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Surface-emitting THz quantum cascade laser frequency comb with tunable external mirror dispersion compensation

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Abstract. We present a surface emitting THz quantum cascade laser frequency comb with an adjustable chromatic dispersion compensation via a mechanically tunable GTI cavity. Surface emission and high optical feedback into the laser cavity are achieved by a planarized ridge waveguide design with low reflectivity facets and two broadband patch array antennas for coupling to an external mirror (back side) and for power extraction (front side). We demonstrate direct and reproducible manipulation of the frequency comb state, specifically the comb stability and beatnote frequency tuning, by controlling the position of an external movable mirror.

1 Introduction

Terahertz (THz) frequency quantum cascade lasers (QCLs) [1] are compact semiconductor devices capable of emitting coherent THz radiation spanning a wide spectral range. QCL-based frequency combs [2] and dual combs [3] are particularly appealing for high-resolution spectroscopy, metrology, imaging and sensing.
Our recently developed planarized double metal waveguide platform [4] for THz QCLs improves dispersion, RF and thermal properties and allows to lithographically define metallic structures on top of a low-loss polymer BCB surrounding the active waveguide and, therefore, also enables the co-integration of passive waveguide components.
Chromatic dispersion in the active region has a significant impact on the performance of THz QCL combs, limiting the comb bandwidth and stability.
In this work, we present a tunable scheme for compensating the dispersion by changing the position of a gold mirror placed in the proximity of the back laser facet.

2 Results

2.1. Fabricated device

The cavity structure presented in this work consists of a planarized ridge waveguide with low reflectivity planarized facets and a broadband patch array antenna for surface emission on both ends of the ridge. The antenna is based on the narrowband design from Ref. [5], but re-optimized for octave-spanning emission spectra (2-4 THz).
The planarization is made by embedding the active waveguide in a low-loss BCB polymer, and allows the

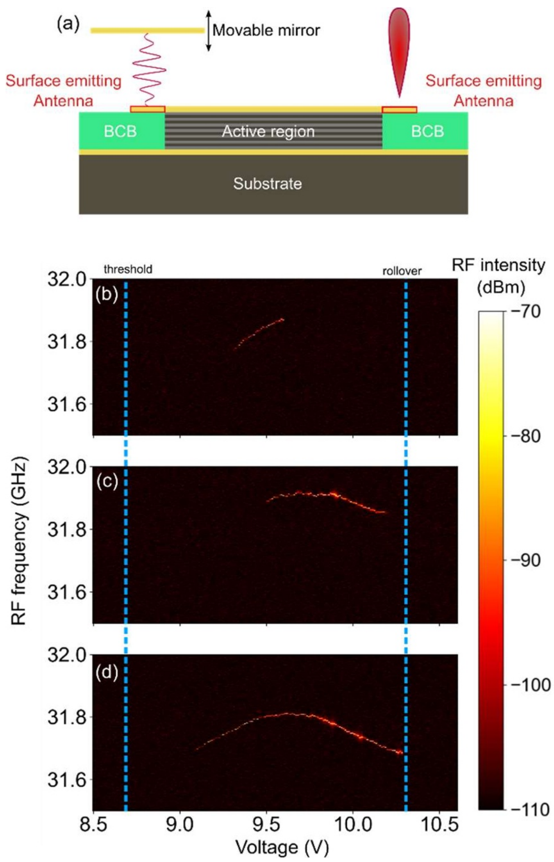

Fig. 1. (a) 2D-schematic of the device showing the planarized double metal waveguide embedded in a low-loss BCB polymer. The two surface emitting antennas are highlighted: on the back side the gold movable mirror is placed; on the front side power is extracted. (b-d) Beatnote maps for different mirror positions, showing how the latter affects the beatnote stability across the full dynamic range.

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extension of the top metallization beyond the width of the active waveguide.

A schematic of the device can be seen in Fig. 1(a), together with the illustration of the external mirror placement. Specifically, on the backside, a gold movable mirror is placed above the surface emitting antenna. On the frontside, the antenna is left uncovered for power extraction. The gold mirror is mounted on a piezoelectric stage, allowing its translation during cryogenic operation. The movable mirror acts as a mechanically tunable Gires Tournois interferometer (GTI) for dispersion compensation [6]. Changing its position affects the amplitude and the phase of the reflected THz wave and, therefore, the optical feedback back in the laser cavity.

This, in turn, induces a group delay dispersion (GDD), strongly affecting the comb operation and stability.

2.2 Measurement results

All measurements were performed on a flow cold-finger cryostat at a heatsink temperature of 80 K.

To study the effect of the gold mirror position on the comb stability we map the electrical beatnote across the full dynamic range of the QCL for different positions. The measurements are shown in Fig. 1(b-d). For optimal positioning of the mirror a strong single RF beatnote is observed over nearly the full dynamic range. In contrast, deviations from the optimal mirror position visibly reduce the single beatnote voltage range.

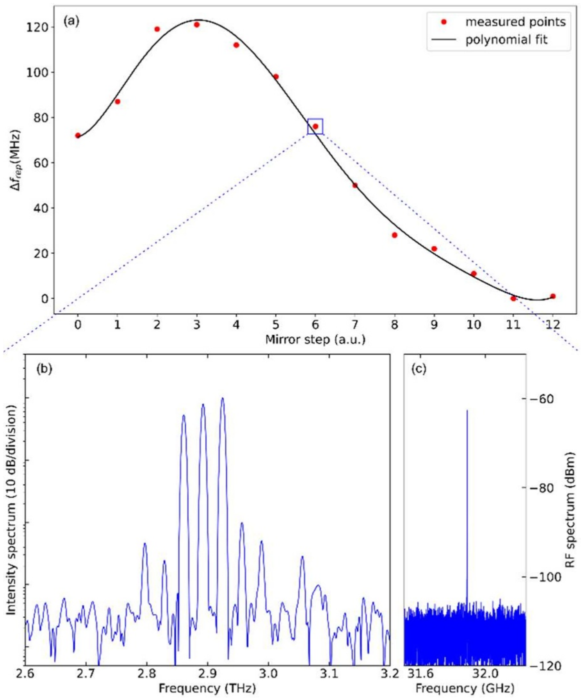

Fig. 2. (a) Tuning of f_{rep} (red dots) as function of the relative distance between two mirror positions. The solid line is a 6th order polynomial fit to the data. (b,c) Spectrum and beatnote at mirror step number 6.

Additionally, we study the tuning of the beatnote frequency with mirror position for fixed laser conditions (224 mA driving current at 80 K). As shown in Fig. 2(a), we are able to tune the beatnote frequency by more than 100 MHz, and the recorded relation suggests a periodic behavior as expected from a GTI cavity. In Fig. 2(b), we show the measured THz emission spectrum spanning over 300 GHz with a strong single RF beatnote at 31.89 GHz.

3 Conclusion

We presented a surface emitting THz QCL comb with a mechanically tunable GTI dispersion compensation which can improve the comb stability and enables to tune the beatnote frequency.

In combination with focusing mirrors and RF injection, both comb bandwidth and stability could be further improved.

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