Time-resolved THz Laser spectra using a Fibre-interfaced Optical Heterodyne system

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Abstract: We report the first fully fiber-interfaced heterodyne system for time-resolved spectral characterization of THz quantum cascade lasers. By exploiting the bias probe rise time we study the current dependent mode tuning with 50ns temporal resolution.
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1. Introduction

Time-resolved spectral investigation of THz Quantum Cascade Laser (QCL) emission is crucial for applications requiring high emission stability, such as coherent communications and spectroscopy. Earlier work has shown that it is possible to temporally resolve such spectral emission by heterodyning two THz QCLs on a whisker Schottky diode [1]. In this paper we up-convert THz signals to the near infrared (NIR) inside the QCL cavity [2] to demonstrate, to the best of our knowledge, the first fully optical fiber-interfaced communication system for the time-resolved heterodyne characterization of THz laser emission. The heterodyne waveform can be measured by oscilloscope and split into 50ns time frames, each containing spectral information about the emission of the QCL, which is extracted via a Fourier transform. By exploiting standard fiber optic communication technology, this system is more compact, cost-effective and-flexible than working directly in the THz, and could be used to demonstrate coherent on-chip signal processing and transmission via THz QCL.

2. Device Fabrication, Characterization and Methods

Terahertz QCLs based upon semi-insulating surface plasmon waveguides were fabricated from a $GaAs/Al_{0.15}Ga_{0.85}As$ wafer, using a bound to continuum active region with integrated NIR guide layer [2]. THz laser emission was first measured directly using a Bruker Vertex 80 FTIR. The THz QCL was biased using a pulse generator running at a variety of currents and repetition rates at 15K. This bias circuit provides a rise time delay of ~700 ns measured at room temperature using a high speed current probe (see figure 2a). The scheme used for generation of THz side modes and subsequent measurement of a radio-frequency (RF) beat note is illustrated in Figure 1a. First, NIR light from a tuneable 1.3µm external cavity laser was injected into the QCL waveguide via butt coupling single mode optical fiber to a QCL facet. The subsequent intracavity up-conversion of THz light to a telecoms side mode via nonlinear mixing with NIR light has been discussed in ref [2]. The generated THz side modes were collected from the other facet of the QCL using a second butt coupled single mode fiber, and measured using both a fast photodiode (Thorlabs DET08CFC/M) and an optical spectrum analyzer (Yokogawa AQ6370Z). To generate the heterodyne signal, light from a second 1.3µm external cavity laser was injected into the fiber via a coupler after the QCL. The generated RF beat was amplified using a 20MHz – 3GHz 22dB low noise amplifier (Minicircuits ZX60-3018G-S+), and then detected by a Keysight Infinium MSO9104A oscilloscope. A sample waveform of the RF beat note generated between the THz side mode and the second external cavity laser is shown in figure 1b, with the current pulse illustrated on the figure. This waveform was broken down into separate 50ns frames, and a Fourier transform was performed frame by frame to analyze transient frequency variations in the RF beat note (figure 1c). The frequencies of both NIR lasers do not vary significantly over the time period of the pulse (2µs), so changes in beat note frequency can be attributed to the QCL emission.

3. Results and Conclusions

An indicative heterodyne measurement of QCL emission when driven by a 2µs long current pulse is presented in figure 2b. After a short delay for the current to rise above threshold, lasing begins and there appears to be significant frequency tuning with a net tuning range of at least 1.7GHz, after which the frequency stabilizes as the driving current reaches close to its maximum value. As expected, the timescale of this frequency tuning is comparable with that of the applied current pulse (figure 2a) passing through the QCL, suggesting that this tuning can be attributed to the shape of the current pulse. This transient frequency tuning (>1.7GHz) is similar to the current tuning measured via the FTIR (2.6GHz shown in figure 2c(i)). Current tuning is frequently attributed to Joule heating of the active region, as time resolved photoluminescence measurements of QCLs suggest that the active region temperature may increase by as much as 10K across pulses of the order of 2µs long [4]. However, characterization of the QCL emission by FTIR (figure 2(c)(ii)) shows that only 1.2GHz of frequency tuning could be achieved using as much as 40K variation in laser temperature. This suggests that the >1.7GHz transient tuning cannot be attributed to Joule heating. We can instead attribute this current tuning to the gain properties of the active region [3]. Inter-subband transitions are intrinsically fast, any variations in driving current will rapidly change the gain shape of the QCL. Variations in this effective gain profile will alter the modal mode pulling and lead to rapid frequency tuning, as observed in this experiment.

In conclusion, we have developed the first fully optical fiber compatible heterodyne technique for the time-resolved measurement of THz QCL emission. This system could be used for coherent communication experiments using THz QCLs. We observe that when a THz QCL is operated with non-ideal current pulses there is significant modal tuning, attributed to variations in the gain profile with driving current. This work was partly supported by EPSRC NOWNANO funding. The authors would like to thank Dr. D. Heard (Yenista Optics) for loan of a 1.3µm laser.

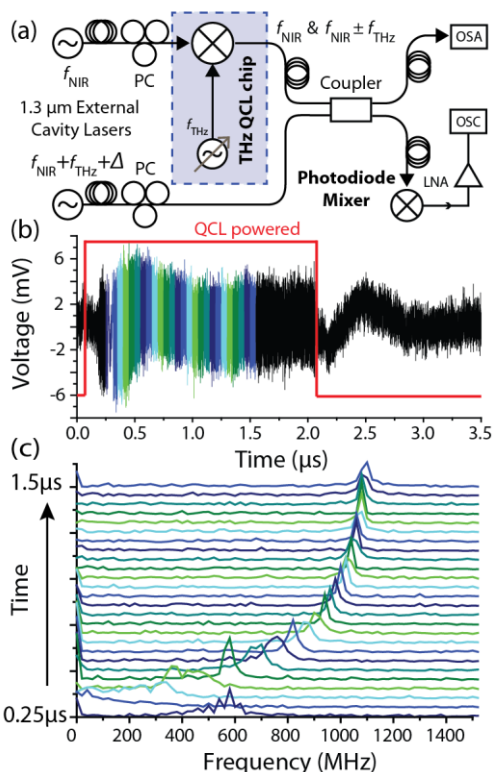

Figure 1. (a) is a schematic representation of our beat note detection setup (b) shows a sample waveform of the electrical beat note generated by our heterodyne system. By splitting the waveform into 50ns windows and performing the Fourier transform (c) we can track the frequency of the generated RF with 20MHz resolution.

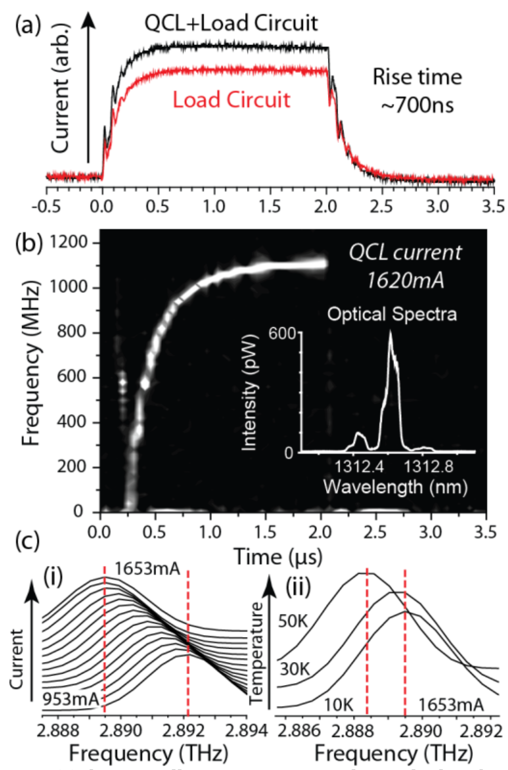

Figure 2. (a) shows an illustrative current pulse applied to the QCL at 100kHz with a 20% duty cycle. (b) shows the frequency of the beat note as a function of time, where the BN passes through DC at ~250ns. (c) shows fine tuning in the QCL with both (i) current, and (ii) temperature.

4. References

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