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Uniform Dispersion of Nanoparticles in PMMA Waveguides for Luminescent Solar Concentrators

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Background

- Luminescent solar Concentrators (LSCs) are a promising solution to rising global energy demands. [1]
- Before LSCs can be commercially viable, four key loss mechanisms must be addressed to ensure their efficiency: [2]
  1. Insufficient Solar Absorption.
  2. Non-Unity Photo Luminescent Quantum Yield (PLQY)
  3. Compounding Self-Absorption and Escape Cone Losses
  4. Scattering Losses due to Nanocrystal Aggregation
- Copper Indium Disulfide/ Zinc Sulfide (CIS) Nanocrystals (NCs) go a long way towards addressing loss mechanisms 1-3:
  - Broad band solar absorption
  - Potential for high PLQY
  - Large effective Stokes shift
- With increasing QD loadings, CIS/ZnS NCs aggregate in Poly(Methyl Methacrylate) (PMMA). Consequently, inconsistencies in the refractive index of the LSC matrix dramatically increases optical losses due to light scattering.
- Our work focuses on resolving such optical losses in order to achieve higher and commercially viable LSC efficiencies.

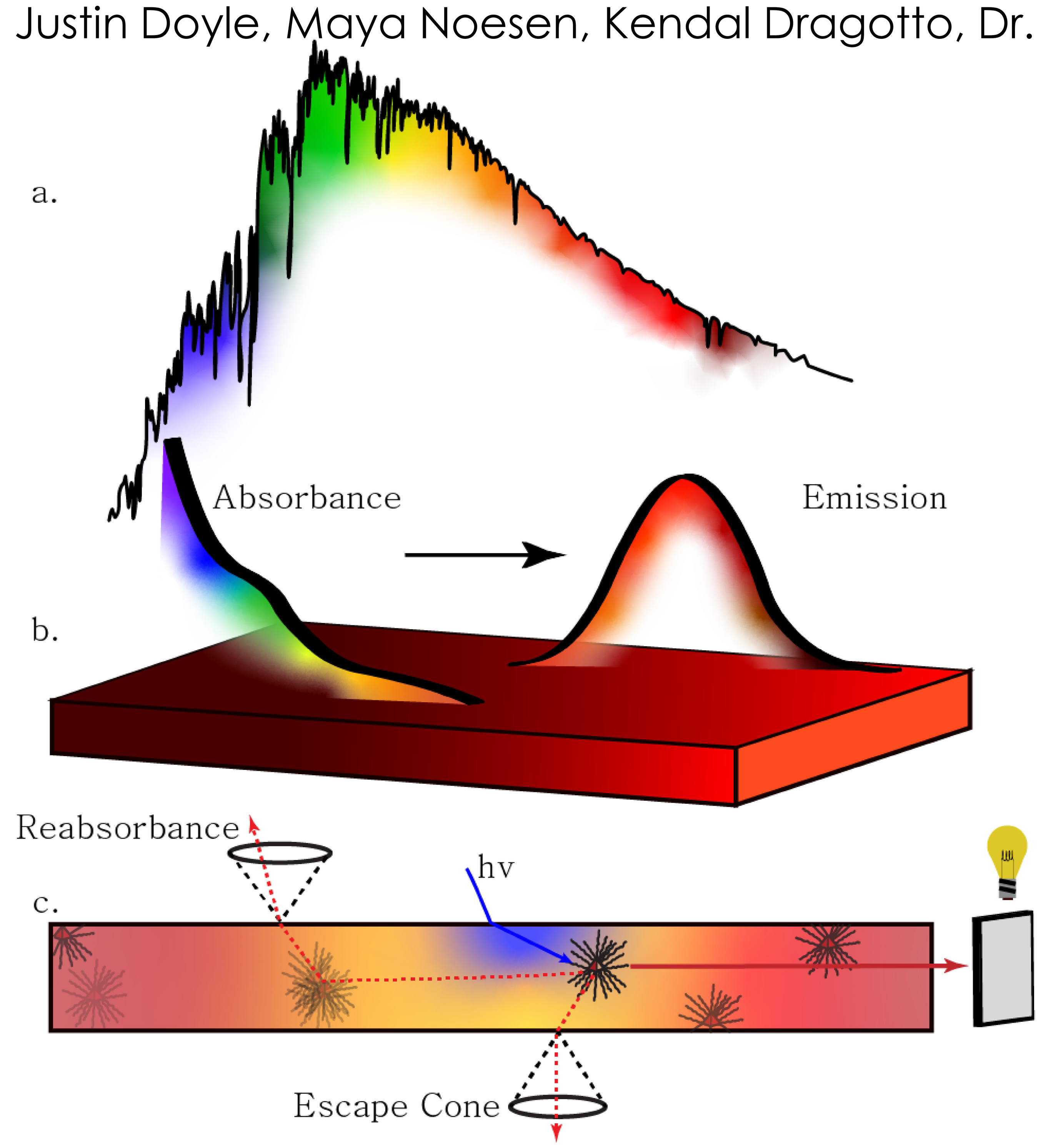

Figure 1. A cartoon CIS/ZnS absorbance and emission over a schematic solar spectrum displayed over a mock-LSC (a,b). Typical loss modes are cartooned for a hypothetical LSC (c).

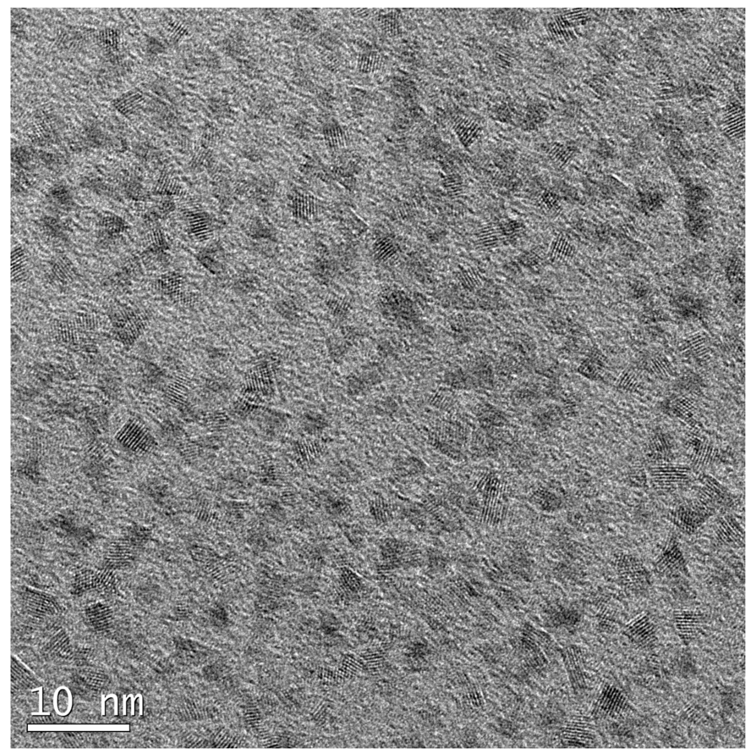

Figure 2. TEM image of CIS/ZnS Core Shell structure. The average particle size is 3 ± 0.8 nm.

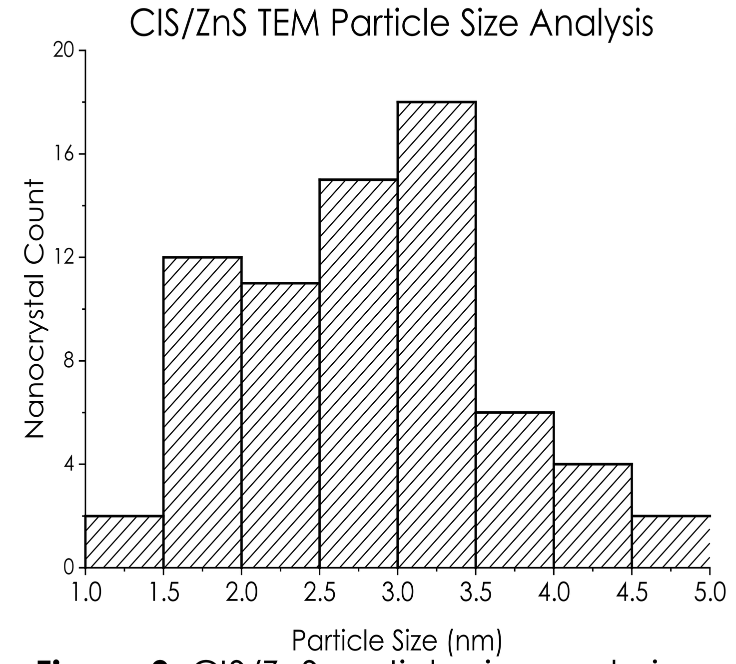

Figure 3. CIS/ZnS particle size analysis from Fig 2.

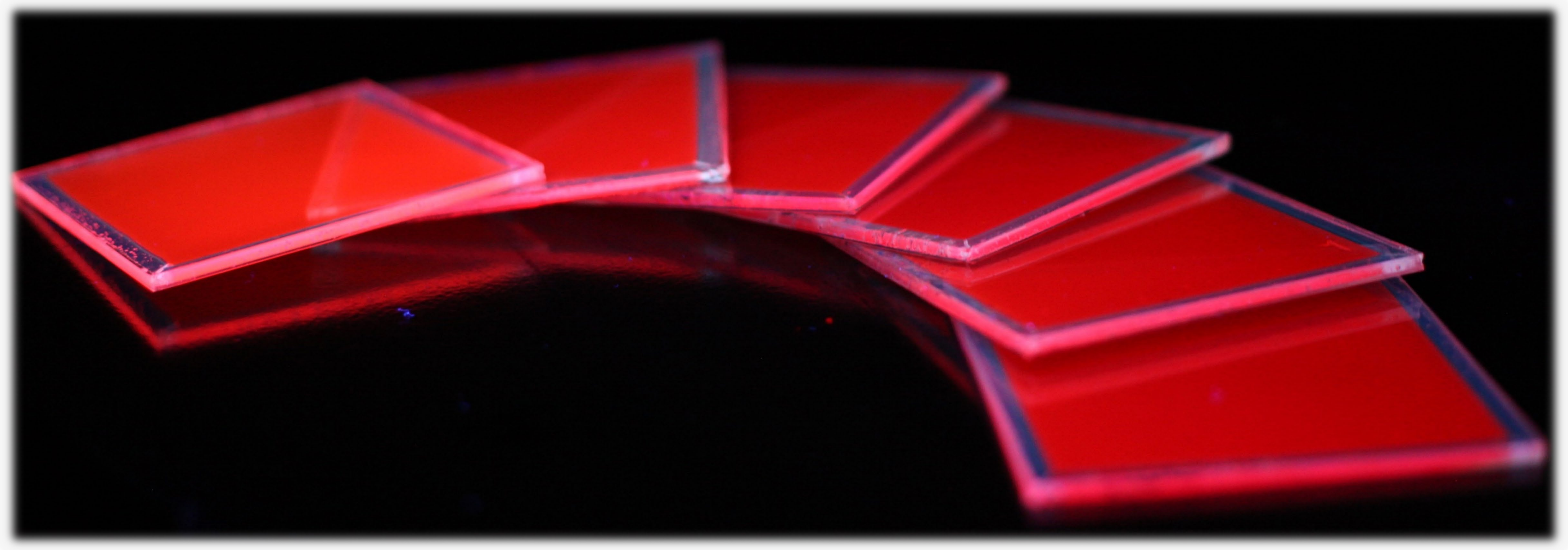

Figure 11. A series of UV-illuminated LSCs ranging from 0.1 to 0.6 wt% QDs.

Optimization of Quantum Dot Synthesis

- Our Copper Indium Disulfide/ Zinc Sulfide Quantum Dots are synthesized by a solvothermal "heat-up" method adapted from Klimov et. al. [3]
- In order to maximize LSC efficiency when paired with a solar cell, integrated luminophores must have near unity PLQY as well as an exceptionally red emission profile.
- By independently testing each synthetic parameter for the CIS core synthesis and the ZnS shell overgrowth, we have increased our NCs

	Klimov et. al.	Optimized
Cu/In (mol)	1/1	0.75/1
Zn/Cu (mol)	8/1	4/1
Shell Growth Solvent	1-Octadecene	Paraffin Oil
Shell Growth Steps	1	2
Mean PLQY	38%	80%
Mean Max Emission (nm)	650	754

Table 1. Differences between a synthetic regime adopted from the work of Klimov et. al. and Patrick groups optimized synthetic recipe.

Typical Absorbance and Emission of CIS/ZnS

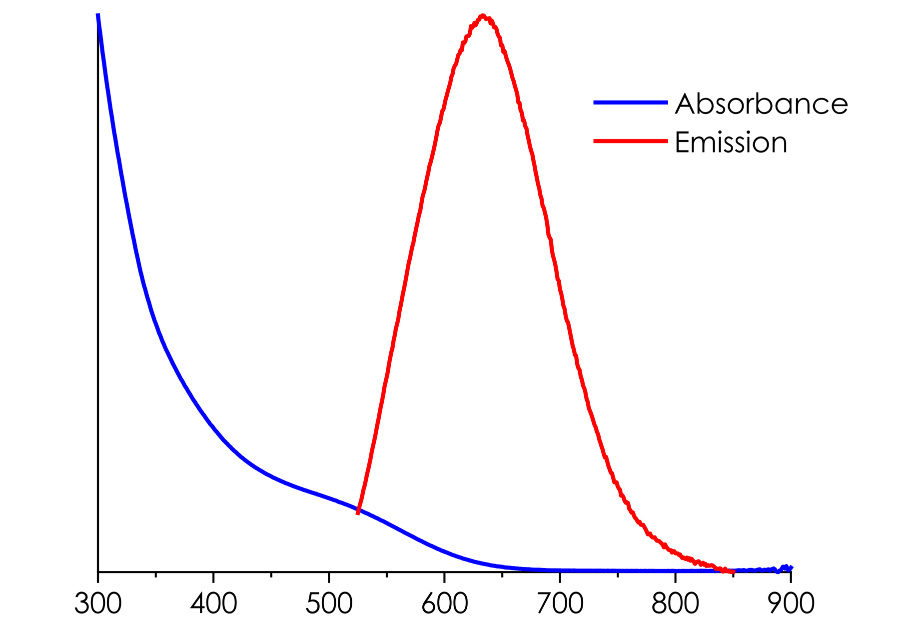

Figure 4. Normalized absorption (red) and emission (red) spectra of typical CIS/ZnS NCs.

Apeture Optical Quantum Efficiency for a Filtered NC LSC

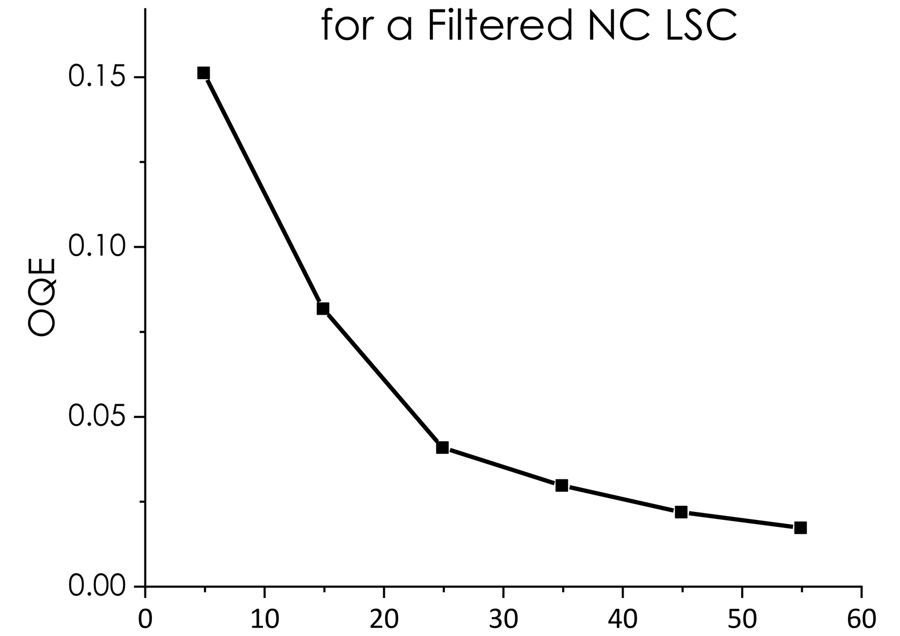

Figure 5. OQE, the ratio of photons absorbed by an LSC to the photons delivered to its edge, plotted against illumination distance from the excitation beam to the aperture of an integration sphere.

Polymeric Dispersion Methods

Ligand Exchange

- A sulfur-terminated Poly(Methyl Methacrylate)-based ligand has been employed to increase the compatibility of CIS/ZnS QDs in the PMMA matrix of our LSCs. [4]
- A steric inhibitor ("Linker") has been exploited to prevent the auto-formation of a thiolactone ring, keeping the terminal thiol chemically available to bind to the QD.
- Recent NMR and TGA experiments corroborate that the total polymer ligand exchange is about a 35% replacement for the native ligand DDT.

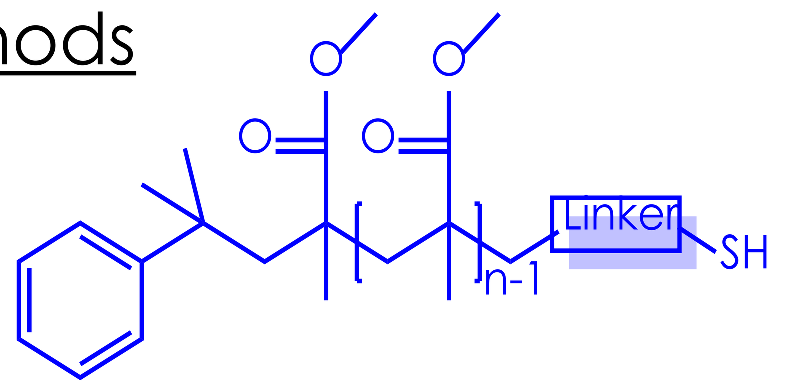

Figure 6. Sulfur terminated PMMA ligand.

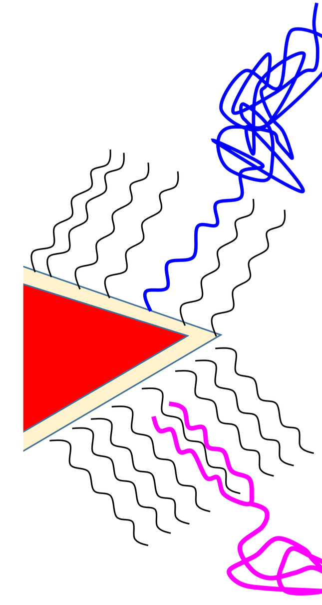

Figure 7. A CIS/ZnS QD cartoon depicting the chemical binding of the polymer ligand and the interdigitation of the polymer surfactant with the QDs native ligands, 1-Dodecanethiol.

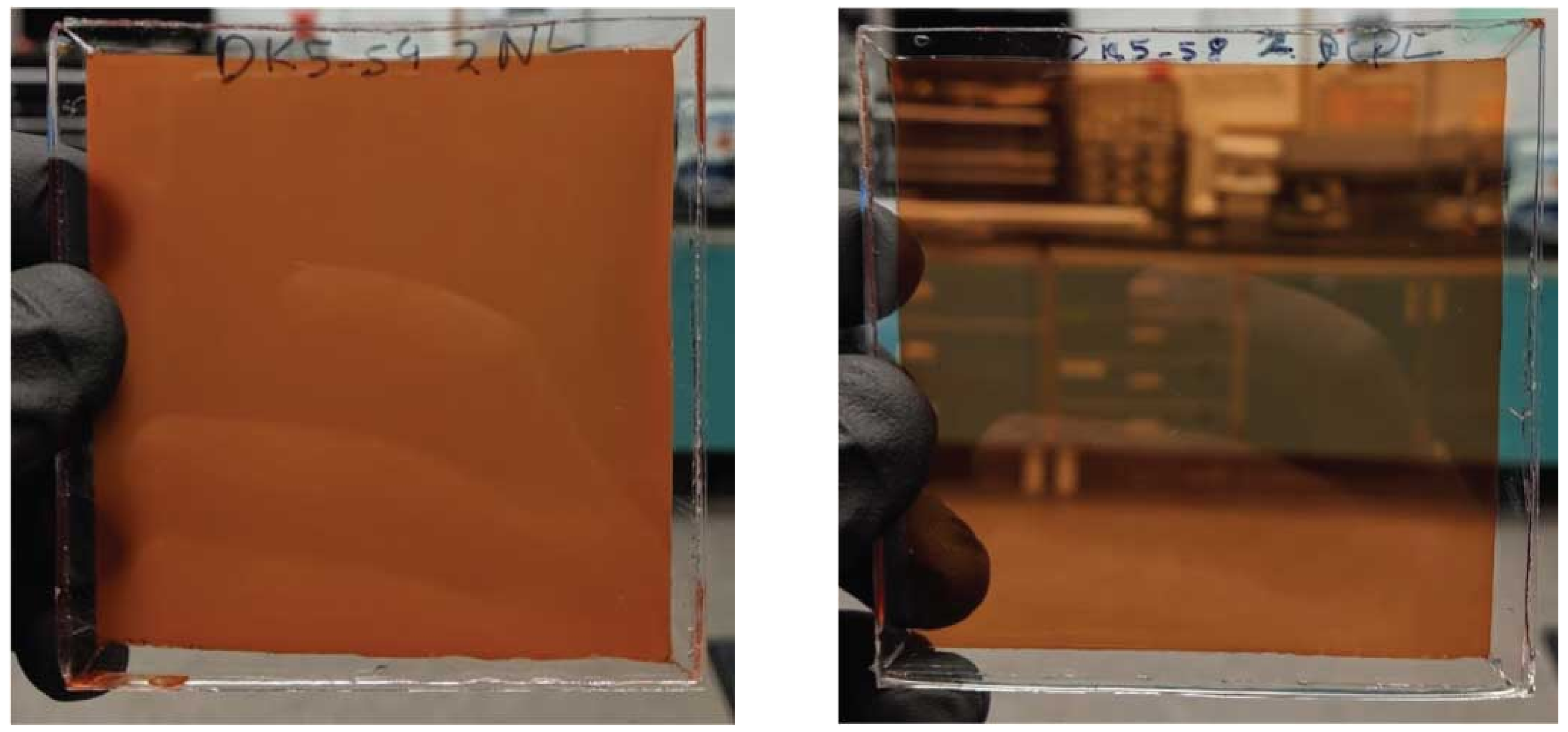

Figure 8. Two LSCs. Left is constructed without use of the polymer ligand. The Right LSC utilizes only polymer ligand functionalized QDs, improving its dispersion and clarity.

Polymeric Surfactants

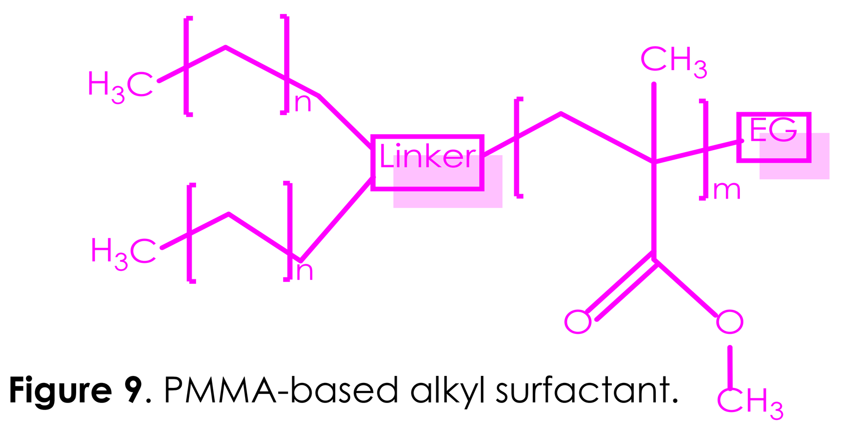

Figure 9. PMMA-based alkyl surfactant.

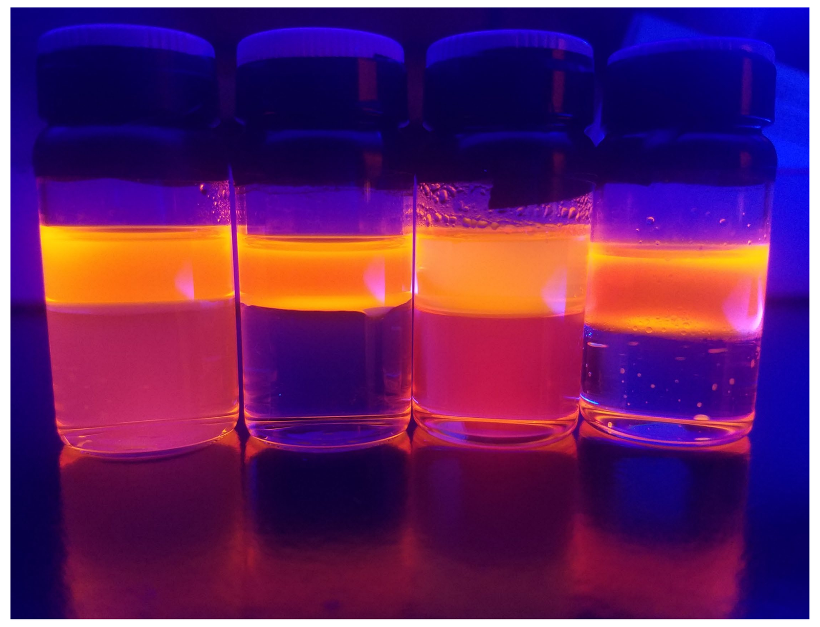

Figure 10. From left to right; QDs in hexanes atop acetonitrile with PS, QDs in hexanes atop acetonitrile, QDs in hexanes atop DMSO with PS, QDs in hexanes atop DMSO.

- A PMMA-based surfactant (PS) with two alkyl chains has been designed to interdigitate with the surface ligands of the QD. [5]
- The Polymer Surfactant has been shown to stabilize CIS/ZnS QDs in orthogonal solvent pairings.
- Future work will entail characterization of how well the PS disperses QDs in non-solvents and in PMMA LSCs.

Sources and Acknowledgements

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