

# CW-THz Wave Generation Using a Multimode Semiconductor Laser at Room Temperature

Sylwester Latkowski, Pascal Landais  
RINCE, School of Electronic Engineering  
Dublin City University  
Glasnevin, Dublin 9, Ireland  
Email: sylwester@eeng.dcu.ie

Frederic Surre  
Physics Department  
Trinity College Dublin  
Dublin 2, Ireland  
Email: surref@tcd.ie

Stephen A. Lynch  
London Centre for Nanotechnology  
University College London  
London, UK  
Email: slynch@ucl.uk

**Abstract**— Multimode semiconductor lasers under certain DC bias conditions generate electromagnetic waves from the beating between the longitudinal lasing modes. The frequency of those waves is directly related to the free spectral range of the involved modes. Our recent experimental work is carried out on slotted Fabry-Perot lasers with mode separation of 330GHz. The devices are at room temperature biased at 3 times the threshold current. Using a bolometer coupled to an FT-IR interferometer we are able to observe radiation at 660GHz, in the terahertz range.

## I. INTRODUCTION

Modes beating in DC biased semiconductor multimode laser generates a fluctuation of the light emission, sometimes referred as self-pulsation (SP) [1]. The frequency of this fluctuation corresponds to the free-spectral range (FSR) or multiples of it.

It has been demonstrated that multimode distributed Bragg reflector (DBR) lasers with a FSR of 40GHz are able to synchronize its SP frequency to the clock frequency of an external optical data signal [2]. The clock recovery achieved in this matter could be used in all-optical data processing such as in re-amplify, re-time, and re-shape (3R) function or in logical gate. It has been proven and demonstrated that the origin of the SP in these multimode DBR lasers relies on the carrier density pulsation (CDP). This four-wave-mixing (FWM) effect results in the nonlinearity which leads to a passive locking of the phase of the lasing modes demonstrated by the fact that the linewidth of the 40GHz signal is smaller than the sum of the linewidth of the optical lasing modes [3].

If the detuning between modes increases, can we still assume that FWM effects can contribute to this passive mode-locking? Is it possible to generate a THz signal with a multimode laser? In this presentation, we would like to address these questions. We present and discuss some results achieved with a devices where beating frequency falls into the THz regime.

## II. DEVICE UNDER TEST AND CHARACTERIZATION

The device under test is a multi-quantum wells InAlGaAs Fabry-Perot (FP) laser. It is a 2.5 $\mu\text{m}$  ridge waveguide laser resulting in spatial single mode output. It is 350 $\mu\text{m}$  long and the associated spectral range is calculated at  $\sim 123\text{GHz}$  as measured in Fig. 1. By etching grooves at key positions along

the top contact of the active layer it is possible to design a one dimensional photonic band-gap. The FP resonance determines the spectral separation between consecutive modes, but the etched band-gap suppresses or enhances some specific modes. It is possible therefore to choose some given modes and to control the detuning between modes, therefore the SP frequency.

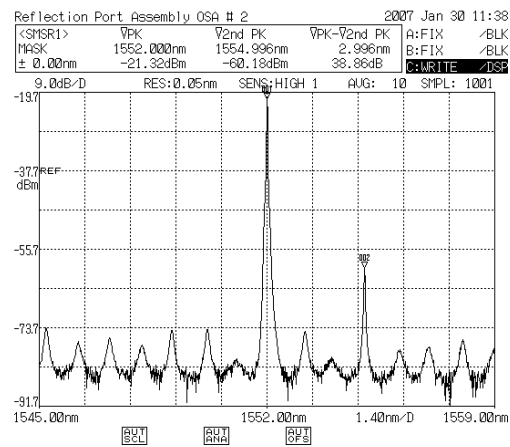


Fig. 1. Optical spectrum of the laser under DC bias at 60mA and temperature controlled at 25°C.

The optical spectrum shown in Fig.1 has been recorded for a bias current of 60mA, corresponding to three times the threshold current. The laser is temperature controlled at 25°C. The resolution of the optical spectrum analyzer is 0.05nm. The longitudinal spectrum features a main mode at 1552.00nm and the second mode at 1554.99nm. The side-mode-suppression-ratio is greater than 30dB and the device is considered single-mode for telecommunication applications. In the light-current curve (not presented in this document) there is no presence of hysteresis loop, thus the laser cavity does not include a saturable absorber section. The separation between the modes is of 330GHz.

## III. THz EXPERIMENTAL SETUP AND RESULTS

The THz signal is investigated using a Fourier-Transform infrared (FT-IR) spectrometer equipped with a bolometer. The

spectral resolution of this set-up is  $0.05\text{cm}^{-1}$ . The emission of the laser is collimated to the bolometer by a  $125\mu\text{m}$  beamsplitter limiting the detection between  $50$  and  $5\text{cm}^{-1}$ . Hence it is expected that only the THz signal is launched into the detector and no optical signal. The beating between the main modes of the device is  $330\text{GHz}$ , and this is just below the range of detectivity of the bolometer set-up, thus it was not possible to observe the beating signal with this set-up. However, a THz signal is observed. This spectrum is shown in Fig.2. It features a THz signal at  $0.66\text{THz}$ , with a linewidth of  $27\text{GHz}$ . For this measurement, the laser is DC biased  $60\text{mA}$  and temperature controlled at  $25^\circ\text{C}$ . The signal observed corresponds to second harmonic of the beating. It is well above the noise floor. It is expected that the fundamental mode at  $330\text{GHz}$  has a linewidth smaller than  $27\text{GHz}$ .

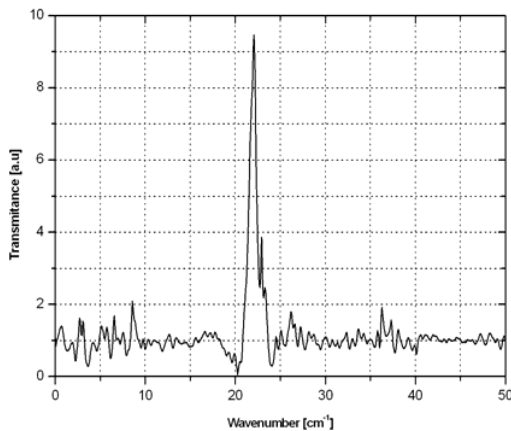


Fig. 2. THz signal measured from device under DC bias at  $60\text{mA}$  and temperature controlled at  $25^\circ\text{C}$ .

Using a frequency resolved optical gating (FROG) analyser, the output signal of the laser can be analysed in the frequency and in the time domains. The time variation of the second harmonic signal from the two main modes is presented in Fig. 3. The two main modes are out of phase, varying sinusoidally at a frequency of  $370\text{GHz}$ . At this frequency, the time associated with the carrier density pulsation is not fast enough to provide such modulation, therefore the modulation of the signals is produced by intra-band effects, and at this frequency the dominant effect is carrier heating. It is also clear from Fig. 3 that the two modes are synchronized and therefore the carrier heating effect is contributing to the passive modelocking of the two main modes.

#### IV. CONCLUSIONS

We have demonstrated the generation of THz waves from mode beating in a multimode laser. The laser studied is a Fabry-Perot cavity with slots implemented to control the longitudinal spectrum, which results in two modes separated

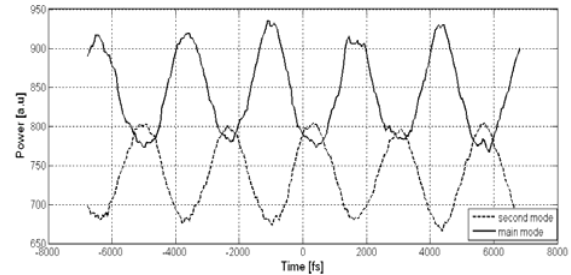


Fig. 3. Time variation of the second harmonic generation of the two main modes.

by  $3\text{nm}$ . Even though the laser is DC biased and at room temperature it produces an electromagnetic waves at  $370\text{GHz}$  and  $660\text{GHz}$  corresponding to multiple of the free spectral range. The origin of this modulation relies in carrier heating nonlinear effect and produces a passive synchronization of the optical modes.

#### REFERENCES

- [1] K. Sato, "100 GHz optical pulse generation using Fabry-Perot laser under continuous wave operation," *Electronics Letters*, vol. 37, pp. 763-764, 2001.
- [2] J. Renaudier, B. Lavigne, P. Gallion, G.-H Duan, "Study of phase-noise properties and timing jitter of 40-GHz all-optical clock recovery using self-pulsating semiconductor lasers," *J. Lightwave Technology*, vol. 24, pp. 3734-3742, 2006.
- [3] J. Renaudier, G.-H. Duan, P. Landais, P. Gallion, "Phase correlation and linewidth reduction of 40 GHz self-pulsation in distributed Bragg reflector semiconductor lasers," *IEEE J. Quantum Electron.*, vol. 43, pp. 147-156, 2006.