Colloidal quantum dot lasers poised to come of age

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LOS ALAMOS, N.M., Feb. 17, 2021—A new paper by authors from Los Alamos and Argonne national laboratories sums up the recent progress in colloidal-quantum-dot research and highlights the remaining challenges and opportunities in the rapidly developing field, which is poised to enable a wide array of new laser-based and LED-based technology applications.

“These tiny specs of semiconductor matter can generate spectrally tunable lasing light, opening tremendous opportunities in areas of photonic circuits, optical communications, lab-on-a-chip sensing, and medical diagnostics,” said Victor Klimov, lead author of the review article published Feb. 16 in *Nature Reviews Materials* and leader of the team at Los Alamos National Laboratory that has pioneered a range of discoveries with colloidal quantum dots.

Twenty years ago, Los Alamos scientists demonstrated for the first time that colloidal quantum dots can generate spectrally tunable lasing light. This discovery opened an exciting area of research into fundamental and applied aspects of light amplification with chemically fabricated nanomaterials.

Colloidal quantum dots are assembled from semiconductor precursors suspended in a solution. They are easily synthesized without a clean room and behave like big atoms that follow the rules of quantum mechanics.

A distinctive feature of colloidal quantum dots is that the color of their emission depends on particle size. That’s a consequence of their extremely small dimensions, comparable to the spatial extent of electronic wave functions. Highly efficient, spectrally tunable emission from colloidal nanocrystals has already been exploited in commercial products such as televisions and displays.

Colloidal nanomaterials are also attractive for applications in lasing technologies as they can enable a completely new class of color-selectable lasing devices that can be processed from a solution.

Despite their excellent light-emitting properties, semiconductor nanocrystals are “difficult” lasing materials. Los Alamos researchers discovered 20 years ago that the primary problem was ultrafast deactivation of optical gain caused by nonradiative Auger recombination. In this process, energy released by an excited semiconductor is not emitted as a photon but is dissipated as wasteful heat.

In 2000, the Los Alamos quantum dot group, led by Klimov, published two consecutive articles in the journal *Science* that, first, identified the problem of Auger decay and, second, devised a practical strategy for resolving this challenge. Two essential elements of the proposed solution were the use of a dense, close-packed quantum dot solid as a gain medium and very fast optical-gain activation with femtosecond pulses.

The first successful demonstration of quantum-dot lasing by Los Alamos scientists launched a world-wide effort to create practical devices based on colloidal nanomaterials. However, colloidal quantum dot lasers still remain within the bounds of a research laboratory. The primary obstacle towards technologically viable devices remains the same - fast decay of optical gain because of a nonradiative Auger process.

As discussed in the new review article, over the past few years Los Alamos scientists have devised several effective approaches for tackling the problem of Auger decay. These developments allowed for a number of recent breakthroughs, including the demonstration of ultralow-threshold lasers operating with “sub-single-exciton” pumping, the realization of optical gain with electrical injection, and the development of dual-function devices that operate as an optically pumped laser and a standard electrically excited light emitting diode. All of these results suggest that practical lasing devices based on colloidal quantum dots are just around the corner.

The paper: “Colloidal Quantum Dot Lasers,” Young-Shin Park, Jeongkyun Roh, Benjamin T. Diroll, Richard D. Schaller, Victor I. Klimov, *Nature Reviews Materials*, Feb. 16, 2021.

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