Analysis and simulation of the relative intensity noise in a Fabry-Perot interband cascade laser highlight relaxation oscillations in the GHz range

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During the past two decades, the mid-infrared (mid-IR) domain has been under the spotlight as it can address many applications. Novel materials and devices have been introduced to design more powerful, more energy-efficient and more versatile optical systems [1]. Interband cascade lasers (ICLs) are very promising mid-IR sources due to their low-power consumption, combined with emission wavelength up to 7 µm under continuous wave and room temperature [1]. We study the relative intensity noise (RIN) of an ICL and show for the first time experimental evidence of a relaxation oscillation in the GHz range, which is promising for high-frequency modulation. Numerical simulations show good agreement with our experimental efforts and strengthen our claims.

(a)

Cavity length, L	$2\ mm$	Injection efficiency η	0.64
Cavity width, W	$4.4\ \mu m$	Differential gain a_0	$0.1 \times 10^{-10} cm$
Facet reflectivity R	0.32	Transparent carrier number N_{tr}	$6.2 \times 1e7$
Refractive index n_r	3.58	Spontaneous emission factor β	10^{-4}
Optical confinement factor Γ_p	0.04	Linewidth broadening factor α_H	2.2
Internal loss α_i	$5.7\ cm^{-1}$	Stage number m	7

(b)

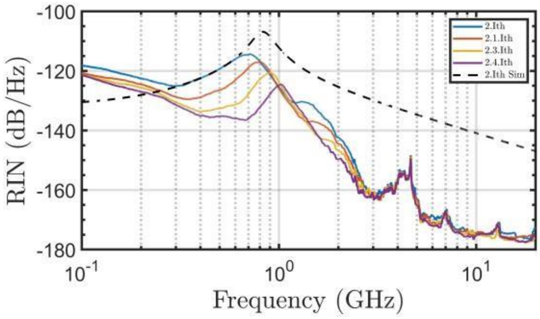

Figure 1. (a) Parameters for the numerical simulation of the RIN. (b) RIN value and simulation over the 0.1-20GHz interval at 293K. Experimental and numerical RF spectra show evidence of a peak at the relaxation frequency in the GHz range for the FP ICL under study.

The Fabry-Perot (FP) ICL is grown by molecular beam epitaxy on a GaSb substrate. The active region is made with seven-stage cascade periods composed of type-II "W" quantum wells whose design is optimized for lasing emission at 4.1 µm at room temperature. The active medium is surrounded by GaSb optical confinement layers and claddings with AlSb / InAs superlattices. The laser is kept at 293K and biased above current threshold (I_{th} = 72 mA) with a low-noise source. The mid-IR beam illuminates a Mercury-Cadmium-Telluride detector with 700 MHz bandwidth and both DC and AC ports. The photovoltaic current corresponds to the DC part of the signal and is assessed to evaluate the shot noise. After being amplified by 25 dB with a low-noise wide-band amplifier, the AC component is recorded with a spectrum analyser. The analysis leads to the solid curves in Fig. 1 (b), where the evolution of relaxation frequency with bias current is clearly seen, unlike in previous experimental investigations [2]. Besides, we carry out a numerical simulation to derive the RIN value using the method described in ref [3]. From the dashed curve in Fig. 1 (b), we obtain a relaxation frequency of 850 MHz at 2.0 $* I_{th}$ and this is in good agreement with the experimental result.

References

[1] E. Tournié & L. Cerutti, Mid-infrared Optoelectronics: Materials, Devices, and Applications, Woodhead Publishing (2019)

[2] Y. Deng et al., Optics Letters, vol. 44, 1375-1378 (2019)

[3] Y. Deng & C. Wang, IEEE Journal of Quantum Electronics, vol. 56, 1-9 (2020)