface-emitting lasers (EL-VECSELs) for the generation of short pulses at multi-GHz repetition rates. Partner ETHZ achievements include the design and development of EP-VECSEL devices generating >100 mW CW power. Homogeneous current injection is achieved even for large devices, showing very good agreement with the numerical simulations.



Left: The design of the EP-VECSEL developed by ETHZ. Right: Output power and differential quantum efficiency vs pump power.

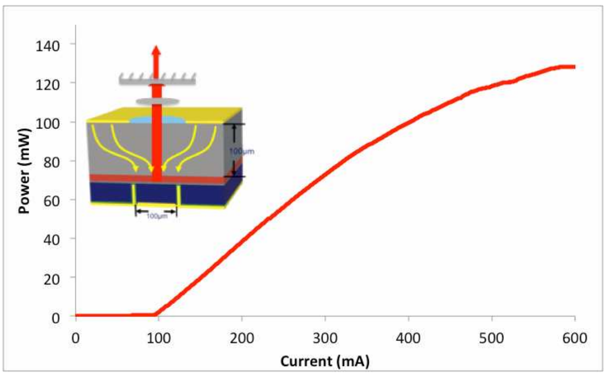
Realization of an electrically-pumped Vertical External Cavity Surface Emitting Laser for passive mode-locking

Modelocked optically pumped vertical external cavity surface emitting lasers (VECSELs) have generated up to 6.4-W average power, which is higher than for any other semiconductor lasers. Electrical pumping of mode-locked VECSELs is the next step toward a higher level of integration. With continuous wave (cw) electrically pumped (EP) VECSELs, an average output power of 900 mW has been demonstrated from the undisclosed proprietary novalux extended cavity surface emitting laser (NECSEL) design. In contrast, mode-locked NECSELs have only been demonstrated at 40 mW. FAST-DOT partner ETH demonstrated the first realization of previously designed EP-VECSELs suitable for mode-locked operation14. Power scaling is achieved with a lateral mode size increase. The competing electrical and optical requirements are, on the electrical side, low ohmic resistance, and on the optical side, low optical losses and low dispersion. Additionally, the device needs to operate in a fundamental mode for stable modelocking. 60 EP-VECSELs with varying dimensions have been fabricated and characterized. The tradeoff between good beam quality and output power is a point of discussion with an outlook to the modelocking of these EP-VECSELs. Initial EP-VECSEL devices have generated >100 mW of cw output power.



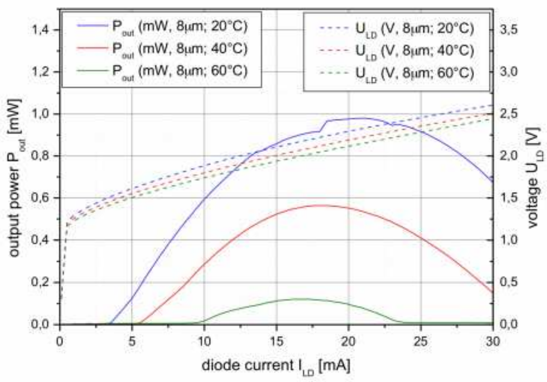
Design and fabrication of an electrically-pumped Vertical External Cavity Surface Emitting Laser based on substrate emission

Within FAST-DOT, USFD have designed, grown, fabricated and tested electrically pumped VCSELs based on a substrate emission and carrier spreading layer. The gain medium consists of six strain balanced QWs for high round trip gain. A range of device geometries have been investigated, and high output powers have been achieved from size scaling up to 100um diameter. In this case, a threshold current of 1200A/cm^2 with external quantum efficiency of 30% and 30K/W heat dissipation leads to 130mW CW output power. This power is limited by uniformity of lateral carrier injection and efficiency of heat extraction. There is scope for both of these to be further improved.

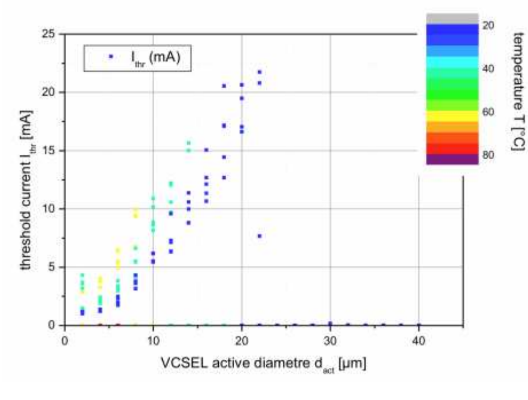


Mode locking of these USFD devices has been successfully achieved at DUNDEE in a Z-cavity configuration. The cavity round trip time led to a pulse repetition rate of 1.49GHz. In order to increase the internal cavity power incident on the SESAM, an output coupler of 2% was used, which led to an average output power of 1mW. In order to increase output power, the output coupler reflectivity can be reduced, in this case, a maximum of 8 mW was achieved with 10% output coupling before the device became unstable. Further improvements to both the EP-VECSEL and the SESAM are being carried out to greatly improve this performance. Nonetheless, this result represents a significant step forward in realising ultra compact low cost ultra fast pulsed lasers suitable for battery operated handheld devices. The figure above shows a schematic of the EP-VECSEL device yielding 130mW CW power in a straight cavity with 20% out-coupling mirror.

Development of QD EP-VECSELs



One wafer with quantum dots as active material was grown at INNO and sent to PHILIPS for processing and analysis. The processing was done using an advanced mask set and process that provides several active diameters and test-structures on the same wafer. Characteristic curves were measured for VCSEL-devices with different active diameter and at various temperatures of the heat sink. Figure 8 shows as an example three characteristic curves for an EP-QD-VCSEL at heat sink temperatures of 20, 40 and 60°C. As can be seen (figure), a maximum output power of roughly 1mW is obtained for the lowest heat sink temperature. Furthermore, the output power drops significantly for the higher temperatures, while laser thresholds increase and the slope efficiencies decrease. Threshold currents from the smallest devices were around 1mA, however expressed in terms of threshold current densities these were >5kA/cm^2 for all sizes. This actually equates to just over 150A/cm^2 per QD layer. The smallest devices reach threshold at ~1kA/cm^2 per QD layer.



In summary, a wafer with QD-active material was successfully processed and EP-QD-VCSELs were realized. The performance however, was lower than expected: The maximum output power was ~1mW, and the maximum wall-plug efficiency 4.5%, which is lower than that found for comparable QW-VCSELs. As such, significant improvements of the gain material properties are needed in order to fabricate successful QD EP-VECSELs