Tapered Quantum Cascade Lasers in the long-wavelength mid infrared region

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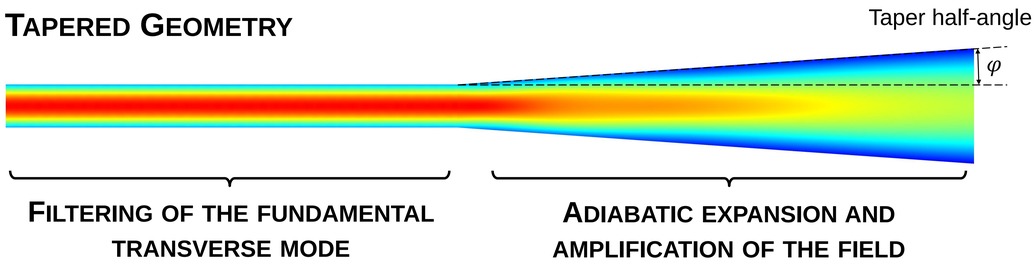
Introduction & motivation

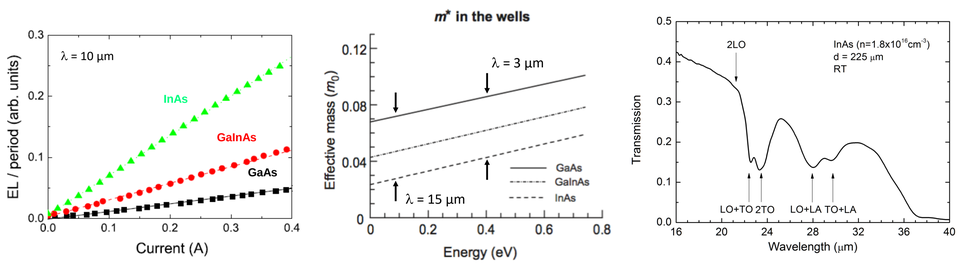
- Long-wavelength Quantum Cascade Lasers (LW-QCLs) find application in several fields, such as in molecular spectroscopy. The small photon energy limits the output power of such devices
- **High-power** and **good beam quality** are often desired in many applications for better performances
- **Tapered lasers** deliver higher output power, preserving beam quality, and reducing beam divergence along the slow-axis



LW-QCLs features and fabrication

InAs/AlSb system

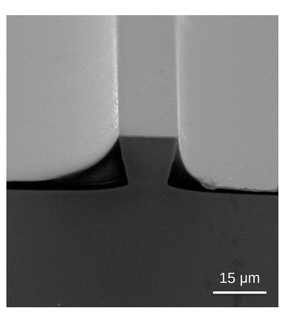
- LW-QCLs are based on **InAs/AlSb system** to exploit small m_e^* of InAs quantum wells
- Reduced absorption from **Reststrahlen band**



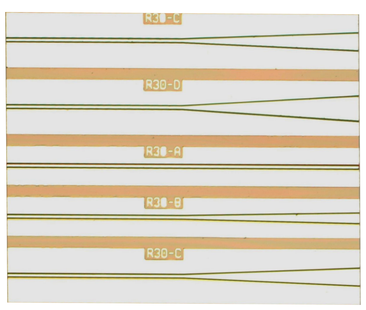
E. Benveniste et al., Appl. Phys. Lett. 93, 131108 (2008) - MPQ

Fabrication process of Tapered LW-QCL

1. Lithography to define tapered MESAs and deep MESA wet chemical etching
2. Lithography for insulation aperture via photoresist hard baking
3. Top contact metallization via Ti/Au/Cr/Au e-beam evaporation



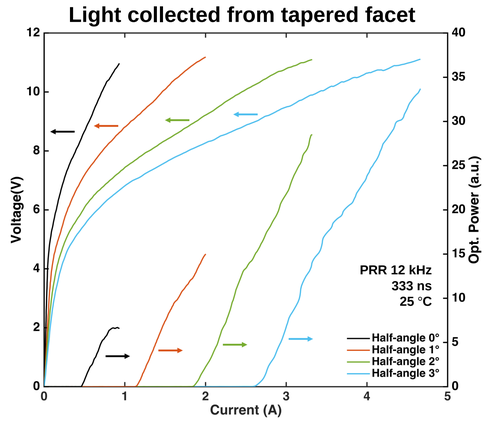
Straight-side facet of LW-QCL under SEM.

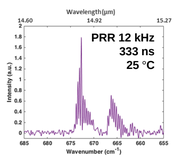


Tapered LW-QCLs with half-angles of 0°, 1°, 2° and 3° - indicated with A, B, C and D, respectively.

Results

Electrical and optical characterization

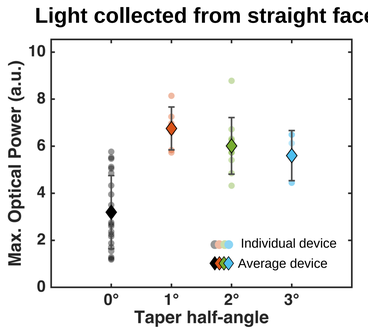




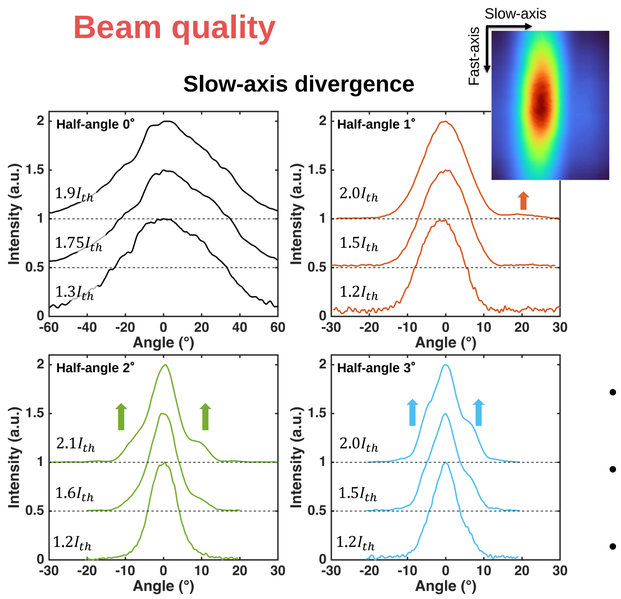
Emission spectrum of tapered LW-QCL in pulsed mode (12 kHz, 333 ns, 25 ° C)

- Fabry-Pérot (multimodal) behavior with emission range $660 - 675\ \mathrm{cm}^{-1}$ (14.9 μm)

- Tapered lasers exhibit increased power output compared to straight lasers
- For an even comparison, light must be collected from straight facet (different collection efficiency)
- Best performance are achieved for small taper half-angles ($\sim 1° - 2°$)



Beam quality



Beam quality factor:

$$M^2 = \frac{4\pi\sigma_0\sigma_\theta}{\lambda}$$

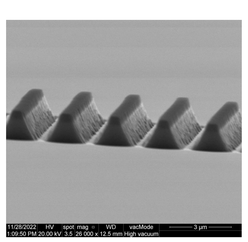
$\sigma_{0(\theta)}$ standard deviation of intensity spatial (angular) distribution

Taper half-angle	σ_θ (low → high current)	M^2 (low → high current)
0°	~ 26°	$\gtrsim 1$
1°	5.6° → 6.5°	1.07 → 1.23
2°	3.7° → 5.0°	1.31 → 1.77
3°	4.0° → 5.0°	2.00 → 2.52

- **Reduced slow-axis divergence** in tapered devices
- Appearance of **side lobes** at higher operating currents
- Worse beam quality for higher taper angles

Conclusions & Outlooks

- Tapered LW-QCLs demonstrated an **improved power output**, together with a **reduced slow-axis divergence**
- Higher half-taper angles devices displayed **suboptimal characteristics** such as worse beam quality (due to sidelobes) and limited power output



- An optimal taper half-angle could be found around 1°

Future perspectives

- High-reflection and anti-reflection coating for further improvement of the outcoupled optical power
- **Single longitudinal mode** operation will be achieved by grating fabrication on top of the MESA, for use in spectroscopy applications (DFB laser)

OPTAPHI has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 860808