High angular resolution far-field beam pattern of a surface-plasmon THz quantum cascade laser

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***Abstract*— In this work we have developed a new beam pattern measurement setup using a room-temperature pyrodetector and two PC controlled stepper motors. We measured the far-field beam patterns of surface plasmon QCLs, which are 217 μm or 157 μm wide, 1500 μm long, emitted at 2.84 THz in single mode. We discover that the beams contain two types of interference fringes. The type one has a spacing between two fringes which decreases with increasing angle, and occurs in the positive space (opposite to the substrate of the QCL). Type two has nearly equally, closely spaced rings and is observed in the negative space.**

I. INTRODUCTION

Observations of atomic and molecular lines at the terahertz (THz) frequency region can provide important and unique information on astrophysics and the Earth's atmosphere. To detect those lines, it is essential to have an instrument with high sensitivity and high spectral resolution, which should be operated in a balloon-borne or a space-borne observatory because of the water absorption in the air. A heterodyne receiver which mixes a weak THz line signal with a strong line signal generated locally (local oscillator) and down-converts it to a signal at a few GHz, to be further amplified, is the only technique fulfilling the requirements of both high resolution and high sensitivity. The key components of the receiver are a mixer and a THz coherent CW source.

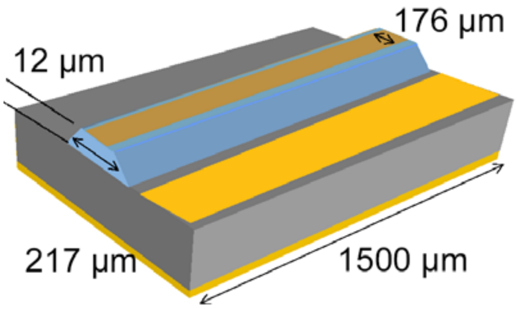
A new type of solid-state THz source was recently developed based on a quantum cascade laser (QCL) structure [1,2]. This new source holds great promise for LO applications because of the following characteristics: the frequency coverage (1.2 - 5 THz demonstrated so far), high output power (≥ 1 mW), compactness, linear polarization, narrow linewidth, and phase locking capability. THz QCLs based on a double metal waveguide have been successfully demonstrated as local oscillator in the laboratory [3-5].

The far-field beam pattern of a THz QCL has been recognized to be crucial to couple the power to a mixer. Despite of mW-output power of a QCL, it turns out experimentally that the effective power, which could be coupled to a hot electron bolometer mixer is still limited because of divergent far-field beam and interference fringes. The interference fringes have been reported in a double-metal waveguide QCL [6], surface plasmon waveguide QCL [5], and surface plasmon QCL with a DFB structure [7].

Surface plasmon waveguide QCLs [5,7] show more dense interference fringes than double metal waveguide QCLs, which makes it very challenging to resolve the fingerprint of the interference since it requires detection of the radiation intensity with high angular resolution.

II. THZ SURFACE-PLASMON QCLS

The QCLs used in this work are described in Ref. 8 and are based on a bound-to-continuum active region design and a surface plasmon waveguide. The active region consists of 90 $GaAs/Al_{0.15}Ga_{0.85}As$ repeated modules grown by MBE, giving a total thickness of 11.64 μm. The active layer is grown on the top of a 230 μm thick semi-insulating GaAs substrate, and sandwiched between a metallic top-contact and a heavily n-doped GaAs bottom-contact channel. Therefore, unlike double-metal waveguide QCLs, the optical mode is not fully confined within the active region, but penetrates into the substrate down to a depth of approximately 100 μm at 2.8 THz. We use two laser ridges with widths of 217 μm and 158 μm, respectively, which are cleaved at both ends to form 1500 μm-long Fabry-Perot cavities. The 217 μm wide one is schematically shown in Fig. 1.



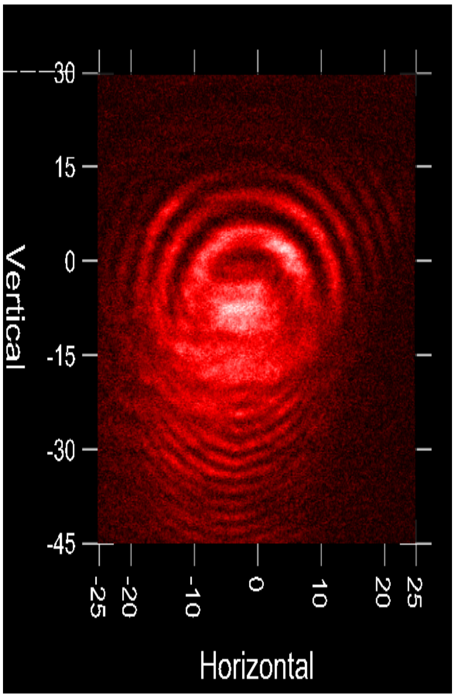


Figure 1. Schematic view of a surface plasmon THz QCL at 2.84 THz (top); measured far-field beam intensity pattern in 2D (horizontal and vertical directions in unit of degree) of the QCL with the zero along the pointing direction of the laser.

We will focus on the 217 µm wide device. Lasing spectra, measured at different bias currents using a Fourier-transform spectrometer with a resolution of ~1 GHz, show single mode emission at 2.835 THz. The maximum output power in continuous wave (CW) mode was about 1.5 mW (measured with a Thomas Keating power meter [5]) when it was operated at 6 V and 900 mA, and at an operating temperature of ~20 K.

III. Experimental setup

We have developed a new beam pattern measurement setup using a room-temperature pyrodetector and two PC controlled stepper motors allowing scanning in both horizontal and vertical directions. The radiation intensity was measured using the pyrodetector with an aperture of 2 mm in diameter, placed at a radial distance of 80 mm from the QCL. This combination limits the angular-resolution to 1.5° in the beam measurement. The laser was operated in pulsed mode and the intensity was measured using a lock-in technique.

IV. Results

Figure 1 shows the measured beam pattern of the 217 µm wide QCL. We find that the beams contain two types of interference fringes. Type one has the spacing between two fringes that decreases with increasing angle, and occurs in the positive space (opposite to the substrate of the QCL). Type two has closely, nearly equally spaced rings and observed in the negative space.

The first type of fringes resembles those found in double metal waveguide QCLs [6], which were explained by the interference of radiation from longitudinally distributed sources within the laser [9]. However, the spacings between the rings in current case are much smaller than what the model predicts. The second type of rings is likely due to the influence of the aperture induced by the metal layer under the QCL substrate on the radiation.

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