Progress in Brightness, Power, and Efficiency of Semiconductor Lasers for High Power Applications

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Speaker: Paul O. Leisher, Ph.D. – Vice President of Research and Fellow, Luminar Technologies

Abstract:

Semiconductor lasers are a key component in numerous emerging photonics-enabled technologies, including additive manufacturing, data centers for artificial intelligence, inertial navigation, optical power beaming, photon sail propulsion for interstellar probes, autonomous vehicles, rapid biomedical diagnostics, laser wakefield acceleration, fusion energy, and directed energy systems. In many of these applications, the laser is the most expensive, power-hungry, and failure-prone component. This presents rich opportunities for physics-driven innovation and continuous improvement. Modern high power semiconductor lasers are extremely good at converting electricity into light (>70% wallplug efficiency) and are very cheap (<\$1/watt), but these devices are fundamentally limited by low coherence and poor beam quality which arise from effects such as thermal, and carrier-induced lensing.

As a result, they are commonly used as pumps for solid-state and fiber lasers, rather than as direct sources. These systems could be greatly improved and simplified if semiconductor lasers could be directly utilized, but this can only be made possible by addressing the fundamental physical limitations of beam quality and coherence in a manner that does not compromise the semiconductor laser's inherent ability to scale power and brightness with high efficiency. This talk explores recent progress in the development of high performance semiconductor lasers. We will examine the physical mechanisms that limit power scalability, coherence, beam quality, and efficiency and review semiconductor laser architectures designed to mitigate these effects. By pushing the limits of brightness and coherence, this research opens the door to more simplified, efficient, and robust laser systems to accelerate their deployment into next-generation technologies and enable new frontiers in science.