# Tapered Quantum Cascade Lasers

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***Abstract*—The authors report on the fabrication of quantum cascade lasers with tapered gain sections. The devices show good room temperature performance with an output-power of more than 100 mW. In addition, a very narrow horizontal farfield with a beam divergence of 8 degrees has been observed.**

## I. Introduction

Quantum cascade lasers are light sources emitting in the far- and mid-infrared wavelength range, which are based on intersubband transitions in repeated multi-quantum well structures. Because of their high operation temperatures and high output powers, these technically mature devices have high potential for several applications (i.e. gas sensing, optical free space communication and imaging). However, the high beam divergence of these devices is a limiting factor for coupling efficiency and resolution. The divergence of the laser beam can be tailored by introducing a tapered gain section [2]. This device design combines the advantages of a wide output-facet and a broad gain section with a narrow ridge section. In consequence, high output powers and a small beam divergence can be obtained simultaneously. Hence, this concept has been realized on quantum cascade lasers in order to improve and extend their capabilities.

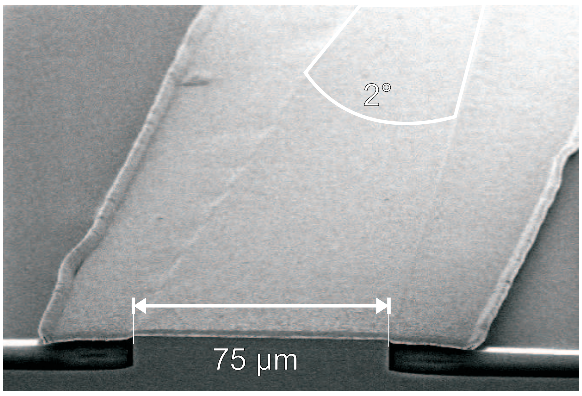


Fig. 1. Scanning electron microscope image of the front facet of a tapered quantum cascade laser.

## II. Device design and fabrication

Usually the approach of gain guided tapered sections is realized for near-infrared diode lasers, since the big difference in the refractive index of the semiconductor and the surrounding material (i.e. air or a polymer) may result in strong reflection of the laser mode when realizing index guided gain sections. These reflections have detrimental influence on the far-field pattern. In order to apply the concept of tapered lasers to quantum cascade laser structures and to achieve optimized results, however, the unique properties of the unipolar quantum cascade lasers have to be taken into account. These devices are based on a multi-quantum well active region, where tunneling through many barriers is a major transport mechanism. This results in a highly anisotropic electrical conductivity. As a consequence etching through the whole active structure becomes a necessity in order to avoid pronounced current spreading. In this work the authors report on tapered QCLs with index-guided gain sections and tapered angles of 2 (see Fig. 1).

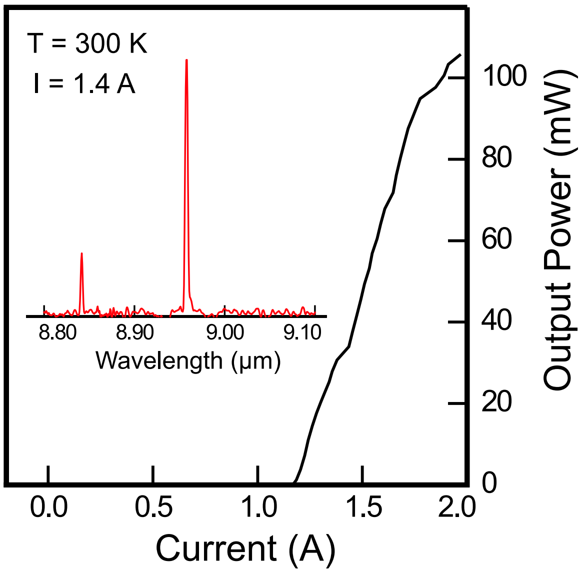


Fig. 2. P-I-curve and emission spectrum of a tapered quantum cascade laser at room temperature.

The devices are based on a 2-LO-phonon design [1], which was grown by a gas-source molecular beam epitaxy system. The active region consists of 35 periods of 22 lattice matched InAlAs/InGaAs layers each. The cascades are embedded in an InGaAs-waveguide-core and the laser-structure is finally capped by 3 $\mu$m of partly highly doped InP acting as top cladding and contact layer. This adds up to a total layer thickness of 6.7 $\mu$m. Hence, an etching depth of at least 7 $\mu$m was chosen. The tapered lasers are defined by optical lithography on the thinned sample and etched by inductively coupled plasma etching using a $Cl_2$/Ar-mixture. The etched structure is subsequently planarized with a polymer and top- and bottom-contacts are finally deposited on the thinned sample. Highly reflective coatings are evaporated on the rear facets (RWG) and anti-reflection coatings on the front facets of the laser resonator. The device design was varied and optimized throughout the process: the different devices consist of a $0.5-1.5$ mm long ridge waveguide (RWG) section with widths of $4-20$ $\mu$m followed by the 2 mm long tapered sections. This results in a $25-75$ $\mu$m wide output facet (see fig. 1), respectively.

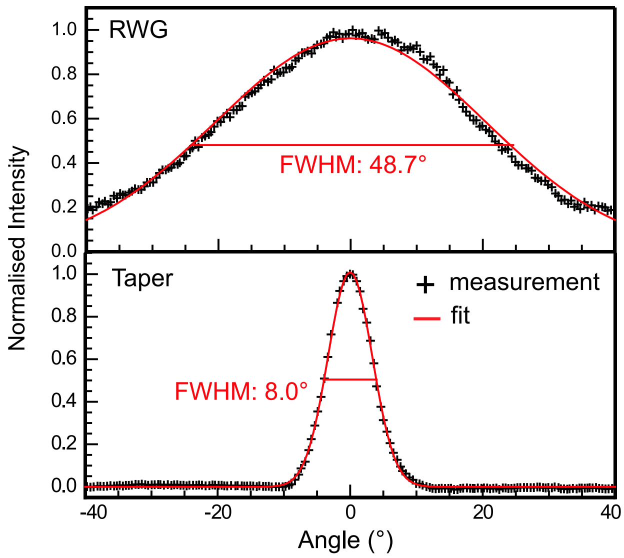


Fig. 3. Measured horizontal far-field of a RWG and a comparable tapered laser device.

## III. Results and discussion

Figure 2 depicts the light-output characteristics (P-I-curve) of a tapered quantum cascade laser at room temperature (300 K). A threshold current of 1.18 A is obtained and the maximum output power exceeds 100 mW. The inset in figure 2 shows an emission spectrum of a tapered laser with a facet width of 75 $\mu$m. The intensity scans of the horizontal far-field of a RWG and a tapered laser of the same sample are shown in figure 3. The RWG is 12 $\mu$m wide, meanwhile the RWG-section of the tapered laser has a width of only 8 $\mu$m. The devices are both 2.5 mm long, the tapered laser expanding to a 75 $\mu$m wide output facet over a length of 2 mm. The RWG shows a measured full width at half maximum of 49 degrees, which is much wider than the FWHM-angle of the comparable taper-device with 8 degrees (see fig. 3). Hence, the tapered quantum cascade laser shows a much smaller divergence. Both measured angles are in good agreement with the simulated values for the fundamental modes.

## IV. Conclusion

Tapered quantum cascade lasers on InP emitting at a wavelength of about 8.9 $\mu$m have been fabricated. The measured horizontal far-fields show very promising results with a very small beam divergence of only about 8 degrees.

## Acknowledgment

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## References

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