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Novel Cavity Concepts for Terahertz Quantum Cascade Lasers

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ABSTRACT

The terahertz (THz) spectral region is of particular interest for future sensing, imaging or detection applications, taking advantage of the unique optical properties of numerous materials at these wavelengths. However, a widespread use of this technology in current applications is impeded by a lack of efficient, compact, and reliable sources, which is known as the so-called THz gap. Quantum cascade lasers (QCLs) are electrically pumped devices, consisting of a semiconductor nanostructure, which are able to emit coherent radiation at THz frequencies and are thus promising candidates for bridging this gap. One great advantage of these devices is the freedom to design the optical and electronic properties of the laser active region (almost) independently of the used semiconductor materials by quantum mechanical methods. Besides the gain medium, the THz QCL cavity can be designed and engineered freely, which is a consequence of the unipolar operation principle of the laser. The comparably long emission wavelength enables the fabrication of sub-wavelength resonators using well established processing techniques. In this way, lasers featuring novel photonic and plasmonic concepts can be realized, which is the main focus of this thesis. In particular, the two most commonly used waveguide types, the double-metal (DM) and the semi-insulating surface plasmon (SISP) waveguide, are investigated in detail, and concepts are developed to improve the device performance by optimizing the laser cavity. Specifically, the influence of the facet type of DM waveguides on the performance of the device is investigated. As a result, a simple method to obtain an asymmetric optical output characteristic is developed, which is typically desired for a laser. Furthermore, a direct wafer bonding technique is introduced to increase the waveguide height, which improves the general performance of devices with DM and SISP waveguides in terms of optical output power and maximum operating temperature. Exceptionally high output powers of almost 1~W in pulsed mode are achieved in this way. In the final section of this work, electrically pumped coupled microdisk lasers are presented, which are realized using THz QCLs with DM waveguides. Due to the narrowband intersubband gain, these systems, in fact, are ideal to investigate the properties of the active region itself and, furthermore, interesting physical phenomena, important for the development of future photonic devices. In particular, a recently predicted effect relying on the occurrence of a so-called exceptional point (EP) in the laser equations, was experimentally verified, which leads to a counter-intuitive reversal of the laser's pump dependence. An increasing pump in this system, effectively, leads to a decreased emission, which can be explained by the specific movement of the system's eigenvalues in the complex plane.