**Passive mode locking of THz quantum cascade lasers**

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**1. Introduction**

It is a well-established fact [] that upon reaching lasing threshold the upper level lifetime of a terahertz (THz) quantum cascade laser (QCL) will rapidly decrease, due to the onset of stimulated emission []. These fast dynamics however, do not pose a substantial hurdle for mode locking, since it is only the purely electronic, *non-radiative* lifetimes of the upper state which play a role. In this contribution, we investigate the possibility of passive mode locking (PML) of THz QCLs via a fast saturable absorber (FSA) in a ring cavity geometry. We show that this simple mechanism could yield a periodic train of ultrashort pulses (one pulse per round trip) over a large variation of the experimental parameters, even for *non-radiative* inversion life-times as few as 10 ps.

**2. Motivation**

Below threshold the electron transport in THz QCLs is mainly driven by non-radiative transitions such as longitudinal optical (LO) phonon scattering or resonant tunnelling []. Pump-probe experimental measurements affirm that at this regime, the typical lifetimes of the upper laser level are somewhere between 10 and 50 ps for both THz and mid-infrared QCLs [], generally depending on the heterostructure design. Measurements of the same rates when the laser is biased above threshold are difficult since the electron transport is dominated by stimulated emission []. However, simple argumentation based on perturbation theory, could lead one to expect that these numbers might not be drastically different from their sub-threshold values.

Here we show that, assuming soliton propagation inside the cavity, the gain recovery time could be even longer than these non-radiative lifetimes, which could also enable successful PML. To see why, assume a simple two level system, the inversion of which has been saturated by a pulse of sufficient intensity, to some minimal value. *After* the passage of the pulse, the inversion begins its recovery to steady state. Now, the processes that govern this recovery of the gain will be mainly the *non-radiative* scattering processes, mentioned above, since there is no photon density to trigger scattering. In the two-level Bloch formalism, we can easily show that in this scenario the gain recovery time is approximately given by

|  |  |
| --- | --- |
|  | (1) |

where is the *non-radiative* lifetime of the inversion, is the inversion at threshold and is the pump parameter (=1 corresponds to pumping at threshold). Importantly, from Eq. (1) we see that could become longer than and furthermore, that it will strongly depend upon the pump parameter and also the strength of the gain saturation (). In the following, we show by simulations that passive mode locking is indeed possible for values of as short as three times smaller than the cavity round trip time ().

**3. Results**

**C:\Users\petz\AppData\Local\Microsoft\Windows\INetCache\Content.Word\ITQWimg.emf**Unlike other known PML approaches, where the main ML mechanisms were the Kerr-lensing effect [] or self-induced transparency mode locking [], we propose passive mode locking with a fast saturable absorber in a ring cavity THz QCLs. The envisaged geometry is one of a microring resonator, similar to the ones in Ref. [] and [], incorporating a gain and an absorber section in a serial fashion as depicted in Fig. 1a. Both the amplifier and the absorber can be suitably engineered as quantum well heterostructures and are assumed to have the same optical transition energy. Also the absorber is taken to be in a completely non-inverted state, whereas the gain medium to be pumped to -times above threshold.

Fig 1. (a) The modelled ring cavity consisting of a gain and absorber section.(b) The optical power spectrum, (c) the intracavity power (left y-axis) and inversion (right y-axis) and (d) the gain recovery tme as a function of the pump parameter .

Our calculations, based on the semi-classical Maxwell-Bloch equations, show that within this configuration pulse generation could be possible for self-starting, free-running lasers and for a large variation of the input parameters (specifically we observed puelse formation for values of between ps. The simulated pulse, for the case when s, its spectrum, together with the calculated gain recovery time are depicted in Fig. 1b-d. All other simulation parameters are typical values found in literature and are omitted here for brevity.

**References**

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