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Far-field engineering of metal-metal terahertz quantum cascade lasers with integrated horn antennas

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Introduction

Terahertz (THz) quantum cascade laser (QCL) are semiconductor sources based on intersubband transitions and permit laser emission over a large portion of the THz spectrum. THz QCLs have shown considerable advancements with high power output and high temperature operation. However, typically these two parameters cannot be demonstrated simultaneously. The highest temperature operation of 200K has been demonstrated with metal-metal (MM) waveguides, where the high modal confinement permits a high modal gain. However, a disadvantage of the latter is a highly diffracted beam and a large facet reflectivity leading to weak directionality and low output powers, respectively.

Several monolithic methods have been proposed and realized to resolve this problem. These are based on second-order grating or photonic structures for surface emission [1] but are inherently mono-frequency and thus not adapted for broadband emission. The latter is interesting in the case of modelocking or frequency comb generation. Most broadband techniques, however, have been based manual positioning techniques such as silicon laser placed on the facet or suspended antenna structures [2].

Results

A promising technique has been recently demonstrated where planar horn antennas (PHAs) are etched onto the top of the QCL surface, permitting the confined mode to be better matched to a radiative mode [3]. This has allowed a considerable increase in the output power without effecting greatly the temperature performance of the QCL. This greatly simplified approach has proven to be stable and broadband. Indeed injection seeding of bound-to-continuum QCLs have been recently demonstrated taking advantage of the inherent broadband characteristics of the antenna structure [3]. However, no control of the far-field was demonstrated with only one-dimensional profiles of the far field investigated. In this work, we demonstrate how the far-field can be controlled by engineering the transverse modes and the geometry of the horn antenna and ridge. We show two dimensional far field patterns and compare these with electromagnetic simulations that show a good agreement, as shown in figure 1 for a QCL operating at 3.2THz and held at a temperature of 77K. As shown, there is a good agreement between simulated (right) and measured (left) far-fields with the horn antennas extracting more power from the cavity. We also show that the ridge width is an important factor with the large ridge coupling out a high order bi-lobe mode of the QCL while a thin ridge allows coupling of the only the fundamental mode.

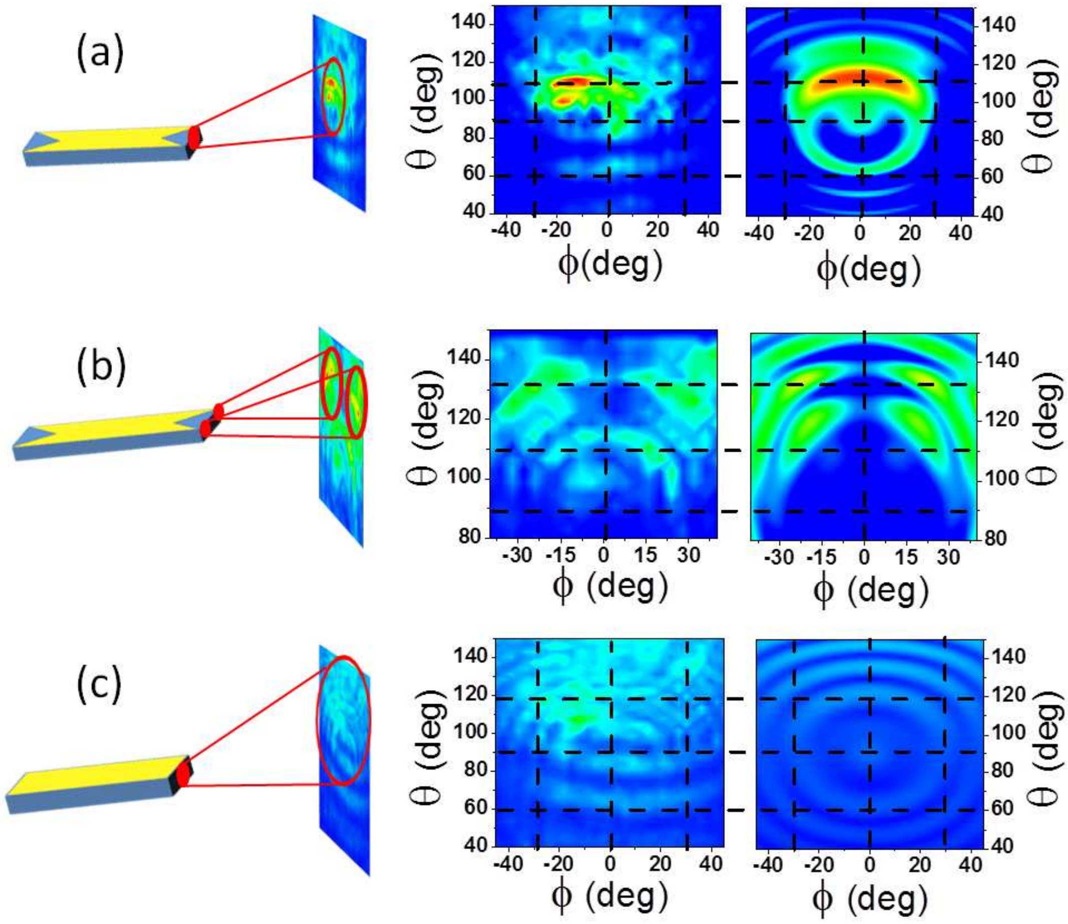

Fig. 1. Simulated far-field patterns (right side) of metal-metal THz QCLs and theirs corresponding far-field patterns measured at 77K (left). (a) 40μm-wide metal-metal THz QCL (b) 80μm-wide metal-metal THz QCL. a) and b) are with ~150μm-long planar horn antennas integrated onto QCL top metal at both side of the facet. (c) 60μm-wide metal-metal THz QCL without any planar horn antenna

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