On-chip coherent THz photonics with frequency combs

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Abstract: We discuss the on-chip generation of THz comb states in the 1-4 THz bandwidth and their on-chip manipulation. We demonstrate broadband (2.5-3.5 THz) frequency comb operation both in AM and FM regimes as well as integrated wavelength division multiplexing .

On-chip coherent THz signal generation and control [1] [2], is extremely appealing in a variety of different implementations from fundamental research to applications such telecommunication and spectroscopy. In the last 10 years, THz quantum cascade laser (QCL) frequency combs [3] have seen a tremendous development, with demonstration of dual-comb spectroscopy[4], dissipative Kerr solitons[5], passive and active mode locking [6], [7], [8]. We will discuss the generation of coherent THz signals in the bandwidth 1 to 5 THz and their on-chip manipulation. We leverage the frequency agility of the semiconductor intersubband gain medium combined with the ultrabroadband nature of double metal planarized waveguides to demonstrate broadband frequency combs operation both in AM and FM regimes. Particularly, we report on the generation of coherent pulse trains with arbitrary repetition rate from a monolithic on-chip device [9]. It is a novel regime of active mode-locking, which allows for an arbitrary amount of detuning between the modulation frequency f_{mod} and the natural repetition rate $f_{rep,0}$.

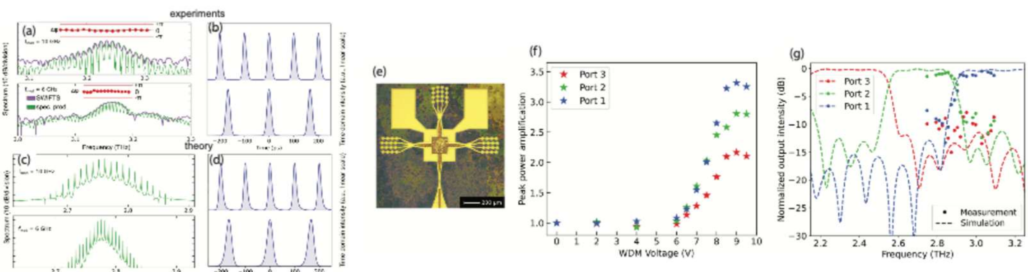

Fig.1. **a,b** Experimental SWIFTS results showing the tunable spectral mode spacing and repetition rate of the coherent pulse train. **c,d:** Numerical simulation for the same conditions in **a,b** have excellent agreement with experiments. **e:** Optical microscope image of the WDM. **f:** Measurement of the peak power amplification of the WDM output as a function of the bias voltage of the demultiplexer. **g:** Comparison of the WDM normalized output intensity with time domain 3D simulations.

We investigated a planarized THz QCL sample with a length of 6 mm ($f_{rep,0}$ = 6.61 GHz), active waveguide width of 40 µm, and top metal width of 300 µm, by performing a modulation frequency sweep study between 4-16 GHz. In this whole range we could observe pulse generation for arbitrarily injected RF frequencies. In Fig. 1(a,b), we show the experimental SWIFT spectroscopy results for modulation frequencies of 6 and 10 GHz, i.e., below and above the $f_{rep,0}$. Both the spectral mode spacing and the repetition rate of the coherent pulse train match exactly the modulation frequency in each case. We also developed a numerical simulation model based on a semiclassical Maxwell-density matrix formalism, whose results reported in Fig. 1(c,d) show excellent agreement with experimental data.

We will discuss as well the performance of an active, on-chip, three channels wavelength division multiplexer (WDM)[10] . WDM's are essential components in signal processing, to fully exploit the highly coherent comb sources, allowing signal manipulation and routing directly on-chip. Previously, on-chip THz WDM's were demonstrated at maximum frequencies below 500 GHz. A unique property of our WDM, conceived using inverse design, is that it is an active device with gain, allowing for simultaneous spectral selection and amplification. In Fig.1e is visible a micrograph of the processed device. Figures 1e and 1f display the amplification and the spectral output intensity for each channel. Experimental data show a good agreement with simulation. The integrated laser operates as a frequency comb, yielding an on-chip integrated device that produces coherent THz radiation and routes it in the bandwidth 2.6-3.2 THz. Recent advances in high-temperature, Peltier-cooled quantum cascade lasers operating in a standard HHL mount will be also reported [11].

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