Quantum Cascade Lasers and Applications, Opportunities and Limitations

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Quantum cascade (QC) lasers continue to make considerable progress in both device performance and novel designs and applications. The field is re-shaped by a continually increasing number of groups joining the field of QC-laser research in experiment and theory, introducing new material systems, and applying them in more varied ways. Examples of new and recent developments are THz lasers and nonlinear optical effects in QC lasers. Exciting new material systems are InAs/GaSb, in which lasers have recently been demonstrated, and Si/SiGe, as well as large band-offset II-VI, IV-VI, and nitride-based materials. Applications abound in trace gas sensing and are starting to find a foothold in the medical arena; whereas application to free-space optical wireless communication is contemplated by various research groups.

The field of QC laser research has furthermore evolved from fundamental research to the inclusion of commercialization, focused on applications in sensing and information. The emergence of commercialization has naturally generated diverging views of how the field is best developed further. Applications are thirsting for a higher performance of established QC laser devices, requiring room temperature continuous wave operation and specification of single-mode emission wavelength by the nanometer as standard features, all while keeping the device cost low and considering secondary device specifications such as tunability, modulation capabilities, and beam quality. More fundamentally inclined research endeavors are instead focused on developing new ideas quite independent of the initial wavelength and likely operating at low temperatures.

In this presentation we will first take stock of the present state of the art QC lasers and we will also summarize what applications of QC lasers have been demonstrated and how they measure up with other methods. Suppliers of QC lasers are constantly besieged by requests for higher performing lasers; we will discuss the effort needed to achieve such performance. This debate naturally includes a discussion of the fundamental performance limits of QC lasers. Finally, one frontier of QC lasers that is still relatively unexplored is the short infrared wavelength region. Performance of QC lasers drops noticeably for wavelengths below about 4.5 μm, and no QC laser has been demonstrated at wavelengths shorter than 3.5 μm. High-performance interband lasers typically do not operate at wavelengths longer than about 2 μm. This leaves us with a small spectral gap, with nevertheless important applications in sensing and communications, which is only partly served by the so-called "type-II" cascade lasers or Sb-based interband lasers. We will discuss the prospects of QC lasers capable of operating in this short wavelength range, either by choice of novel materials, or by frequency up-conversion of QC lasers operating in the their "sweet-spot" region around 7–9 μm.

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