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Dynamics of Optical Frequency Combs in Ring and Fabry-Perot Quantum Cascade Lasers

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Since the demonstration that multimode Quantum Cascade Lasers (QCLs) can operate as sources of Optical Frequency Combs (OFC) [1], an extended class of theoretical models, based on standard two or three level Maxwell-Bloch equations, has been proposed to interpret such phenomenology.

We present an efficient framework for simulating QCL spatio-temporal field dynamics in either Fabry-Perot (FP) or ring cavity with and without external field injection. In both cases we demonstrate the formation of stable OFCs in good agreement with several experimental findings [2]. The model encompasses coherent polarization effects, spatial carrier grating and a non-zero linewidth enhancement factor (LEF).

For the FP configuration the coexistence of a FM and AM regime reported in [3] could be reproduced (Fig.1a: power pulses in blue line and linear frequency chirp in red line). We have also demonstrated that the current range for OFC emission is strongly determined by the LEF, the carrier lifetime and the gain bandwidth [4]. For LEF≈ 0.7-1 and carrier lifetime of about 1ps, the OFCs are found only for certain current ranges above threshold. For current values much above threshold the OFC is lost and the multimode regime is irregular.

Our model can also describe the ring configuration where an OFC appears, induced by phase turbulence as reported experimentally by M. Piccardo et al. [5] [6]; see for example Fig.1b where power pulses are periodic and optical modes are separated by twice the roundtrip frequency. Finally, by injecting a coherent external field, detuned with respect to the solitary ring lasing frequency, we demonstrate the formation of cavity solitons (see Fig. 1c) in agreement with the recent predictions we obtained in a general model approach, valid in the limit of small field injection and small frequency detuning [7].

The present approach is therefore a comprehensive simulation framework not limited by simplified assumptions, that can be used to test simplified but fastest approaches, interpret complex experimental results or design optimized cavity structures.

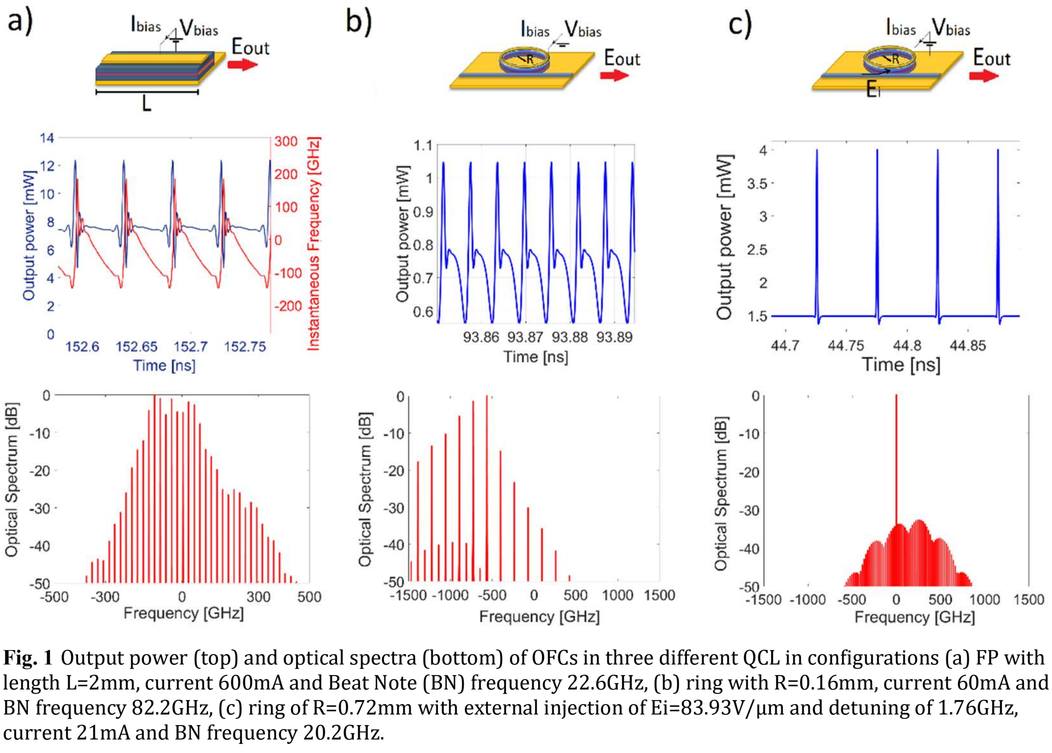

Fig. 1 Output power (top) and optical spectra (bottom) of OFCs in three different QCL in configurations (a) FP with length L=2mm, current 600mA and Beat Note (BN) frequency 22.6GHz, (b) ring with R=0.16mm, current 60mA and BN frequency 82.2GHz, (c) ring of R=0.72mm with external injection of Ei=83.93V/μm and detuning of 1.76GHz, current 21mA and BN frequency 20.2GHz.

References

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