

# Rethinking and Redesigning the Semiconductor Laser/ Quantum Noise Controlled Semiconductor Lasers

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## Abstract

The present canonical design of the semiconductor laser (SCL), in force since the early 1970s, is incompatible with high coherence (narrow linewidth). The reason is fundamental and is a consequence of the quantum-mandated umbilical relationship between induced emission (gain) and spontaneous emission (noise) exacerbated by the modal concentration of optical energy in the high loss III-V material. We demonstrate, theoretically and experimentally, a new design paradigm which results in over three orders of magnitude reduction in the spectral linewidth of the SCL compared to commercial lasers now deployed. The key difference is a radical (some 99% in our case) transfer of stored optical energy from the III-V material to nearly transparent silicon which is an integral part of the laser resonator. This laser should constitute a serious candidate to take over the role of the Distributed Feedback (DFB) SCL as the light source for future coherent optical networks.

The present-day SCL laser, including the dominant DFB design, is arguably, the least coherent laser when compared to other members of the laser family with similar power outputs. We show that the main reason for this difference is the very large modal losses attendant upon the prevailing SCL mode design in which the optical energy is concentrated in the high loss (free carrier absorption) III-V material. To compensate for this loss requires a large population of injected (inverted) electrons and holes. The portion of spontaneous recombination radiation from these inverted carriers which is fed into the laser mode is the principal reason for the reduced coherence. Starting with the hybrid Si/III-V laser platform developed by the Bowers group at UCSB and an extension of the Purcell-like control of spontaneous emission we designed the laser resonator such that some 99% of the optical energy is carried within the low loss Si with the remainder available for gain in the active region. In the process the laser threshold current remains essentially a constant. The reduced loss results in some 2 orders of magnitude lowering in the inverted carrier population needed to reach oscillation threshold and a corresponding reduction in the rate of, noisy, spontaneous emission power into the laser mode. Furthermore, we fashion the Si as a high Q "defect" waveguide resonator to increase the stored optical energy in the laser mode which (energy) provides a flywheel-like phase stabilizing effect. The two effects, reinforcing each other, conspire to endow our lasers, fabricated in the Kavli facility at Caltech, with Schawlow-Townes linewidths as narrow as 500 Hz. This number, which is some three orders of magnitude lower than in commercial lasers, is subject to major further reductions. The fundamental and large modification of the induced and spontaneous transition rates inherent to our laser gives rise to major departures in its characteristics compared to

conventional SC lasers. Specifically: In addition to the reduced noise our lasers display some x100 reduction in the relaxation resonance frequency as well as a large insensitivity to reflection feedback. Both of these effects are under investigation and the latest results will be disclosed.

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