

The first **non-invasive** microscope to observe **live** chemical and material processes

High-Throughput QC of Quantum-Dots

High-performance quantum-dot-based devices rely on a uniformly high PLQY. iSCAT delivers rapid, particle-by-particle mapping of size and emission, enabling precise isolation of structural defects from photophysical limitations. This insight drives synthesis refinement, stability optimization, and scalable, predictable production.

iSCAT: How it works – in a nutshell

Imagine throwing a pebble into a rough sea: its ripples quickly fade. Now toss the same pebble into a smooth pond. The ripple perturbs the surface of the water, making even the smallest disturbances visible.

Let us keep this picture in mind and walk over to the laboratory. The sea now will be an illuminated interface to the sample, and the disturbance is scattering from e.g. nanoscopic objects that will become easily visible to the detector. Unlike brightfield microscopy, where the overwhelming background masks the nano-object's signal, iSCAT employs interferometry to detect the smallest signal over the background (Figure 1). Since this signal, named contrast, is directly proportional to volume, iSCAT can determine the sizes of nano-objects directly, and allows also to compare them quickly among each other.

What if every quantum dot's size could be correlated with the yield in one single go?

In QD-based devices the active layer is often made of particles whose size and emission efficiency—the PLQY—spans a wide, often bimodal, distribution. Conventional ensemble PLQY measurements average over thousands of dots. This hides outliers, and overshadows dark or rapidly degrading

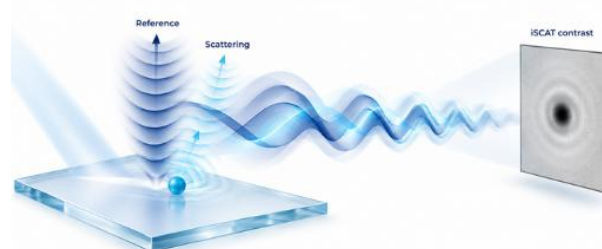


Figure 1: Basics of interferometric scattering (iSCAT). The particles scattered field is amplified by mixing with a strong reference beam, the beam reflection on the glass.

particles, which drag down the overall brightness, efficiency, and lifetime of the QD-based devices. iSCAT eliminates these ambiguities. It measures each particle's size *in situ* and in real time, simultaneously coupling it to, for example, its emission properties; all in a single measurement without further correlation requirements. The result of this example is a complete particle-by-particle correlation between physical size and photophysical performance. Moreover, depending on the experimental design, iSCAT could also reveal other aspects of the material like surface defects, composition, or extrinsic factors such as aggregation or ligand shedding. A distinction that other techniques struggle to provide this quickly and easily.

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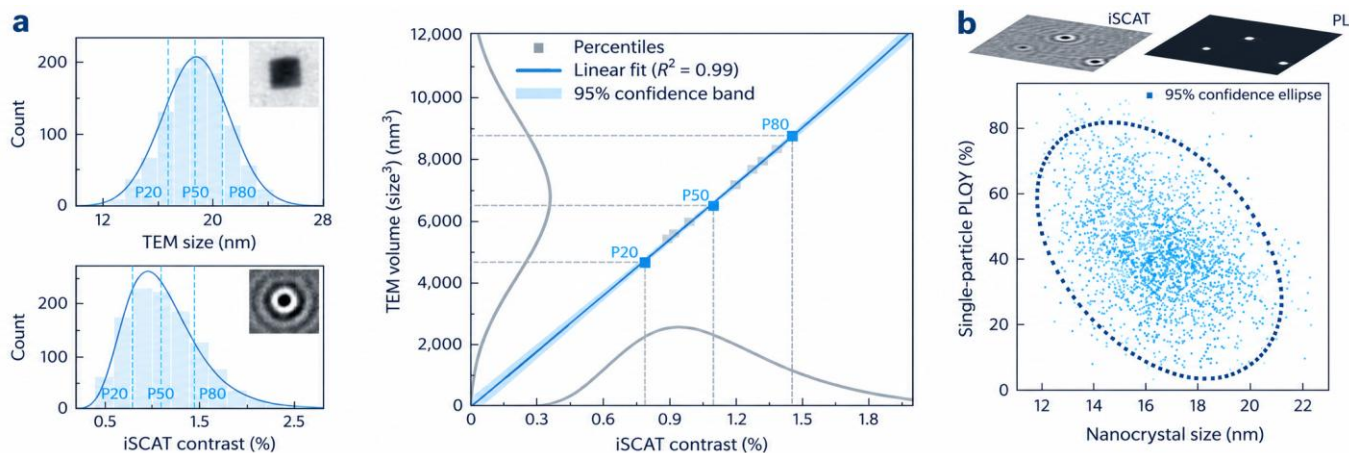


Figure 2: Calibration and Size-PLQY Mapping. **(a)**- Linear fit of iSCAT contrast versus TEM-measured nanocrystal volume ($R^2 \approx 0.99$). **(b)**- Scatter plot of individual QDs' PLQY versus calibrated volume, revealing the size dependence of PLQY. (Reproduced with permission of the authors)

The workflow presented here empowers QD-manufacturers to perform rapid batch screenings. It allows rejection of faulty batches, stemming from non-ideal syntheses conditions, or refining process parameters on the fly. Also, it facilitates device-lifetime-modelling predictions by quantifying the fraction of “dark” or unstable particles that forecast device degradation. All of this is delivered in a single, high-throughput readout that requires minimal sample preparation and keeps turnaround times low, enabling true in-line quality control for QD-based technologies.

To determine the volume of every nanoparticle, in this case a subset of perovskites (CsPbBr_3), the iSCAT contrast was evaluated against TEM analysis. As this contrast is proportional to the size, plotting TEM size analysis against iSCAT provides a robust, linear calibration (see Figure 2). In turn, this results in a lower effort and faster iSCAT measurement instead of the TEM from there on. Furthermore, the *in-situ* size to optical property correlation enabled by iSCAT allows researchers and engineers alike, to pinpoint mechanisms, investigate ways to improve

formulations and observed phenomena, so far deemed out of reach.

In-situ defects engineering

By measuring both the interferometric contrast and the photoluminescence (PL) of each nanocrystal in a single combined experiment, we

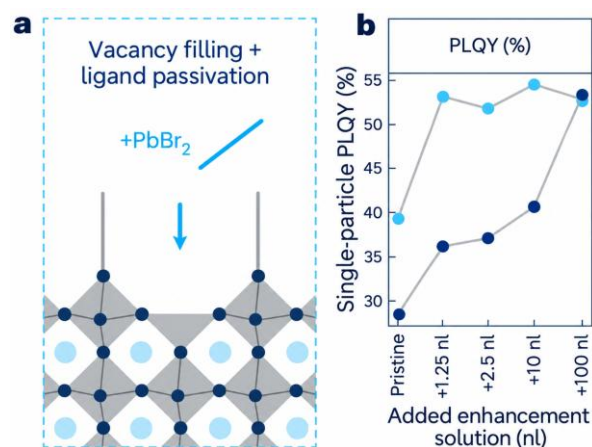


Figure 3. Perovskite nanocrystals during post-synthesis treatment with enhancement solution. **(a)**- Scheme of the effect of enhancement solution. **(b)**- Relative increase in PLQY for small (pink) and big (violet) nanocrystals. (Reproduced with permission of the authors)

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can track how every particle's size and optical efficiency evolve during a defect-repair protocol. We gradually added an "enhancement solution" (see figure 3) composed of a filler for halide vacancies (PbBr_2) and a ligand pair (OAm/OAc). Subsequently, we measure the PLQY of >100 crystals after each addition step. The population-average PLQY rises from 31.2 % to 52.4 % (≈ 70 % gain) over four additions, confirming that the mix enhances the emission efficiency (figure 3b). Interestingly, if we analysed the data by

particle size, small cubes (12–14 nm) have a PLQY increase from ~ 39 % to 53 % after the first addition and then it plateaus, while larger cubes (17–19 nm) go from 28 % to 36 % after the first step and gradually reach 53 % after the final addition. This size-selective response highlights the benefit of applying iSCAT-PL measurements in combination. It allows the QD-manufacturer to better understand how to enhance their nanocrystals post synthesis.

Photobleaching-driven degradation

As outlined before, using iSCAT allows to follow a nanoparticle in real time as they bleach by continuous laser illumination. After the particles bind to the surface, both their PL and contrast fall rapidly and then reach a steady state where there is no PL emission anymore (Figure 4). They still exhibit a reduced but steady iSCAT contrast. This lower signal confirms that the nanocrystal is not fully destroyed, which could be concluded from a pure PL measurement. The presence of the iSCAT contrast confirms the loss of luminescence, but a "dark" core remains. Tracking hundreds of particles shows a broad distribution of volume loss ($\approx 15 - 50$ %), largely independent of the initial size, but on the laser power. Crucially, these results allow us to better understand the mechanism of degradation depending on the laser power, which controls both the rate and final extent of degradation.

Conclusion

Our non-invasive, in-situ technique easily delivers the size and photophysical properties of thousands of nanocrystals within just a couple of minutes, while eliminating the need for elaborate and time-consuming sample preparation. By revealing the

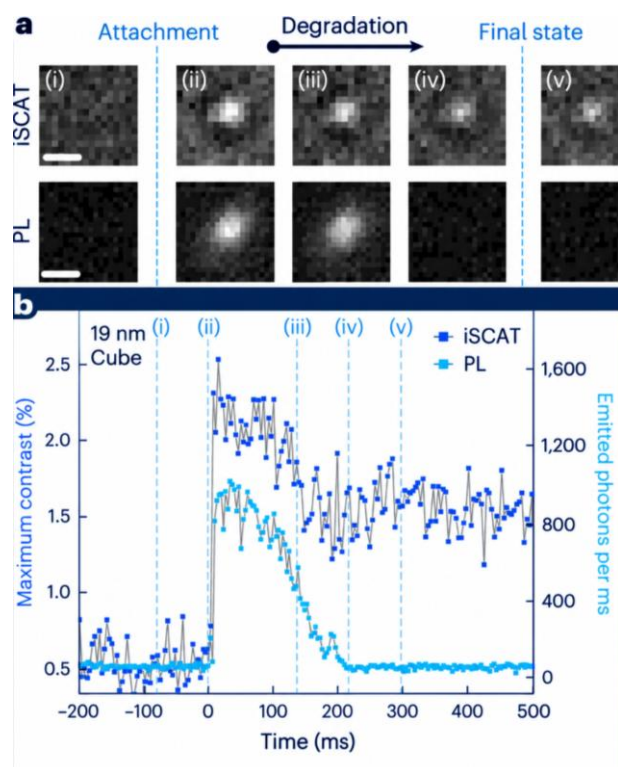


Figure 4. (a) iSCAT and PL snapshots of a single 19-nm perovskite nanocube binding to a glass surface in hexane while it is illuminated. The frames show the cube's attachment, followed by a rapid drop in contrast in both channels – the PL signal extinguishes entirely, whereas the iSCAT contrast reaches a steady, lower value. (b) Degradation traces for the images in (a) confirm that even after the PL is lost, a residual iSCAT signal persists, indicating a surviving non-luminescent particle. (Reproduced with permission of the authors)

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size-dependent life-cycle of individual nanocrystals, otherwise hidden in bulk average readings, the method uncovers the underlying defect dynamics that governs stability and performance. Harnessing these single-particle insights accelerates the optimization of synthesis routes and passivation strategies, paving the way for more robust, high-efficiency QD-driven-devices.

Further reading

Gruber, C.G., *et al.* High-throughput in situ sizing and quantum yield determination of individual perovskite nanocrystals. *Nat. Mater.* 25, 1344–1351 (2026).

