Development of low power consumption quantum cascade lasers at 2.7 THz for compact and ultra-sensitive heterodyne detectors

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There is a particular interest in astronomy for the detection of radiation emission from cold interstellar gases. These emissions typically fall in the THz range of the electromagnetic spectrum: for instance, an important transition of deuterated hydrogen falls at 2.7 THz ($90cm^{-1}$). Heterodyne detection is ideally suited to capture these weak signals.

Heterodyne detection requires local oscillator sources that operate a few GHz away from the frequency of interest. THz quantum cascade lasers(*1*) (QCL) emerge therefore as suitable sources for the detection of signals above 2 THz. The combination of a THz QCL with an ultra-sensitive hot electron bolometer (HEB) cooled at 4K for the mixing(*2*) is an optimal setup configuration.

The first building-block of our system is a single mode emission, low power consumption THz QCL operating at a specified target frequency. The Fabry-Pérot THz QCL is of limited use since its output power is distributed over many spectral modes. The approach we have chosen is the distributed-feedback (DFB) architecture, in particular the 3rd-order DFB approach that can provide single mode emission as well as small beam divergence(*3*). The DFB is implemented by introducing a deeply-etched lateral corrugation along the laser ridge that provides the necessary distributed feedback.

To obtain single mode operation at the desired frequency we have fabricated several devices with different grating periods and/or grating duty cycle. This strategy permits to finely cover a relatively broad range of emission frequencies. Upon electro-optical characterization of the lasers, the devices that best suit the application can be selected. The laser implementation is based on judicious electromagnetic modeling. In particular, care have been taken in order to reduce the overall size as much as possible, in order to minimize the power dissipation. We obtained devices with total dissipation inferior to 100 mW, a value compatible with HEB integration.

Finally, we have developed a system based on a Pirex dielectric hollow waveguide(*4*)(*5*) to to re-shape the QCL output beam into a Gaussian beam, as well behaved far-field patterns are required for efficient coupling with the HEB. This approach also improves the simplicity of the quasi-optical coupling and alignment with the mixer.

1. C. Sirtori, S. Barbieri, R. Colombelli, Wave engineering with THz quantum cascade lasers. *Nat. Photonics*. **7**, 691–701 (2013).
2. G. Gay, Mélangeurs à bolomètres à électrons chauds sur membranes fonctionnant au-delà du THz pour l'instrument post-Herschel (2013) (available at https://tel.archives-ouvertes.fr/tel-00976996/).
3. M. I. Amanti, G. Scalari, F. Castellano, M. Beck, J. Faist, Low divergence Terahertz photonic-wire laser. *Opt. Express*. **18**, 6390–5 (2010).
4. E. Snitzer, Cylindrical Dielectric Waveguide Modes. *J. Opt. Soc. Am.* **51**, 491 (1961).
5. A. A. Danylov *et al.*, Transformation of the multimode terahertz quantum cascade laser beam into a Gaussian, using a hollow dielectric waveguide. *Appl. Opt.* **46**, 5051 (2007).