On Passive Mode Locking in THz Quantum Cascade Lasers

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Quantum cascade lasers (QCLs) are unipolar semiconductor devices emitting in the mid- and far-infrared spectral ranges. 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) [1,2]. However, the successful mode locking of QCLs is of utmost importance as it could allow generation of ultrashort pulses and also formation of broadband frequency combs. As a consequence, the research community 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 prospect of passively mode locking a THz QCL via a fast saturable absorber (FSA). Our results, based on the numerical solution of the Maxwell-Bloch equations, show that it could be possible to implement a “text-book” FSA-PML mechanism, robust over large variations of the experimental parameters.

Figure 1(a) illustrates the envisaged cavity design, i.e. a ring cavity incorporating an absorber and a gain section in a way similar to typical gain-absorber geometries for lasers in the optical range. The FSA medium is assumed to have the same resonance frequency as the gain medium, and can be constructed from a suitably engineered quantum cascade heterostructure. In contrast to the gain section, the FSA is assumed to have different coupling to light and not to be in inverted state. Note that this arrangement has not been attempted before, as PML in QCLs, to the best of our knowledge, has been only considered within the context of the optical Kerr effect [3] or self-induced transparency mode locking [4].

Within a reasonable range of parameters (illustrated in the tables of Fig. 1), namely a fast recovery of the absorber (T1a) and a relatively slow, but still realistic [5], recovery (T1g) of the gain (Figs. 1(b) and 1(c)), our simulations yield pulses with full width at half maximum duration of around 2 ps. Those values are comparable with the shortest pulse lengths ever produced by active mode locking of QCLs [1,2]. When decreasing the gain recovery time from 30 ps down to 20 ps, we observe that the fundamental mode locking is preserved until the break-down of single pulse operation into a pair of co-propagating pulses for T1g = 10 ps and lower. The latter can be explained intuitively by the fact that the round trip time is approximately 34 ps, and so the pulse splits into two identical copies, such that, as seen by the inversion, 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.

**Fig. 1**. (a) The modelled ring cavity consisting of a gain and absorber section. (b)-(d) The intracavity power (left y-axis) and inversion (right y-axis) inside the resonator for decreasing gain recovery and assumed facet area of 40x10 μm2. (e)-(g) The corresponding spectrum.



**References**

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