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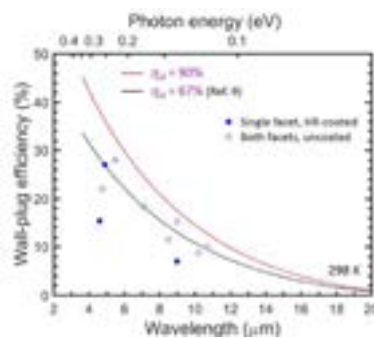


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High-internal-efficiency quantum cascade lasers: the road to mid-infrared lasers of 40% CW wall-plug efficiency

The internal efficiency η_i of quantum cascade lasers (QCLs) is the factor in the expression for the external differential efficiency that encompasses all differential carrier-usage (i.e., the injection efficiency) and lasing-photon-transition efficiencies. For conventional QCLs the η_i values have been found to be rather low: 50-60% in the 4.5-6.0 μm wavelength range and 57-67% in the 7-11 μm wavelength range; with, until recently, no clear explanation why that was the case. With the advent of combining carrier-leakage suppression with fast, efficient carrier extraction out of the active regions of QCLs, the η_i values have steadily increased and are approaching their fundamental upper limit of $\sim 90\%$ for mid-infrared (IR)-emitting devices. We will review the developments that led to high η_i values throughout the mid-IR wavelength range. Conduction-band engineering has led to the so-called step-taper active-region (STA) QCLs which have provided η_i values 30-50% higher than in conventional QCLs over both the 4.5-6.0 μm and 7-11 μm wavelength ranges. A record-high, single-facet, continuous-wave (CW) power, for 8.0 μm -emitting QCLs, of 1.0 Watt has been achieved from STA-type QCLs. Furthermore, the recognition that the fundamental limit for η_i (i.e., 90%) is 34% higher than the η_i value employed a decade ago when determining the fundamental limit for the wall-plug efficiency of mid-IR QCLs, has led to the realization that wall-plug efficiencies $\geq 40\%$ can be achieved for 4.5-5.0 μm -emitting QCLs. The practical benefits of achieving such high performance from mid-IR emitting semiconductor lasers will be discussed as well.



Wall-plug-efficiency fundamental limits for mid-infrared-emitting QCLs

Biography

Dan Botez is Philip Dunham Reed Professor in the Department of Electrical and Computer Engineering at University of Wisconsin (UW) - Madison. In 1976, he obtained a PhD degree in Electrical Engineering from University of California, Berkeley. He has carried out and led research in semiconductor lasers at RCA Labs, Princeton, NJ and TRW Research Center, Redondo Beach, CA before joining, in 1993, the faculty at UW-Madison. His research interests lie in three areas of semiconductor-laser physics: high-power, coherent edge-emitting lasers; high-power, coherent grating-coupled surface-emitting lasers; and quantum cascade lasers. The first two are based on one- and two-dimensional, high-index-contrast, photonic-crystal structures, respectively, for insuring both long-range spatial coherence and stable operation under continuous-wave (CW) driving conditions. The third involves electron transitions between the sub-bands of multi-quantum-well structures and is focused on achieving high-efficiency CW operation in the mid-infrared wavelength range: 3-10 microns, via multi-dimensional conduction-band engineering.

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