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Enhanced Thermal Stability of Mercury Telluride Quantum Dots Using ALD

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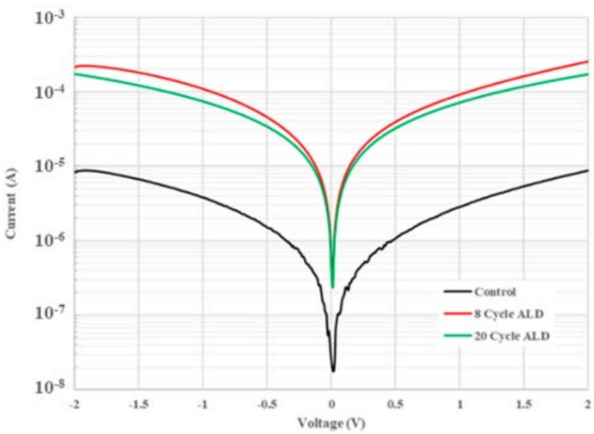
Colloidal quantum dots (CQDs) are promising materials for optoelectronic applications, including LEDs, photovoltaics, and photodetectors. Conductive HgTe CQDs are particularly significant as an emerging low-cost, scalable nanomaterial replacement alternative to expensive epitaxial HgCdTe detectors, which are widely used in surveillance and thermal infrared imaging.

A major challenge in CQD technology is thermal sintering—a process where neighboring CQDs fuse at elevated temperatures during use or manufacturing. Sintering degrades device performance by broadening the absorption spectrum and causing detrimental electrical changes.

A common approach to mitigate CQD sintering is creating a protective shell around the core. However, for HgTe CQDs, this method drastically reduces carrier mobility and degrades the core's electrical properties, even with a monolayer-thick shell and under mild heating conditions. This limitation necessitates alternative solutions to prevent sintering effectively.



Researchers at QDIR, Inc., and Argonne National Laboratory have [demonstrated a breakthrough approach]() using Arradiance's GEMStar™ low-temperature ALD system, optimized for high exposure/soak mode.[1] They developed and characterized metal oxide ALD coatings to infill spaces within CQD films. These coatings improve charge carrier transport, prevent sintering, and provide thermal oxidation protection.

Zinc oxide (ZnO), titanium dioxide (TiO_2), and alumina (Al_2O_3) were evaluated as in-fill materials, deposited via high-exposure ALD (up to 20 minutes per cycle). Their effectiveness was assessed using infrared FTIR spectroscopy on sapphire substrates and electronic measurements on FET-like interdigitated gold comb structures on Si/SiO_2 substrates.

- ZnO and TiO_2 coatings both proved ineffective against sintering.
- Al_2O_3 provided excellent protection, preventing sintering at temperatures up to 160°C for 5 hours, while also preserving the crucial exciton absorption feature of HgTe CQDs. Additionally, Al_2O_3 significantly improved charge carrier mobility, by an order of magnitude, for p-type HgTe CQDs (attributed to the p-doping effect of alumina). The effect not being observed in n-type HgTe CQDs confirmed Al_2O_3's selective interaction with CQD types.

These findings highlight the need for a deeper understanding of CQD structure, surface chemistry, and ALD material interactions to develop thermally robust CQD optoelectronic devices.

Arradiance provides cutting-edge ALD solutions for thin-film semiconductor, solar, scientific and green energy applications. For more information on GEMStar™ Technology, ALD systems or Foundry services, please contact Arradiance.

[1]Edward W. Malachosky, Matthew M. Ackerman, and Liliana Stan, Nanomaterials 2024, 14, 1354. https://doi.org/10.3390/nano14161354