QWIPs and QCDs for Characterization of Mid-Infrared Frequency Combs

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Abstract

The development of optical frequency combs has pushed high-precision spectroscopy to new limits. Optical frequency combs were initially developed in the near infrared region, based on fundamentally mode-locked lasers. Nowadays, large efforts are being made to bring frequency comb technology into the mid-infrared spectral region with a similar degree of maturity. One way is the generation of mid-IR frequency combs with monolithic semiconductor lasers like QCLs. Typical Fabry-Perot QCLs have cavity lengths between 2 and 6 mm resulting in a repetition frequency around 10 GHz. One needs therefore detectors with a bandwidth larger than the repetition frequency to investigate the locking mechanism of the QCLs. In 2006 it was shown that photovoltaic quantum cascade detectors (QCD) show a comparatively flat frequency response up to 4 GHz limited only by the circuit used to contact the detector [1]. One can now engineer this circuit to increase the detector bandwidth by defining a coplanar waveguide (CPW) to contact the detector mesa. With this principle, it was already demonstrated that mid-IR detectors based on intersubband transitions can cover up to 30 GHz of bandwidth [2].

We demonstrate the connection of the QWIP to commercial available RF connectors with a coplanar waveguide. By calculating the gap width of the CPW as function of the center conductor while trying to maintain the characteristic impedance of 50 Ohm, it is possible to suppress reflections due to impedance mismatches. The COMSOL simulation used to model the CPW includes the finite dimensions of the InP substrate and the CPW width, which revealed a non-linear relation between center conductor and gap width. Fig. 2a shows the geometry of the CPW used to connect a 50x50 μm^2 QWIP mesa.

We examined the frequency response of the QWIP by injecting an AM radiofrequency signal into the microwave CPW and sweeping the carrier frequency (Fig. 1a). The signal generates a rectified signal around the injection frequency due to the non-linear IV-curve of the QWIP which decreases if the carrier frequency is higher than the cut-off frequency of the detector. The measurement of the rectified signal reveals a cut-off frequency around 10 GHz. Furthermore, we show that it is possible to measure the RF beatnote created by the beating of the Fabry-Pérot modes of a 4 mm long interband cascade laser with an SNR exceeding 15 dB using our RF QWIP at 80 K (Fig 1b).

Another exciting application of infrared detectors is dual-comb spectroscopy at room temperature. Due to the photovoltaic principle, the performance of QWIPs decreases drastically with increasing temperature. Therefore, they are not suitable for room-temperature operation. A solution for this problem is the use of quantum cascade detectors (QCD).

We report on a single-period QCD with a room-temperature quantum efficiency of 40 percent and a responsivity of 0.86 A/W (Fig 2b) [3]. With such a high responsivity, it is possible to measure the multiheterodyne beating of two frequency combs on the detector and perform dual-comb spectroscopy. The frequency cut-off around 500 MHz is high enough to cover the highest frequency of the multiheterodyne beatings.

References

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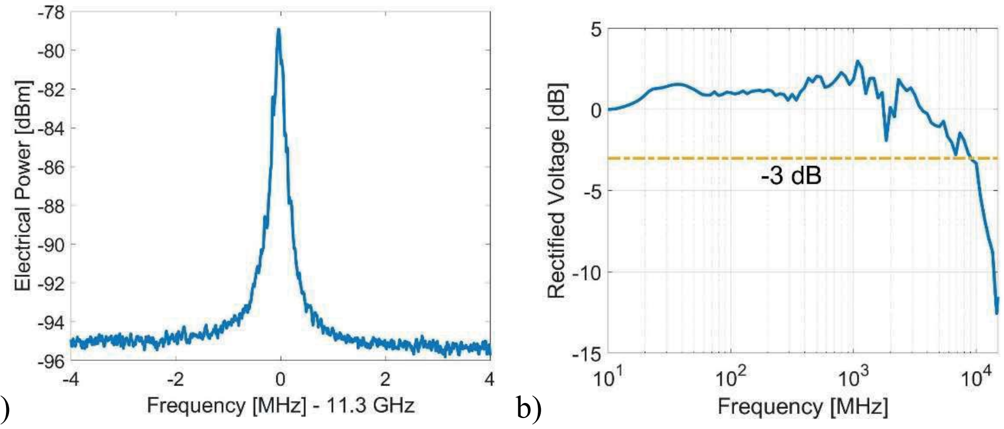
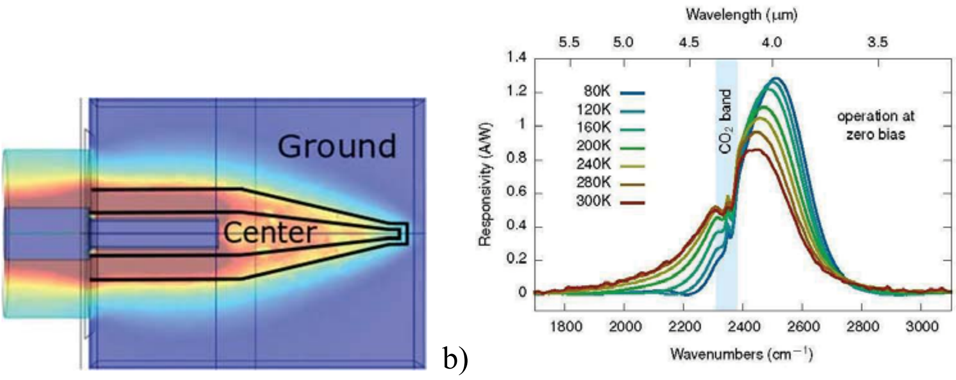


a) b)

Fig. 1: a) ICL Beatnote measured with a QWIP, b) Measurement of the rectification signal



a) b)

Fig. 2: a) COMSOL simulation profile b) single-period QCD responsivity curve