Towards transverse multiplexing of THz photo-driven emitters driven by a dual-transverse-mode dual-frequency laser

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Abstract: **Recent performances of vertical-external-cavity surface-emitting lasers that operate at two frequencies for THz photo-generation, thanks to a dual-transverse-modes operation, are presented. THz emission is demonstrated from 50 GHz up to few THz with a linewidth of 150 kHz (during 3-ms), for a power of 1 µW at 260 GHz, limited by the photo-mixer. Possibility of power upscaling is discussed by taking advantage of the optical transverse coherence to realize a network of photo-emitters, thus paving the way to compact and agile coherent THz sources offering an output power over few mW's at frequencies of 100's of GHz.**

Coherent, tunable and compact continuous-wave Terahertz (THz) sources are required for many applications, such as bio-medical sensing and imaging, communications, or security. A large variety of solutions exists for THz emission, from optics to electronics, but existing solutions are often cumbersome or limited in terms of output power, tunability and/or modulation bandwidth. Photo-mixing techniques offer precious advantages such as wideband tunability and high-modulation bandwidth at room temperature.

In order to preserve longitudinal coherence, dual-frequency lasers are usually recommended, most of technical frequency noise being possibly correlated for the two emitted frequencies, thus offering a reduced frequency noise at the beat frequency (in the THz range). Among the possible laser designs, Vertical-external-Cavity Surface-Emitting Lasers (VeCSEL) are very promising solutions as they are relatively compact, wavelength flexible, widely tunable, powerful and highly coherent (spectrally, spatially and in terms of polarization). However, as homogeneous-gain leads to modal competition, dual-frequency operation requires to separate the modes to ensure sufficient stability, using either polarization, longitudinal or transverse mode splitting. Dual-frequency operation has been already demonstrated using a VeCSEL by stabilization of two polarization modes [1] or two longitudinal modes [2], but do not provide an inherently robust, compact/integrated and flexible solution for cw, coherent and tunable beat signals in the GHz–THz range as proposed thanks to the stabilization of two transverse modes in a single-axis cavity VeCSEL [3].

The dual-frequency VeCSEL based on two transverse modes is based on the stable simultaneous operation of two Laguerre–Gauss (LG) transverse modes in a single-axis short cavity, using an integrated sub-wavelength-thick metallic mask. We demonstrated a >80 mW output power at 1064 nm for an optical pump of 400 mW, diffraction-limited beam, narrow linewidth of <300 kHz, linear polarization state (>45 dB), and low intensity noise class-A dynamics of <0.3% rms.

By exciting a single commercial uni-traveling carrier photodiode (UTC-PD) by a single lobe of the LG_{03}/LG_{00} transverse overlap, as reported in [4], coherent and tunable THz emission was demonstrated. Modes frequency difference is driven by thermal effects, band-filling effects and/or phase masks, allowing THz emission from 50 GHz to few THz. Coherent THz emission spectra are presented in Fig. 1 (left), with a linewidth of about 150 kHz for 3-ms acquisition time, and an output power limited by the photodiode (typically 1 μW at 300 GHz).

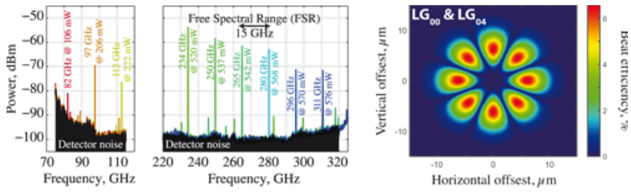

Fig. 1. Left: THz spectra for various pump power showing coherent and tunable THz emission within the available heterodyne receiver ranges (75–110 GHz and 220–325 GHz), for the LG_{00} & LG_{03} transverse modes couple. Right: Beat efficiency map for LG_{00} & LG_{04} transverse modes couple proposed for transverse multiplexing of THz emitters.

In order to increase the output power, that is a key-point for THz applications, we will discuss about the possibility to exploit all the possible lobes of a given LG-couple transverse overlap. To do so, one straightforward solution is to increase the number of lobes. We were able to demonstrate a laser operation for the LG_{00}/LG_{04} mode couple, and to calculate the possible beat efficiency as shown in Fig. 1 (right). Therefore, by implementing a transverse network of 8 photo-mixers, the output power could be multiplied by the same number. Additionally, the commercial UTC PD we used was designed for a 1550-nm excitation, so a higher THz output power could be expected for a specifically-designed photo-mixer at 1064 nm, either a UTC PD or any other photo-mixer.

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