High-frequency modulation of mid-infrared emitting ring quantum cascade lasers

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1. Introduction

The identification of different molecules in the mid-IR spectral range is an important task e.g. in the analysis of greenhouse-processes related to global warming. Hereby, the very sensitive detection of species like CO_2, N_2O or CH_4 are of specific interest. One novel class of optical sensors which is based on so-called dispersion spectroscopy techniques addresses this and related tasks. These measurement techniques combine features like baseline-/normalization-free behavior (immune to source-power fluctuations) with a linear output-dependency on gas samples concentration and are realized e.g. in CLaDs [1], HPSDS [2] or most-recently 2f-WM FP-PTI [3]. All those techniques have in common that they rely on high performance mid-IR quantum cascade lasers (QCLs) which can be rapidly current-modulated up to MHz-/GHz-frequencies.

2. Results

In this work we investigate the current-modulation capabilities of surface emitting ring QCLs via a 2nd order distributed feedback (DFB) grating at ~7.56 µm wavelength. Ring-QCLs have their advantages in narrow and manipulable farfield emission capabilities as well as possibilities for compact array configurations. Previous modulation-studies focused on Fabry-Pérot (FP) ridge waveguides only, and showed their potential for modulation frequencies up to the GHz-range [4,5]. Here, we compare ring-QCLs and FP-devices from the same material system (regular two-phonon resonance design [6]) for their modulation-characteristics.

The analysis is performed in the time- as well as frequency-domain between 5 kHz and 160 MHz (maximum of our setup). We use a state-of-the-art amplitude-to-frequency conversion technique [7], based on the absorption line of CH_4 around 1322 cm^{-1}. The time trace of the dispersed signal is recorded by a fast MCT-detector and analyzed afterwards using the signal of a lock-in amplifier. For data analysis we use a similar model to Hangauer et al. [8].

To avoid scaling effects with the modulation current I_{AC}, Fig. 1(a) shows the frequency tuning amplitude Δf *normalized* by the intensity modulation index m. As can be seen, this value is typically larger for the ring-devices compared to the similar FP-lasers, but both still follow the same trend. The discrepancy might originate from geometrical differences in the devices or different driving current densities for both lasers and will be further analyzed in future experiments. In Fig. 1(b) we show the corresponding FM-IM phase shift. Again the trend is similar in both devices, this time also with comparable *absolute* values. Above 1 MHz we observe the expected decay due to the transition to the electronic tuning regime (spectral blue-shift, zero FM-IM phase) which is fully achieved above ~40-50 MHz. On the other hand, the increase between 100 kHz and ~1 MHz is in strong contrast to the results in [8] and needs a more detailed analysis.

In good agreement with [8] we see a quasi-single-sideband regime (sideband ratio is reduced significantly) achieved for both devices, while again the ring-QCL differs somewhat from the FP-device by showing higher values for the sideband ratio E_{-1}/E_{+1} (see Fig. 2).

In conclusion, we observe partially similar behavior for both types of devices, while some features are somewhat more pronounced in the ring-devices (see e.g. Fig. 1(a)). This means that in general singlemode emitting ring-QCL devices are very suitable candidates for experiments, where rapid current-tuning characteristics (at least up to ~200 MHz) are beneficial.

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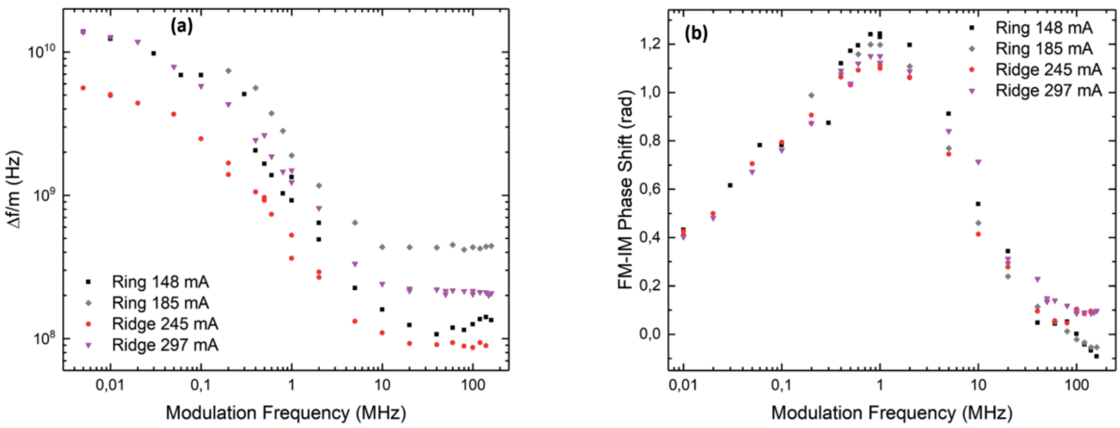

Fig. 1: (a) Amplitude of frequency tuning Δf normalized to the intensity modulation index m as function of the modulation index in the range between 5 kHz and 160 MHz (ring- and ridge-laser at different driving conditions). (b) FM-IM phase shift between 100 kHz and 160 MHz for the same driving conditions as in (a).

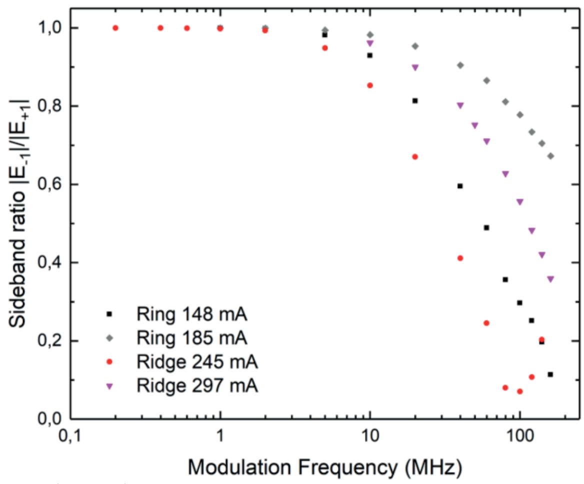

Fig. 2: Sideband ratio of the -1st to +1st order electrical fields within the modulation range of 200 kHz to 160 MHz.