

# Strain-induced energy level splitting in colloidal quantum dots: ensemble measurements

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Producing zero-dimensional semiconductor structures to obtain discrete and customizable energy levels for charge carriers is now common place. However, fine tuning these levels to obtain complete control over their quantum states is still challenging. Progress on this matter is typically expected from perfectly crystalline, epitaxially grown semiconductor heterostructures, but the constraints on materials that can be used are severe and the possible shapes and sizes of zero-dimensional epitaxial quantum dots are limited. Comparatively, organometallic synthesis imposes less limitations on the growth of colloidal quantum dots (cQDs). Here, we even show that controlled strain in as-grown cQDs can split an exciton energy level lifting a degeneracy. This fine tuning indicate that cQDs have their part to play in the research on entangled photons and other quantum optic themes.

Control of strain is also essential to obtain defect-free cQDs lessening their well-known photoluminescence (PL) instabilities.[1] Such a control is now achievable thanks to shell growth methods on cQD cores such as Successive Ion Layer Adhesion and Reaction (SILAR).[2] We can now synthesize diverse semiconductor heterostructures at the nanoscale, such as low-strain well-passivated cQDs with small lattice mismatch between multiple shells of semiconductors with increasing bandgaps.[3] Full strain control however requires more systematic studies of lattice mismatch effects.

In this perspective, a series of cQD samples has been prepared with a CdSe core and  $\text{Cd}_x\text{Zn}_{1-x}\text{S}$  shell varying the relative concentration of Cd:Zn between  $x = 0$  and  $x = 1$ . According to the SILAR method, half-

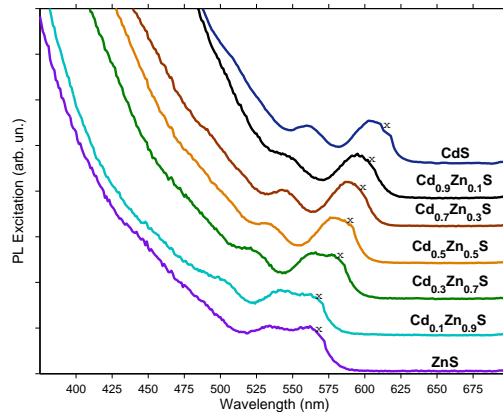


Figure 1: PL excitation spectra for a series of QD samples where the CdSe core is covered with a  $\text{Cd}_x\text{Zn}_{1-x}\text{S}$  alloy shell. The relative Cd:Zn concentration is varied from  $x = 1$  (top) to  $x = 0$  (bottom).

monolayers were successively grown on the cores by alternating the injection of cation and anion precursors in the reaction flask. Enough material was injected to grow a 7 monolayer shell on the cQD cores in each sample, however transmission electron microscopy (TEM) images showed that a higher percentage of Zn yields smaller cQDs. The diameter of CdSe/ZnS cQDs was  $\approx 3\text{nm}$  less than CdSe/CdS ones. This behavior can be expected from the lattice mismatch between core and shell increasing from 3.9% to 12% with the Zn:Cd ratio. The resulting stress also created more defects in the cQDs and large surface roughness became visible on TEM images of cQDs with high Zn content in their shell. Increasing the structural stress and accompanying strain perturbed the electronic configuration of the cQDs and the PL excitation spectra displayed in figure 1 suggest a progressive splitting of the  $1S_e-1S_{3/2}$  transition.

## References

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