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Terahertz laser frequency combs Supplementary information

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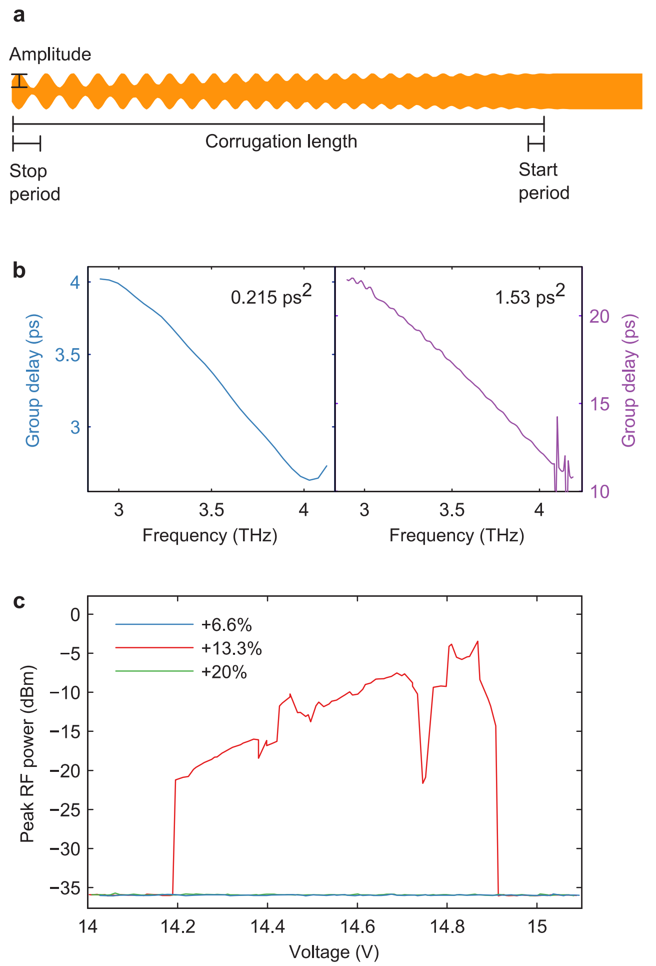
Design of dispersion-compensating corrugations

In order to design the corrugations used for dispersion compensation, one-dimensional simulations were first performed that captured the essential behavior of the structures. The key parameters, shown in Supp. Fig. 1a, are the corrugation length, its start period, its stop period, how quickly its amplitude tapers on (e.g., linearly), and its largest amplitude. To first order, the start and stop periods determine the maximum and minimum frequencies at which dispersion is compensated, while the corrugation length determines the amount of compensation. How quickly the amplitude tapers on determines how strong ripples in the final group delay are, while the largest amplitude determines the bandwidth over which the group delay can remain linear. Full-wave finite element (FEM) simulations were then performed to verify design efficacy, and the compensators' group delay versus frequency were plotted. Supp. Fig. 1b shows two such designs. Even though they differ in their compensation by nearly an order of magnitude, linearity is maintained over the whole design range of 3 THz to 4 THz. Though sidewall-based corrugations were used here, any perturbation that introduces a refractive index change into the waveguide (such as an etched trench or a region of removed metal) can also be used to construct compensators.

To demonstrate the necessity of proper compensation, we plot in Supp. Fig. 1c the RF power generated by three QCLs differing in their dispersion compensation by steps of only 6.7%. When the compensation is detuned from the correct compensation of 1.25 ps^2/mm (+13.3%) even slightly, no RF beatnote is generated and no comb is formed. (At high biases in the devices' negative differential resistance regimes, RF radiation spanning several GHz can be generated, though this is merely due to electrical instability.) Indeed, this highly sensitive dependence on proper dispersion compensation explains why no spontaneous broadband comb formation has ever been reported in THz QCLs to date.

Setup for frequency locking and SWIFTS

Supplementary Figure 2a shows both the setup used for stabilizing the QCL's repetition rate against mechanical vibration of the cryocooler and for homodyne interferometry (SWIFTS). For repetition rate stabilization, the free-running beatnote emanating from the QCL is first observed on a spectrum analyzer, which is typically near 6.8 GHz. An external frequency synthesizer (HP 8673E) is tuned to be 10 MHz away from the free-running signal. The QCL beatnote is then downconverted twice, first to 10 MHz and then to DC, and is used as the error signal for a PI controller. The output of the PI controller is added to the QCL bias with a 3 kΩ resistor, and since the QCL's bias affects the refractive index and



Supplementary Figure 1 | Dispersion compensation design. a, Schematic showing the key parameters of the dispersion compensators. **b,** Simulated group delay versus frequency plots for the smallest and the largest compensators developed, respectively. A linear response compensates for second-order dispersion. **c,** RF beatnote emanating from three QCLs with compensations of 1.17 ps^2/mm (+6.6%), 1.25 ps^2/mm (+13.3%), and 1.32 ps^2/mm (+20%).

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