Analysis of Passive Mode Locking of THz Quantum Cascade Lasers

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Quantum cascade lasers are unipolar semiconductor devices emitting in the mid- and far-infrared portions of the electromagnetic spectrum. Due to their relatively narrow linewidths and short gain recovery times, these lasers have been deemed difficult, if not impossible, to passively mode lock (PML) [1]. Nevertheless, the successful mode locking of QCLs is of utmost importance as it could allow the generation of ultrashort pulses and also the formation of stable broadband frequency combs. As a consequence, the research community has invested substantial effort and funds in devising methods for active mode locking of QCLs with some limited success achieved [1,2]. In this submission, we revise the possibility of passively mode locking a THz quantum cascade laser via a fast saturable absorber, which can also be constructed as a quantum well heterostructure with suitably chosen well and barrier thicknesses [3]. Our results are based on the numerical solution of the Maxwell-Bloch equations.



**Fig. 1.** (a) The modelled linear cavity design consisting of a gain and absorber section. (b)-(d) A snapshot of pulse propagation inside the cavity for decreasing gain recovery. (e)-(g) The corresponding optical power spectra. The used simulation parameters are displayed in the tables in the lower left corner.

Figure 1(a) illustrates the envisaged cavity design, incorporating an absorber and a gain section in a serial fashion and not parallel, as previously suggested for the case of SIT mode locking of mid-infrared devices [3]. The gain and absorber medium are assumed to have the same resonance frequency and to be positively and negatively inverted, respectively, at the onset of our simulations. Within a reasonable range of parameters, illustrated in the tables of Fig. 1, namely a fast recovery of the absorber (T1a) and a relatively long, but still realistic [4], recovery (T1g) of the gain, as can be seen from Fig. 1(b) and 1(c), our simulations produce pulses with full width at half maximum (FWHM) duration of around 2 ps. Note that these values are comparable to the shortest pulse lengths ever produced by QCLs with applied active modulation of the injection current [1,2]. When decreasing the gain recovery time from 30 ps down to 20 ps, we observe that the mode locking is preserved, indicating the robustness of the method, until the break-down of the single pulse operation into a pair of co-propagating pulses for the case T1g = 10 ps and lower. This can be explained intuitively by the fact that the round trip time is approx. 34 ps, and so the pulse splits into two identical copies, such that, as seen by the active medium, the effective round trip time reduces to about half of the original value. All simulations have been performed for a self-starting, free-running configuration, which shows the practical potential of this approach.

**References**

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