

PhD THESIS DEFENSE: Solution-processed quantum dot infrared lasers

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Colloidal semiconductors quantum dots (CQDs) have emerged as a promising solutionprocessed gain material that can be engineered via low-cost and scalable chemical techniques. Owing to quantum confinement, their emission wavelengths and optical properties can be tuned from the visible to the infrared. Despite these possible advantages, the realization of lasing action in CQDs is complicated and fundamentally stems from the non-unity degeneracy of the band-edge state. This results in high optical gain thresholds, demanding multiexcitons for achieving lasing action. This, in turn, leads to a very short optical gain lifetime which is caused by Auger recombination.
Following the first demonstration of lasing action in CQDs, this field has thus far experienced remarkable development with materials offering emission in the visible showing limited

application potential. However, the possibility of lasing in the infrared region would open a new realm of applications for this material platform in optical telecommunications, photonic integrated circuits, and LIDAR applications. To unleash those applications, the demonstration of solution-processed infrared lasers in the eye-safe window between 1.5-1.6 ?m operating robustly at room temperature is a prerequisite.

Midgap trap states in CQDs limit the performance of optoelectronics devices. In particular, PbS CQDs suffer from a very fast trap-assisted Auger process leading to high lasing thresholds. To suppress this type of Auger process, in this work, we use a binary nanocomposite of PbS CQDs and ZnO nanocrsystals (NCs) where the former serves as the infrared gain medium and the latter as a remote passivant for midgap traps in PbS CQDs. This binary heterostructure drastically suppresses the Auger process and lowers the lasing thresholds.

Low threshold infrared CQD-laser has been thought to be not possible because of 8-fold degeneracy of the band-edge state in the infrared-emitting Pb-chalcogenide CQDs. In this Thesis, we demonstrate that using core-alloyed shell heterostructured CQD comprising PbS as core and PbSSe as shell allows suppressing Auger process. Furthermore, by applying doping to specially engineered CQDs, we demonstrate a substantial reduction in lasing threshold down to sub-single exciton level per-dot thanks to the blocking of the ground state absorption. Employing these CQDs has drastically improved the net modal coefficient of the medium and brought it on par with a gain coefficient of epitaxially grown III-V infrared semiconductors.

The realization of CQD infrared laser-diodes will have a profound impact in many disciplines. Here, by engineering the electric field distribution in our devices, we show stimulated emission in a record ultra-thin gain media which is beyond the slab waveguide theoretical limit by introducing scatterers implemented by ZnO NCs. We employ this thin gain media as the active layer in a full-stack light emitting diode (LED) device. Also, to overcome the existing challenge underpinned by the optical losses of the metal contacts that have prevented the realization of stimulated emission in a LED, we use an engineered transparent conductive oxide and graphene as anode and cathodeof the LED, respectively. Finally, our proposed LED structure leads us to realize a dual function device showing strong infrared spontaneous- and stimulated-emission under electrical- and optical-pumping, respectively.

In summary, we have demonstrated that CQDs can emerge as a robust technology for the realization of infrared lasers. Our proposed CQD systems lead us to achieve high performance laser devices under optical excitation and using CQD heterostructures asan active medium in the proposed LED structure paves the way towards the future development of infrared CQD-laser diodes.

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