Phd Thesis Defense: Collodial Quantum Dot Emitters in the Shortwave Infrared Region

ADITYA MALLA

May 29, 2026
10:00
ICFO Auditorium

Shortwave infrared (SWIR) light sources are indispensable for applications including advanced imaging, spectroscopy, and sensing; however, their widespread adoption is hindered by the high cost and limited scalability of epitaxial semiconductor technologies such as InGaAs. Colloidal quantum dots (QDs) offer an attractive alternative owing to their high photoluminescence quantum yield, size-tunable emission, large-area processability, and compatibility with low-cost solution-based fabrication. Among various QD-based emitters employing lead sulphide (PbS), this thesis focuses on two complementary technologies: electrically driven quantum-dot light-emitting diodes (QLEDs) and optically pumped downconverters (DCs).

The first part of this thesis addresses performance enhancement in QLEDs (emitting at 1380 nm) through systematic device engineering. Charge imbalance is identified as a key factor limiting QLED efficiency and radiance. By optimising the ZnO electron transport layer via controlled annealing-temperature tuning, electron injection was modulated, leading to a maximum external quantum efficiency (EQE) of 20%. Furthermore, the charge balance within the emissive layer was optimised by controlling its thickness, resulting in an increase in maximum radiance from 5 W.sr-1.m-2 to 17.5 W.sr-1.m-2. Building upon this, a dual electron transport layer architecture was implemented to decouple interfacial quality from bulk electron transport, enabling a further enhancement in maximum radiance to 30 W.sr-1.m-2 while maintaining comparable EQE.

Light extraction and Joule heating constitute an additional bottleneck in achieving high-performance QLEDs. To overcome substantial optical losses into substrate modes inherent in conventional bottom-emission devices, top-emission QLED (TQLED) architectures were investigated. These offer improved light extraction and allow for the use of opaque, high-thermal-conductivity silicon substrates to manage Joule heating. A high-performance sputtered indium tin oxide (ITO) electrode was developed, exhibiting optical transmission exceeding 85% at 1400 nm and a low sheet resistance of 33 ?/?. By utilising optimised architecture with integrated ITO optical spacers and a dielectric/metal/dielectric top electrode, a low-Q microcavity was established. This modified the far-field radiation pattern to a forward-directed profile and narrowed the emission linewidth. The synergy between this resonant optical design and superior thermal dissipation enabled a record radiance exceeding 100 W.sr-1.m-2, and allowed for the first demonstration of active see-through SWIR imaging illuminated solely by QLEDs.

The second part of the thesis is focused on lead sulphide QD-based DCs. The QD-DCs suffer from performance degradation under high excitation power densities due to the significant heat generation in the process of light absorption. We have developed high-power, stable, and spectrally tunable narrowband and broadband SWIR DCs (1000 nm - 1600 nm). By mixing two different-sized QDs, we exploit Forster resonance energy transfer and photon reabsorption to realise a binary system with a high photoluminescence quantum yield of 35 %. Embedding the QDs in a poly(methyl methacrylate) host mitigates local thermal stress on the QDs, enabling standalone DCs with a high emission power density (EmPD) of 110 mW.cm-2 at 1380 nm. Further optimisation with a spectrally selective distributed Bragg reflector for enhanced light extraction and a sapphire substrate for efficient heat dissipation, we achieved a record EmPD of 385 mW.cm-2 at 1380 nm with optical power conversion efficiency of 10% and operational stability above 230 hours at an EmPD of 190 mW.cm-2. This demonstrates a scalable route to low-cost SWIR light sources, narrowing the performance gap between solution-processed DCs and conventional epitaxial semiconductors.

Friday May 29, 10.00 h. ICFO Auditorium
Thesis Director: Prof. Dr. Gerasimos Konstantatos

Hosted by: Academic Affairs