Dispersancy: The key to enabling nanoparticle-based technology

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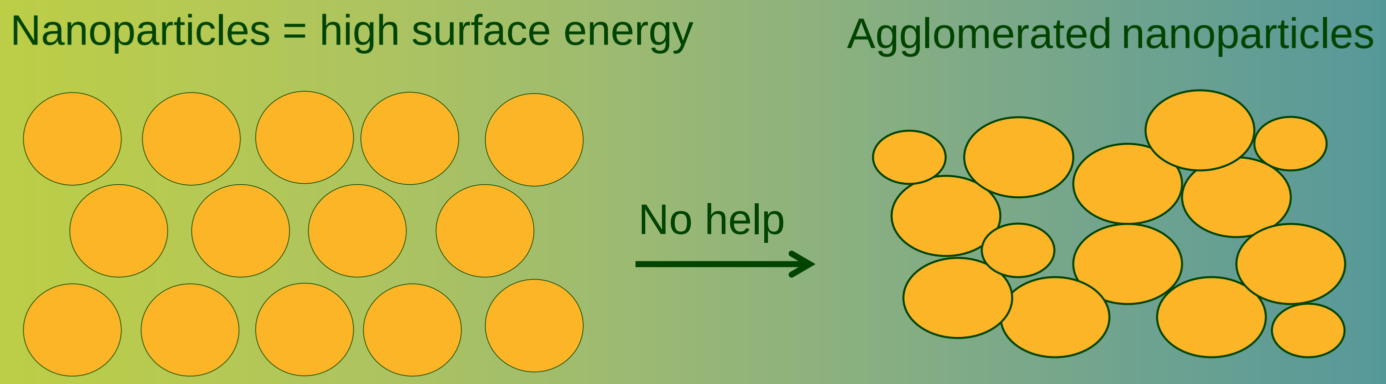
What is dispersancy?

Dispersancy is the concept of keeping one phase (e.g., solid) separated and discrete within a continuous phase (e.g., liquid)



Outline

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Dispersancy in Nanoparticle Synthesis
Bottom-up and top-down approaches to getting stable, usable nanoparticles

2

Nanoparticle Integration
A look at how improving dispersion enables integration of nanoparticles into usable form factors

3

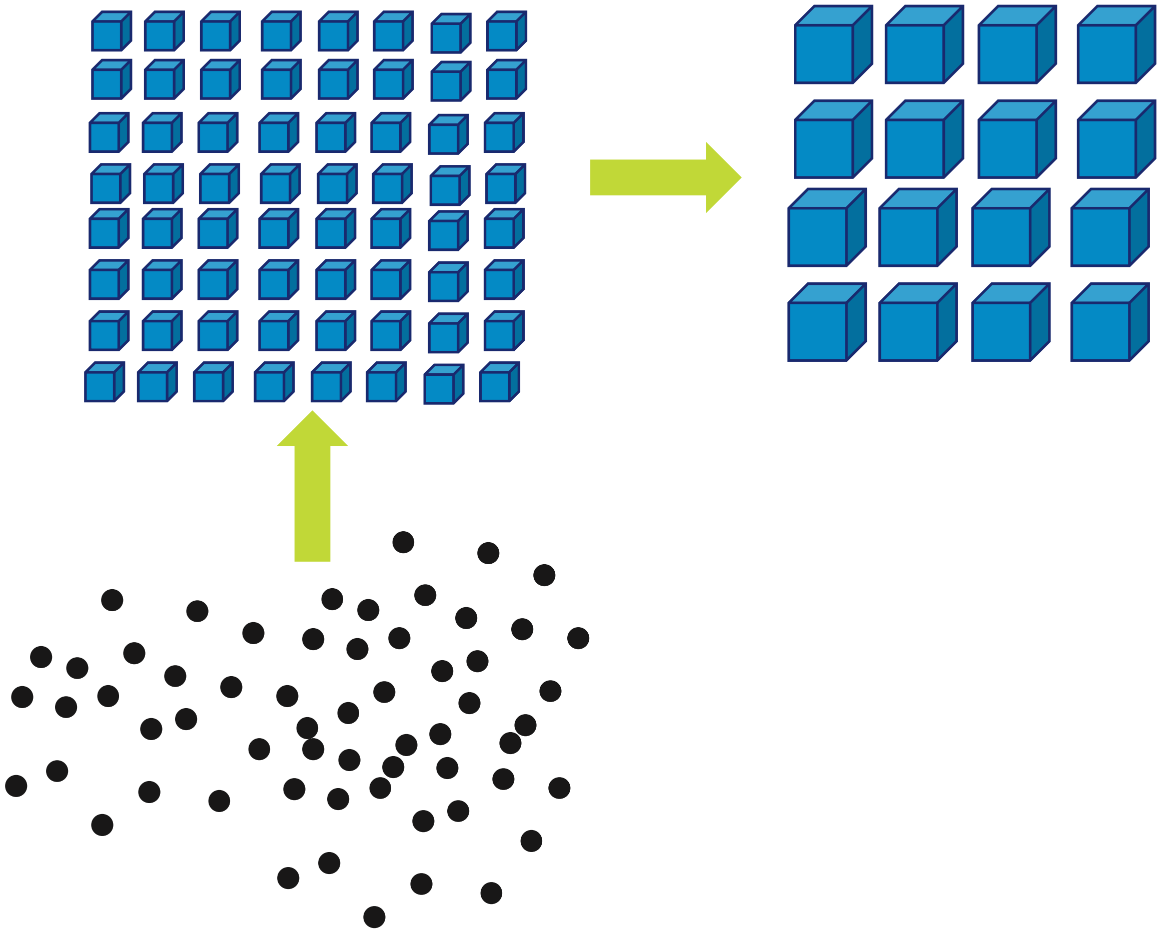
Printing and Nanotechnology
How dispersancy increases the viability of low-cost methods of manufacturing nanoparticle-based technology

Dispersancy in nanoparticle synthesis

Smart science to improve lives™

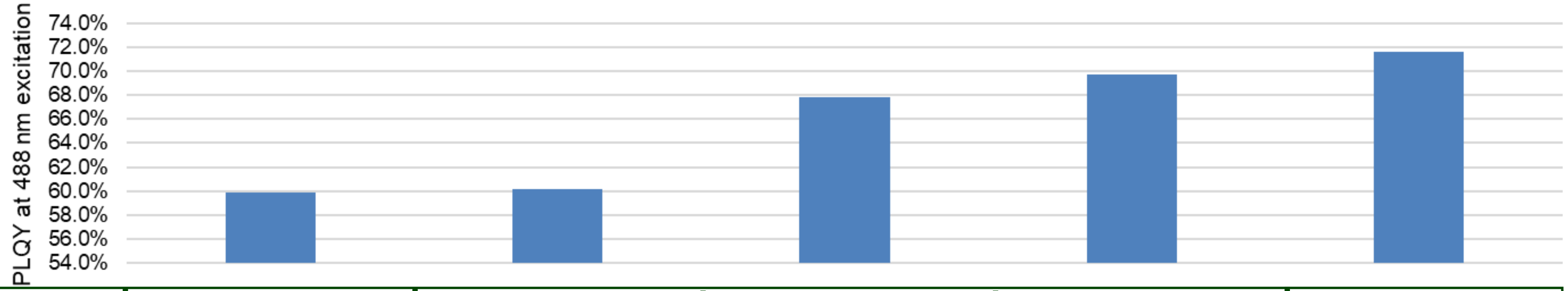
Common bottom-up techniques

- **Precipitation**
  - Very difficult to control size to get nanoparticles
- **Sol-gel**
  - Offshoot of precipitation where size uniformity is achieved
  - Requires lots of solvent that generally must be removed
- **Solvothermal/hydrothermal synthesis**
  - Energy consuming process with difficulty for size control
- **Chemical vapor deposition**
  - Time consuming and energy intensive method for synthesis
  - Does not require using dispersancy principles
- **Flame/plasma/laser reaction**
  - High yields but energy intensive
  - Produces agglomerated powders



Example: Solvothermal synthesis of quantum dots

- Quantum dots must be nano-sized to emit light
  - Used primarily in displays
- Made through a high temperature colloidal synthesis process which is controlled by ligand choice
- High temperatures involved limit selection to nonpolar solvents
- Ligands must be therefore also be nonpolar for solvent compatibility
- Improving compatibility of ligands to solvent leads to be better quantum dot stability and higher brightness (PLQY)
  - Using Hypermer™ SL318, Prisorine™ 3505 and Super Refined™ Oleic Acid lead to improved brightness



Shell Ligand	90% Tech Grade Zinc Oleate	90% Tech Grade Zinc Oleate	90% Tech Grade Zinc Oleate	Hypermer SL318	Hypermer SL318
Core Ligand	90% Tech Grade Oleic Acid	Super Refined Oleic Acid	Prisorine 3505	90% Tech Grade Oleic Acid	Super Refined Oleic Acid

Common Top-down nanoparticle synthesis techniques

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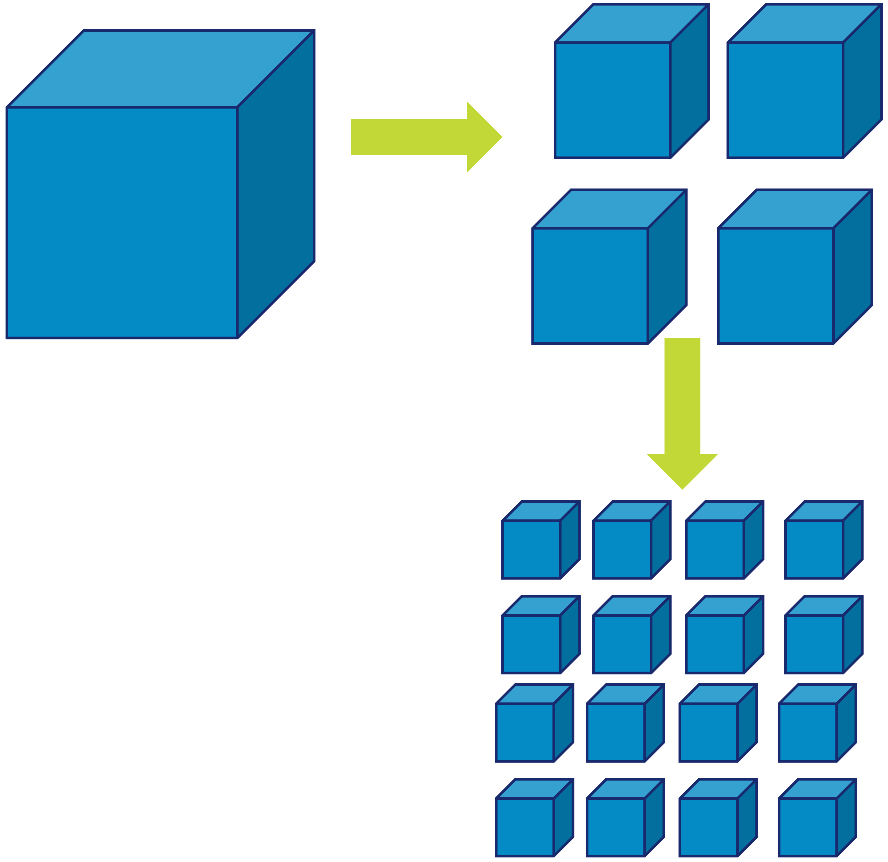
- **Milling**
  - Straightforward high energy process
  - Limit in minimum particle size

- **Laser ablation in solution**
  - High cost, high energy but can produce high yields of uniform nanoparticles

- **Exfoliation**
  - Two types: mechanical and chemical
  - Only works for platelet crystal shapes
  - Mechanical is yield limited
  - Chemical is limited in uniformity



Example: Milling of $BaCO_3$ nanoparticles

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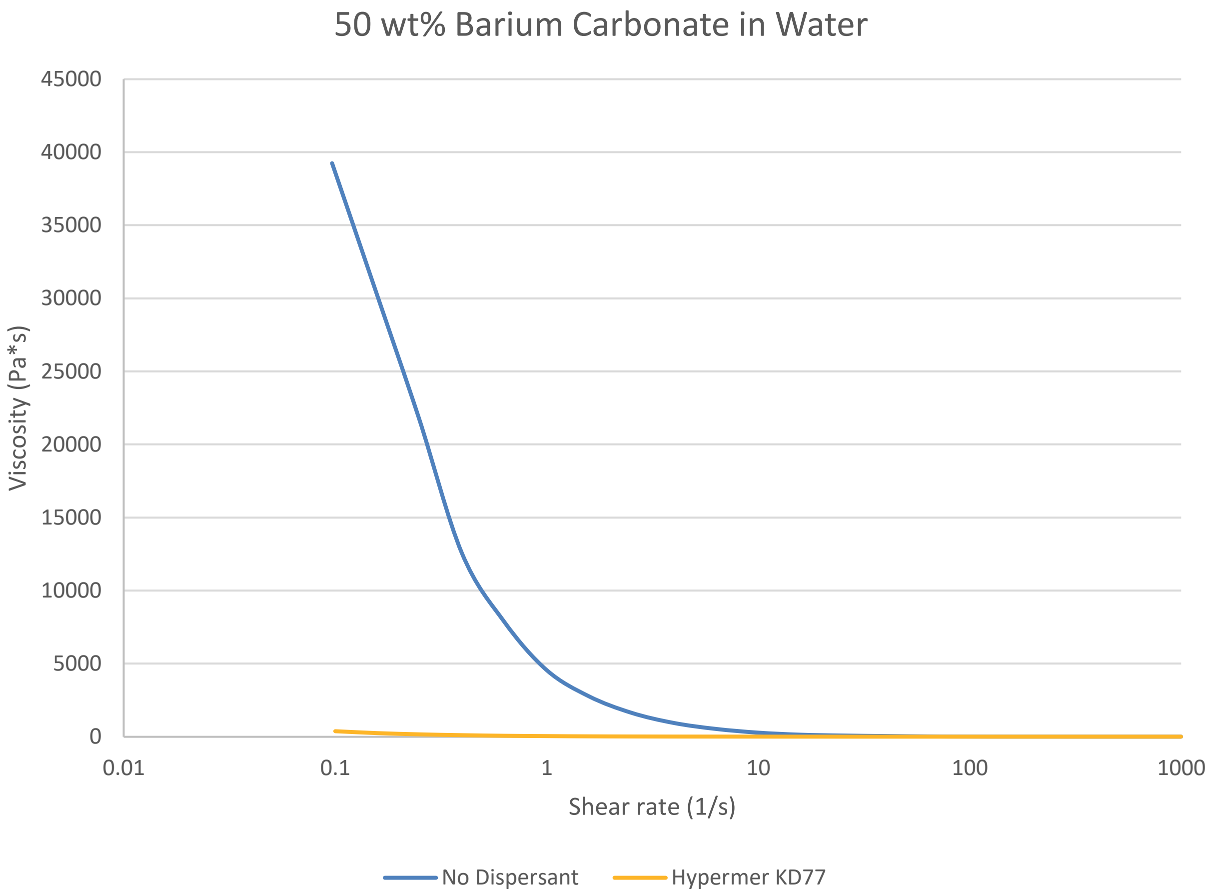
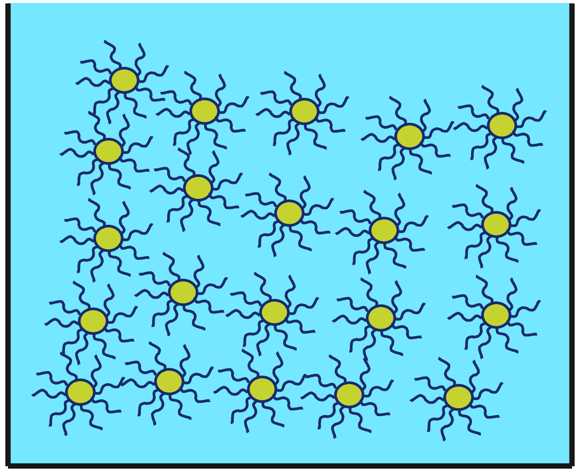
- Used for sensor/catalyst applications or as a precursor for solid phase reaction to produce barium titanate nanoparticles
  - Barium titanate nanoparticles important for multilayered ceramic capacitor (MLCC) miniaturization
- With effective milling you break the particles into nano-sized primary particles
  - Surface energy, however, is so high that they agglomerate together or altogether prevent milling from breaking down primary particle size
- Viscosity vs shear rate curve correlates to particle size stability
  - Steep drop indicates agglomerated particles
  - Low shear rate viscosity also higher
- No dispersant leads to high levels of agglomeration and difficulties in processing
  - Ex: Hypermer KD77 significantly improves rheology curve



Nanoparticle integration

Difficulties in using nanoparticles

- Self-dispersed nanoparticle solutions
  - Generally well-stabilized
  - Typically at lower concentrations than desired
  - Synthesis process might lead to certain ligands that are not compatible with implementation solutions
- Nanopowders
  - Generally agglomerated
  - Safety concerns
  - Difficult to get into solution

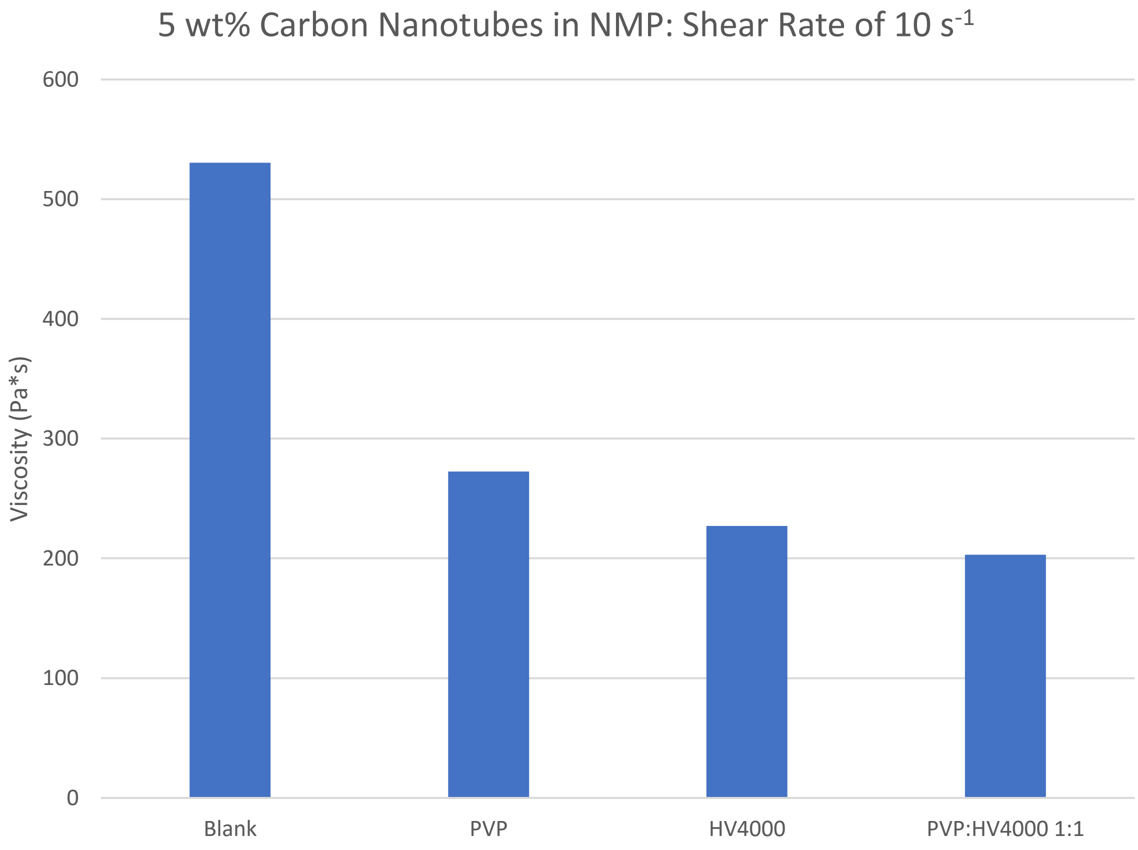


Patterning with quantum dots

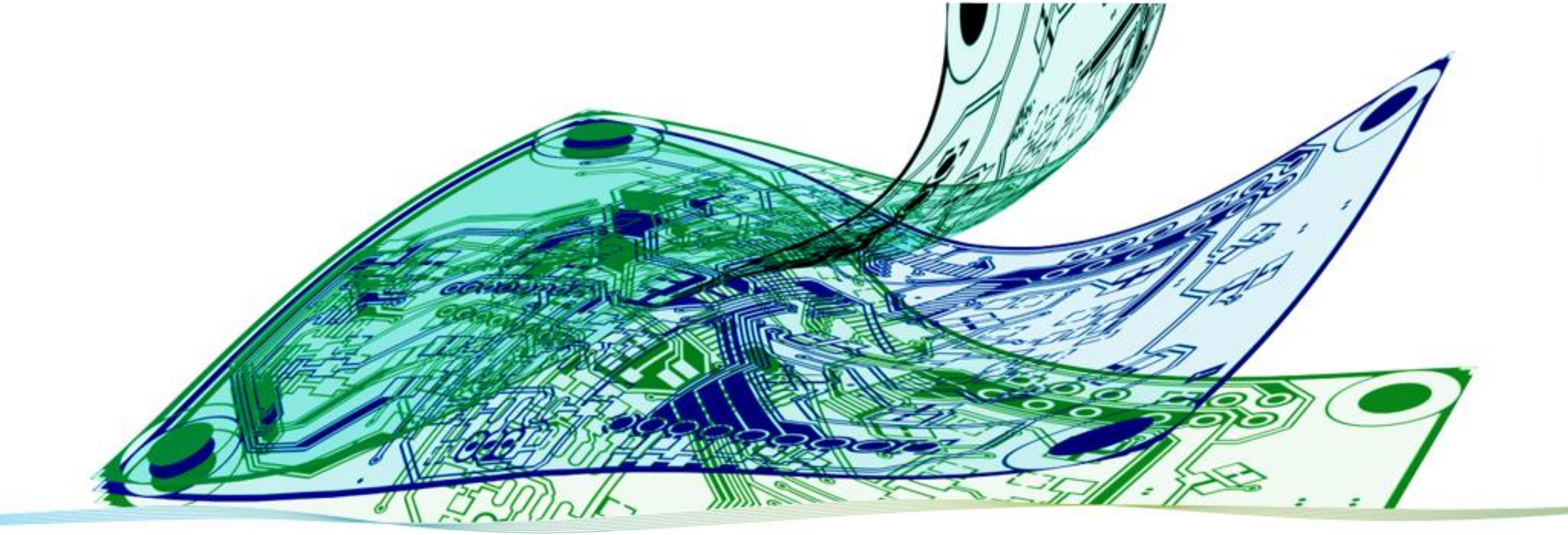
- Currently quantum dots are implemented into displays as sheet that blue light passes through
  - Able to disperse QDs into nonpolar polymer sheet that is compatible with nonpolar ligands native to QD surface
  - Does not provide high enough color contrast as compared to OLEDs
- Next generation of QD displays to compete with OLEDs need specific patterning
  - Patterning techniques such as photoresists and inkjet printing require dispersion of QDs into polar media
- Ligand exchange procedures needed
  - Require ligands that bind to QD surface but are compatible with polar media
  - QDs then can be self-dispersible

Carbon nanotubes in Li ion battery cathode formulations

- Notoriously difficult to process
- High aspect ratio and high surface energy leads to high levels of agglomeration
- With so many agglomerates, slurries are hard to make at viable loadings
- Using a dispersant lowers viscosity of suspension enabling easier processing
  - Ex. Polyvinylpyrrolidone (PVP) and Hypermer Volt 4000 (HV4000) are effective dispersants for CNTs in NMP

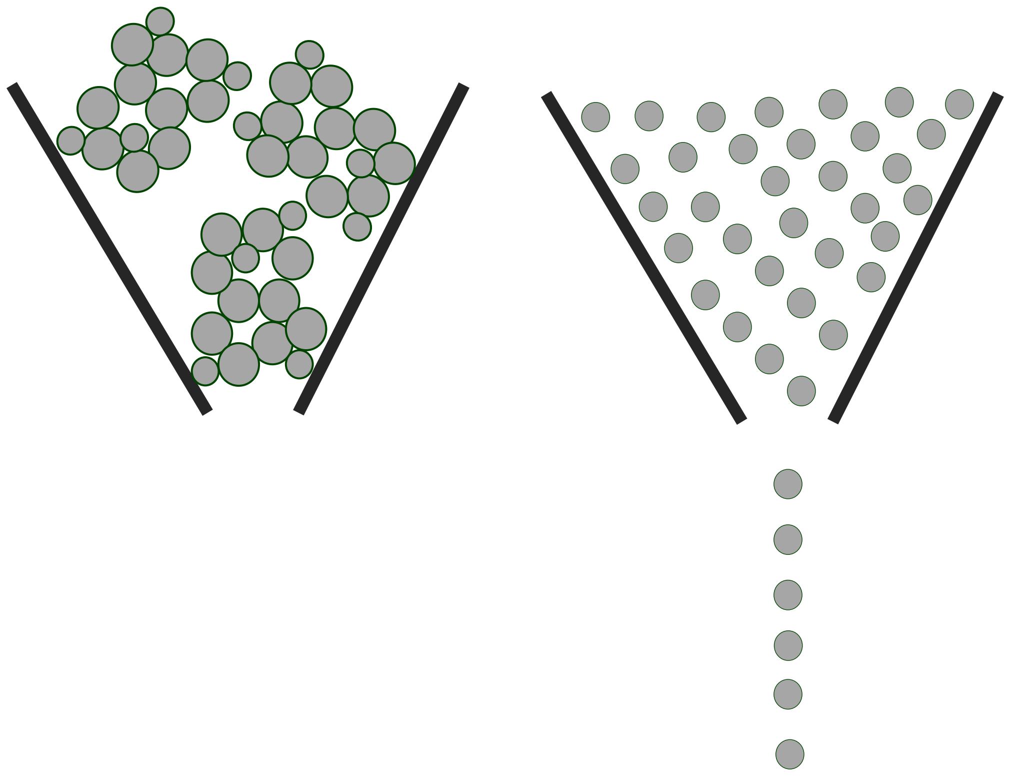


Printing and nanotechnology



Inkjet printing of conductive inks

- Trend developing toward using nanoparticles in conductive inks
  - Major reason is for creating finer features in trend toward further miniaturization
  - Silver, copper and graphene are most researched
- Nanosilver is particularly useful for low-temperature sintering
  - This enables low-cost flexible polymers, i.e. PET, to be used as a printing substrate
  - Copper oxidizes too easily and graphene does not have enough conductivity unless truly monolayered (and becomes much more expensive), so silver is most promising
- Nanosilver as with other nanoparticles tends to agglomerate
  - Can lead to nozzle clogs and significant down time during manufacturing

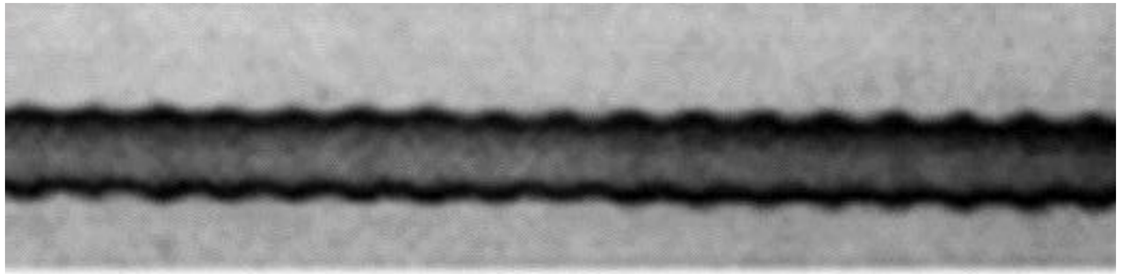


Finished print effect

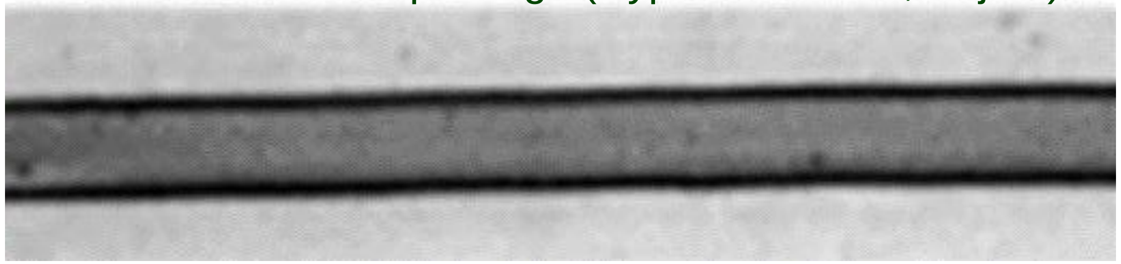
- Good dispersion beyond preventing nozzle clogs also improves uniformity in printed lines

- These fine/smooth lines allow for increased conductivity in the print

Control



Croda surfactant package (Hypermer KD16, Brij L4)



*Inks contain silver particles (20%) and polar solvent Texanol

Conclusion

- Many nanoparticle synthesis techniques require dispersancy principles
  - Those that do not, either require it in implementation or consume incredible amounts of time, energy, and/or material
- Using dispersants or changing self-dispersion methods help to integrate nanoparticles into usable systems
  - Changing out ligands make nanoparticles self-dispersible and compatible with new form factors
  - Dispersants break up agglomerates making them processible and improving their effect
- Inkjet printing of nanoparticles inks not possible without good dispersion
  - Affordable manufacturing method but must have no clogging of printheads and must have line uniformity

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Non-warranty

SMCP059/00