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Injection seeding of metal-metal Terahertz quantum cascade lasers

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A recent development in THz QCLs is the coherent detection of its emission [1]. This is an important application for QCLs as the coherent detection allows one access to both the amplitude and phase of the emission on ultrafast timescales. It has allowed, for example, the demonstration of modelocking [2] as well as bringing insights into the QCL's ultrafast dynamics [3]. It also allows QCLs to be integrated with THz time-domain spectroscopy (TDS) systems, which could allow for dynamic investigations using a powerful, narrow-band QCL pump and a broadband THz probe. Until now, this technique for coherent detection has only been used with QCLs that use a single plasmon waveguide. However, the highest performance THz QCLs, in terms of temperature, are obtained with a metal-metal (MM) waveguide. The major reason that MM QCLs have not been used is the difficulty of injecting a THz seed pulse into the small modal volume of the sub-wavelength MM waveguide. This small mode volume and high modal index also means that MM QCLs tend to have poor output powers and highly divergent beams. In this work [4], we demonstrate the realization of MM QCL waveguides with enhanced broadband free-space waveguide coupling through the use of planar horn antennas integrated onto the ridge of the QCL. The fabrication of these structures is greatly simplified compared to the previous attempts to integrate horn-antenna-like couplers with MM QCLs. We show that these devices are well suited to optical injection seeding, which allows for the coherent detection of the emitted radiation by electro-optic sampling.

The planar horn antennas are realized on both ends of the QCL cavity via V-shape geometries to adapt the confined mode to a free space mode. Short THz pulses (~1ps), which are used as a seed, are focused onto the entry facet of a 2.7 THz bound-to-continuum QCL [1] and synchronized with the switch on of the QCL Figure 1a shows the measured transmitted electric field of the input seed as a function of time. The input seed is amplified over ~200ps and eventually saturates indicating the QCL has been seeded by the short THz pulse. The detail of the electric field can be seen in figure 1b showing a quasi CW operation at ~2.7THz.

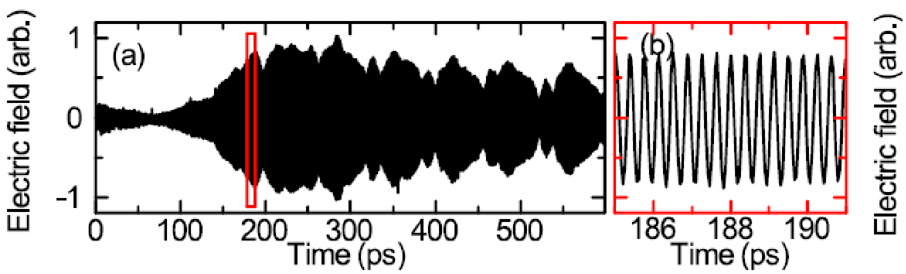

Fig. 1. Coherent detection of the MM QCL emission (a) The time domain electric field emitted by the QCL in the first 600 ps after the seed pulse arrives (b) Detail of 185–191 ps showing the electric field.

This concept of planar horn antennas has also been applied to the injection seeding of a LO phonon-depopulation based MM QCL operating at 3.1THz. Indeed as these devices routinely operate up to relatively high temperatures compared to bound-to-continuum devices, we have demonstrated injection seeding at 77K (all previous measurements have been performed at 10K). Further as the gain bandwidth of these designs is greater we demonstrate injection seeding over a bandwidth of 600GHz for a 3mm long device. This much broader gain is of interest for the demonstration of short intense pulse generation via active mode locking, as well as the application of THz QCLs to time domain spectroscopy.

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[4] A. Brewer et al, "Coherent detection of metal-metal terahertz quantum cascade lasers with improved emission characteristics" Appl.Phys. Lett. 104, 081107 (2014)