New Quantum Cascade Laser Architectures

II–VI Quantum Cascade Emitters, High k-Space Lasing, & Short Injectors

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Abstract

Quantum cascade (QC) lasers are today's most capable mid-infrared light sources. With up to watt-level room temperature emission over a broad swath of mid-infrared wavelengths, these tiny semiconductor devices enable a variety of applications and technologies such as ultra-sensitive systems for detecting trace molecules in the vapor phase. The foundation of a QC structure lies in alternating hundreds of wide- and narrow-bandgap semiconductor layers to form a coupled quantum well system. In this way, the laws of quantum mechanics are used to precisely engineer electron transport and create artificial optical transitions. The result is a material with capabilities not found in nature, a truly "designer" material.

As a central theme in this thesis, we stress the remarkable flexibility of the quantum cascade—the ability to highly tailor device structure for creative design concepts. The QC idea, in fact, relies on no particular material system for its implementation. While all QC lasers to date have been fabricated from III–V materials such as InGaAs/AlInAs, I detail our preliminary work on ZnCdSe/ZnCdMgSe—a II–VI materials system—where we have demonstrated electroluminescence.

We then further discuss how the inherent QC flexibility can be exploited for new devices that extend QC performance and capabilities. In this regard, we offer the examples of excited state transitions and short injectors. Excited state transitions are an avenue to enhancing optical gain, which is especially needed for longer-wavelength devices where optical losses hinder performance. Likewise, shortening the QC injector length over a conventional QC structure has powerful implications for threshold current, output power, and wall-plug efficiency. In both cases, novel physical effects are discovered. Pumping electrons into highly excited states led to the discovery of high k-space lasing from highly non-equilibrium electron distributions. Shortening QC injector regions allowed us to observe "classical" superlattice effects such as negative differential resistance and pulse instabilities. While interesting from a scientific perspective, these unique phenomena shed new insight on internal QC laser processes and may themselves lead to further improvements in device performance.