# Low-power consumption THz quantum-cascade VECSEL using patch-based metasurface

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Terahertz (THz) quantum-cascade (QC) lasers are attractive sources of local oscillator power for THz heterodyne receiver systems thanks to their high power and efficiency at frequencies in the 2-5 THz range [1]. In particular, THz QC-lasers have been deployed as local oscillators for the OI line at 4.74 THz. Although THz QC-lasers have traditionally been implemented in surface-plasmon or metal-metal ridge waveguides, a new architecture is the THz QC vertical-external-cavity surface-emitting laser (QC-VECSELs), which is promising due to its high-quality beam, high output power, and broadband frequency tunability [2]. The enabling component of the THz QC-VECSEL is an amplifying metasurface based on a subwavelength array of metal-metal antenna elements loaded with QC gain material. Because THz QC-lasers must be operated at cryogenic temperatures, the laser's power consumption critically determines the cryocooler load and total system power consumption. In this work, we demonstrate QC-VECSELs at ~4.7 THz based on extremely sparse metasurfaces allowing for reduced power consumption and improved temperature performance.

To date, the metasurfaces used for THz QC-VECSELs have been based on a subwavelength array of long, narrow metal-metal waveguides coupled to surface radiation via the $TM_{01}$ cutoff resonance of the waveguides. Here, we instead use a subwavelength array of patch antennas, similarly coupled to surface radiation via their $TM_{010}$ patch resonance. While the areal fill factor (area of QC-loaded antenna elements / total area of metasurface) of a typical ridge-waveguide based metasurface is limited to a minimum of ~15%, the fill factor of a patch array can be reduced to <5%, which reduces the required pump power for a given metasurface area, and improves temperature performance by allowing extraction of heat along two axes, instead of one.

The demonstrated device is designed to operate in a single mode at 4.63 THz and has a fill factor of 4% (47 $\mu$m periodicity along both axes of the 2-dimensional surface, and one patch per period that is 11.5 $\mu$m wide and 7.5 $\mu$m long). Additionally, the metasurface is designed with a spatially varying phase response to provide a focusing effect for improved beam quality and reduced diffraction loss [3]. The measured current, voltage, and THz power characteristics are plotted in Fig. 1. A maximum of 0.45 mW of power is measured in continuous-wave mode at 77 K, with a total power consumption of 1.25 W, for a wall plug efficiency of 0.036%.

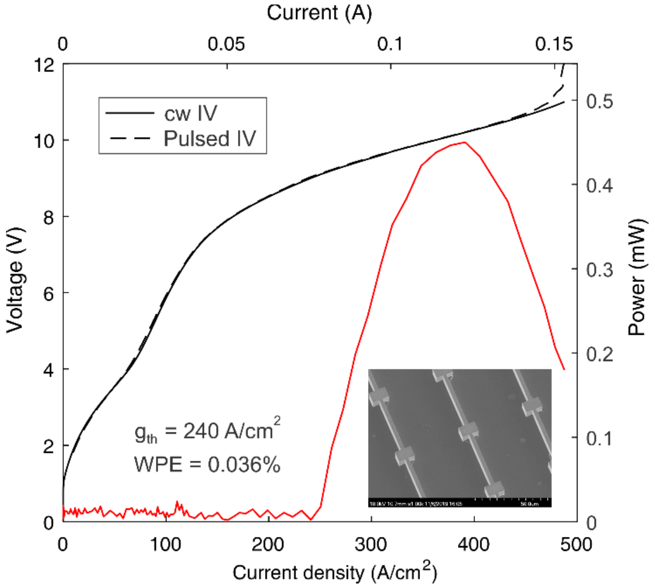

Fig. 1. Current – voltage curve of the measured devices operating at 77 K, and corresponding THz output power. Up to 0.45 mW of THz power is obtained with a wall-plug efficiency of 0.036%. The current – voltage curve measured in pulsed mode (1% duty cycle) is almost identical as that in continuous wave, indicating minimal thermal impact by operating in continuous wave mode. Inset shows SEM of fabricated metasurface.

## REFERENCES

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