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Reshaping the emission of a THz quantum cascade laser frequency comb through an on-chip graphene modulator

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Graphene possesses a peculiar potential for the development of optoelectronic components capable to actively manipulate infrared light [1]. Its electrostatically tunable optical conductivity, band structure and transport characteristics, and the possibility to be grown over large areas, offer an intriguing playground for engineering, at the nanoscale, amplitude modulators, spatial light modulators and switches, combining high efficiency (> 50%) intensity modulation, reasonably high speeds (> µs response times), and spectral tunability in the underexploited high (> 1.5 THz) terahertz-frequency range [2], where frontier applications in quantum communications, quantum computing, adaptive and quantum optics are still at their infancy.

We devise a single layer graphene-on-polyimide modulator [3] with a tunable-by-design optical bandwidth, in which the electrostatic gating of the single layer graphene conductivity, achieved through a metamaterial grating gate coupler patterned on a λ/4-polyimide layer on Au waveguide cavity, allows 90% modulation efficiency, combined with a 20 KHz electrical bandwidth in the 1.9-2.7 THz frequency range (see Figure 1).

The graphene modulator is then exploited as a dispersion compensator of a THz-frequency, broadband semiconductor heterostructure laser [4]. To this purpose, we integrate our modulator, on-chip, with a quantum-engineered multimode THz quantum cascade laser (QCL). Adjusting, by-design, the modulator operational bandwidth, we demonstrate that the SLG modulator can compensate the QCL cavity dispersion, resulting in an integrated laser behaving as a stable optical frequency comb synthesizer over a record dynamic range of 35% [3].

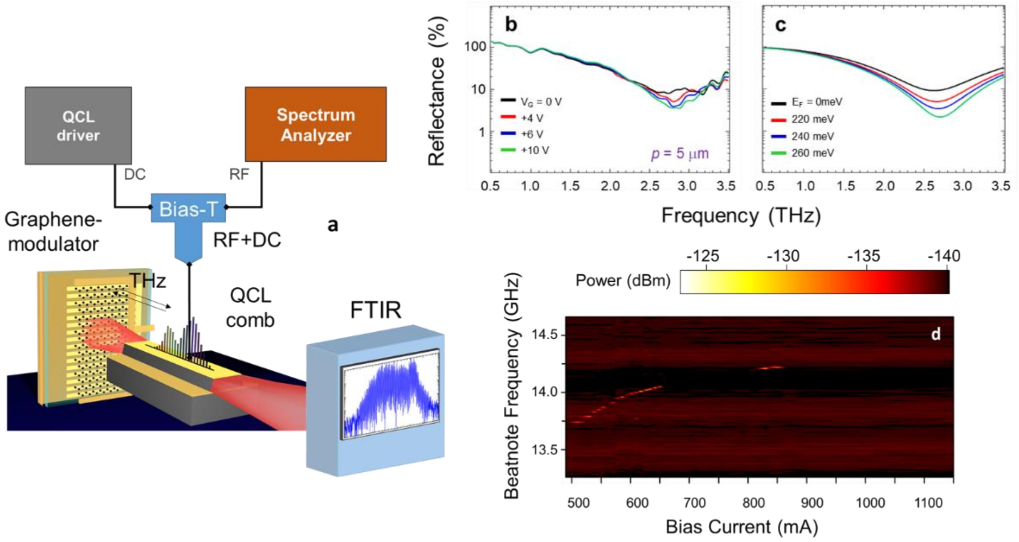

Fig. 1(a) schematic layout of the experimental setup, with the graphene modulator is positioned on a moving piezoelectric stage in close proximity of the back facet of the THz QCL frequency comb. (b) total reflectance measured as a function of the gate bias with a time domain spectrometer on the modulators with grating periodicity p =5 µm; (c) Calculated reflectance for the same grating of panel (b) at different Fermi energies; the Fermi energies chosen to reproduce the experimental data. (d) Intermode beatnote map as a function of the continuous wave driving current measured at 15 K in the QCL-modulator system shown in (a) (p = 5 µm).

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