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Study of the intensity correlations in harmonic comb terahertz quantum sources

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Abstract: we present an experimental study of the intensity noise of the modes of a terahertz quantum cascade laser harmonic frequency comb, a fundamental step toward the identification of the quantum nature of the emitted light

Quantum cascade lasers (QCLs) are ideal candidates for the generation of multi-mode squeezed states of light, due to the presence of inherently quantum-correlated side-band modes relying on four-wave-mixing, the nonlinear mechanism responsible for mode-locking in QCL frequency combs. Under specific operational conditions, QCLs can operate as harmonic frequency combs (HFCs)[1], with optical power concentrated in few modes ($N \leq 5$), spaced by multiples of the cavity free spectral range. Stable harmonic regime[2,3] is established by modulating the intracavity field distribution, engineering a linear array of metal defects, open-air or graphene scatters patterned on the laser's top metal cladding[2], inferring the desired harmonic order, by design. Here we report on the experimental assessment of the intensity noise of the different modes of a HFC having as core structure a THz QCLs, a fundamental step toward the identification of the quantum correlations effects.

We employ a QCL with a central frequency at ~3.15 THz and ~0.6 THz bandwidth operating as an 8th-order HFC, with a 125 GHz frequency spacing (Fig.1a). The QCL comprises 9 regularly distributed air gaps on the top metal contacts, that define a set of sub-cavities and forces the suppression of non-harmonic modes. We engineered our experimental setup to separate and collect, individually, the spectral lines emitted by the HFC (Fig.1b), with the help of blaze grating, designed and fabricated to separate the QCL modes at specific angles, and then to refocus and collect them into a Hot Electron Bolometer (HEB). This allows to analyse the intensity fluctuations of each mode separately, and to unveil the presence of classical or quantum correlation. We measured the intensity noise power spectral density (INPSD, Fig.1c) as a function of the QCL driving current, and the relative intensity noise (RIN, Fig.1d)[4]. When compared with the dark INPSD, measured with the QCL off, we retrieved a modulation of the INPSD that depends on the bias point. For bias currents >~471mA, the increase in the noise density is associated to the QCL transition to the regular comb regime. Fig. 1e-f show the INPDSD (Fig.1e) and RIN (Fig.1f) extracted for the most powerful laser lines, λ1 and λ4, collected at the corresponding diffraction angles, by setting the bias current at 470 mA. Overall, the INPSD and the RIN extracted for the individual lines are up to one order of magnitude higher than the same quantities retrieved form the total signal, a result that may be evidencing the presence of intensity correlation[4].

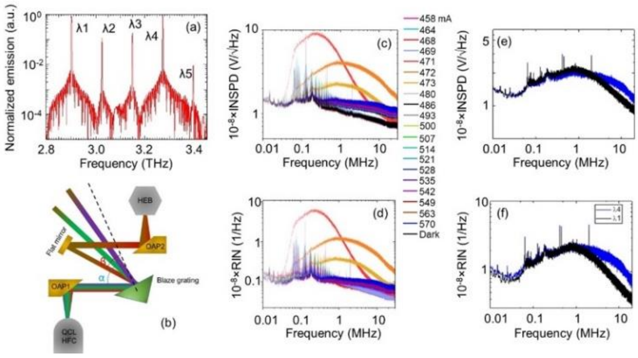

Fig. 1 (a) Normalized emission spectrum of the HFC acquired in cw at 25K and current bias 470 mA. b) Experimental arrangement of the correlation experiment. The QCL beam and the collection beam direction are fixed by the off axis parabolic mirrors (OAP1 and the OAP2) and by the flat mirror positions, respectively. (c-d) INPSD (c) and RIN (d) measured with a RF spectrum analyser, while driving the QCL in cw, at 25K, at various bias currents. (e-f) INPSD (e) and RIN (f) of the most intense laser lines λ1 (black) and λ4 (blue), acquired after separating the modes through the grating reflection

References

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