High power extraction in surface-emitting terahertz quantum cascade lasers using type-II photonic heterostructures

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BIOGRAPHY

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TECHNICAL ABSTRACT

We report high-power, single-mode surface-emission from THz quantum cascade (QC) lasers with a type-II photonic heterostructure (PHS) resonator. Such resonator selectively excites the unusual radiative mode with significantly enhanced radiation efficiency. The PHS lasers (f ~ 3.4 THz) exhibit record-high single-mode peak output powers, as well as directional single-lobed beam patterns.

In traditional (THz) 2nd-order distributed feedback (DFB) QC lasers [1], radiative and non-radiative modes exist at the center of the photonic band structure, separated by an energy band gap. The radiative mode exhibits a significantly larger radiation loss ($\alpha_{rad}$) because of its field symmetry. Lasers therefore usually operate on the non-radiative mode, but with very low power extraction efficiencies which are essentially determined by the finite size of the device. If it were possible to operate such lasers on radiative modes instead, much higher power extraction/slope efficiencies would be obtained [2]. We present a technique for achieving this goal using a novel 1D resonator concept – a spatially graded 2nd-order metallic grating is fabricated onto the top surface of a QC laser with metal-metal waveguides. The periodicity is symmetrically and gradually decreased from the centre to each end of the grating. Such a system can be interpreted as a Type-II photonic heterostructure (PHS) since the photonic band gap is position-dependent. The non-radiative mode is spatially delocalized, whilst the radiative modes are confined and their frequencies quantized, very much like holes and electrons in a type-II quantum well. PHS resonator reverses the mode competition and activates the mode with higher radiation loss, which is never the natural lasing mode in traditional 1D/2D photonic crystal lasers.

PHS surface-emitting lasers exhibit high external quantum efficiency (230 mW/A), which is more than 10 times higher than their DFB counterparts at the same wavelength (3.4 THz). A record-high single-mode peak output power of 103 mW is achieved at 20K. A direction single-lobed far-field beam pattern is also realized, which addresses another important issue of THz QC laser: the beam divergence. Lithographically tunable single mode surface emission is demonstrated. Recent results on continuous wave operation of PHS lasers will also be shown.

The concept of type-II photonic heterostructure opens up new possibilities for surface-emitting semiconductor lasers to achieve high efficiency/output power with directional single-lobed far-field beam patterns.


Keywords: Terahertz, quantum cascade laser, photonic heterostructure

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