Passively Phase-Locked Multimode Semiconductor Laser: From Millimetre to Terahertz Wave Generation

Sylwester Latkowski, Frederic Surre, Elif Degirmenci, Pascal Landais
Research Institute for Networks and Communications Engineering
Dublin City University, Glasnevin, Dublin 9, Ireland
sylwester@eeng.dcu.ie

Abstract: Generation of narrow microwave signals produced from the mode beating of a DBR laser is presented. The application of this process to the cw-THz wave generation is also demonstrated using a slotted FP laser.

1. Introduction

Until recently, multimode lasers have been discarded in fiber networks due to pulse temporal spreading introduced by the chromatic dispersion. However, it has been demonstrated that their optical output is modulated at a fixed frequency, even when they are DC-biased. This is commonly referred as a self-pulsation (SP) [1]. The self-pulsation frequency is related to the separation of the free spectral range between modes. This feature can be exploited for microwave generation, with applications such as clock recovery in optical telecommunications where the value of SP frequency synchronizes to the bit-rate of an incoming optical data signal [2]. The clock recovery achieved in this matter could be used in all-optical data processing to realize 3R-function. The low cost and the reduced footprint of the multimode semiconductor laser allow it to be an interesting alternative as a millimeter-wave source. In this paper, we demonstrate a micro-wave signal at *40GHz* from a multi-mode distributed Bragg reflector laser, with a *3MHz* spectral linewidth smaller than the sum of the optical modes beating. With a larger free-spectral-range we achieved a THz-wave signal from a slotted Fabry-Perot laser.

2. Theoretical approach

Each optical electric field generated in a multimode laser cavity can be described as a monochromatic wave with slowly time-varying amplitude, noted E_k, with an angular frequency ω_k. For a multimode laser, a beating occurs, leading to a quadratic temporal average of a total field expressed by:

$$\left\langle \left|E_T\right|^2 \right\rangle = \sum_{k=1}^{M} \left\langle \left|E_k\right|^2 \right\rangle + \sum_{k=1}^{M} \sum_{j \neq k} 2 \left\langle E_k E_j \cos\left(\Omega_{kj} t + \left(\phi_j(t) - \phi_k(t)\right)\right) \right\rangle \qquad (1)$$

where Ω_{jk} is defined as $(\omega_j - \omega_k)$ beating between any two modes. The consequence of this beating is a signal generated at the frequency $\Omega_{jk}/2\pi$. The assumption that the phase of each mode is uncorrelated implies that the second term in the right hand side of (1) is equal to zero and so the linewidth of the RF signal is equal to the sum of linewidth of the optical modes. However, if the modes are phase correlated, this term is non-zero and the resulting linewidth will be smaller than the sum of a linewidth of the optical modes. This property would be of interest in the generation of millimeter waves and beyond.

3. Millimeter wave

The laser under test has a short Bragg section of *150µm* allowing for multimode longitudinal spectrum. The active section is *900µm* long and consists of six quantum wells and five barriers of thickness of *8nm* and *10nm* respectively, surrounded by two separated confinement hetero-structure guiding layers of total thickness of *200nm*. The *1.5µm* width of the waveguide ensures a single transverse mode of the electric field. The phase section is *100µm* long, with a waveguide width expanding linearly up to the *1.8µm* width in the Bragg section. This phase section was designed to adapt the optical modes between the active and the passive optical waveguides. It is kept unbiased for all experiments reported in this article since it is only used for a fine tuning of the emitted wavelength. The different sections are electrically isolated (*~1MΩ*) by ion implantation. Optical spectrum for DC-bias conditions of *200mA* for the gain section and *246mA* for the Bragg section is shown of Fig. 1. There are few modes separated by *0.3nm*. The electrical spectrum shown in Fig. 2 features a *40GHz* signal resulting from the beating between these modes, with a *3MHz* linewidth. This linewidth is much smaller than that of the sum of the modes generates equals to *~400MHz*. This result occurs due to the passive mode-locking resulting from the carrier density pulsation [3].

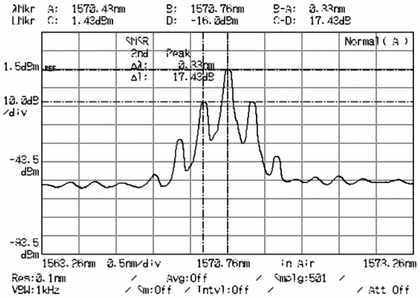

Fig. 1. Optical spectrum I $_{gain}$= *200mA* I $_{Bragg}$= *246mA*, temperature *20ºC*. The modes are separated by *0.3nm.*

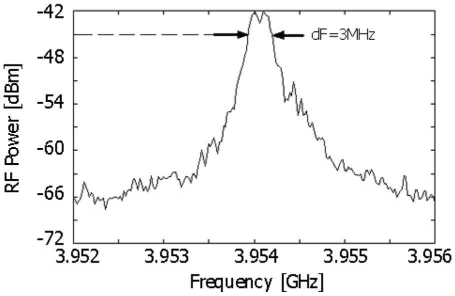

Fig. 2. RF spectrum of the beating signal centered at *40GHz*. The linewidth is *3MHz*.

4. Terahertz generation

The second device tested was a *350µm* long multi-quantum well InAlGaAs Fabry-Perot laser. The *2.5µm* ridge waveguide provides a spatial single mode output. Grooves are implemented on the surface of the p-side, in order to control the longitudinal mode spectrum. The depth and the width of the groove are *1µm* and *1µm*, respectively. The laser is temperature controlled at *25°C* and DC biased. The resulting longitudinal spectrum is shown in Fig. 3. It features a main mode at *1551.98nm* and a second mode at *1554.98nm* resulting with a side-mode-suppression ratio of *39dB* approximately at *60mA*. The THz signal is investigated using a Fourier-Transform infrared spectrometer equipped with a bolometer [4].

The spectral resolution of this set-up is $0.05cm^{-1}$. The emission of the laser is collimated to the bolometer through a *125µm* beam splitter limiting the detection between *50* and $10cm^{-1}$. Hence it is expected that only the THz signal is launched into the detector with no optical signal present. The beating between the main modes of the device is *373GHz* which is below the detection range of the experimental setup, thus it was not possible to observe the beating signal. However, the THz signal shown in Fig. 4 which corresponds to the second order harmonic of the optical modes beating was recorded[4].

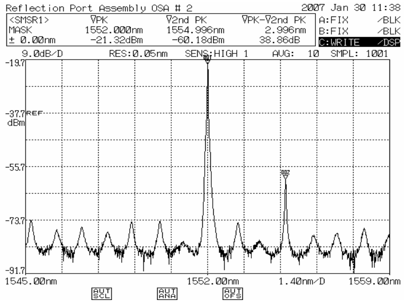

Fig. 3. Optical spectrum of the laser at *60mA*.

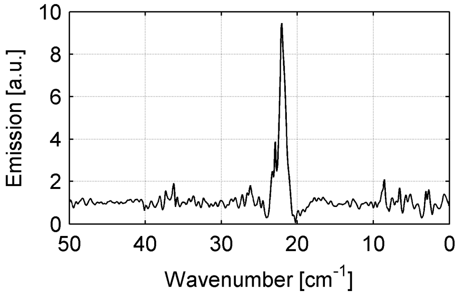

Fig. 4. THz signal recorded at *60mA* of bias current and at *25ºC*.

4. Conclusion

It was shown that mode beating in multimode semiconductor laser is relevant to generate signals in the microwave or in the terahertz domain. The devices under study are easy to manufacture and cheap to run as they work at room temperature.

5. References

[1] K. Sato, "100 GHz optical pulse generation using Fabry-Perot laser under continuous wave operation," Electronics Letters **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 **24**, pp. 3734-3742, 2006.

[3] J.Renaudier , G-H.Duan, P.Landais , P.Gallion, "Phase Correlation and Linewidth Reduction of 40GHz Self-Pulsation in Distributed Bragg Reflector Semiconductor Lasers," accepted for publication in IEEE J. Quantum Elect., (2007).

[4] S.Latkowski, F.Surre, P.Landais, S.A. Lynch **"**CW-THz Wave Generation Using a Multimode Semiconductor Laser at Room Temperature," Lasers and Electro-Optics Society, 2007. LEOS 2007. The 20th Annual Meeting of the IEEE