Continuous wave operation of Quantum Cascade laser array at T = 77 K

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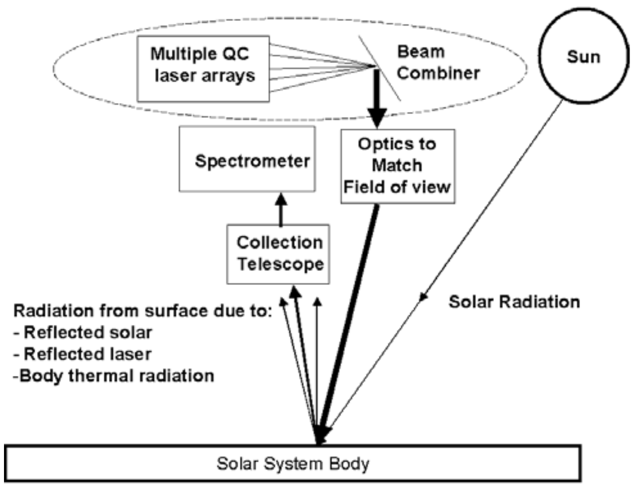
QC lasers for remote sensing

We build mid-infrared lasers to demonstrate a capability to act as the illumination source for conducting active mid-IR reflectance spectroscopy of solid-surfaced objects in the outer Solar System.

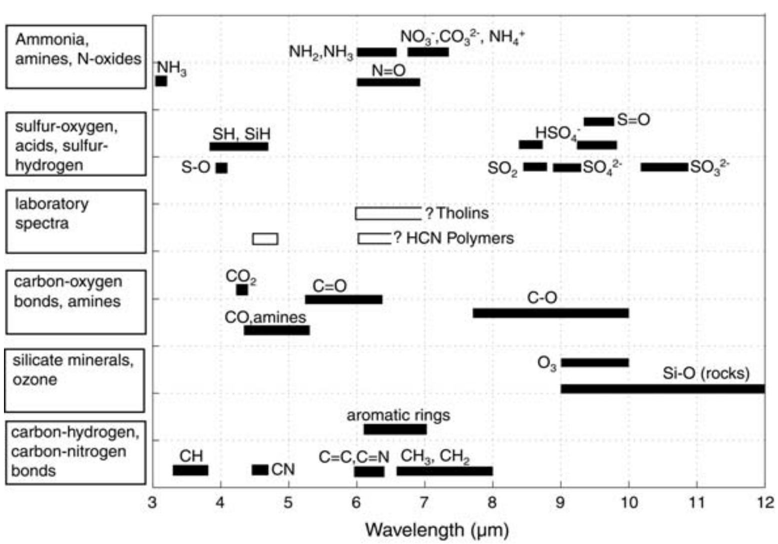


• Could be used from on-orbit, aircraft or rover

• Supplements/replaces solar illumination

• Wavelength availability has been the Achilles' heel of laser sensing. The use of QC lasers enables the entire IR region (4- 12 microns) to be covered and overcomes this limitation

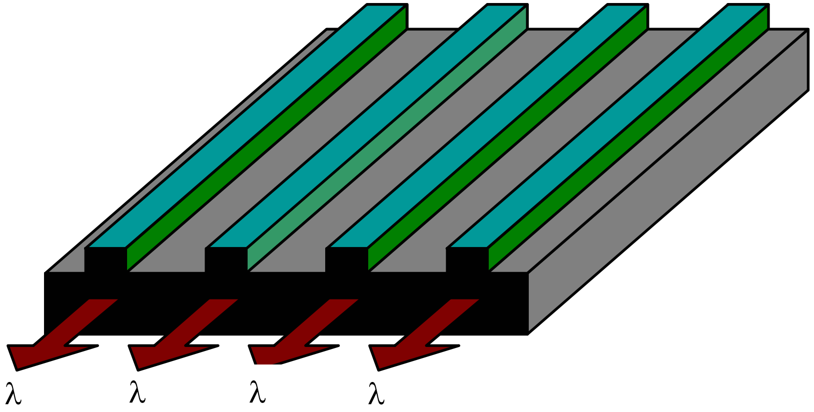
• Spectral observations in this region, made possible with active illumination, will better enable one to determine the silicate and oxide mineralogy, ice composition, and the composition of organic materials on outer solar system surfaces by being able to observe fundamental absorption bands.



Laser Arrays

The output power of the single-element laser is still not sufficient for many applications
For the proposed remote sensing instruments output power at each wavelength > 2 W

To achieve higher output powers, multi-element QC laser arrays must be developed



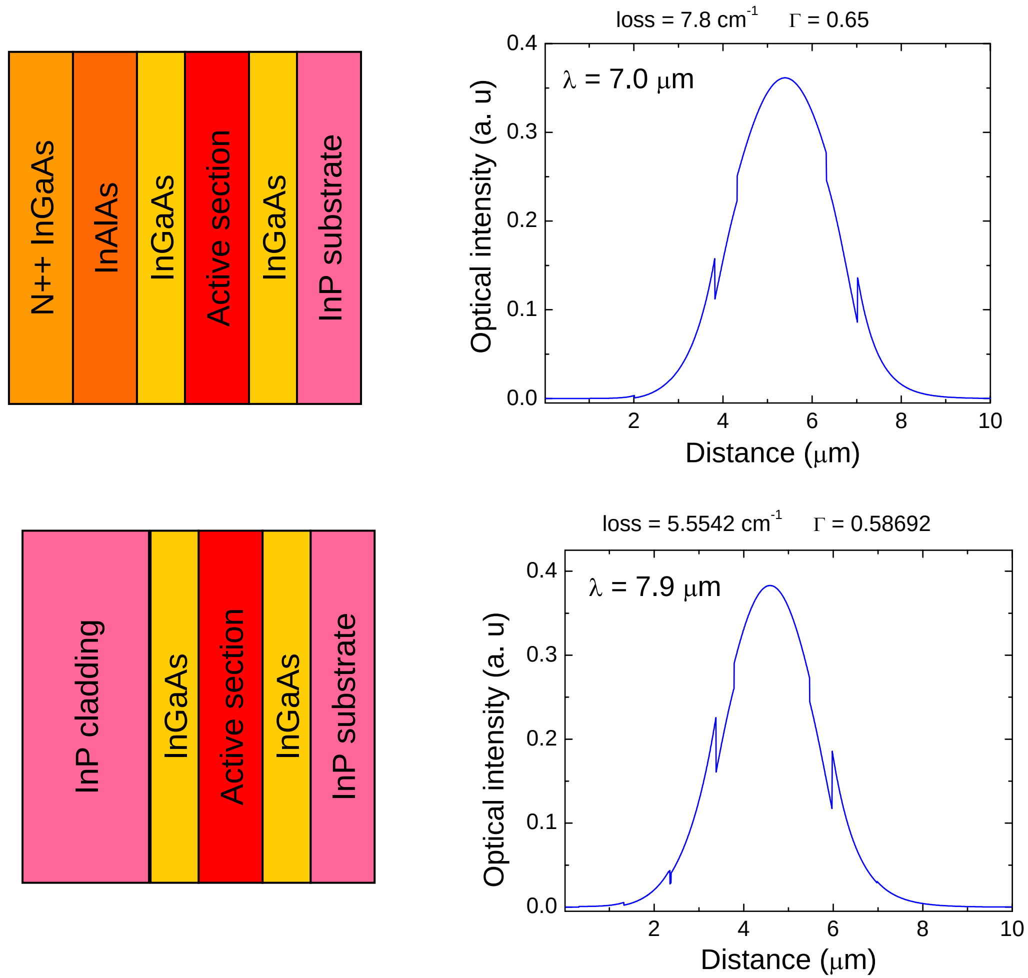
Semiconductor laser array

Two structures for QC laser array

We used two structure for fabrication of QC laser arrays:

QC lasers with a typical InGaAs/InAlAs cladding and operating at λ = 7 μm (Structure 1).

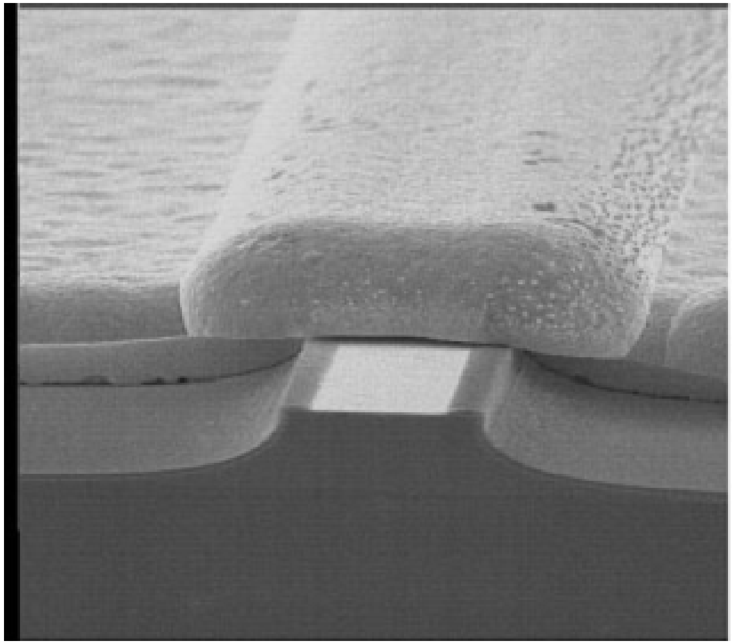
QC lasers with top InP cladding grown by solid source MBE (λ = 7 μm) (Structure 2).



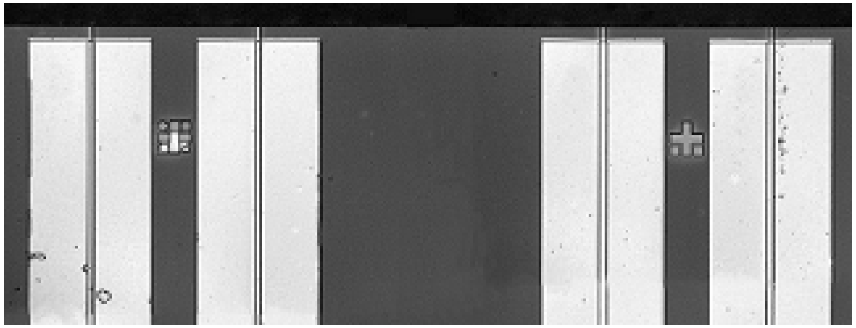
Designs of the InAlAs/InGaAs (top) and InP (bottom) QCL waveguide and calculated intensity distribution of an optical mode

Array fabrication

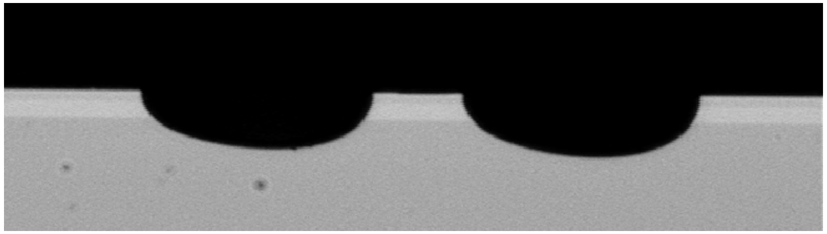
- We fabricated devices with a ridge waveguide devices (Device 1) and with double channel waveguide (Device 2)
- Ridge width (10 – 16 μm) and ridge separation 0.5 mm
- All devices are Au-electroplated



Scanning electron image of QC laser with Au- electroplated coating



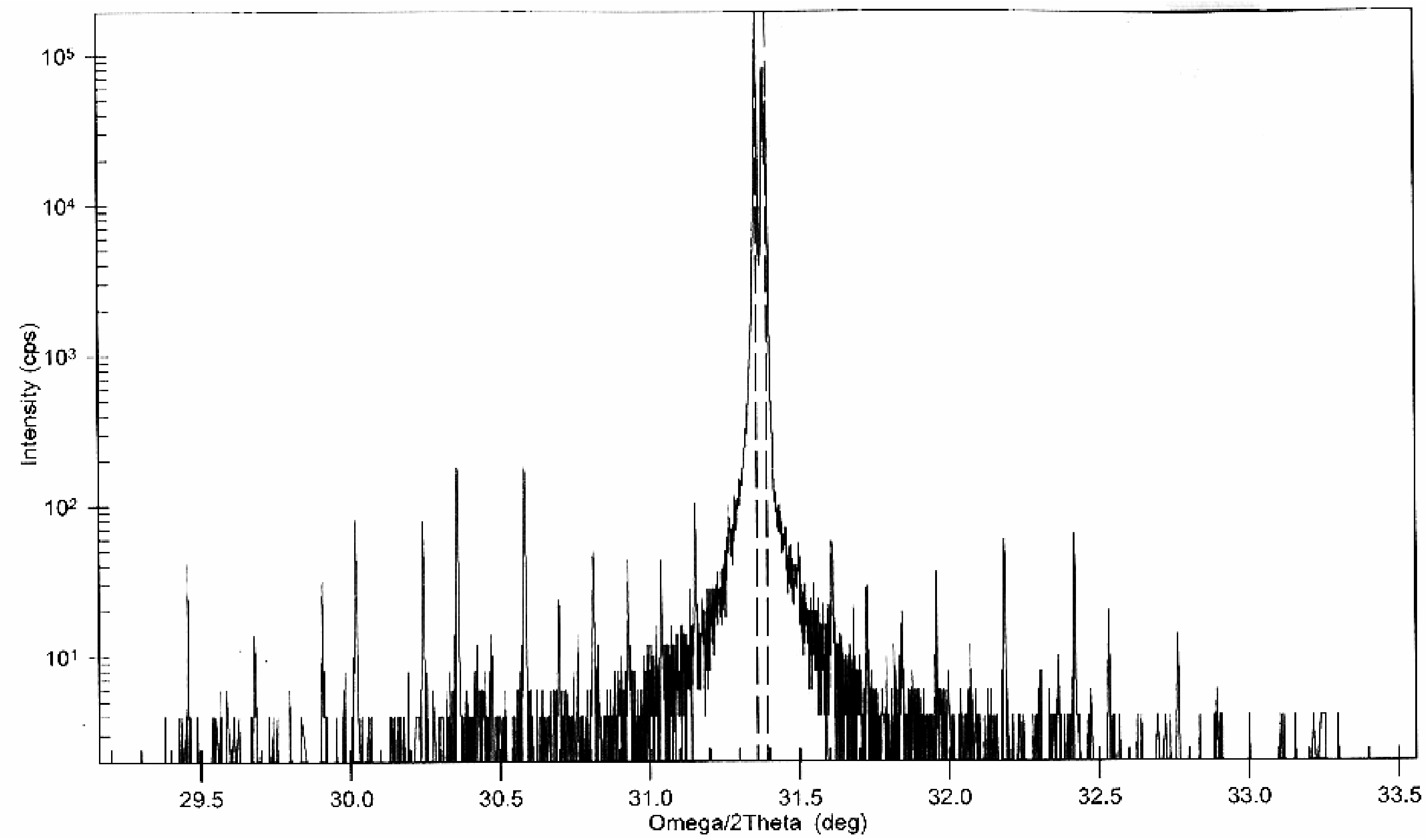
Optical image of QC laser



Optical image of QC laser with double channel waveguide

QC lasers with InP top cladding

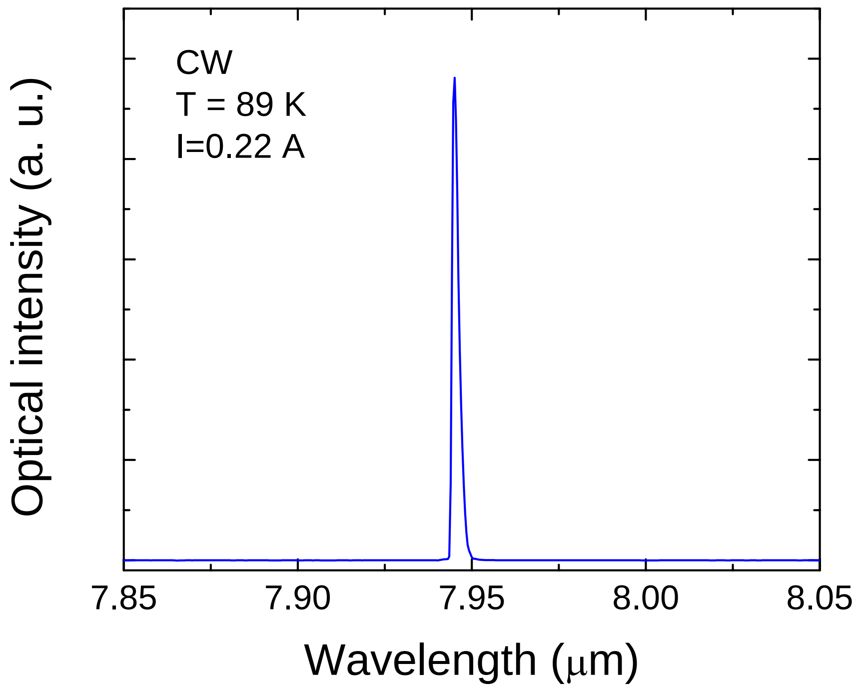
Very high quality of growth was achieved using a solid source MBE



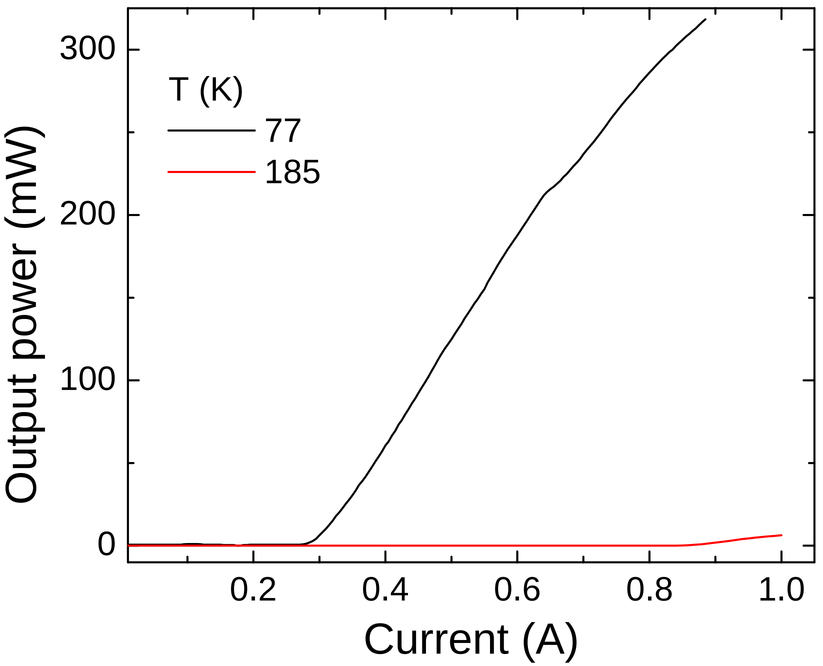
Double-crystal X-ray diffraction spectra (Structure 2)

CW operation of QC laser (Structure 2)

- Lasers operates up to 185 K in cw mode with the output power exceeding 300 mW at 77 K
- Emission wavelengths is very closed to the designed wavelength



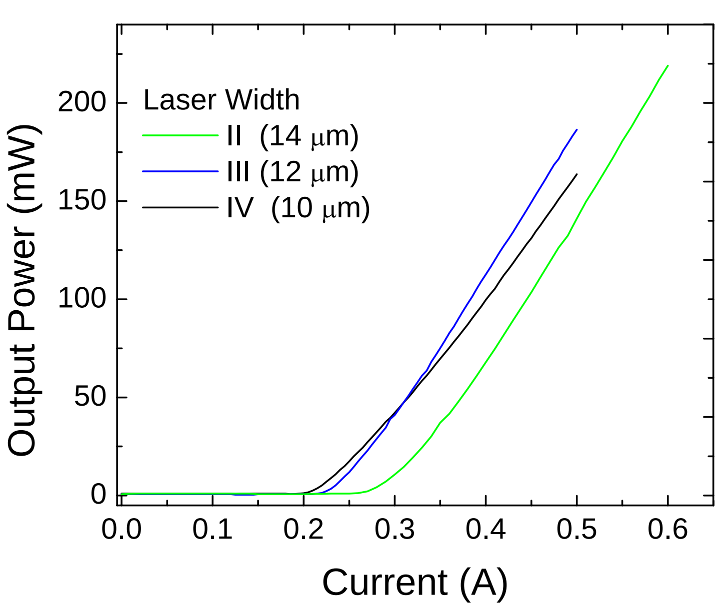
Optical spectrum of QC laser operating at cw mode



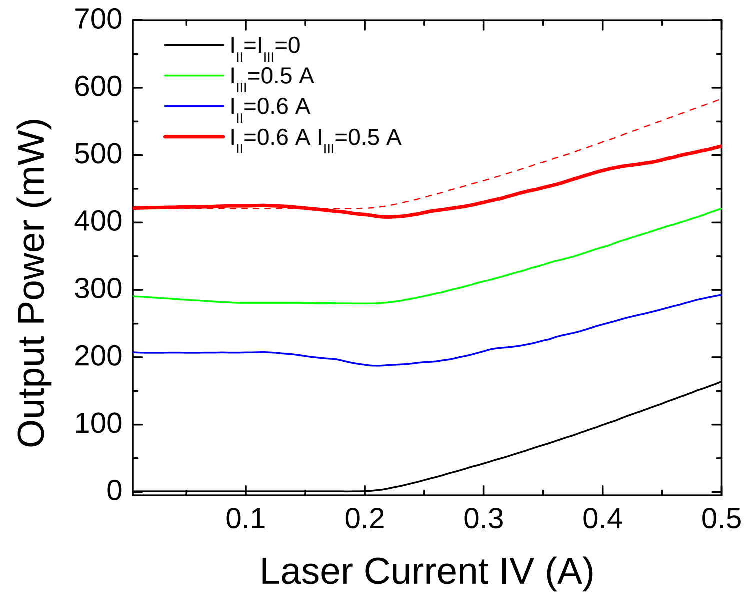
LI characteristics of the QC laser operating in cw mode at different temperatures

QC laser array operation (Structure 2)

- We demonstrated a simultaneous operation of three QC lasers in continous wave mode at T = 77K
- Output power of the array exceeds 500 mW



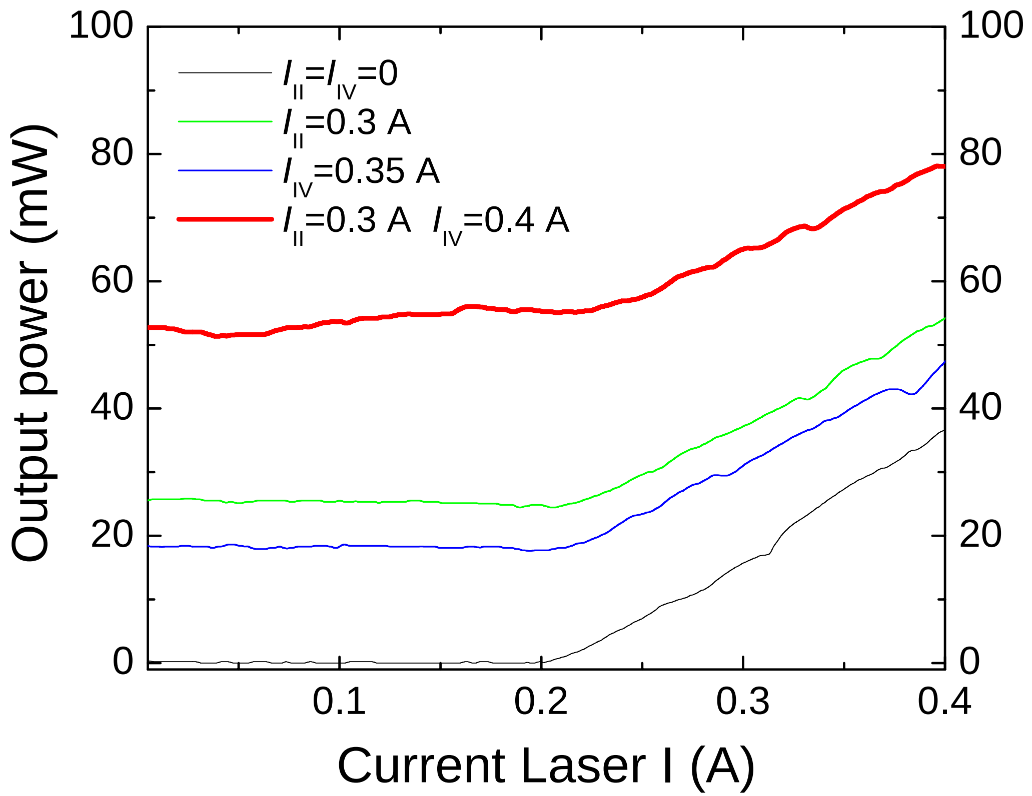
LI characteristics of individual lasers in the array



LI characteristics of the laser IV operating in as a function of dc bias applied to the laser II and III

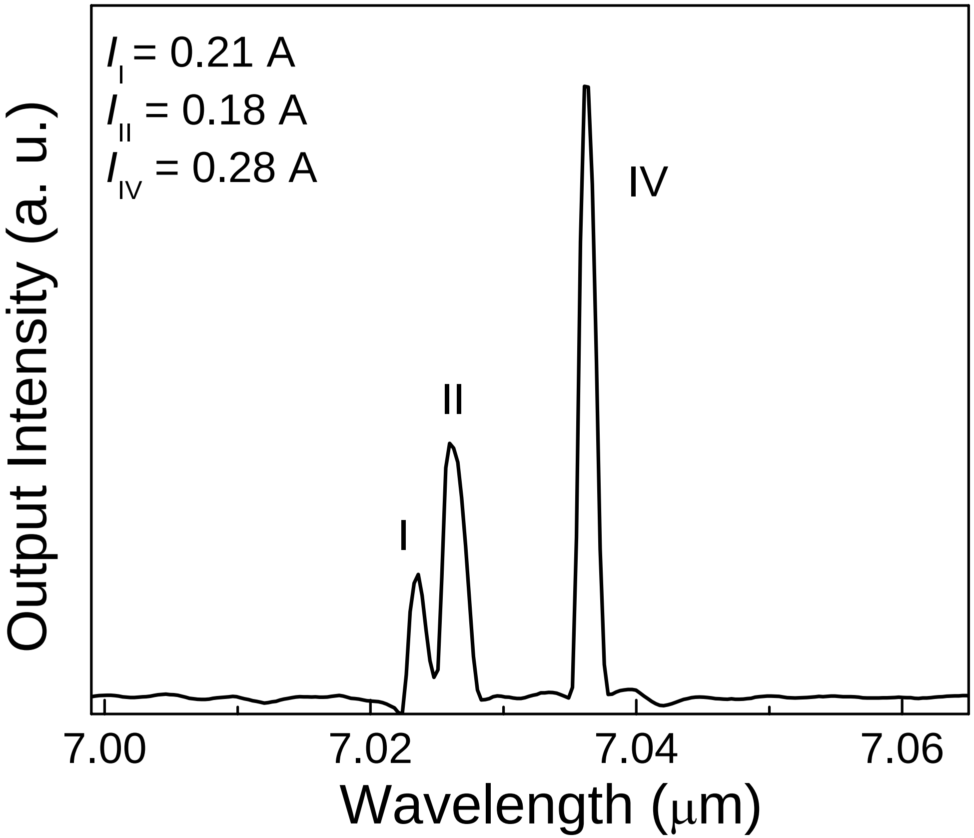
QC laser array operation (Structure 1)

- Structure 1 has a limited output power and higher threshold current
- Yet, array operation has been achieved in the structure too



LI characteristics of the laser I operating in as a function of dc bias applied to the laser II and IV

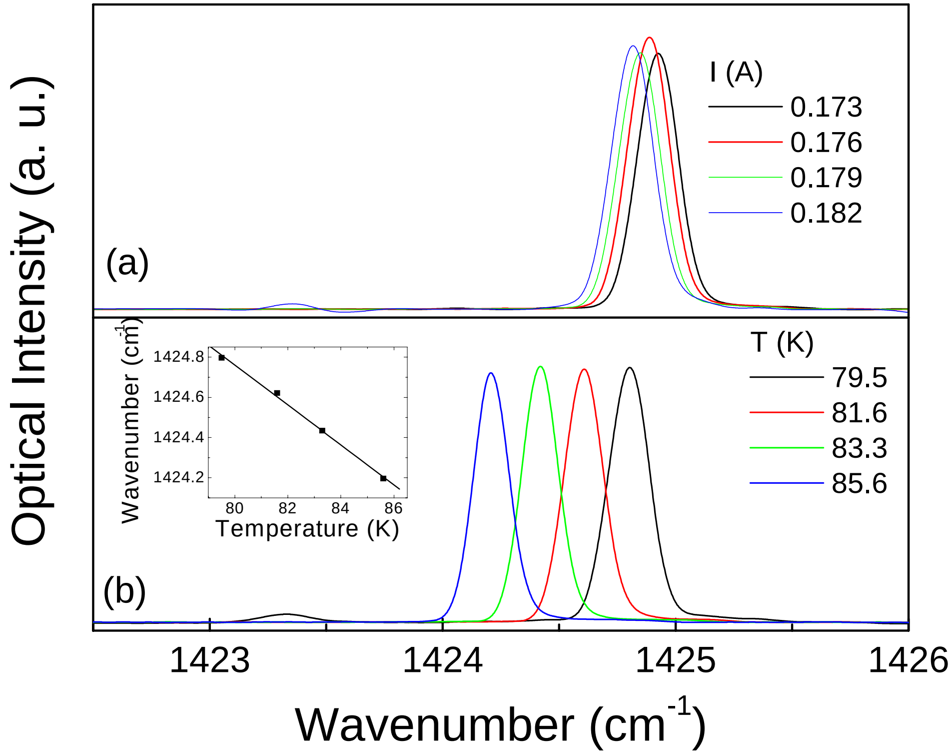
QC laser array operation (Structure 1)



Optical spectra of the QC laser array in cw mode (lasers I, II and IV operating simultaneously)

“Thermal cross-talk” in the QC laser array

We measured the thermal resistance of the lasers from a wavelength shift resulting from variations of the applied current or temperature



$\Delta\nu$ = 0.085 cm^{-1}/K

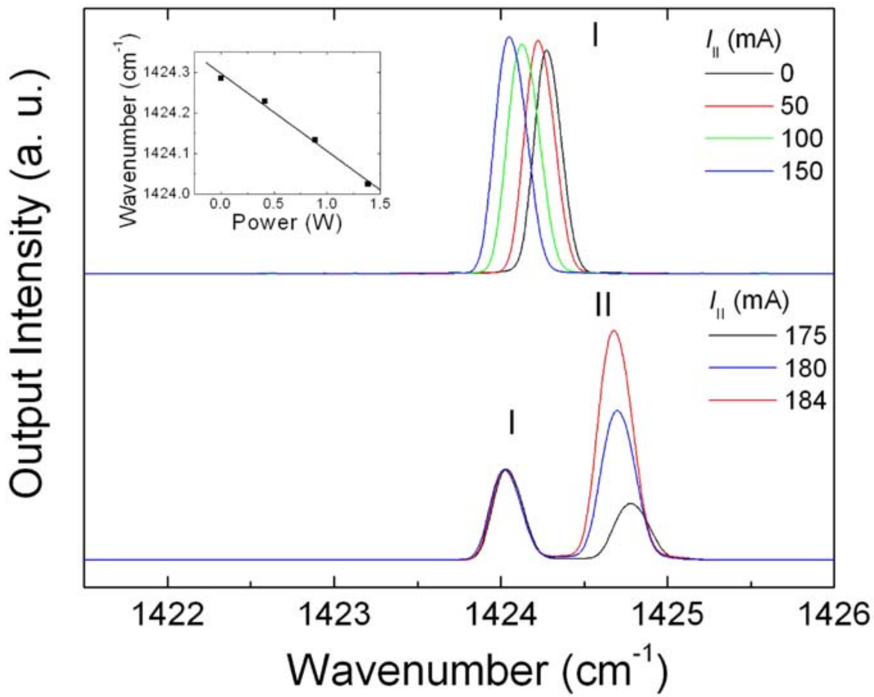
$\Delta\nu$ = 9.7 cm^{-1}/ A

G = 12 K/W

Optical spectra of QC laser vs. applied current (top) and temperature (bottom)

“Thermal cross-talk” in QC laser array

- We measured a wavelength shift of ***laser I*** resulting from variations of the current applied to the ***laser II***
- This wavelength shift is caused by the increase of the temperature of laser I resulting from a raise of temperature / current of laser II

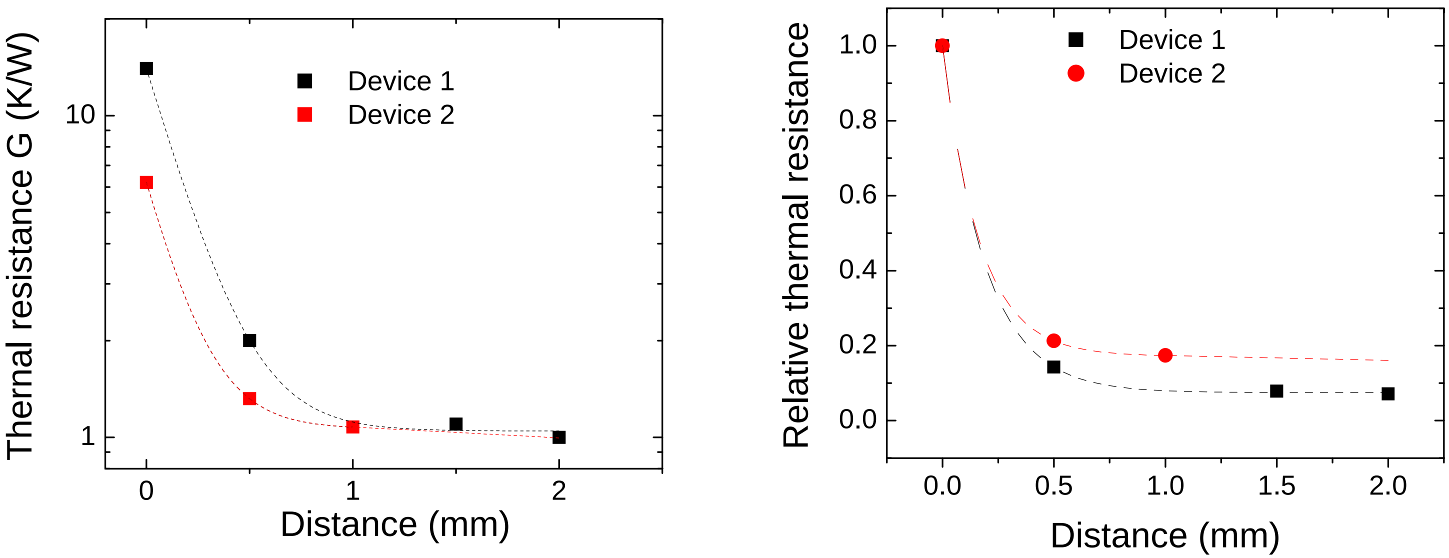


Optical spectra of the ***laser I*** vs. current applied to the ***laser II***

We can find the thermal resistance between these lasers: $G_{I\text{-}II}$ = 2 K/W

“Thermal cross-talk” in QC laser array

- Thermal resistance between the lasers in the array vs. distance
- At zero distance, we use value of the laser thermal resistance
- This allows to compare self-heating effect vs. “cross heating”



Absolute (left) and relative (right) values of the thermal resistance between the lasers plotted vs. lasers separation

Summary

- QC laser array allows to achieve higher output power
- Array allows to achieve the required optical power without pumping the individual laser with very high electrical current
- This will reduce the thermal stress of the laser and will increase the laser life and reliability
- The thermal cross-talk between lasers in the array becomes independent of a distance between lasers at distances longer than 1mm