Ultra narrow linewidth CW sub-THz generation using GS based OFCG and n-i-pn-i-p superlattice photomixers

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We report on the photonic synthesis of ultra narrow linewidth Continuous Wave (CW) sub-THz signals using a Gain-Switching (GS) based Optical Frequency Comb Generator (OFCG), selective optical filtering and a n-i-pn-i-p superlattice photomixer. This setup provides continuous tunability with a tuning resolution in the range of 0.1 Hz at 120 GHz and Full Width at Half Maximum (FWHM) of the generated signals below the limits of the measurement setup (<10 Hz). The advantages of this system make it a great candidate for applications requiring extremely low phase noise and continuous tunability, such as high resolution spectroscopy in the sub-THz and THz range.

Introduction: The sub-THz generation technology has dramatically advanced in the last years given the potential applications in the sub-THz and THz frequency ranges [1] and the great research effort invested on this field. Nowadays, there exist commercially available solutions for sub-THz generation. For photonically generated THz radiation, however, the provided linewidths are not narrow enough for many applications such as high resolution spectroscopy [1] and there is still an important need of ultra narrow sub-THz generation systems with continuous tunability. In this letter, we present a compact system for the photonic synthesis of ultra narrow linewidth Continuous Wave (CW) sub-THz signals using a Gain-Switching (GS) based Optical Frequency Comb Generator (OFCG), selective optical filtering and a n-i-pn-i-p superlattice photomixer. This system meets the abovementioned issues that currently exist in commercial systems regarding Full Width Half Maximum (FWHM) of the synthesized sub-THz signals and the tunability resolution required for these ultra narrow linewidths.

Experimental setup: The ultra narrow linewidth CW sub-THz generation scheme comprises three main parts: OFCG, selective optical filtering stage, and a high bandwidth photomixer. The OFCG employed in this work (Fig. 1) is based on the phase modulation of a GS Discrete Mode (DM) diode laser [2] to obtain a relatively wide span (~140GHz, see Fig. 2) using a scheme without the need of additional non-linear elements usually associated to standard OFCG, thus allowing for a very compact, potentially low-cost and energy efficient OFCG. The GS regime is achieved by modulating the DM, which is biased at 60 mA, with a 28 dBm RF reference. In this case, f_{REF}=10 GHz. The optical output from the DM is delivered to a $LiNbO_3$ phase modulator (PM, Fig. 1). The PM is driven with f_{REF}, which is properly phase trimmed with an electrical phase shifter (PS) to achieve optimum flatness of the optical output of the OFCG [2].

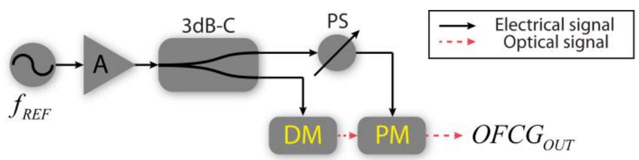

Fig. 1 *OFCG basic scheme. A: electrical amplifier; 3dB-C: 3-dB coupler; DM: Discrete Mode Laser; PS: electrical phase shifter; PM: optical phase modulator.*

The optical output of the OFCG is shown in Fig.2. This output spectrum is introduced in the selective optical filtering scheme [3]. This scheme allows us to extract two longitudinal modes of the optical spectrum with the desired frequency spacing, in order to beat them in the high bandwidth photomixer. Further details on this selective optical filtering setup can be found in [3].

The high bandwidth photomixer employed to beat the two optical frequencies with the desired frequency separation is a n-i-pn-i-p superlattice photomixer [4]. This photomixer has been packaged in order to provide an optical fiber connection, bias input and direct sub-THz free space output by the use of a hyperhemispherical silicon lens coupled to the planar antenna integrated with the photomixer. This allows a direct way to beat the two optical modes and radiate the sub-THz signal in a single packaged device [1].

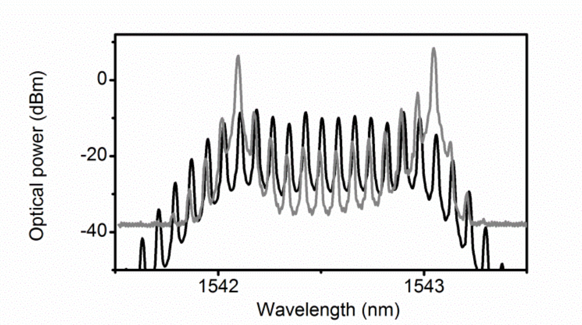

Fig. 2 *Optical spectra of the OFCG output (black trace) and n-i-pn-i-p superlattice photomixer input (grey trace).*

Experimental results: The synthesized sub-THz CW signals are evaluated in terms of electrical spectra (i.e. electrical FWHM) and tunability. For this purpose, the sub-THz signal emitted by the photomixer is collected with a 115 GHz corrugated circular horn antenna. No parabolic mirrors were used to improve the coupling of the quasi-optical beam to the horn. The horn antenna feeds a 90-140 GHz harmonic mixer that is connected to an Electrical Spectrum Analyzer (ESA).

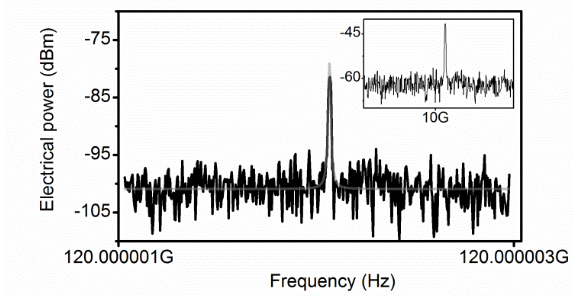

Fig. 3 *Synthesized signal at 120 GHz. Measured (black trace) and Lorentzian fit (grey trace). Inset: reference signal measured with similar dynamic range (same axis).*

As an example of the generated signals, a 120 GHz synthesized signal spectrum, corrected for the harmonic mixer losses (~45 dB), is shown in Fig.3. It has been generated with an average optical input power delivered to the n-i-pn-i-p photomixer of 13 mW. The measurement has been accomplished using a Resolution Bandwidth (RBW) of 10 Hz and the minimum frequency span allowed by the ESA at this frequency range (2.1 kHz). The measured FWHM of the 120 GHz signal is ~10 Hz, which corresponds with the RBW of the ESA. Thus, the actual FWHM for the synthesized signal is ≤10 Hz. For comparison purposes, the reference RF signal at f_{REF}=10 GHz is measured with a similar dynamic range (Fig.3, inset). The measured FWHM of the reference is also ≤10 Hz.

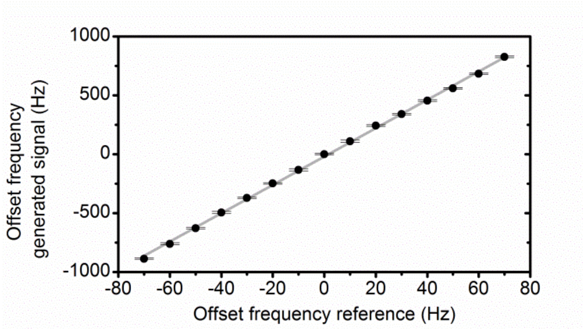

Fig. 4 *Continuous tunability. Measured data (average values: black dots; standard deviation: black caps); and linear fit (grey trace).*

The continuous tunability of the reported system is achieved by tuning f_{REF} (fine continuous tuning) and selecting the desired optical modes using the selective filtering stages (coarse discrete tunability in f_{REF} steps). To characterize the continuous tunability characteristics of the system (fine tuning), the reference signal has been tuned in 10 Hz steps to get frequency steps of the sub-THz signal (~120 Hz) within the frequency readout accuracy of the ESA. The results are shown in Fig. 4 with the minimum frequency span of the ESA (2.1 kHz). The standard deviation of the measurement set (sub-THz frequency) is between 5 and 10 Hz and the linear fit gives a R-square value of 0.999. It must be noted that we are in the frequency accuracy and frequency resolution limits of the ESA, so it cannot be determined whether the standard deviation is due to the system itself or due to the uncertainty associated to the measurement setup. The employed reference RF generator allows 0.01 Hz steps, which would be translated to a tuning resolution of the 120 GHz signal in the range of 0.1 Hz (10^{-12}).

Concerning the power of the synthesized sub-THz signals, it must be noted that the coupling of the divergent THz beam emitted by the photomixer to the horn antenna can be strongly improved using parabolic mirrors with matched numerical apertures. Furthermore, for these photomixers, the generated power is proportional to the square of the optical input power ($P_{THz} \propto P_{OPT}^2$) so the use of higher optical power (i.e. optical amplification) would allow higher power sub-THz signals. In this sense, the heterodyning of just two modes in a photomixer, as employed in this work, is more efficient than direct harmonic generation [5] as all the optical power is concentrated in the desired frequency components [3].

The maximum synthesized frequency is limited by the optical span of the OFCG and the bandwidth of the photomixer. The first can be expanded by the use of already reported techniques (i.e. non-linear fiber [6], non-linear loops [7], and use of more intensity and phase modulators [8] or FWM [8]). The photomixer used in this work features a working bandwidth in excess of 1 THz [4]. So this scheme can be used for higher frequencies synthesis straightforwardly.

Conclusion: We report on the photonic synthesis of ultra narrow linewidth Continuous Wave (CW) sub-THz signals using a Gain-Switching (GS) based Optical Frequency Comb Generator (OFCG), selective optical filtering and a n-i-pn-i-p superlattice photomixer. This compact setup provides continuous tunability with a tuning resolution in the range of 0.1 Hz at 120 GHz and Full Width at Half Maximum (FWHM) of the generated signals below the limits of the measurement setup (<10 Hz). The advantages of this system make it a great candidate for applications requiring extremely low phase noise, such as high resolution spectroscopy in the sub-THz and THz range.

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