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# Patch Antenna Microcavities THz Quantum Cascade Lasers

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**Abstract**—We study the emission of THz quantum cascade lasers (QCLs) designed in arrays of Patch Antenna Microcavities (PAM). The array geometry is an effective strategy to control the losses and to achieve phase locking, allowing for beam shaping and high photon outcoupling efficiency. We demonstrate a 40-fold enhanced emission compared to standard ridge waveguides and a gaussian beam divergence as low as  $2^\circ \times 2^\circ$ .

## I. INTRODUCTION

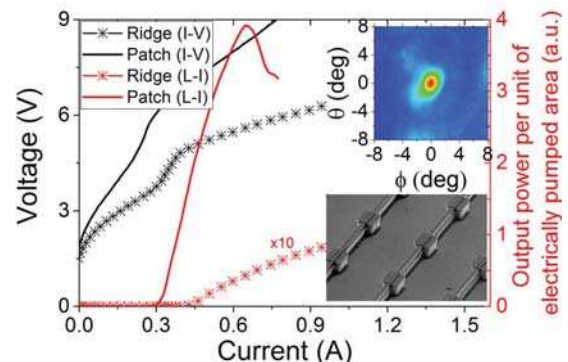
AN effective strategy for achieving highly efficient optoelectronic devices in the optical regime is by confining light into subwavelength volumes, for example in optical microcavities [1]. A promising approach for translating this concept to the THz regime is by using double metal (DM) microcavity structures. The high reflectivity of metals at these frequencies allow the confinement of light far beyond the diffraction limit, resulting in an enhanced light-matter interaction leading to a wide variety of advanced optoelectronics functionalities. For example, hybrid DM antenna-coupled microcavities have been proposed to achieve high performance Mid-IR and THz detectors [2,3], to demonstrate the ultra-strong light-matter coupling regime [4] and enhanced THz electroluminescence [5]. However, the use of DM microcavities for emitters has been challenging due to the low photon out-coupling efficiency and extreme divergence of the far-field radiation inherent to the strong confinement in the DM microcavity. Recently we have studied numerically the possibility to use arrays of patch antenna microcavities (PAMs) to overcome those limitations [6]. Here we present a study on the emission properties of arrays of PAMs based on quantum cascade (QC) active regions. We demonstrate enhanced emission compared to standard THz DM ridge waveguide QCLs owing to the engineered losses provided by the array geometry, and quasi collimation of the THz beam produced by far-field constructive interferences.

## II. RESULTS

We studied emission from arrays of DM PAMs containing GaAs/AlGaAs QC active regions based on a hybrid bound-to-continuum – LO phonon extraction design [7]. We compared the performance of these structures with a reference sample processed in a conventional DM ridge waveguide. Optical and electrical characterization of the fabricated devices (Fig. 1) demonstrate enhanced performance of the PAM array over the ridge waveguides, namely a 40-fold enhancement of the emission efficiency, lower lasing threshold current and improved slope efficiency. Also, quasi collimation of the THz beam was observed. A far-field pattern with gaussian profile

and beam divergence as low as  $2^\circ \times 2^\circ$  was measured. The significant enhancement of the emission properties is attributed to an improved extraction efficiency from PAMs. The high-quality beam profile originates from constructive interferences authorized by the phase-locking, providing a powerful means to shape the beam, similar to what has been widely used in the case of RF antennas [8].

In conclusion, we report the use of arrays of PAMs as a powerful strategy to improve the emission of THz QCLs in DM configuration. Arrays of PAMs allow a precise tuning of the losses, leading to high extraction efficiencies and shaping of the beam. We believe that our design can become an important platform to exploit the benefits of microcavities to achieve efficient and compact THz sources as well as to study novel regimes such as THz optical nonlinearities and amplification, which would be beneficial for many imaging and spectroscopy applications.



**Fig. 1.** L-I-V characteristics of a DM ridge waveguide compared with the PAM array. Inset: (Up) measured far-field pattern of the PAM array. A beam divergence with FWHM =  $2^\circ \times 2^\circ$  was measured. (Down) SEM picture showing a close-up view of a fabricated array device.

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