Dependence of switch-on time on Vernier comb alignment in frequency tunable lasers

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Introduction

Semiconductor lasers based on Vernier frequency selection principle are used extensively to design wideband frequency tunable diode lasers [1], as well as quantum cascade lasers (QCLs) operating at mid-infrared and terahertz (THz) frequencies [2]. Such lasers typically consist of multiple cavity sections, and can include chirped or burst gratings, such that each cavity section supports a comb of frequencies. Emission is selectively favoured at a resonant frequency at which the lines of the individual combs are in Vernier alignment, which results the lowest lasing threshold. Frequency tuning is realised through a controlled index perturbation applied to the two combs which shifts the resonance to an adjacent mode. Steady-state emission characteristics and frequency tuning performances from such lasers are widely reported in the literature. Recently, ultrafast dynamics of mode selection in Vernier lasers and a temporal evolution of a multi-mode emission to a single mode emission was reported by the same authors [3]. This was studied by injection seeding a THz coupled-cavity (CC) QCL with a broadband THz pulse from a photoconductive emitter and exploiting the coherent sampling of THz radiation using time domain spectroscopy (TDS) [4]. Using a similar experimental technique, here we report an observation of a variation in the laser switch-on time as a function the Vernier alignment of combs in a CC THz QCL. The underlying physics is explained through a full multi-mode, temperature dependent carrier and photon transport simulation using a hybrid reduced rate equation (RRE) model [5].

1. Results

A CC geometry was designed such that mode hopping between two emission frequencies could be controlled through a large change in the current supplied to the tuning cavity. This allows a fine control of the alignment between the frequency combs. The CC THz QCL comprise of a 1.38-mm-long active '*lasing*' cavity that is electrically driven above threshold, and a 3.43-mm-long passive '*tuning*' cavity that is electrically driven sub-threshold to induce localised Joule heating and control the emission frequency. A 13-µm-long air gap was used to separate the lasing and tuning cavities. Initially, the free-running steady-state emission spectra were measured with a lasing cavity current of 0.65 A. Single mode emission at 2.825 THz was measured when the tuning cavity current was <1.65 A, and a mode hop to 2.765 THz was observed at tuning cavity current in the range 1.65–2 A.

The temporal dynamics of the CC THz QCL emission were characterised using an injection seeding technique based on THz-TDS [Fig. 1(a)]. The switch-on delay was found to increase as the tuning cavity current was increased from 0.7–1.6 A, corresponding to a progressive misalignment of the frequency combs and an increase in the effective mirror losses at 2.825 THz [Fig. 1(b)]. However, at tuning cavity currents >1.6 A, the switch-on delay was found to decrease after the mode switched to 2.765 THz. The decrease in switch-on delay observed here at higher lattice temperatures indicates a clear influence of the frequency comb alignment on the switch-on delay in such lasers. This was further verified from the laser stabilisation time, simulated using the hybrid-RRE model [Fig. 1(c)]. In agreement with the experimental observations, the longest stabilisation time is predicted at tuning currents close to the current at which the mode hops from 2.825 to 2.765 THz (~1.6 A), which also corresponds to a switch in the alignment of frequency combs in the CC THz QCL.

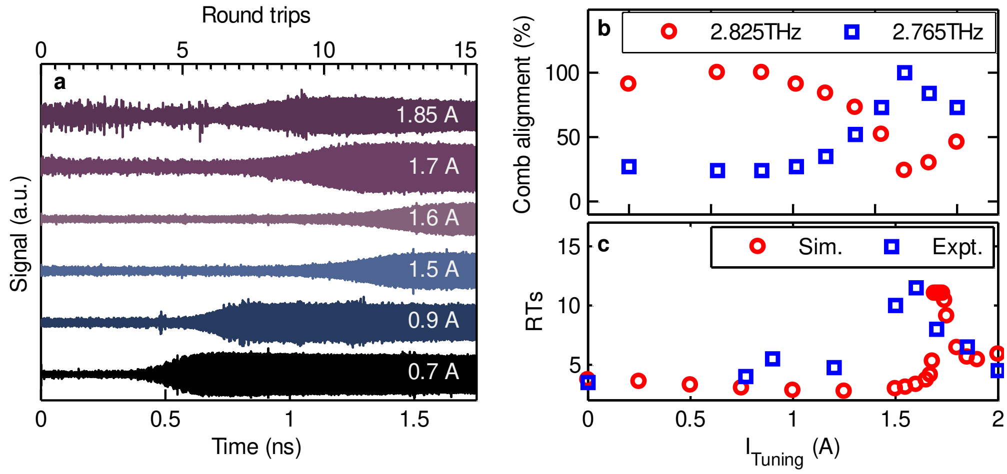

Fig. 1: (a) Electric field measured as a function of time for different tuning cavity currents. (b) Comb alignment calculated at frequencies 2.765 and 2.825 THz. (c) Experimentally measured (blue), and simulated (red) switch-on delay measured as cavity round trips (RTs) as a function of tuning cavity currents.

3. Conclusions

In conclusion, we have measured the ultrafast switch-on dynamics in a CC THz QCL using coherent time-domain sampling of the laser emission. We found that whereas hopping between single modes can be achieved through a small change in tuning current, the stabilisation time in such lasers is more sensitive to the alignment between the frequency combs supported by each cavity section.

References

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