Photonic Crystal Laser Technology Based on Nanostructured III-V Active Material

NSF NIRT Grant DMR 0103134

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Photonic crystals combined with III-V nanostructures form a synergistic solution to device scaling that allows photonic technology to move into the regime controlled by quantum phenomena. Photonic crystals confine photons to the dimensions of the wavelength of light, while III-V nanostructures confine electrons and holes to the dimensions of their thermal de Broglie wavelengths. The result of combining these two approaches is full quantum control over light and charge carriers to create ultra small cavity lasers, in addition to providing the photonic interconnects to realize densely integrated photonic chips.

Small cavity lasers are of interest for a variety of reasons. A decrease of a semiconductor laser's volume to its minimum size, while maintaining high Q, along with a decrease in the electronic confinement potential, can lead to revolutionary advances in device operation. These include high-speed operation below and at threshold, and high efficiency in the spontaneous regime below threshold. In the ultimate limits of small active volume and sufficiently high Q the system can enter the quantum reversible regime necessary to create quantum entangled states. Today both these quantum limits of the photons and electron-hole pairs are possible using III-V nanostructured active material and nanostructured photonic crystals. The goal of this program is to develop the laser and optoelectronic device technologies that achieve photon and electron confinement to generate 0-dimensional states, based on two revolutionary advances in nanolithography and dry etching to fabricate nanocrystals containing self-organized quantum dots.

Our program also studies how to implement these new technologies in ways that are conducive to large scale manufacturing. Photonic crystals require nanolithography, which can be performed in the laboratory using electron-beam writing. However, electron-beam writing is costly and time consuming, which are serious drawbacks for commercializing photonic crystal devices. Imprint lithography, which essentially matches the resolution provided by electron-beam lithography, is being explored in our program as a means to create nanophotonic devices that incorporate the III-V nanostructures.

The materials being employed in these studies are GaAs/AlGaAs/InGaAs strained layer quantum dot heterostructures grown by molecular beam epitaxy, which are fabricated into photonic crystal lasers and microcavities. The III-V heterostructures are grown in The University of Texas at Austin Microelectronics Research Center, and photonic crystal design and fabrication of the III-V heterostructures takes place at the California Institute of Technology using electron-beam lithography. Imprint lithography is performed with The University of Texas at Austin Microelectronics Research Center. Graduate research assistants working towards Ph.D. degrees represent a major component of this research.

Results to date include the first demonstration of a photonic crystal quantum dot laser. The results are shown in Figs. 1, 2 and 3 below.

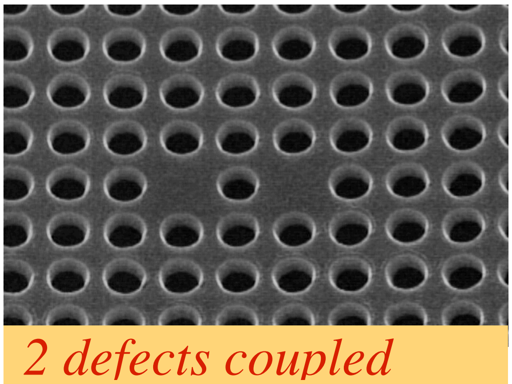

Fig. 1 Scanning electron photograph of a two-defect photonic crystal quantum dot microcavity.

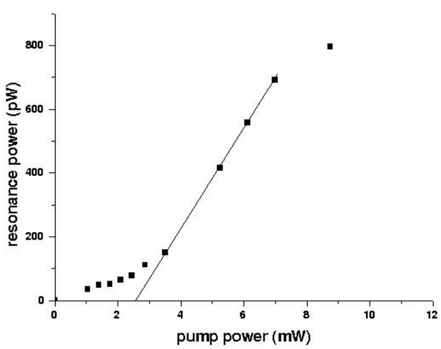

Fig. 2 Light versus pump level for a photonic crystal quantum dot laser.

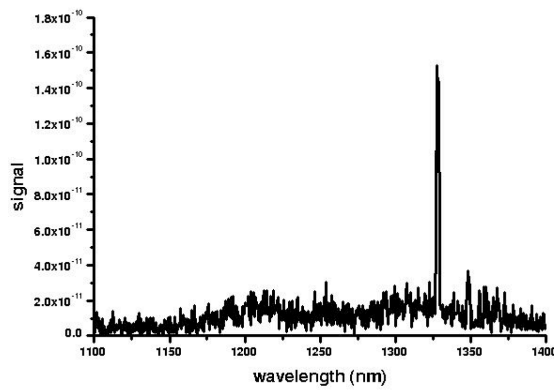

Fig. 3 Lasing spectrum of the quantum dot photonic crystal quantum dot laser.

References

[1] T. Yoshie, O.B. Shchekin, H. Chen, D.G. Deppe, and A. Scherer, “Qauntum dot photonic crystal lasers,” Electron. Lett., vol. 38, 967 (15 August, 2002).