SAND2009-7344C

Directed Assembly of Non-Equilibrium Structures Utilizing Optical Trapping and Surface-Modified Colloids

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Motivation

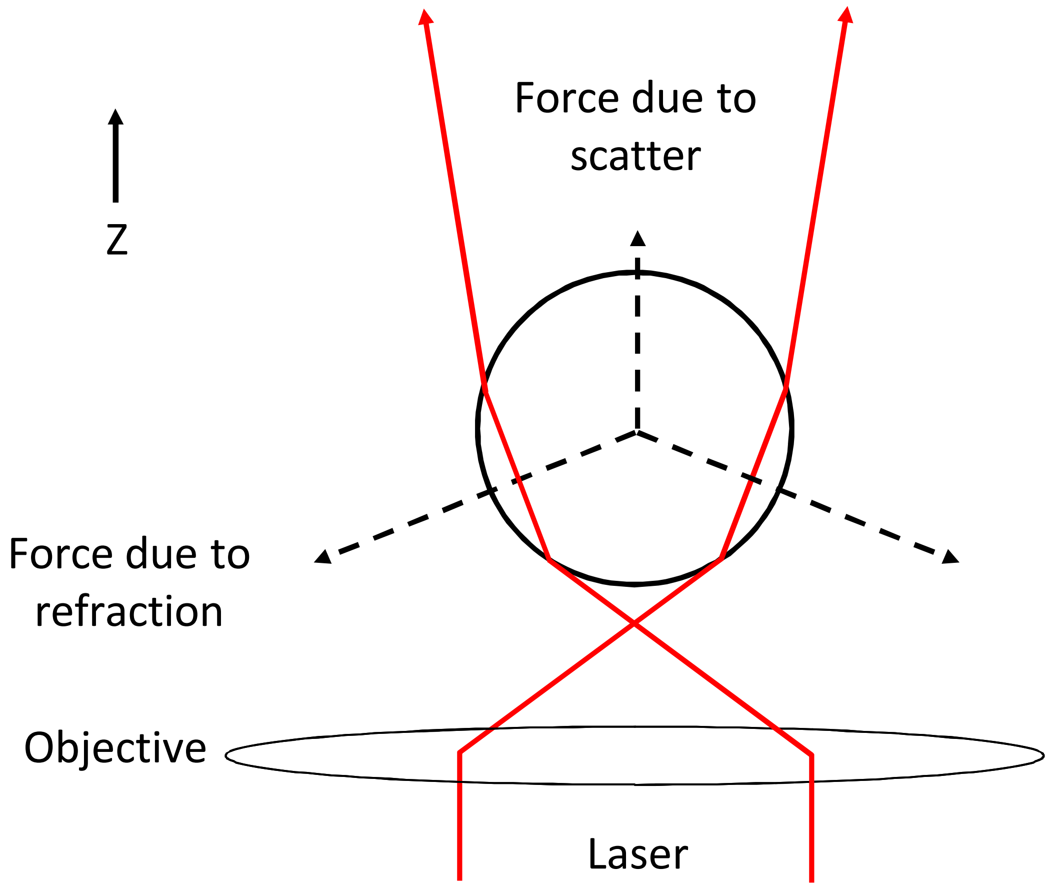
Non-equilibrium microstructures could be used to develop novel materials with interesting optical and/or thermal properties

Directed assembly of photosensitive particles could result in a multitude of unique microstructures

Objective

Develop a technique to assemble non-equilibrium structures using optical tweezers for alignment and surface chemistry to lock-in the aligned structure.

Optical Trapping



A. Ashkin, J.M. Dziedzic, J. E. Bjorkholm, and Steven Chu, Observation of a single-beam gradient force optical trap for dielectric particles, Optics Letters 1989, 5, 288-290.

- Trapping occurs when the force associated from the momentum change of the refracted light balances the force due to light scattering off the surface of the particle.
- The refractive index of the solution must be lower than that of the particle in order for a component of the force due to refraction to be in the negative z direction.
- As the difference between the solvent and particle refractive index increases, the trap stiffness increases → easier to trap particles.

Experimental Setup

- A.A Opto Electronic DTSXY-400-1064
- Agilent E3640A DC Power Supply

Laser

- Ventus Doubled YAG (1064nm)
- < 100 mJ, 10 Hz

CMOS

- Vision Research Miro 4, 12 bit
- Up to 100,000 fps

Microscope

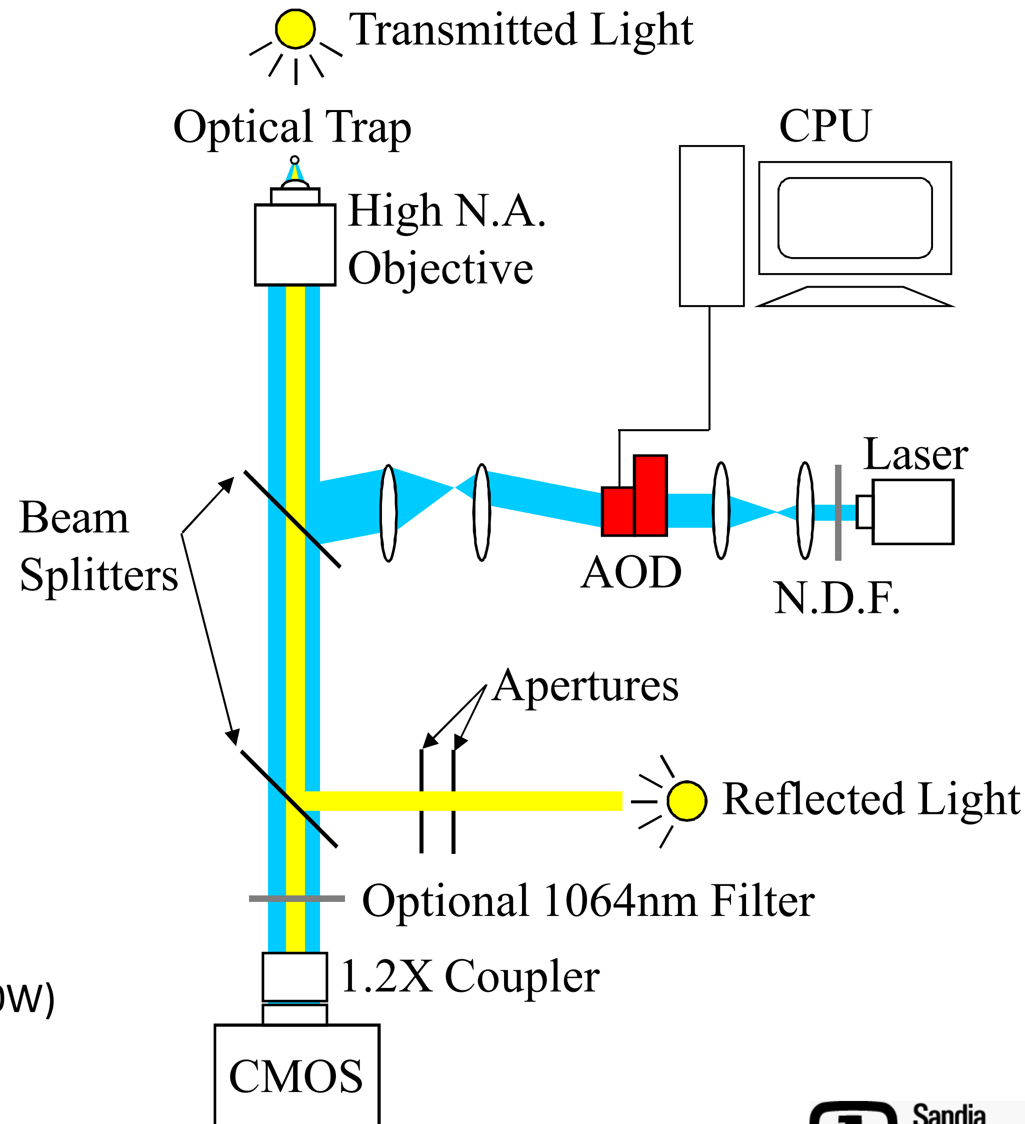
- Nikon TE2000-S
- Prior ProScan II Motorized Stage

High N/A Objective

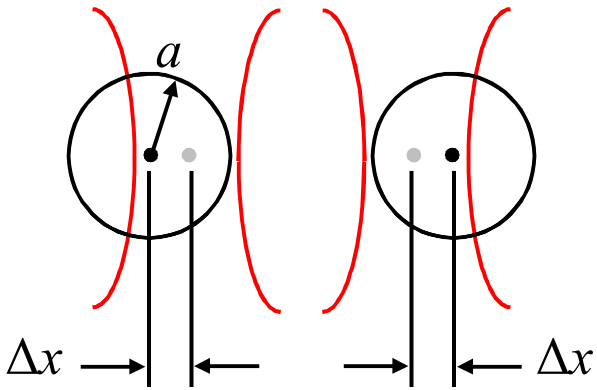
- Nikon Plan Fluor 100x/1.3 Oil Immersion

Reflected Light

- EXFO X-Cite Series 120 Hg-Arc Lamp (120W)

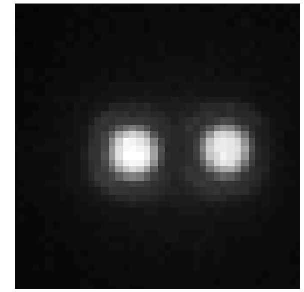


Optical Trapping Applications
Particle Interactions

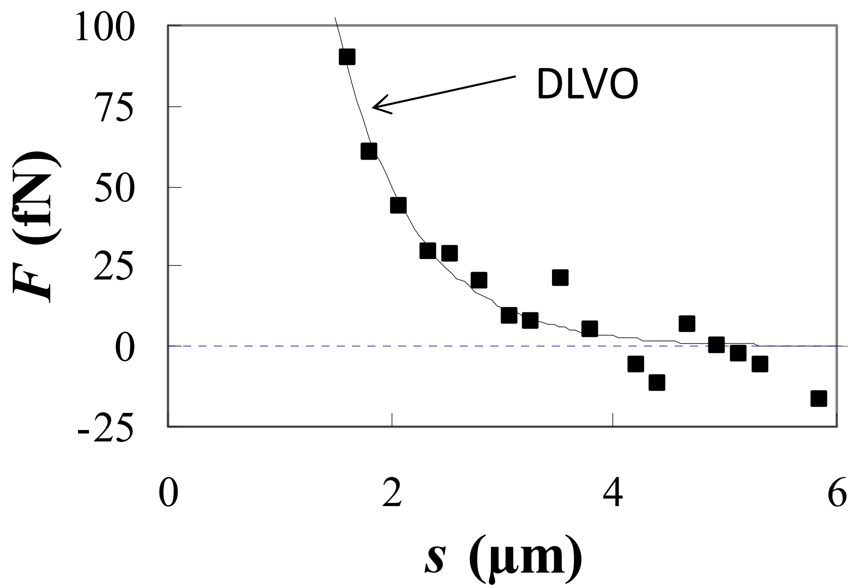


Hookean Force

$$F = k\Delta x$$



Force Versus Separation



2.4 micron Carboxyl-Modified Polystyrene Microspheres in 1mM AOT/Hexadecane

National Nuclear Security Administration

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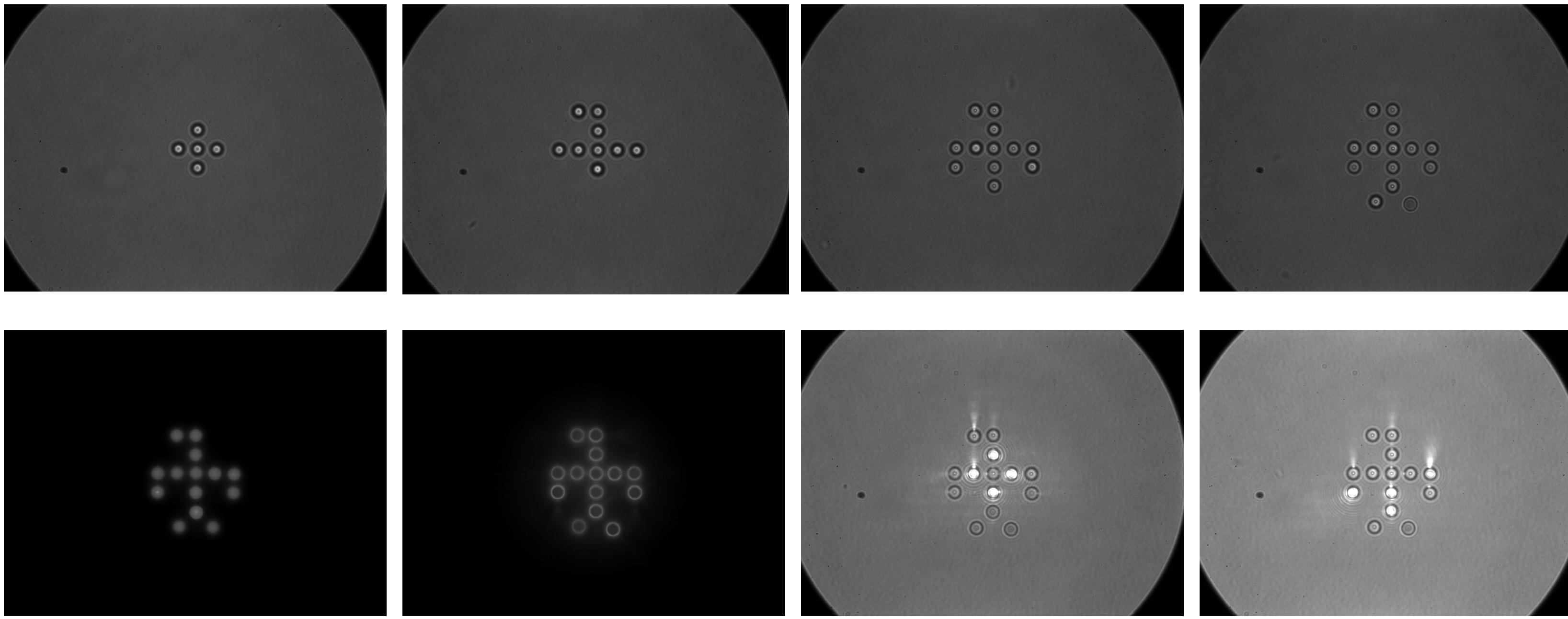
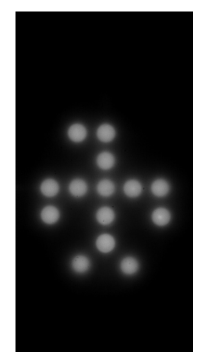
Multiple Optical Traps Allow for Precise Orientation of Silica Particles



- This structure is built using 14 time-shared optical traps.
- These particles are fluorescent polystyrene in water.
- Particles are “caught” by Brownian diffusion into the field of view, and maintained in the position desired by the optical trap.



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Strategic Approach to forming a Photosensitive Colloidal System

Goal: Demonstrate reversible aggregation and dispersion of colloidal particles by photochromic effects.

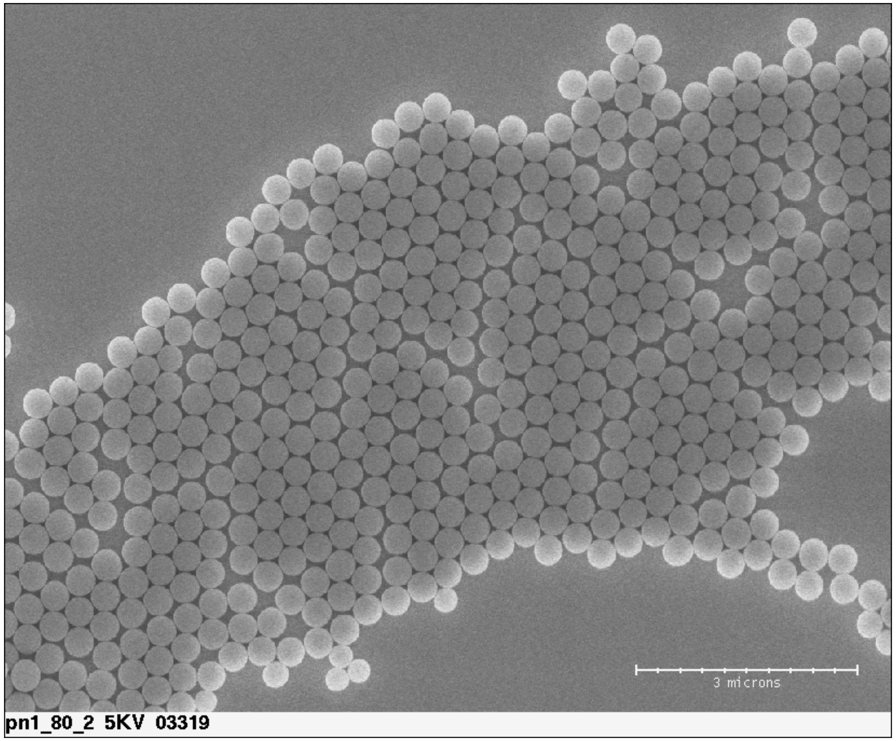
Particle system: Silica

- monodisperse,
- spherical
- common model system
- surface chemistry can be modified using silanes

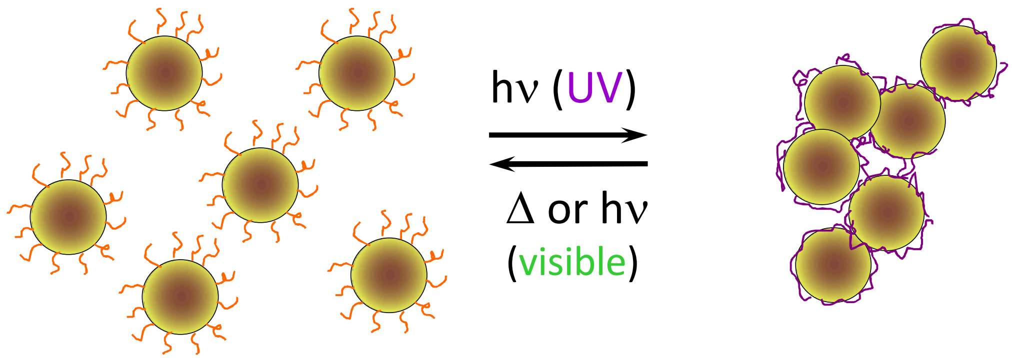
Organic component: spiropyran

- large dipole moment change
- forms a zwitterionic state
- literature states solubility changes of SPMMA polymers in nonaqueous solvents

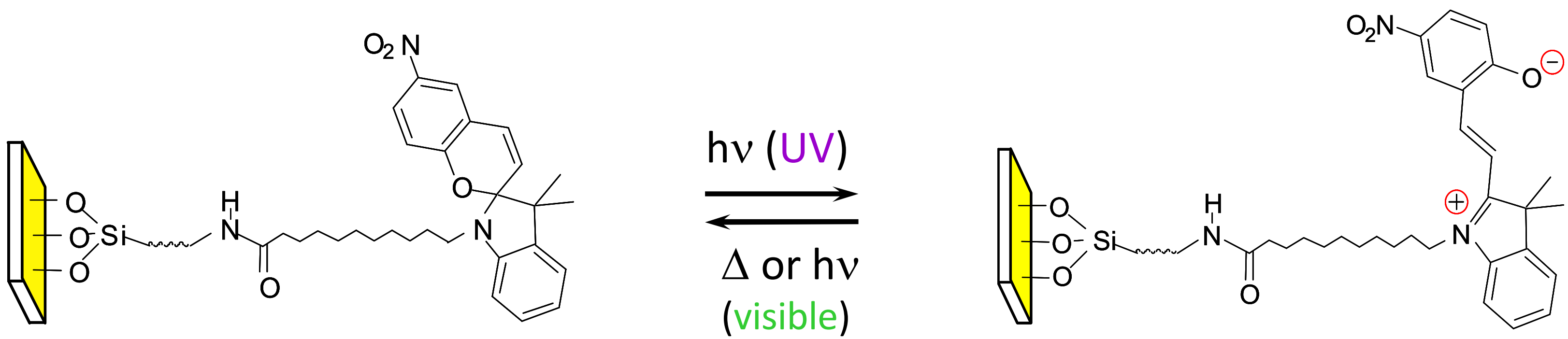
Approach: Derivatize particles with layers of photo-switchable polymer.



Reversible Light-regulated Colloidal Interactions



Approach: Utilize reversible photochemical reaction



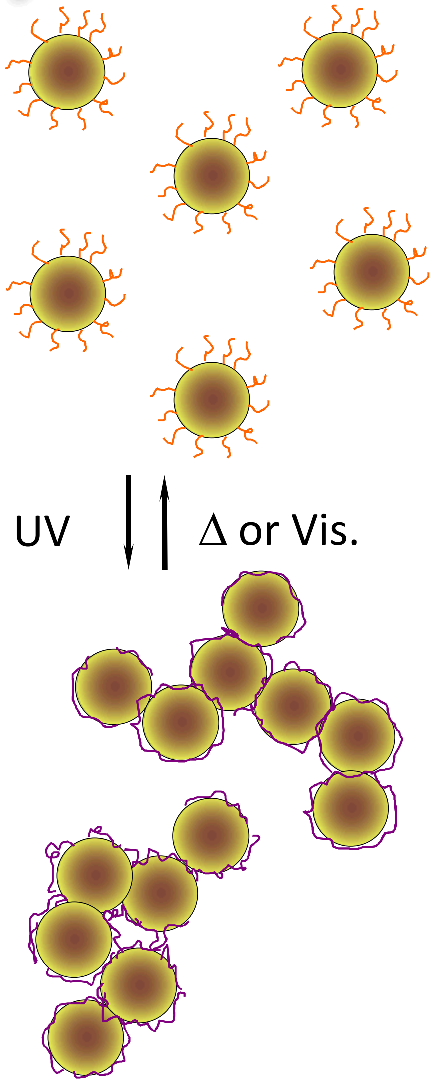
closed form — zwitterionic form

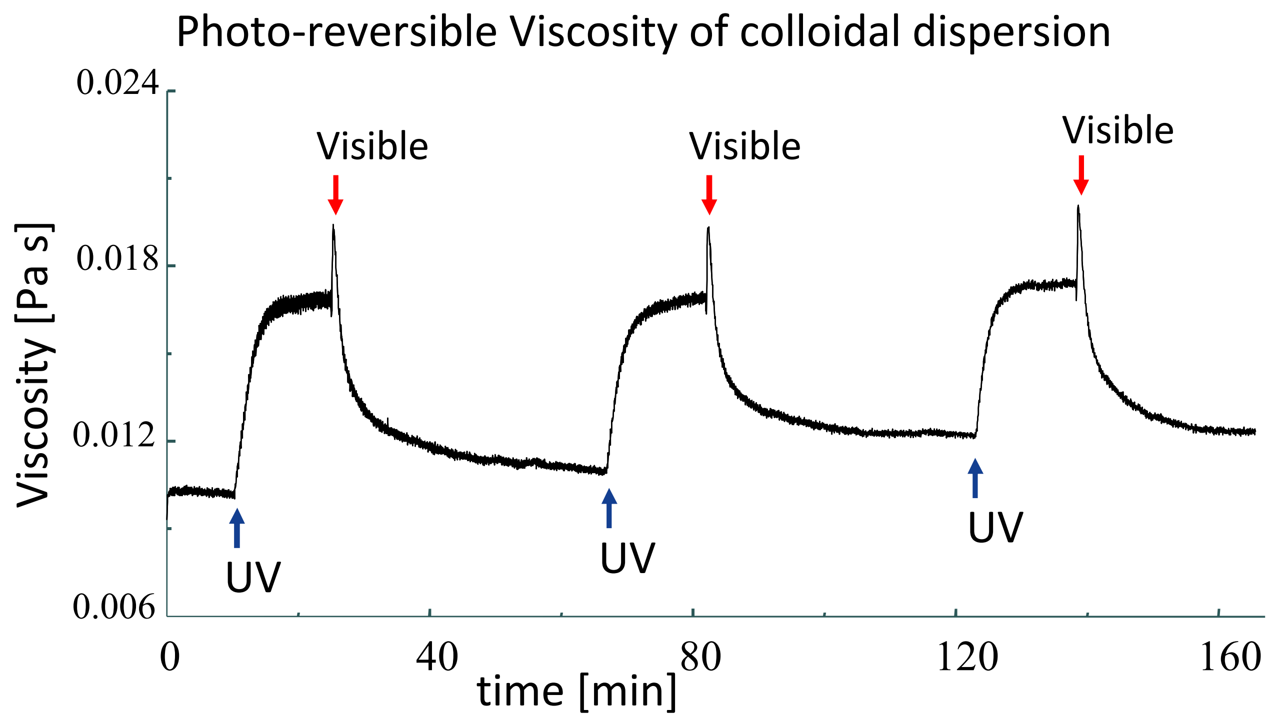
Spirobenzopyran (SP) — Merocyanine (ME)

- Reversible aggregation of SP-coated colloidal particles in non-polar solvents

K. Ichimura, et al. *J. Mat. Chem.* **4**, 883 (1994)

Photo-control of Viscosity in Colloidal Systems



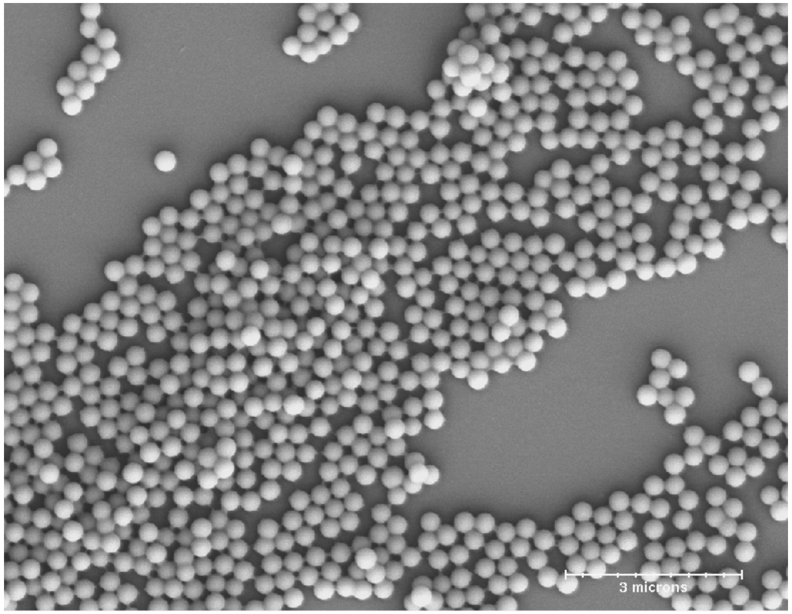


1 μm SP/MMA modified colloids (20% SP) in toluene at ~30 vol.%

N.S. Bell and M Piech, *Langmuir* **2006**, *22*, 1420-1427.

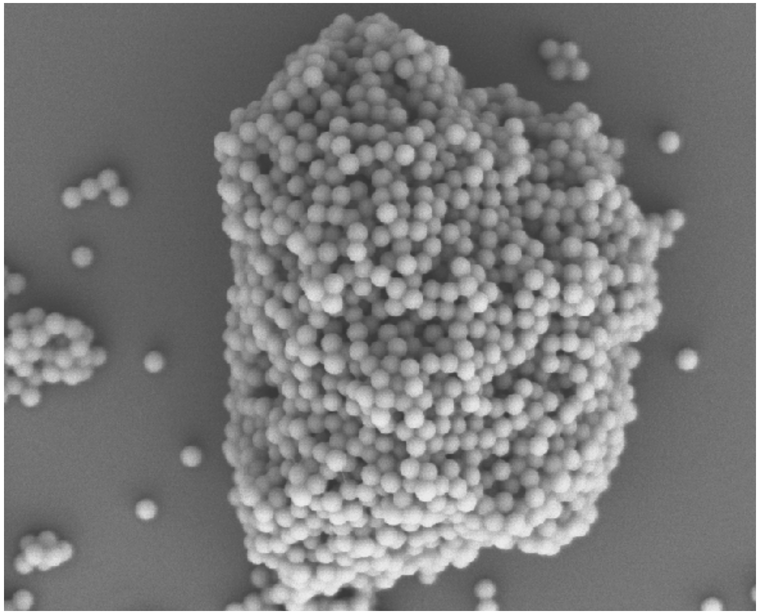
Sediment Comparison via SEM

No UV exposure



Particles form well spread mono- and multi-layer predominant hexagonally packed domains

After 1 min UV irradiation (l=366 nm)



Larger aggregates present in addition to mono- and multi-layers characterized by random particle packing

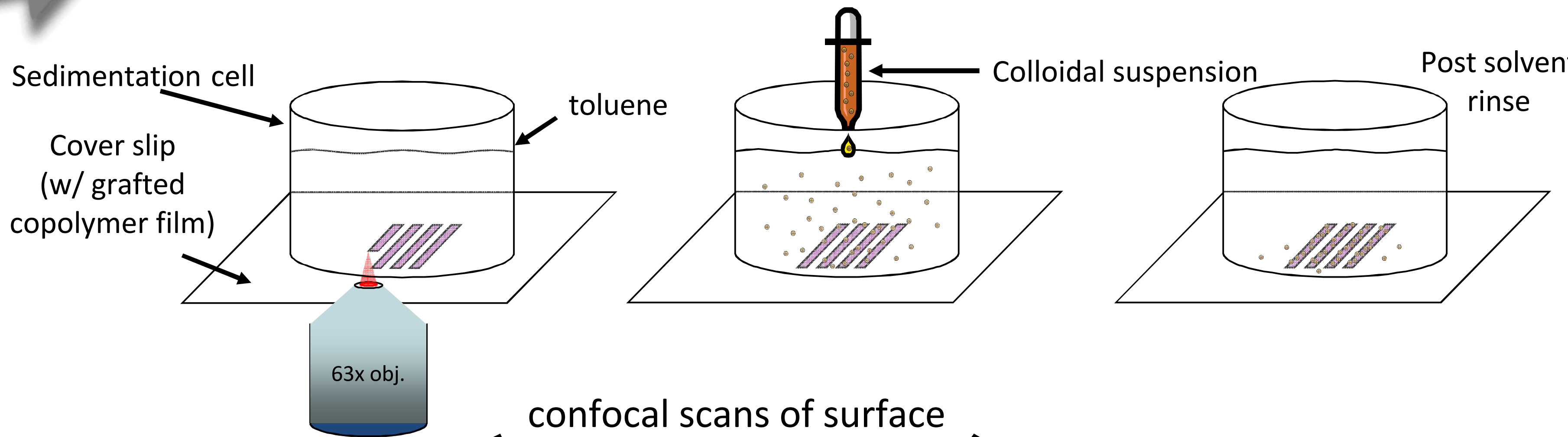
Photoaggregation of SP-MMA Particles in Toluene

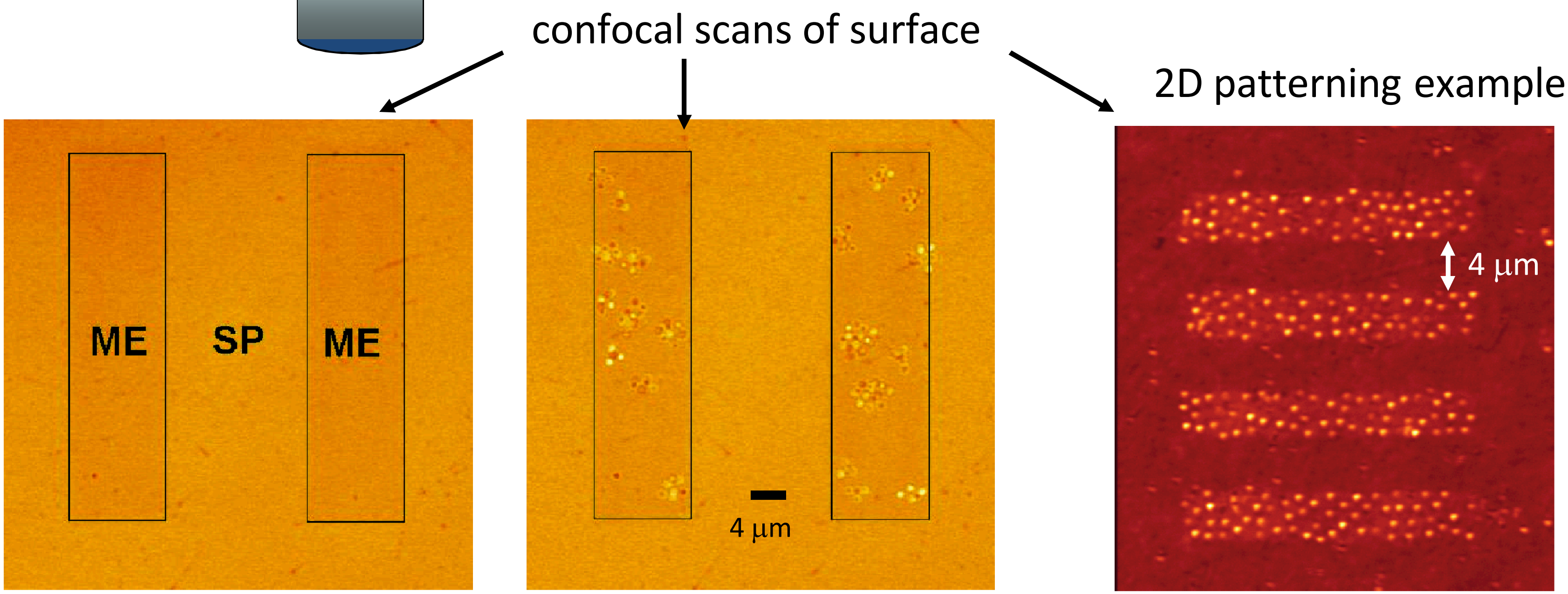
no UV exposure | after 1 min UV

time = 5 sec after shaking | time = 30 sec | time = 45 sec | time = 90 sec

- SP molecules in non-polar, closed form particles are yellow and well dispersed
- UV exposure (λ=366 nm) induces aggregation with SP molecules now in polar, open form; purple particle aggregates quickly sediment

2D Photo-defined Colloidal Adsorption



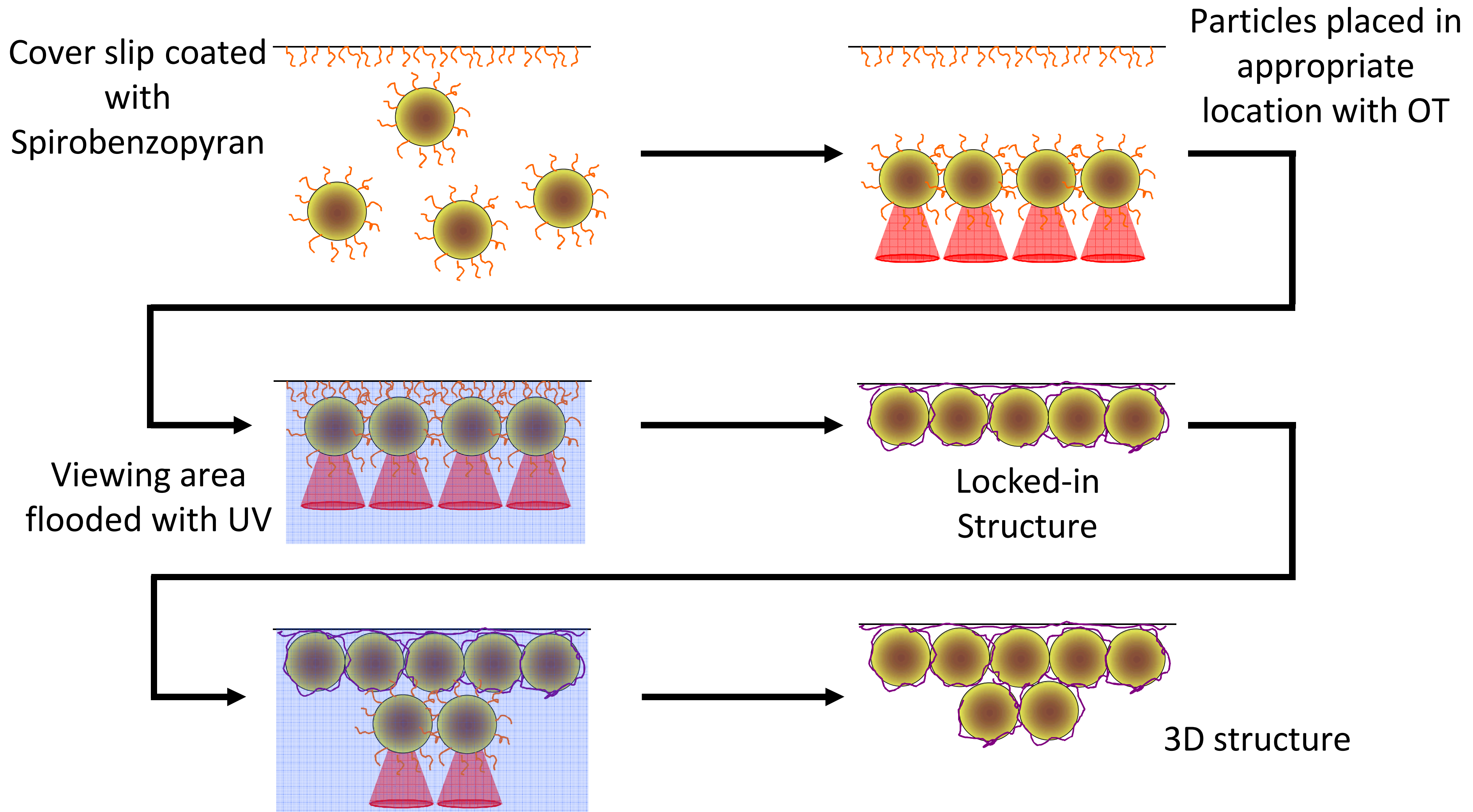


exp. start, t = 0

clusters, t = 660 s

M. Piech, M. C. George, N. S. Bell and P. V. Braun:, *Langmuir*, **22**, 1379-1382 (2006)

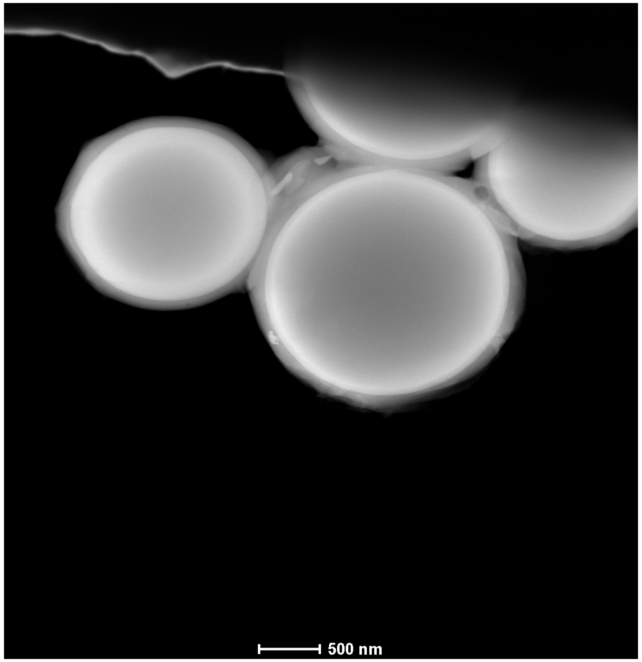
Route to Structure Fabrication using SP-MMA Functionalized Particles

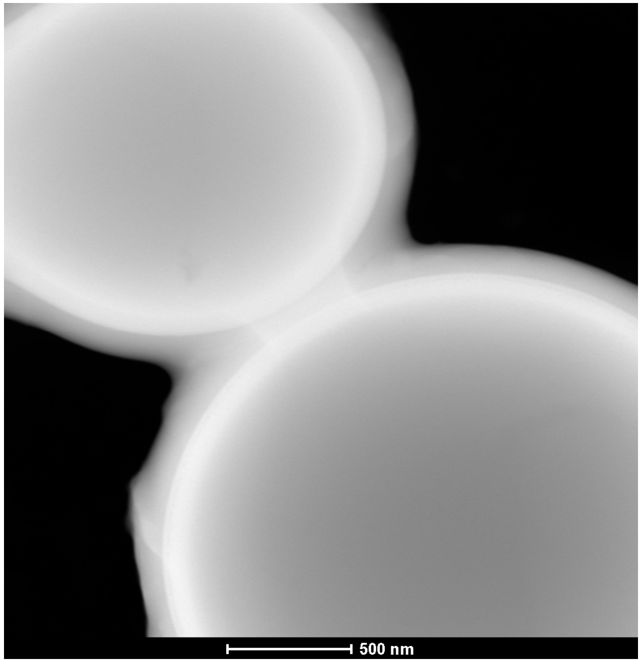


Process repeated by grabbing particles that are outside the viewing area (no previous UV exposure)

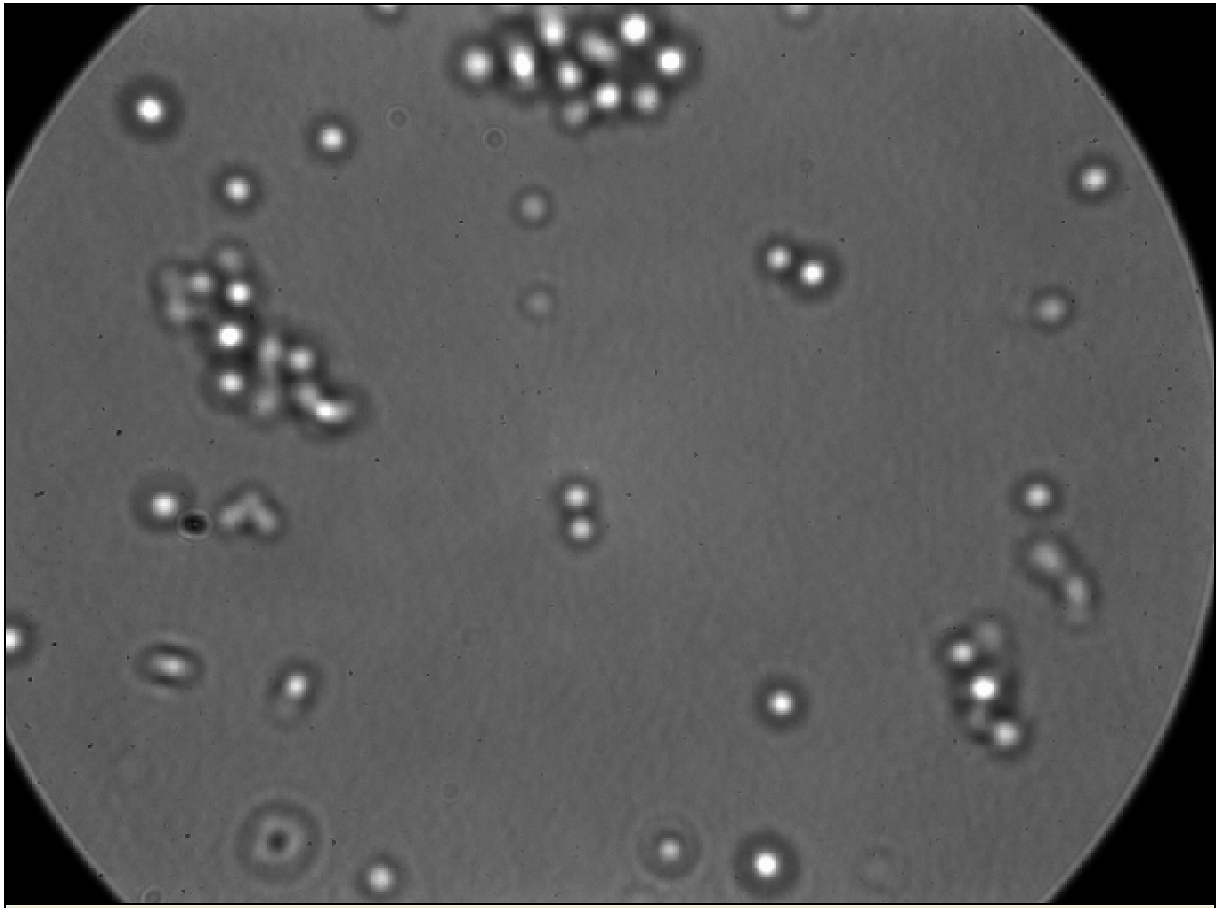
Borosilicate Particles with SP-MMA Layers

- A higher particle refractive index is required for optical trapping in toluene (n = 1.49).
- Particles of borosilicate glass (~2 micron) were coated with 20% SP-MMA layers to created photochromic responses. (n = 1.56)
- The layer thickness is estimated for these particles at ~ 100 nm.



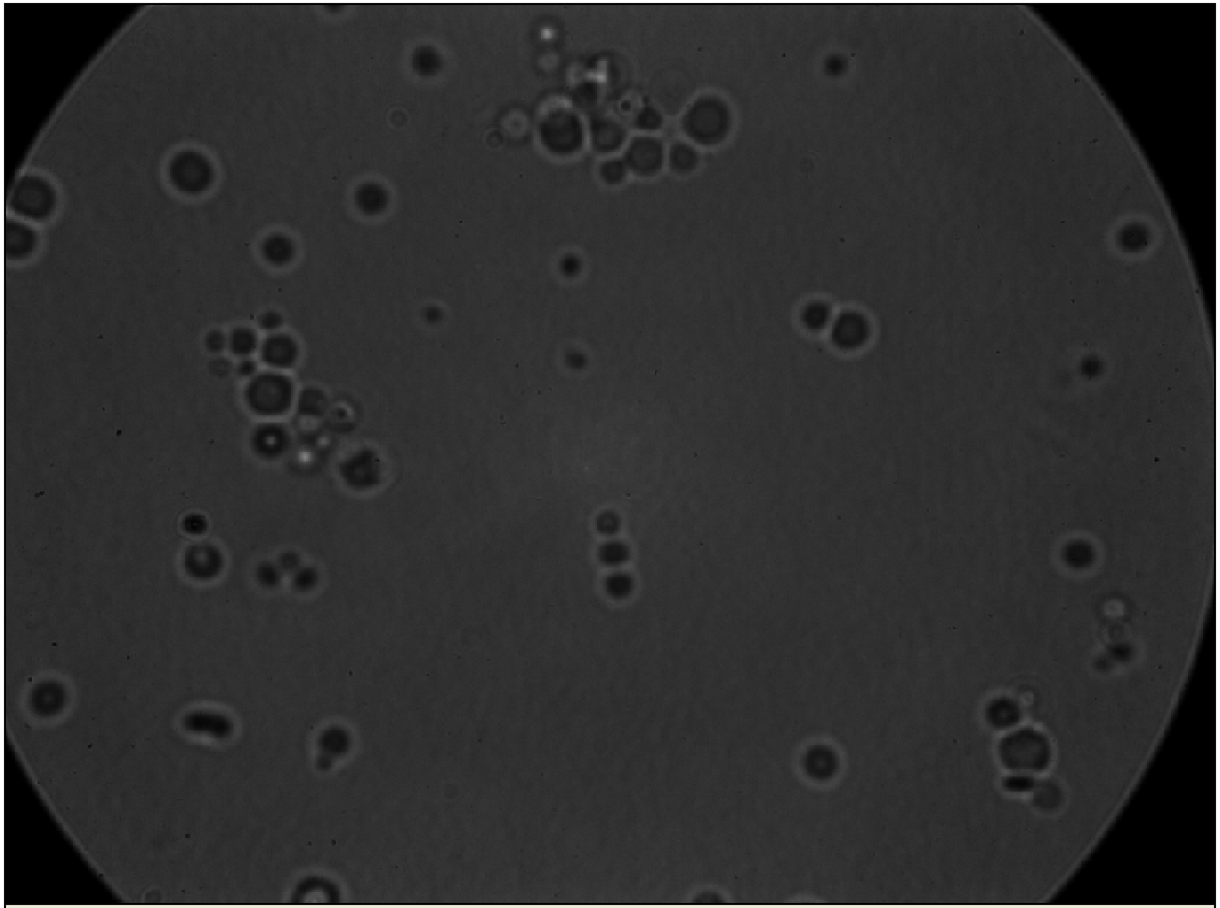


Optical Assembly of Photochromic Particles



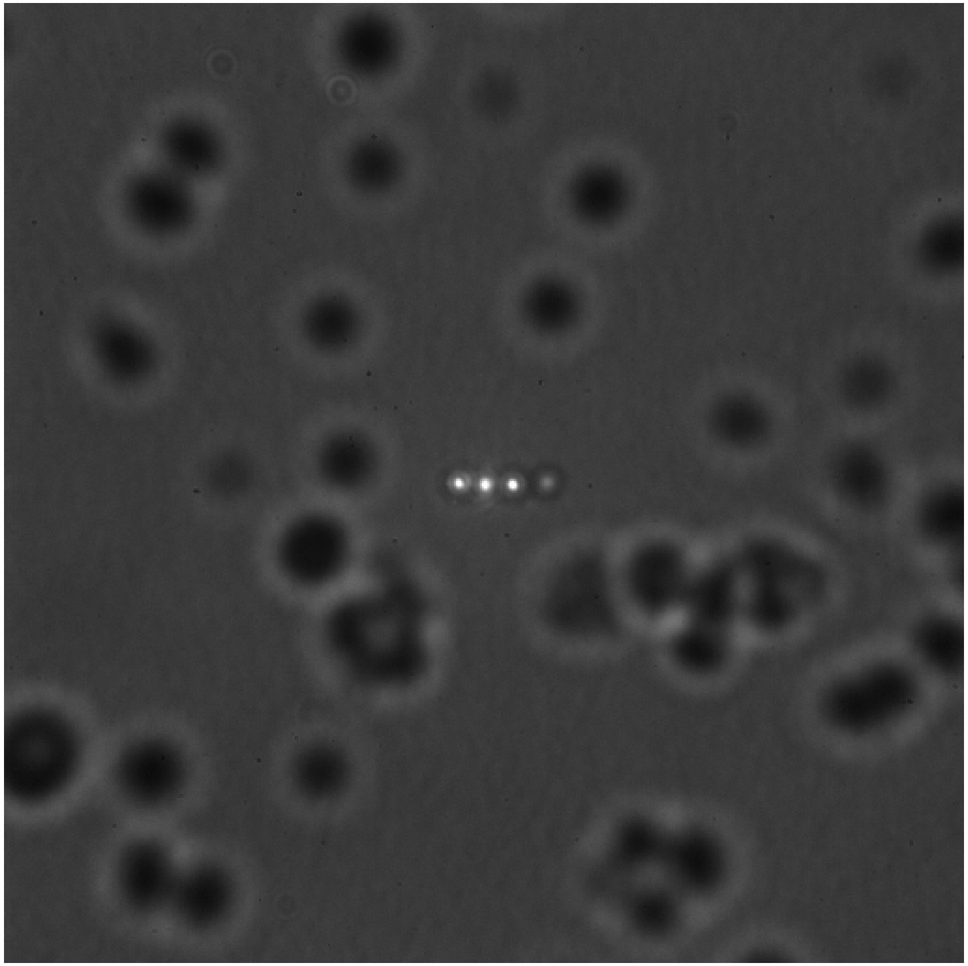
SP_particle_line.avi

Optical Assembly of Photochromic Particles



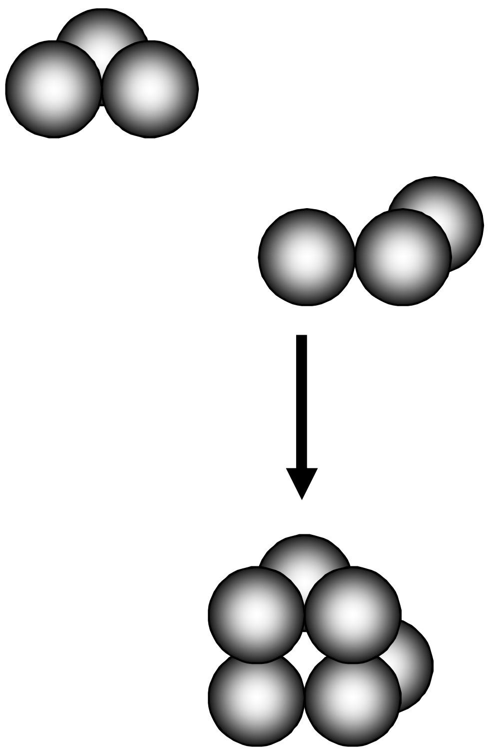
SP_particle_line_2.avi

Optical Trapping of Photochromic Particles



• Three optical traps are active in this line of particles.
• The fourth particle is not trapped.
• A flow cell design is being used to inject more particles into the system.
• Once assembled, the structure diffuses as a single entity, and can be moved to the desired position.
• Work to ordered structures is ongoing.

Microstructure Assembly using Optical Trapping



Conclusions

Successes:

- Photosensitive chemistry can be used to control aggregation of microparticles
- Optical tweezers enable manipulation of particles into non-equilibrium positions
- 3D assembly was possible using borosilicate particles coated in Spyrobenzopyran in toluene

Difficulties:

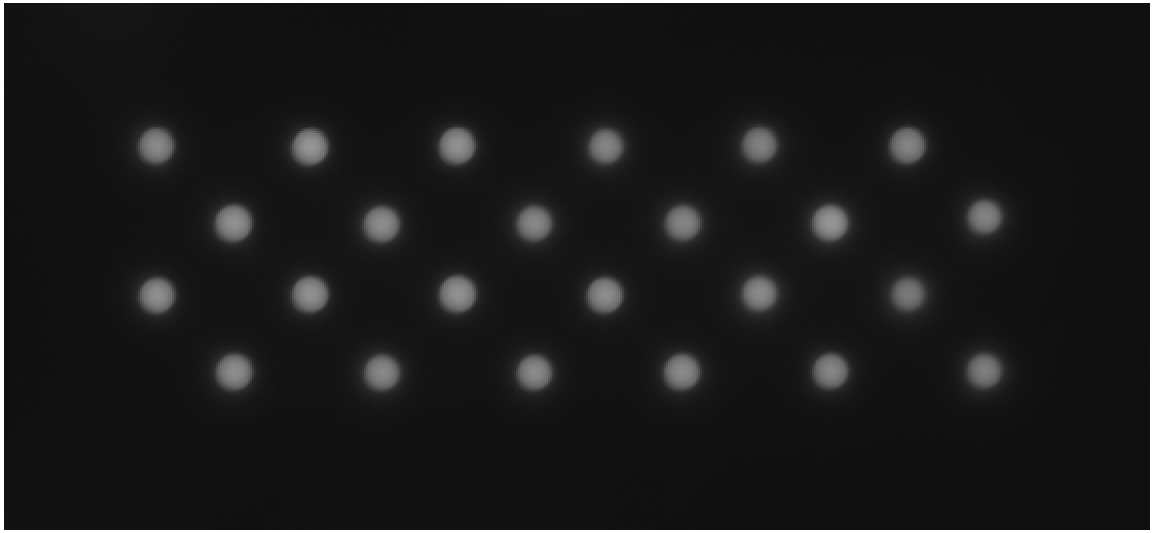
- Spyrobenzopyran brushes are very sensitive to UV and lead to premature agglomeration
- Borosilicate/Toluene system is challenging due to settling

Path forward:

- Holographic optical tweezers are capable of 3D particle manipulation and thus assembly
- Identify lower refractive index solvents to better density match particle/solvent system

Future Work

3D Positioning using Holographic Optical Trapping (HOT)



Acknowledgements

Additional contributors:

- Martin Piech, United Technologies Corporation
- Tom Grasser, Allen Gorby, Paul Kotula and Garry Zinder, Sandia National Laboratory

Funding:

- LDRD and NINE Programs at Sandia National Laboratory
- Army Research Office – MURI Grant
- Department of Energy