Ultrafast response of Harmonic Modelocked THz Lasers

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***Abstract*— Harmonic modelocking of lasers is usually employed to attain high repetition rates. Despite the favourable dynamics of THz quantum cascade lasers (QCLs), harmonic active modelocking has not been demonstrated. In this work, using ultrafast time resolved spectroscopy, we present the first demonstrations of active modelocking performed at the fundamental and second harmonic on metal-metal THz QCL. We will also show that in certain cases, QCLs can spontaneously attain self-starting harmonic behaviour up to the 15th harmonic through self-microwave generation, which highlights the electronic and photonic nature of these devices.**

I. INTRODUCTION

HARMONIC modelocking is routinely used in the visible and near infrared range and consists in the generation of multiple light pulses within the photon roundtrip time of the laser cavity. This offers the possibility of high repetition rate laser systems, reaching GHz and tens of GHz rates, beyond rates that are limited by the laser cavity length. This is of particular interest in high-bit-rate optical communication, photonic analogue-to-digital conversion, multi-photon imaging, and astronomical frequency comb generation [1]. Further, modelocked lasers with high repetition rates can be applied to microwave photonics for radio frequency arbitrary waveform synthesis and for the generation of extremely low noise, high frequency sub-mm waves in future wireless networking technologies. No demonstrations of harmonic modelocking have been shown in the terahertz (THz) range with quantum cascade lasers, which are one of the only practical THz semiconductor lasers [2]. Unlike standard interband lasers, harmonic active modelocking is inherently adapted to QCLs as the unique fast dynamics with picosecond relaxation dynamics permit an ultrafast modulation of the gain and loss. Multiple demonstrations of fundamental active modelocking in QCLs have been reported [3,4], where the QCL is electrically modulated at or close to the round trip frequency (f_{RT} = c/2nL where n is the refractive index of the material, c is the speed of light in vacuum and L is the cavity length, assuming no refractive index dispersion). Recently MIR QCLs have shown self-starting harmonic modelocking [5] and indications were observed in the THz range but no measurements of the ultrafast origins or time behavior have been shown so far.

In this paper we show the first demonstrations of harmonic active modelocking of QCLs (figure 1), as well as self harmonic emission at multiple (15th) harmonics with 15 pulses per round-trip [6]. Importantly we measure directly the time response and show that the latter has its origins in the ultrafast gain dynamics of THz QCLs that permits high frequency microwave generation, which in turn modulates the gain and loss of the system. These conclusions are supported by full-wave Maxwell-Bloch simulations [7] (see figure 2). These effects are unique to THz QCLs, showing both electronic and photonic behaviour. This work further highlights control of the spectral mode spacing at harmonics of the round trip frequency and pulse generation at multiples of the cavity length, resulting in greater than one pulse per round-trip [6]. We will further show how we can approach higher repetition rate using ultrafast dynamics of these devices.

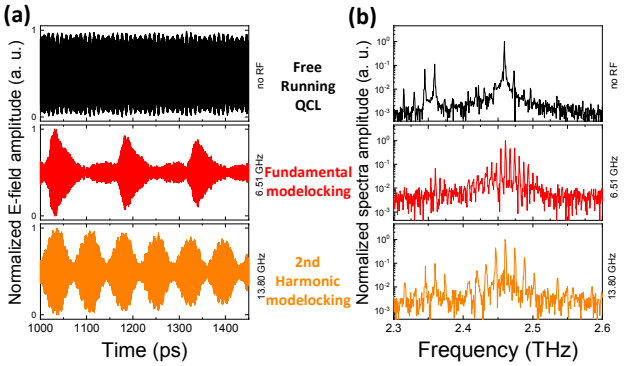

Fig 1. a) field resolved pulses as a function of time and b) the corresponding spectrum (fast fourier transform of a)) showing free running, fundamental modelocking and second harmonic modelocking operation

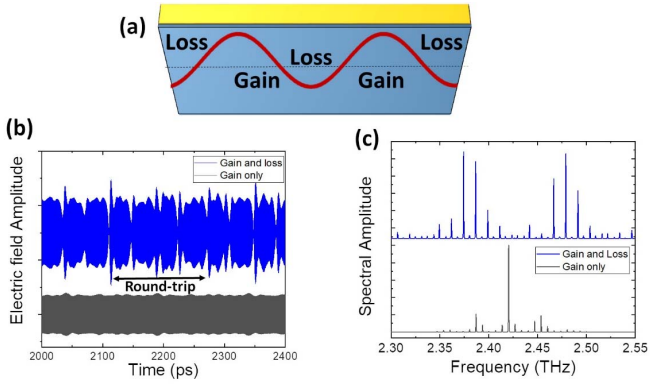

Fig 2. Above: schematic of the spatial modulation creating gain and loss regions in the cavity. Below: Spectral and Temporal Simulations of self-harmonic behaviour of THz QCLs

REFERENCES

[1] U. Keller, Nature 424, 831–838 (2003).
[2] R. Köhler, et al. Nature 417, 156–159 (2002).
[3] Barbieri, S. et al. Nat. Photonics 5, 306–313 (2011).
[4] F. Wang et *al.* Laser Photonics Rev. **11**, 1700013 (2017).
[5] M. Piccardo et *al.* Optica **5**, 475–478 (2018).
[6] F. Wang et *al.* Light :Science and Applications, Accepted (2020)
[7]. P. Tzenov et *al.* New J. Phys. **20**, 053055 (2018).