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Short Pulse Generation and Dispersion in THz Quantum Cascade Lasers

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***Abstract*—We demonstrate the generation of short terahertz pulses from spectrally broad metal-metal quantum cascade lasers at 77 K via active mode-locking, and show the limiting role of phase-matching between the terahertz pulse and the microwave modulation. Furthermore a new concept of THz pulse dispersion control is proposed to go beyond the limitation of the current modulation scheme.**

I. INTRODUCTION

THE generation of ultrashort and intense pulses radiation from QCLs has proved to be challenging. It has been suggested that the ultrafast electron dynamics of these devices leads to inherent multimode instabilities that prevent mode-locking and pulse formation. Nonetheless, active mode-locking has been recently demonstrated [1] [2] in THz QCLs by electronically modulating the device at a microwave frequency corresponding to the cavity round-trip. This has been attributed to the longer gain recovery time of THz QCLs than those operating in the mid-infrared (that are more difficult to modelock [3]).

Here we demonstrate short THz pulse generation via the synchronization between the propagating electronic microwave modulation and the THz pulse within the QCL active region. The active mode locking technique is combined to QCL phase seeding technique for pulse characterization by employing phase resolved detection. The measured QCL electric field embedded in metal-metal (MM) waveguides shows generation of 11 ps THz pulses [4].

II. RESULTS

This work was performed on MM waveguide QCLs employing phonon depopulation active regions. Fig. 1(a) shows the measured electric field as a function of time for a QCL injected with an ultrafast THz seed pulse at 77 K. Fig. 1(b) shows the QCL spectrum via fast Fourier transform of the measured time-domain signal. The spectrum is centred at ~2.6 THz with a bandwidth of ~ 500 GHz. The mode spacing is ~13.2 GHz and was compared to the microwave beat note frequency, measured with a spectrum analyzer, which showed a narrow linewidth at 13 GHz just above laser threshold, which gradually became wider with increasing current (see fig 1(c). The time resolved electric field of the THz QCL at 77 K shows clearly the generation of a train of THz pulses when actively mode-locked with a microwave modulation of 12.4 GHz (see fig. 1(d)). The average pulse width is found to be 11 ps. However, the entire ~ 500 GHz bandwidth is not fully used, where ~ 1ps pulses would be expected. This is a result of the microwave modulation, which limits the pulse width and the number of modes – pulse formation is only present close to laser threshold, which limits the number of modes that can be brought above threshold [5]. As well as presenting these results, we will also discuss the dispersions of THz pulses via waveguide design. Figure 1(e) shows the dispersive effect of a micro-cavity coupled to one facet of the QCL output while actively mode-locked. As can be seen, the successive pulses (here from pulse N to N+2) undergo different pulse broadening while passing several time through the micro-cavity. These will be discussed in detail and their application to short pulse generation.

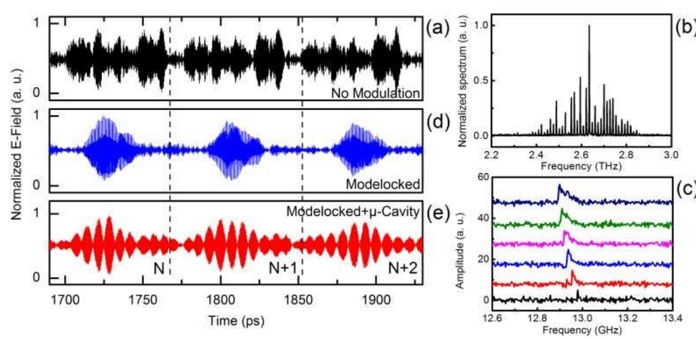

Fig. 1. a) Electric field of QCL emission as a function of time measured at 77K using injection seeding technique. b) QCL THz spectrum. c) Microwave beat-note spectrum of QCL as a function of current. d) Active mode-locking of the metal-metal QCL at 77K. e) Short pulse dispersion via integration of a coupled cavity to the metal-metal QCL.

III. SUMMARY

To conclude, we have shown short pulse generation from mode-locked THz QCLs when phase matching between the microwave phase velocity and the envelope of the THz emission is obtained. This works brings a significantly enhanced understanding of mode-locking of QCLs and will permit new concepts to be explored to generate shorter and more intense pulses in the terahertz and mid-infrared ranges using a compact and practical semiconductor source. Indeed, by employing a coupled cavity as a passive dispersion compensation scheme, combined with the active modulation, we will show the possibility of shortening the pulses down to ~ 4 ps, considerably shorter than the current state-of-the-art (~ 10 ps).

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