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Polarization mode structure in long-wavelength wafer-fused vertical-cavity surface-emitting lasers (VCSELs)

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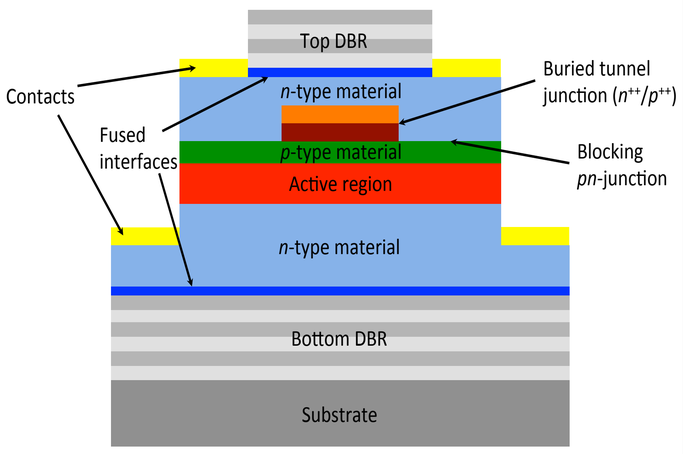
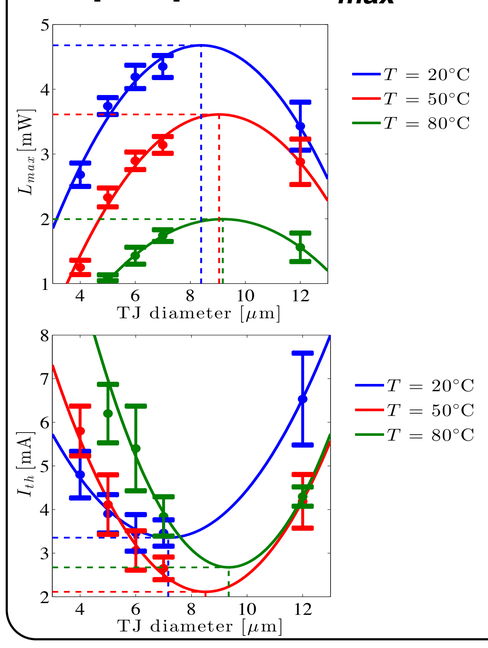
- Statistical study of the influence of the tunnel junction (TJ) diameter on the performance of long-wavelength VCSELs.
- Study of the higher-order transverse modes and of the polarization modes: spectral analysis, near field mapping and control.

Wafer-fused VCSEL

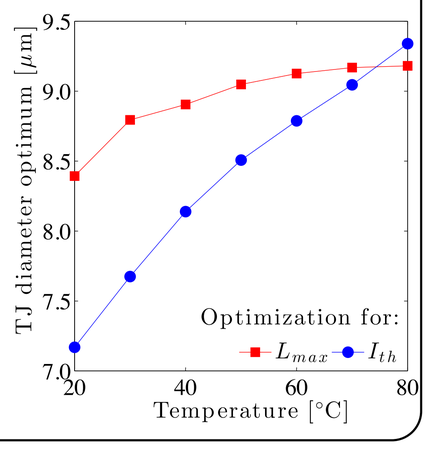


Active region: 6 AlGaInAs QWs
DBRs: undoped GaAs/AlGaAs

Output power L_{max} and threshold current I_{th}

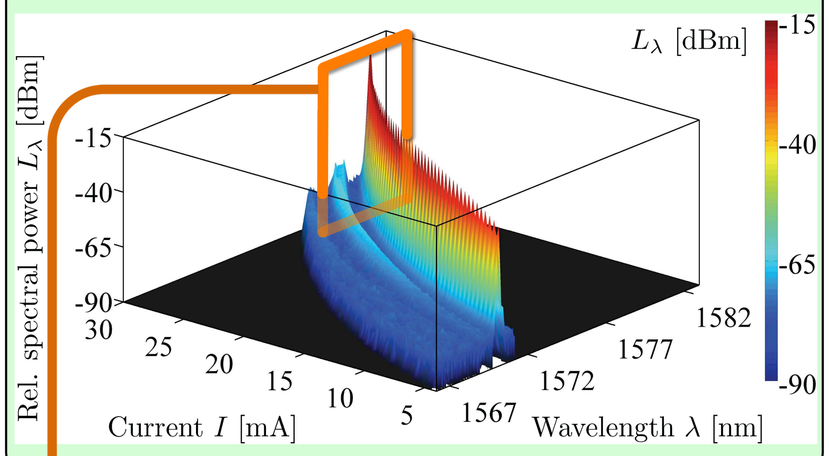


Quadratic fits predict optimum values for the TJ diameter d_{TJ}:

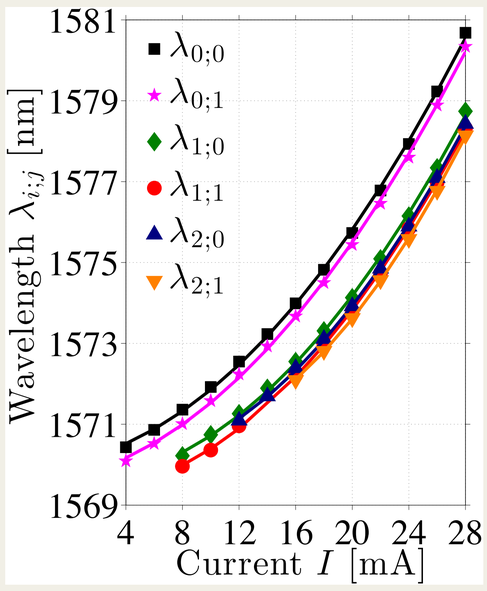


Optical emission ($T = 20°\mathrm{C}$, $d_{TJ} = 7\,\mu\mathrm{m}$)

Appearance of higher-order modes with complex features for larger currents:

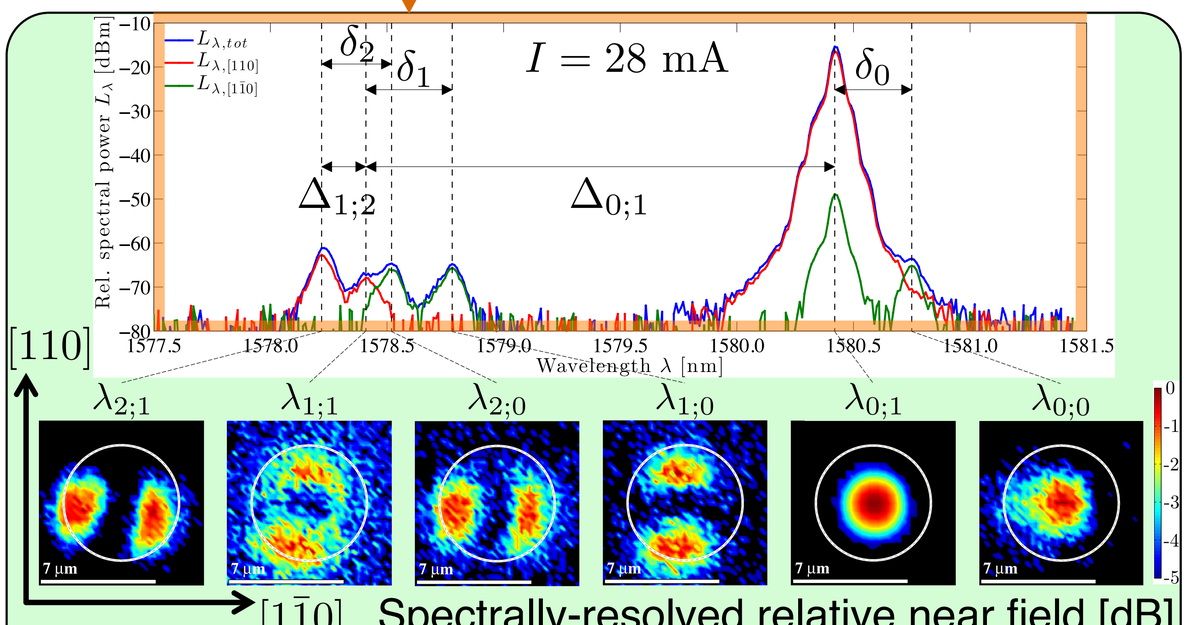


Emission wavelengths versus current



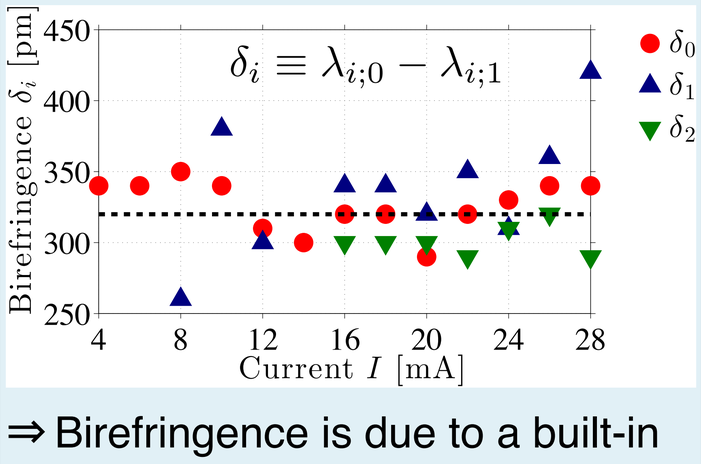
- Dissipated power: $P_d = RI^2$
- Temperature elevation:
  $\Delta T = Z_{th} P_d$ → Thermal impedance
- Variation of refractive index:
  $\Delta n \cong \frac{\partial n}{\partial T} \Delta T$ → Thermal lensing
- Emission wavelength: $\lambda_0 = n\lambda$

⇒ Mode wavelengths depend quadratically on current: $\Delta\lambda_0 \propto I^2$.



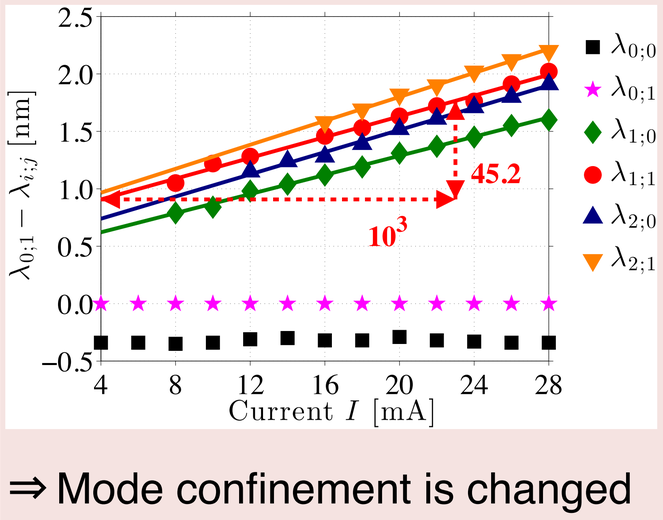
⇒ $\lambda_{i;0}$ and $\lambda_{i;1}$ are polarization modes $(i = 0, 1, 2)$.

Polarization modes spectral separation (= birefringence) does not depend on *I*:



⇒ Birefringence is due to a built-in structure (growth, strain, etc.) and not to the thermal lensing effect.

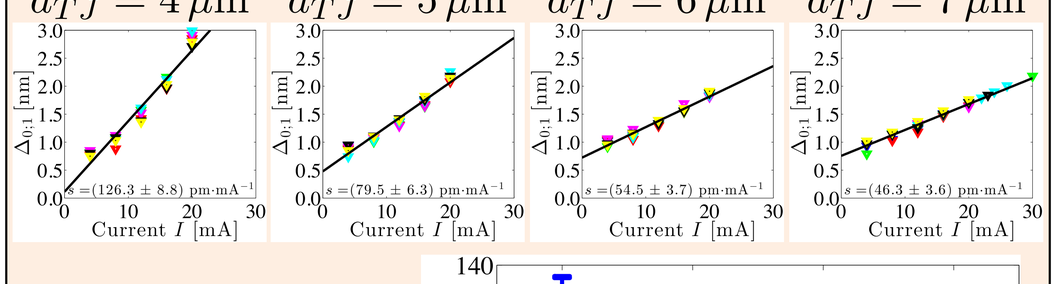
Transverse modes spectral separation does depend on *I*:



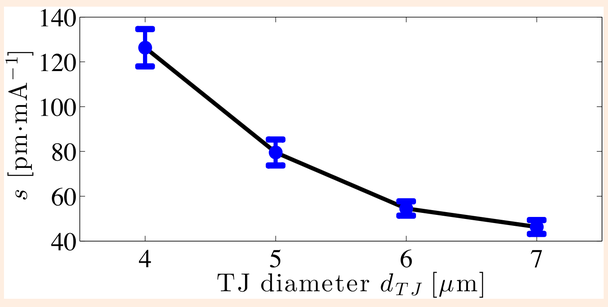
⇒ Mode confinement is changed by the thermal lensing effect.

Analysis of $\Delta_{0;1} \equiv \lambda_{0;1} - \lambda_{1;1}$ for high-performance devices, with different TJ diameters:

$d_{TJ} = 4\,\mu\mathrm{m}$ $d_{TJ} = 5\,\mu\mathrm{m}$ $d_{TJ} = 6\,\mu\mathrm{m}$ $d_{TJ} = 7\,\mu\mathrm{m}$



The slope s of $\Delta_{0;1}$ versus current is characteristic of the TJ diameter:



⇒ Mode confinement is induced by the structured TJ.

- ✓ Establishment of clear relationships of threshold current and maximal output power of the VCSELs as functions of the temperature and tunnel junction diameter.
- ✓ Identification of two empirical parameters describing the mode structure: δ and s.
- ✓ Further calibration of VCSEL numerical models.
- ✓ Present results are the basis for the study of the influence of intra-cavity patterns to stabilize the polarization and to discriminate the high-order transverse modes.

N. Volet, V. Iakovlev, A. Sirbu, A. Caliman, G. Suruceanu, A. Mereuta and E. Kapon, *Proc. SPIE* **8432** (2012).