Technical feasibility and reliability of quantum-dot 850-nm VCSELs operating up to and above 25 Gbaud with a high temperature stability beyond 150°C

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802.3_OMEGA Multi Gigabit Automotive Optical Ethernet SG
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Draft Objectives OMEGA

- Support full duplex operation only
- Support data rates of 2.5 Gb/s, 5 Gb/s, 10 Gb/s, 25 Gb/s, and 50 Gb/s at the MAC/PLS service interface

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Basics of VCSELs

Detuning

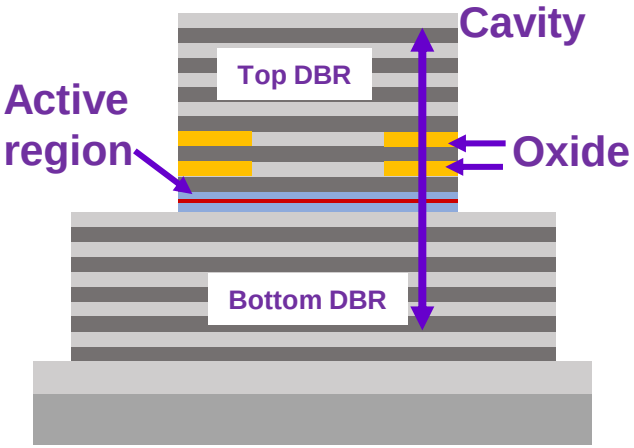
VCSEL is a very short Fabry-Perot laser with the lasing wavelength defined by the cavity resonance

Maximum gain is realized when the cavity resonance dip and the emission peak overlap.

Due to **different redshift** of the cavity and the active region, this overlap happens only at a specific temperature.

Low detuning -> worse performance at high temperatures

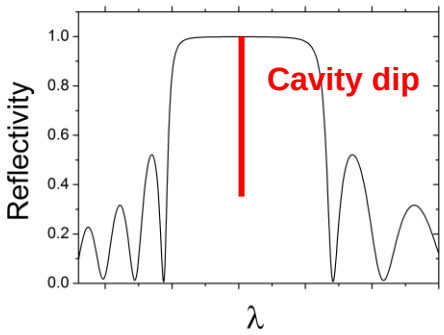
Large detuning -> worse performance at lower temperatures



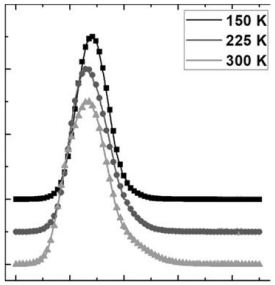
VCSEL

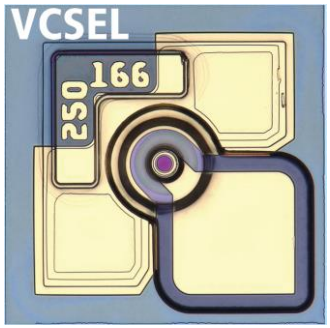
Different temperatue shift of :

DBR reflectivity



Active region emission





Autmotive operation range is very broad from negative temperatures to >105°C

-> Quantum Dot (QD) technology can enable such temperature stability

High density Quantum Dot VCSELs

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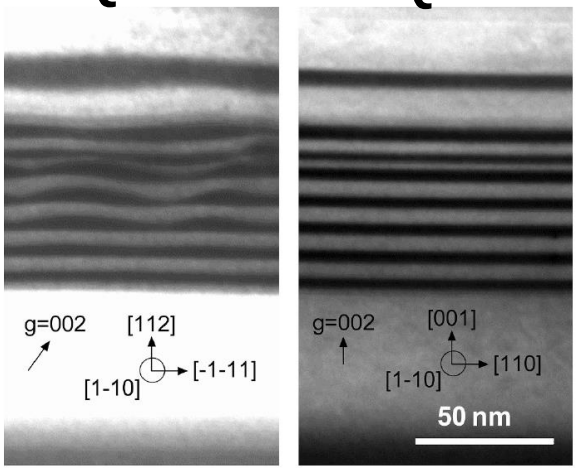
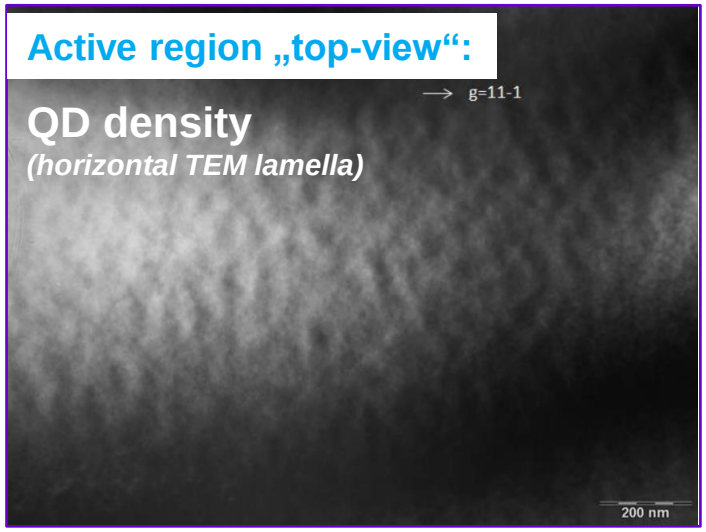
Cros-section:

QD **QW**

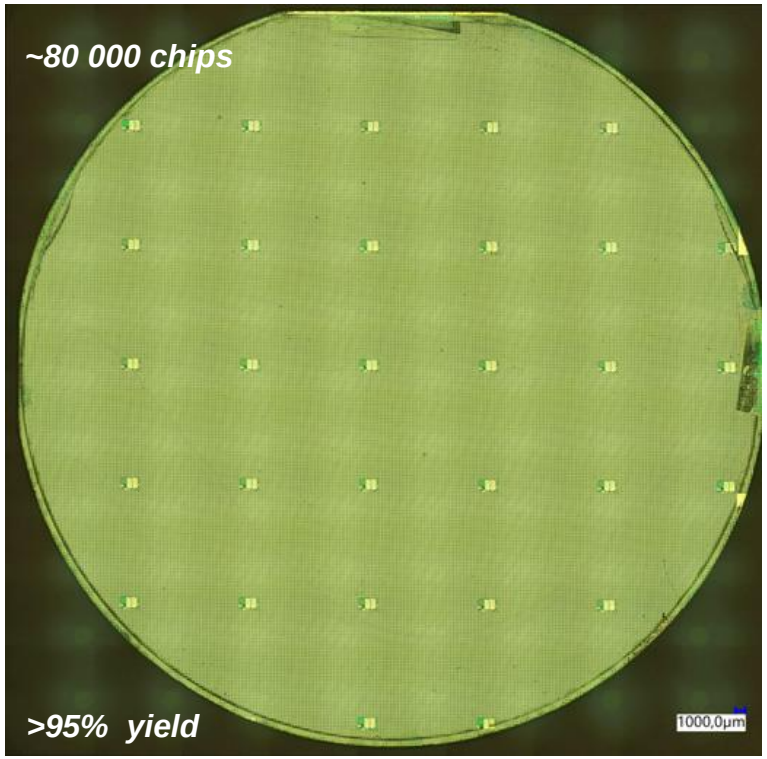


- **Advantages of Quantum Dots (QD)**
- high material gain, suppressed losses and lower carrier diffusion
- -> Better temperature stability

Active region „top-view“:



3“ industrial epitaxy and processing foundry wafer production



Ledentsov Jr., et al.; Vertical-Cavity Surface-Emitting Lasers XXIV, vol. 11300, p. 113000H, 2020

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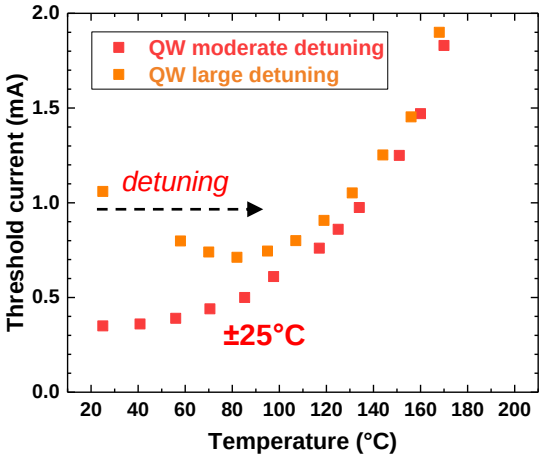
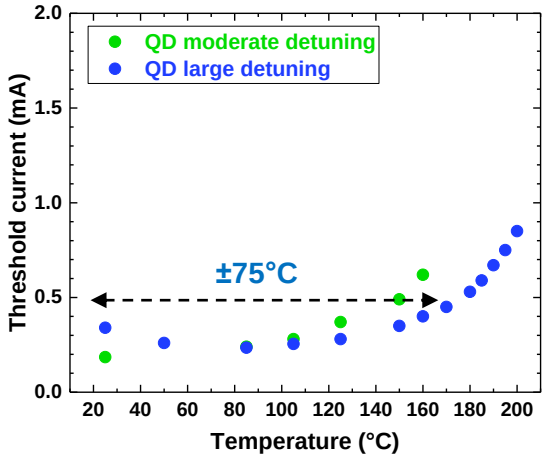
Comparison of QW vs. QD VCSELs

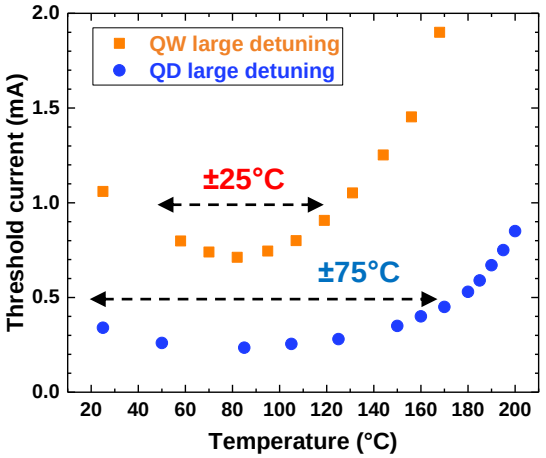
Comparison of QW and QD chips with different detuning ~4 μm oxide aperture



QW VCSELs: High temperature operation comes at the cost of decreased efficiency at low temperatures



QD VCSELs: Wider range of temperatures has threshold current <0.5mA



QD VCSELs: QDs have lower threshold currents

Temperature range with low threshold current, high efficiency and temperature stability of the optical power extended from 50°C in QW VCSELs to 150°C in QD VCSELs

Ith <1mA at 200°C

Ledentsov Jr., et al.; Vertical-Cavity Surface-Emitting Lasers XXIV, vol. 11300, p. 113000H, 2020

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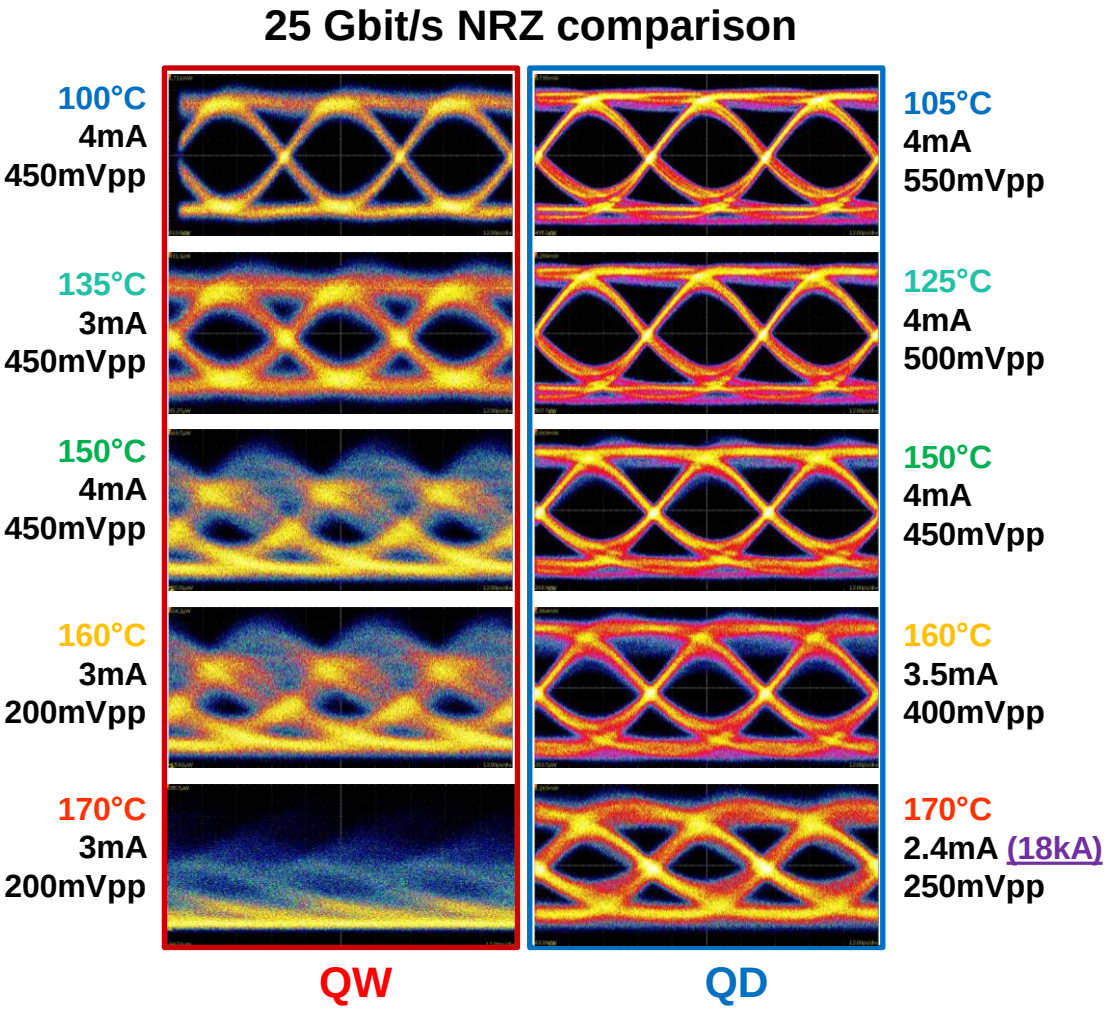
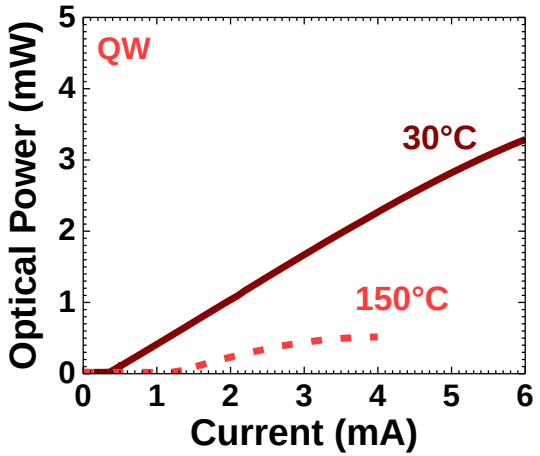
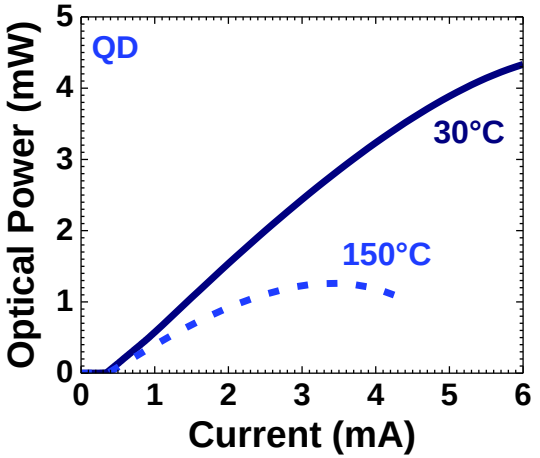
High Frequency Multi-Rate performance

- From 2.5Gb/s NRZ to 50Gb/s PAM4

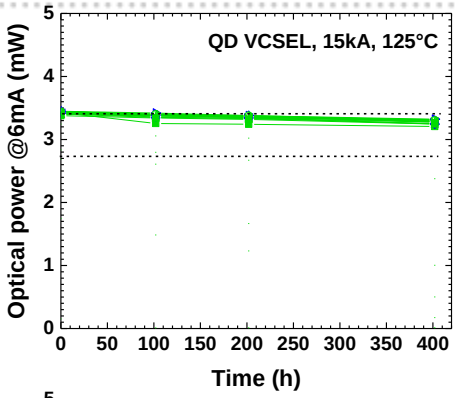


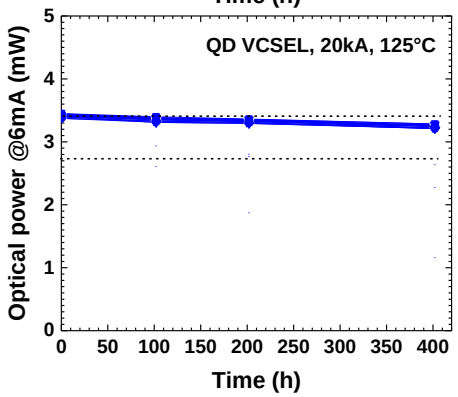


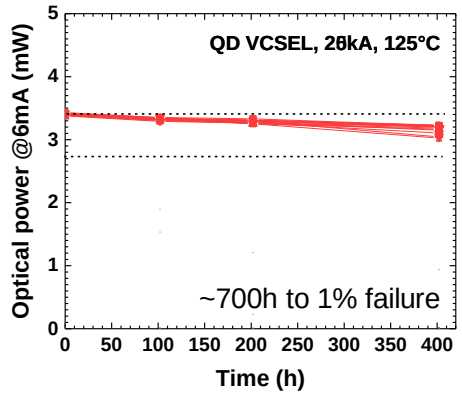


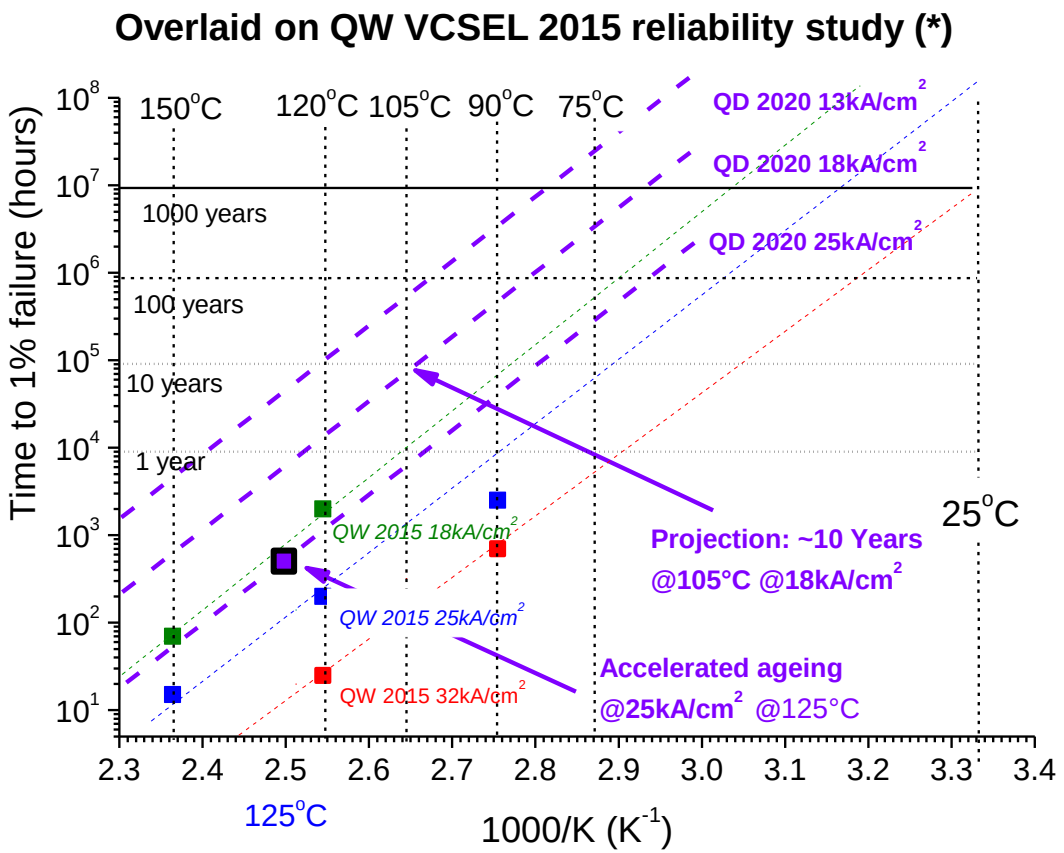
Ledentsov Jr., et al.; Vertical-Cavity Surface-Emitting Lasers XXIV, vol. 11300, p. 113000H, 2020

Reliability









Current data:
~700h time to 1% failure (TT1%F) at 125°C at 25kA/cm²
Extrapolated:
~1 year at 105°C at 25kA/cm ²
>10 years at 105°C at 18kA/cm² *(25 Gbit/s)*
>100 years at 105°C at 13kA/cm2 *(10 Gbit/s or 25Gb/s w. equalization)*

*Kropp, et al., *Semiconductor Science and Technology*, *30*(4), 045001; (2015).

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Conclusion

Temperature stability and high frequency operation:

- Advanced QD VCSELs show a high temperature stability of power (>1mW at 3mA at 150°C)
- Low threshold (<1mA) from ~20°C to ~180°C.
- Lasing up to 200°C
- 25 Gbit/s NRZ performance up to 180°C

Reliability estimates:

- ~1 year at 105°C at 25kA/cm^2
- >10 years at 105°C at 18kA/cm^2 (25 Gbit/s at no equalization)
- >100 years at 105°C at 13kA/cm^2 (10 Gbit/s or 25Gb/s with equalization)

Additional slides:

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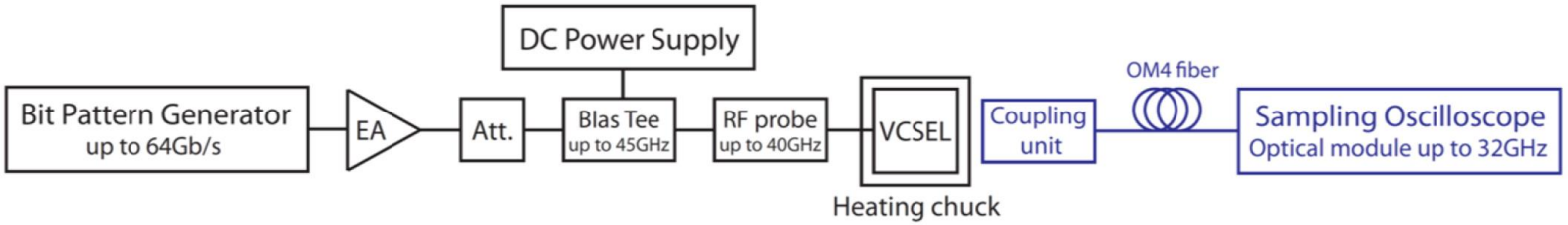
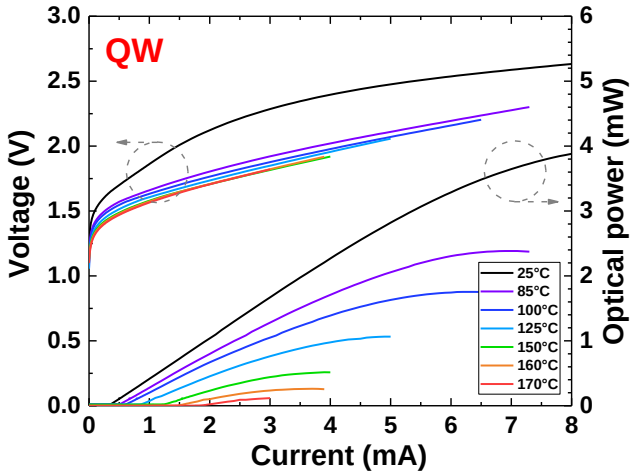
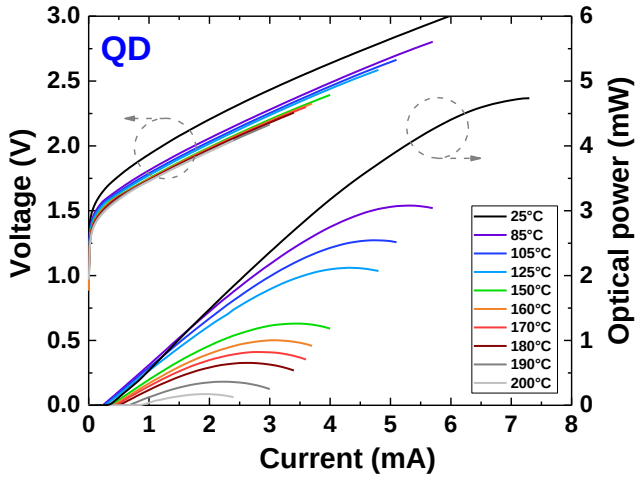
High Frequency testing setup



High speed performance is analyzed on bare chips with standard equipment without pre-emphasis, equalization or signal processing





~4µm aperture QW and QD VCSELs are compared