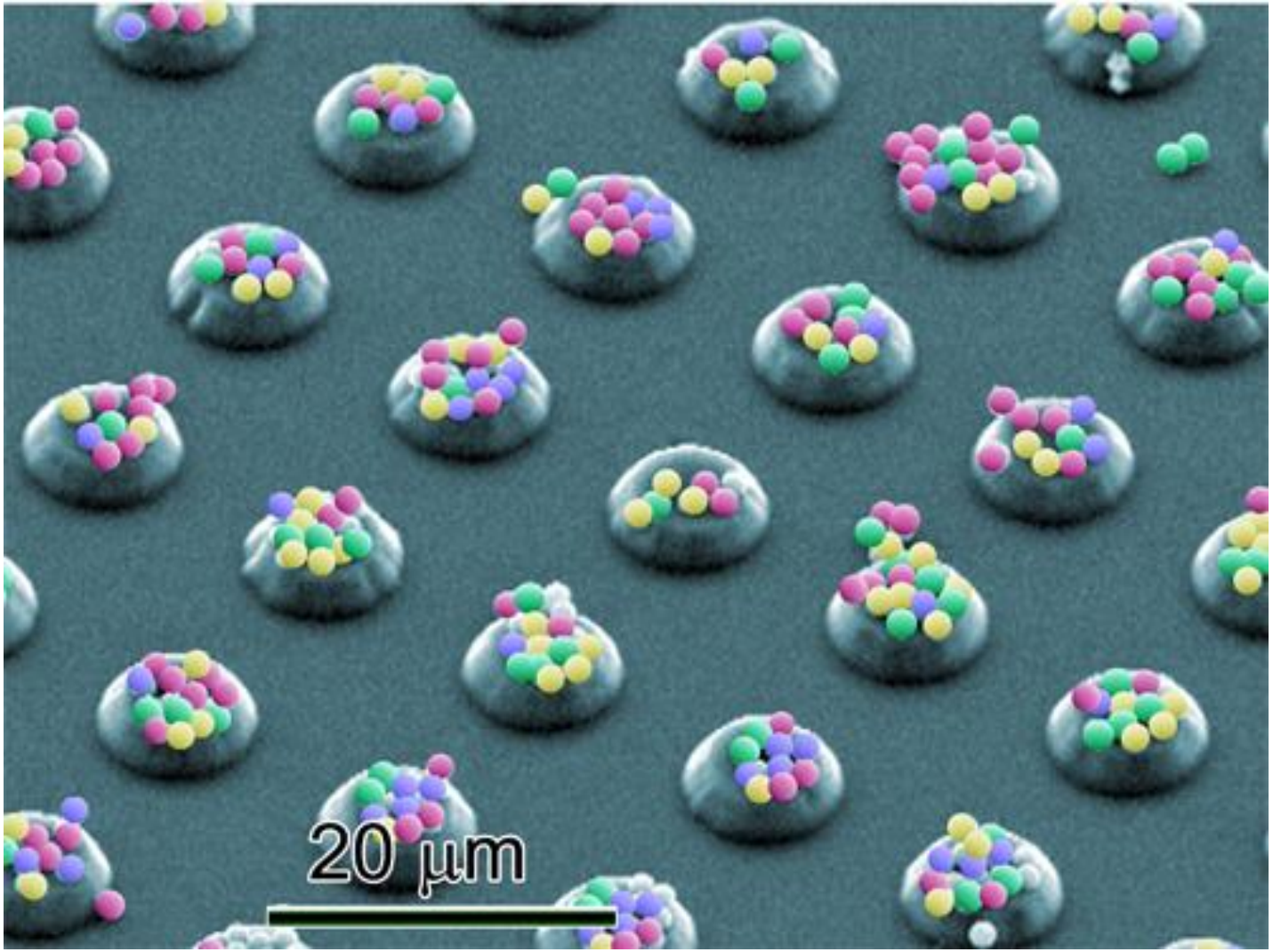
Self-Assembly of Colloidal Particles



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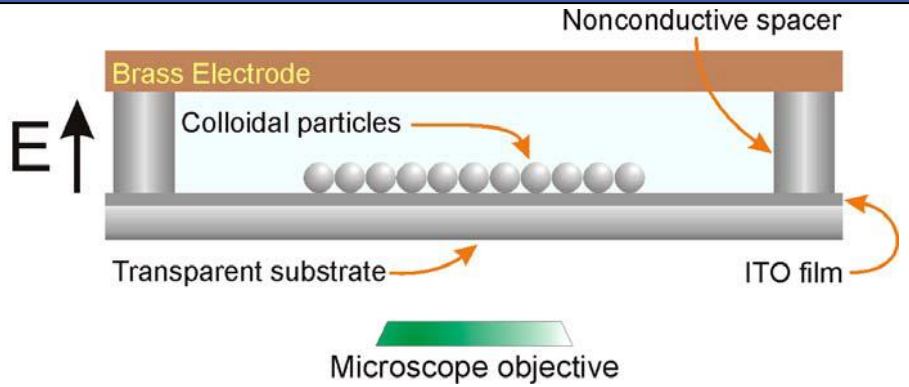
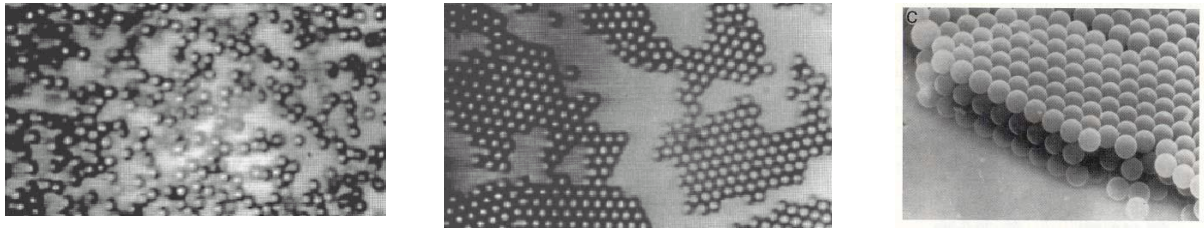
Colloidal Epitaxy for Colloidal Single Crystals

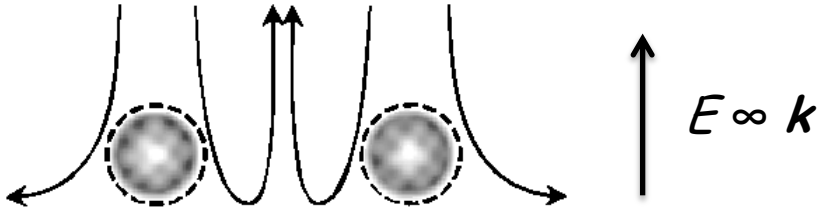


Before e-field: 30s; after e-field: Several hours



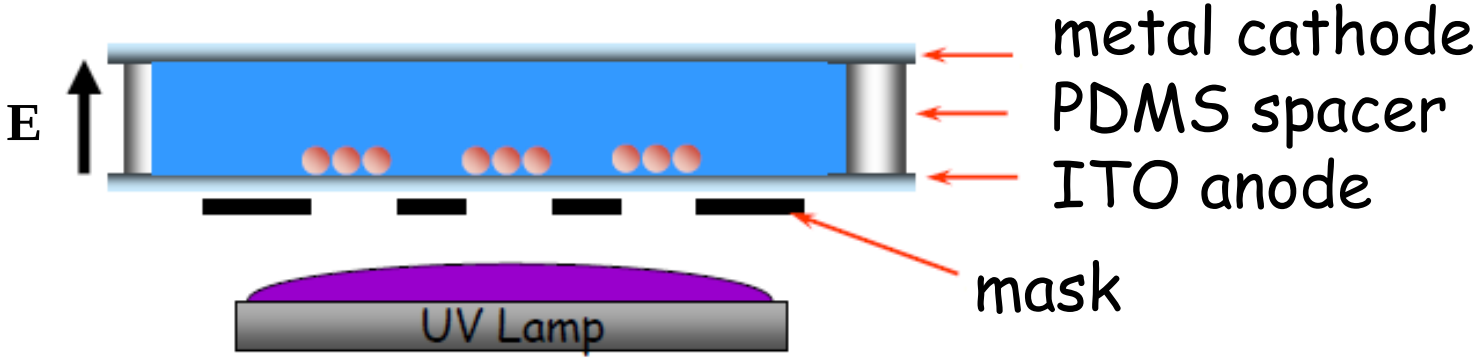
(*Science* 272, 706, 1996)

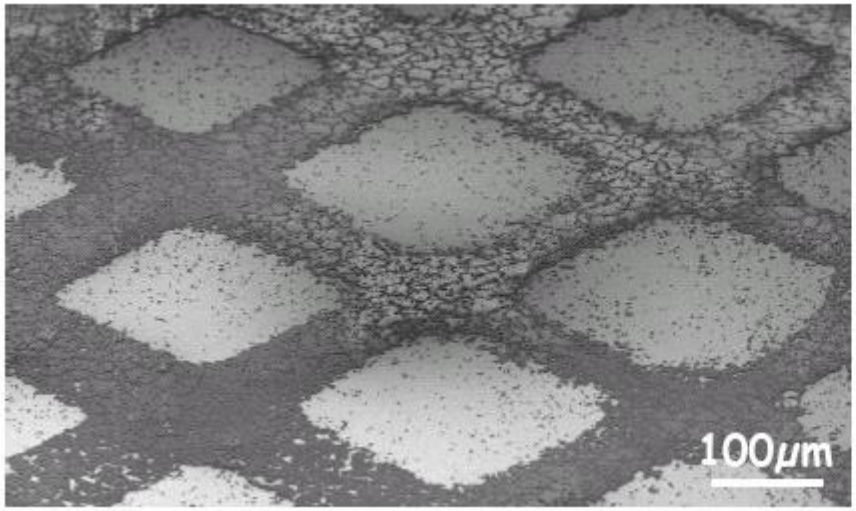
Proposed Mechanism: Electrohydrodynamic Flow

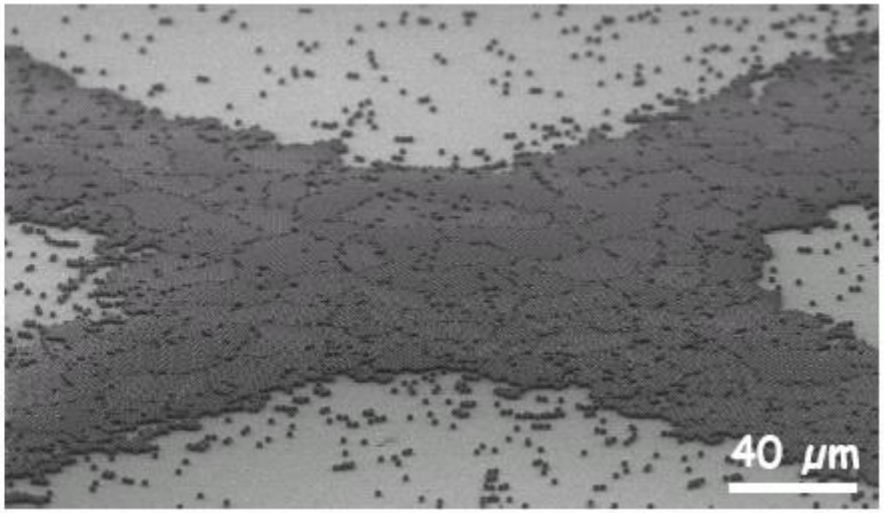


(*Langmuir* 13, 6375, 1997)

Optically Tunable Electrohydrodynamic Assembly



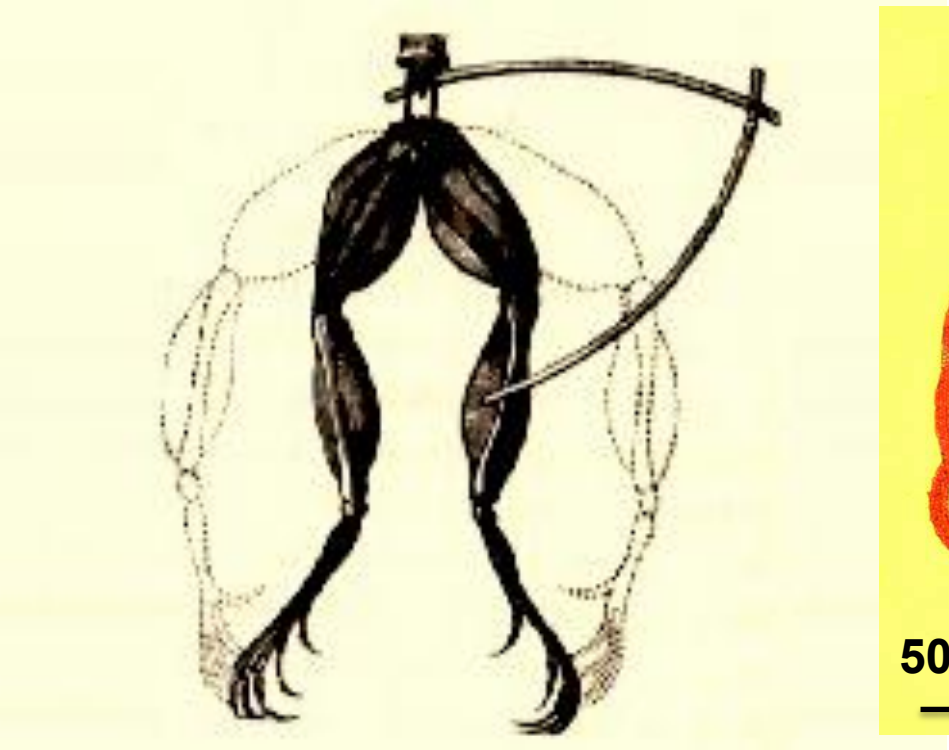


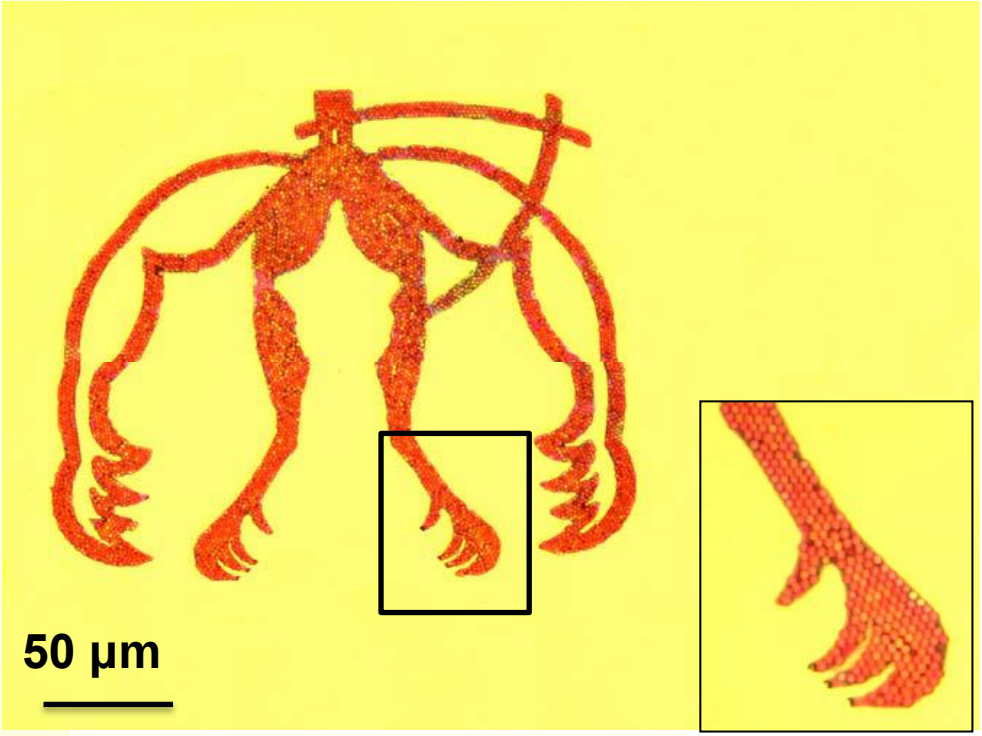


Higher current density in the light regions induces electrohydrodynamic assembly

(*Nature* 404, 56, 2000)

Galvanic Cell Induced Colloidal Assembly



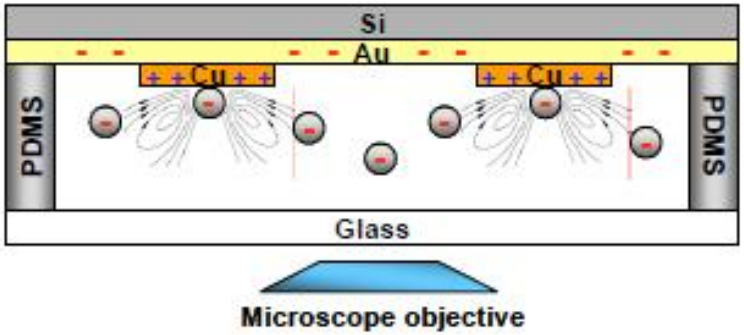


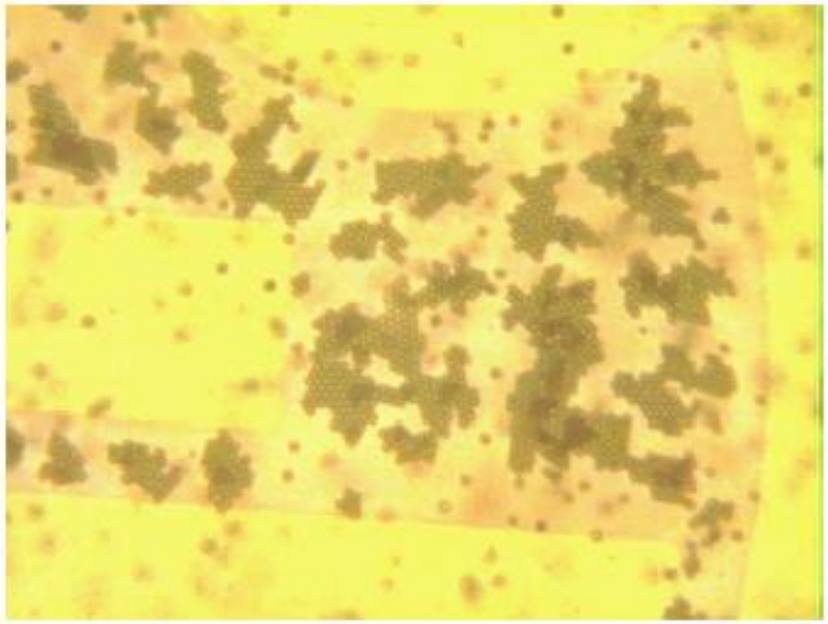
- Aggregation is confined to Cu.
- Multiple sites aggregation.

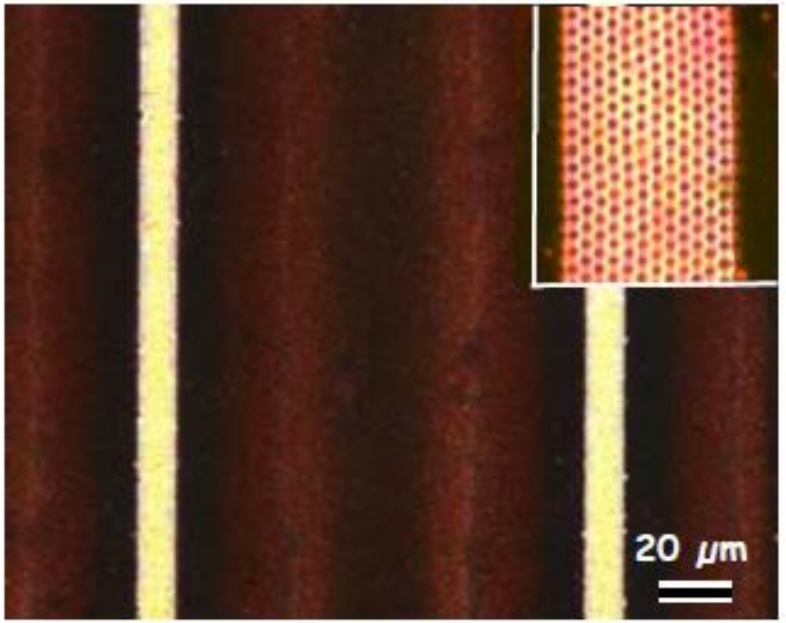
"Galvanography"

(*L. Galvani, Bonon. Sci. Art. Inst. Acad. Comment.* **7**, 363, 1791)

Localized Electroosmotic Flow (EOF) Induced Colloidal Crystallization





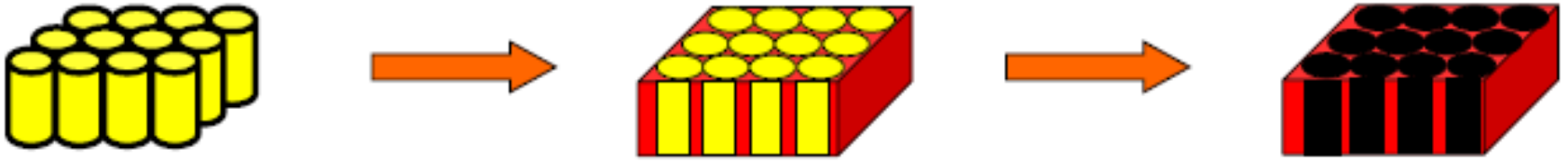


Template Chemistry: Steps Toward Full 3D Gaps

	Refractive index	Absorption Depth
PMMA	1.48	millimeters
Silicon	3.4	depends on λ
TiO2- rutile	2.8-3.0	millimeters
Metals (visible)	very large	angstroms

Template Chemistry Strategy:

1. Form template
2. Fill template
3. Remove template



Self-assembling System

Polymers, Ceramics, Semiconductor, Metal…

Thermal/Chemical treatments

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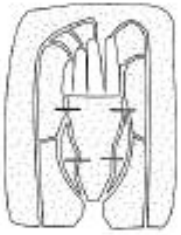
"Lost-Wax" Method – Extending the Availability of Artificial Opals

1. Form a clay figure.

2. Cast a hollow wax replica.

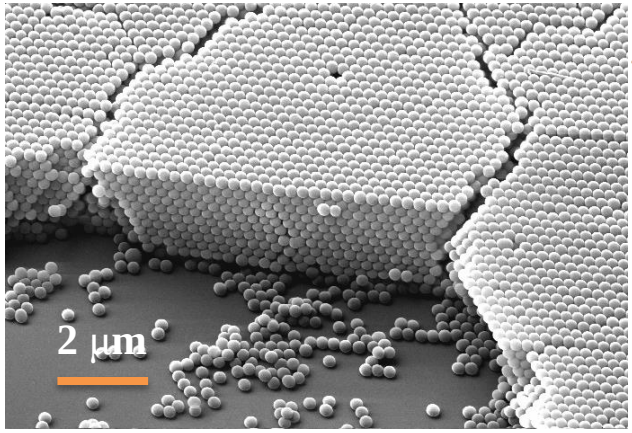


3. Embed in external mold, remove wax through heating.

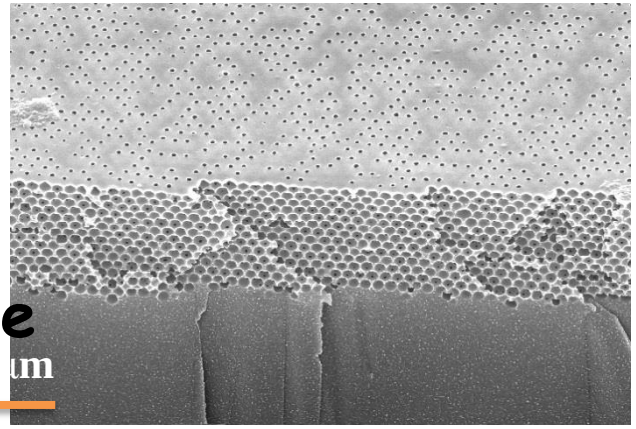
4. Pour bronze into the mold.

(From the Fire of Hephaistos, ed. C. C. Mattusch, Harvard University Press, 1996)

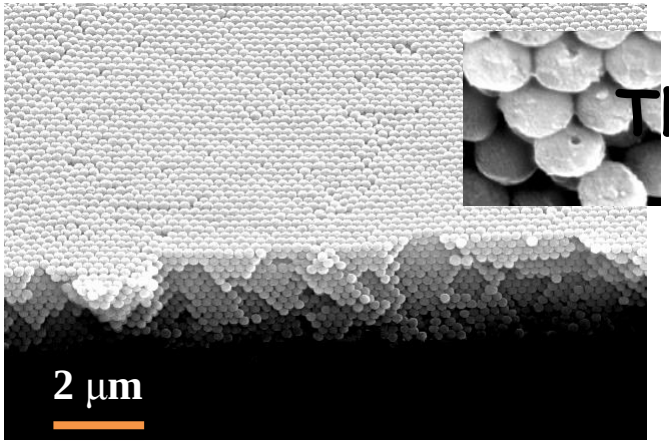
Nanoscale Lost-Wax Method



The "Clay" Figure – Silica Template



The "Wax" Mold – Polymer Template

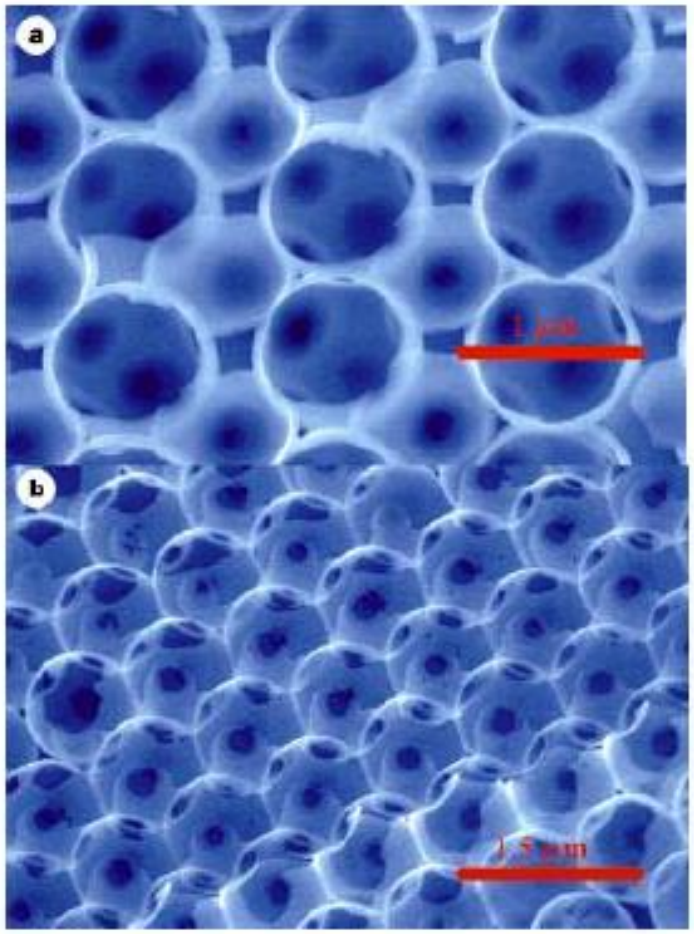


TiO_2 Colloidal Crystals

Colloidal crystals from every major class of functional materials.

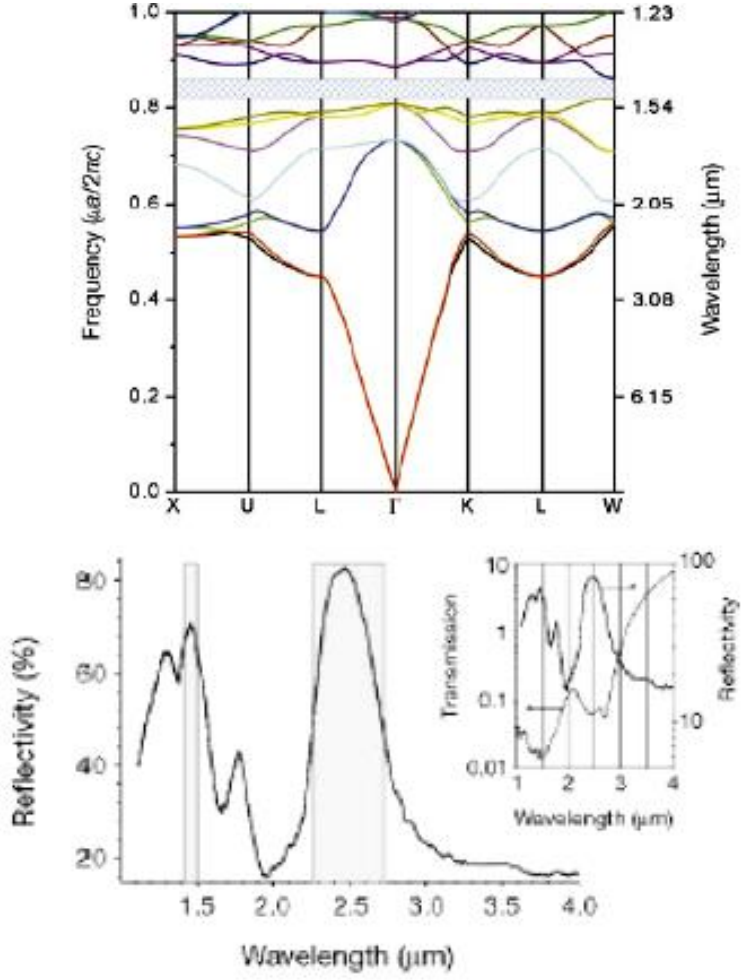
(*Science* **291**, 453, 2001)

Macroporous Silicon with Full Bandgaps



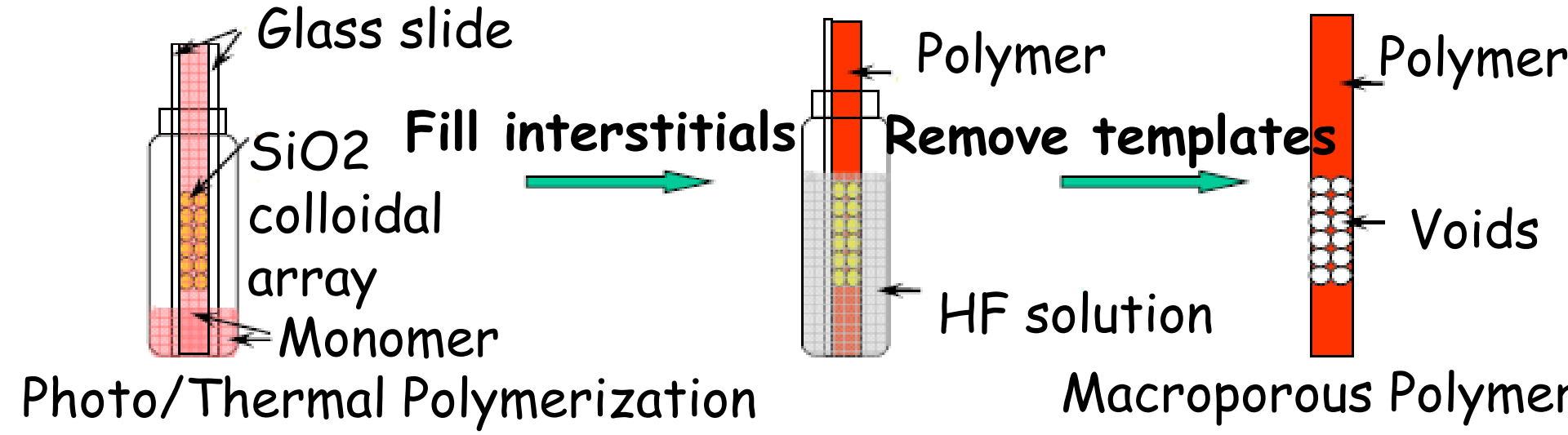
Macroporous Si Inverse Opal

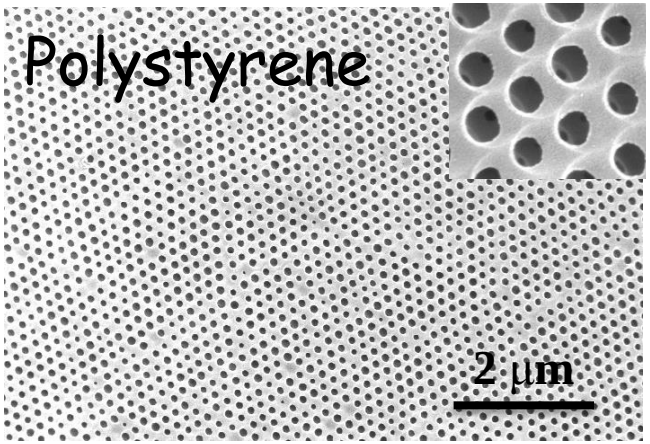
Band Structure of Si Inverse Opal

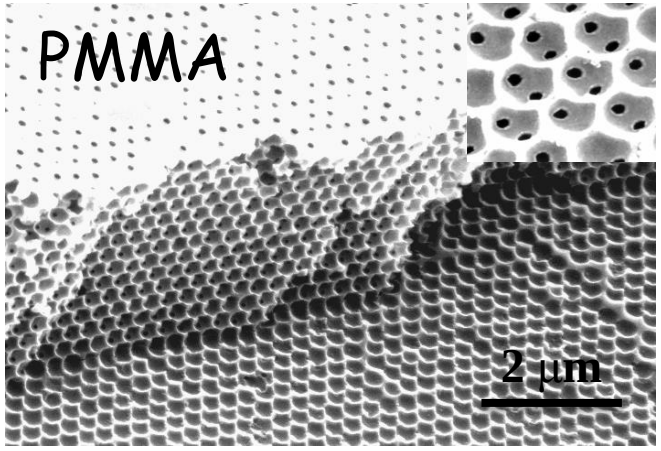


(*Nature* **405**, 437, 2000)

Template Chemistry: Structured Porous Materials







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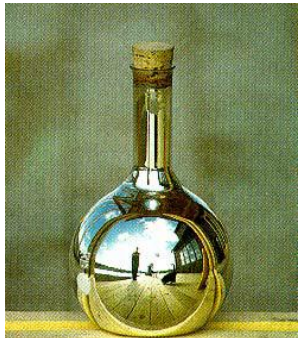
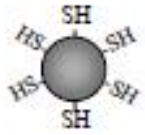
Macroporous Metals from "Seeded" Electroless Plating



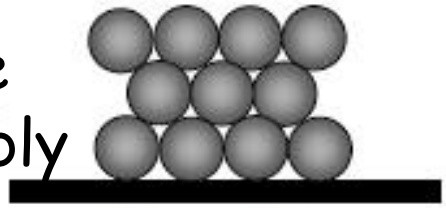
Electroless plating:

$$Mn^{+} + \text{reductant} \xrightarrow{\text{Catalytic Surface}} M0 + \text{by-product}$$



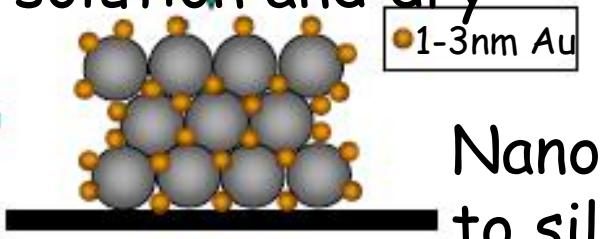
Colloidal silica coated by 3-MPTMS

Convective Self-Assembly



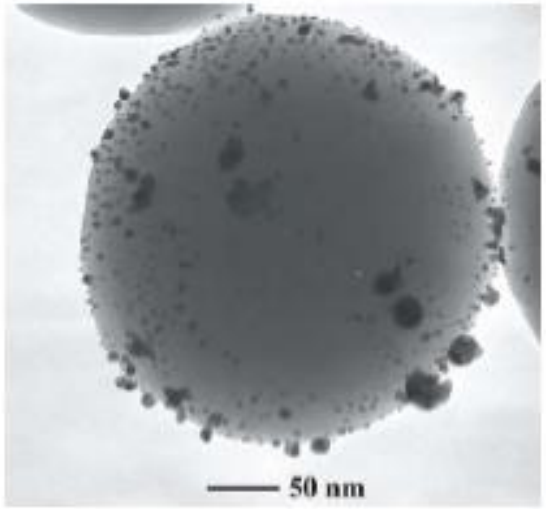
Silica Colloidal Crystal

Dip in nano-Au solution and dry



Air voids

Macroporous Metal



Nanocrystal gold attaches to silica surfaces.

(*J. Am. Chem. Soc.* **121**, 7957, 1999)

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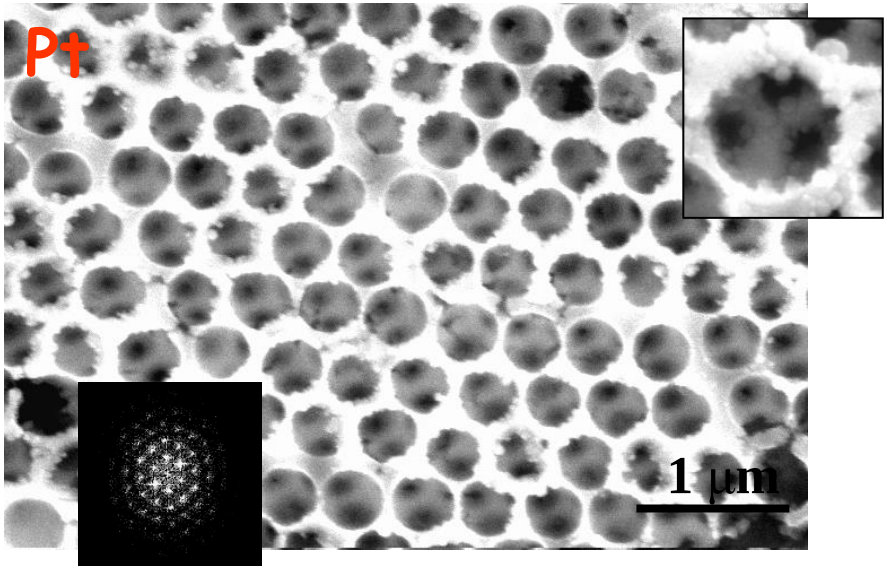
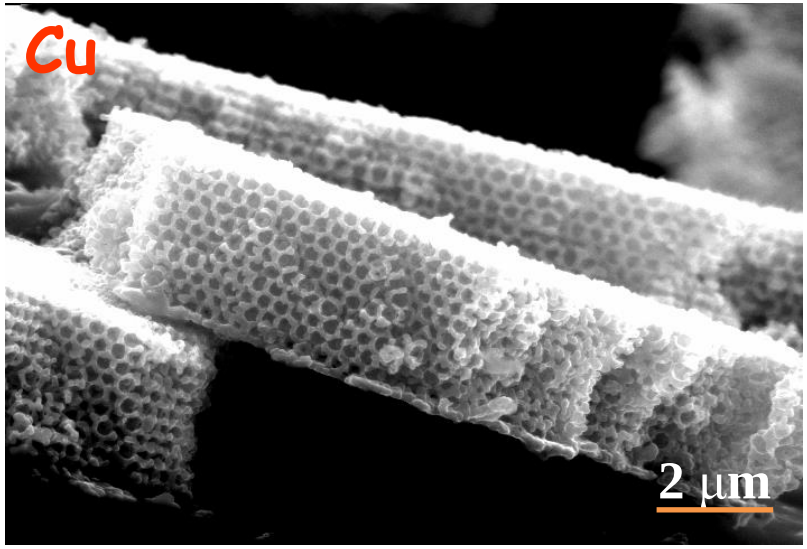
Monolithic Macroporous Metals

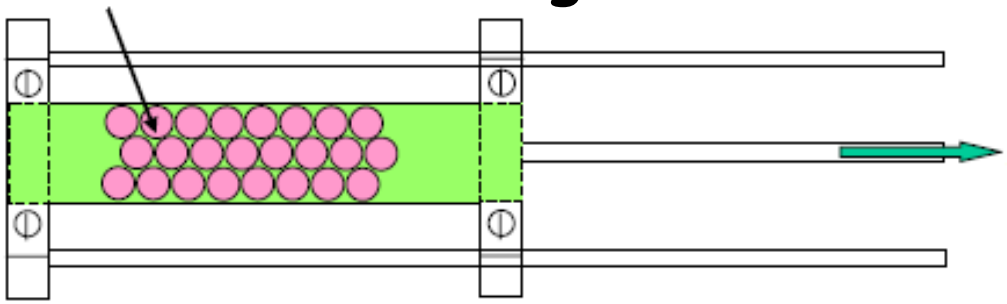


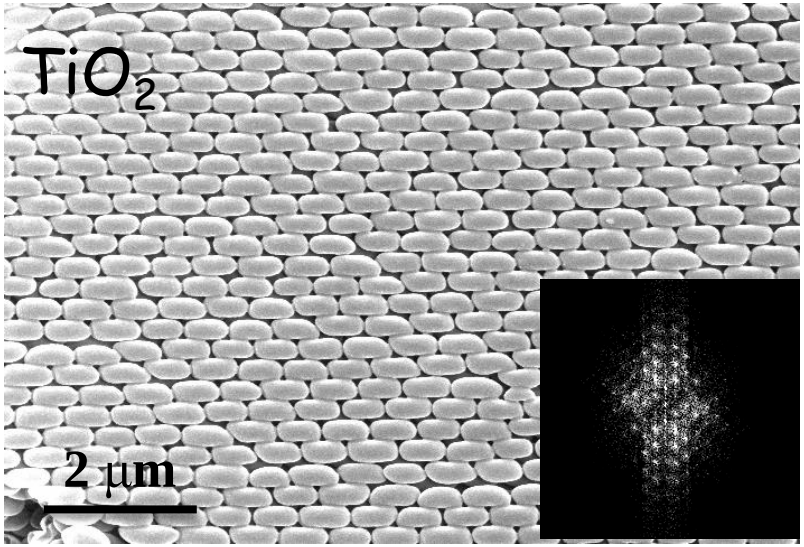


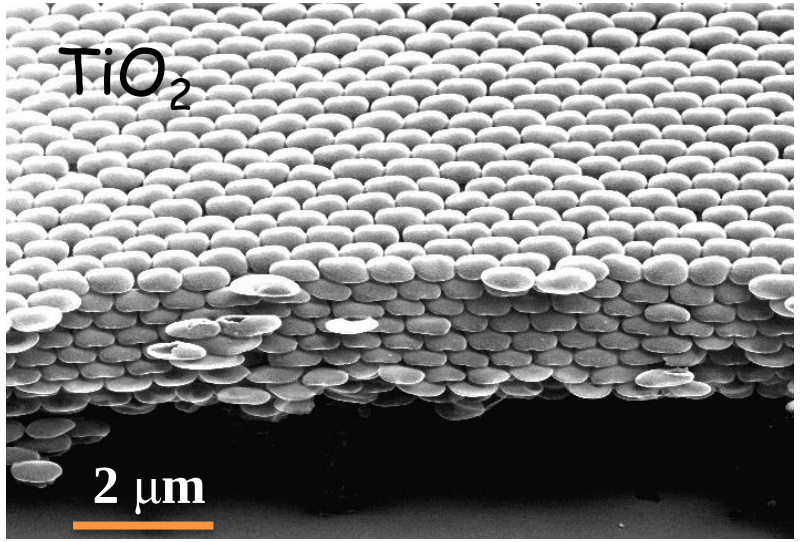
Break the Symmetry – Elliptical Spheres

Macroporous polymer

T > Tg







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Nature is the Ultimate Nanotechnologist
Displays & Vapor Detectors

Desert Spider Beetle

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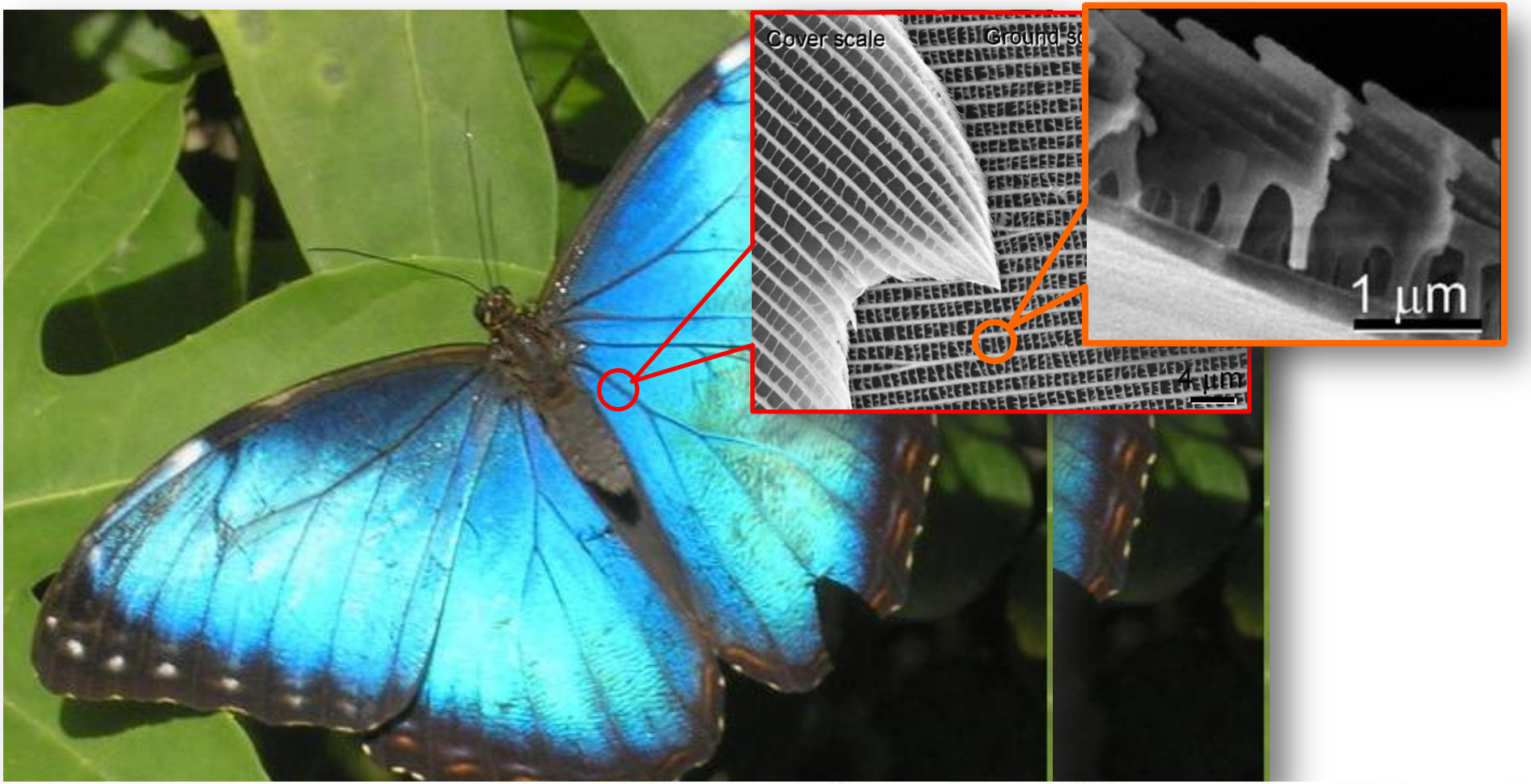
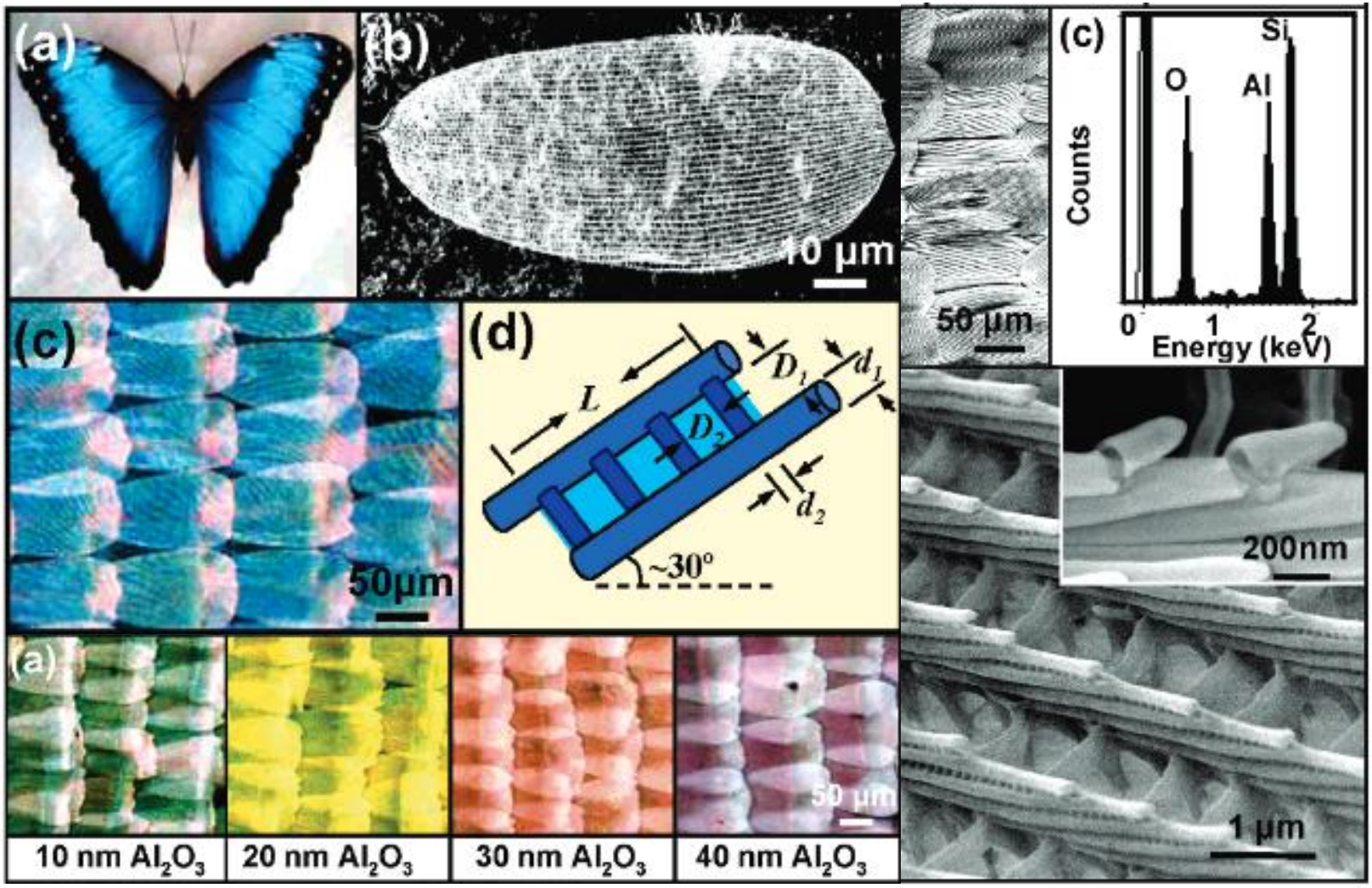
Butterfly Wings



Circularly Polarized Wave Metamaterials



Z. Wang et al., *Nano Lett.*, 10, 2325 (2006)

Bragg's Diffraction

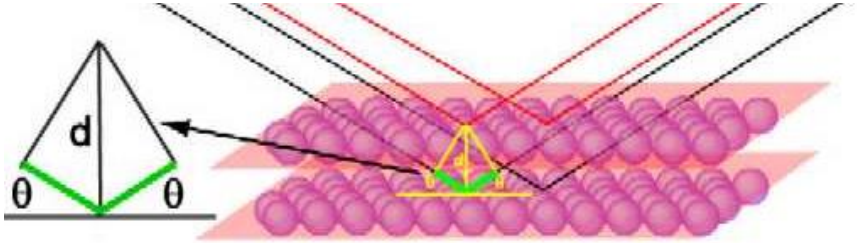
Bragg's Law

$\lambda = 2n_{avg} d \sin\theta$

$\lambda_{max} = 2n_{avg} d$

n - Refractive index

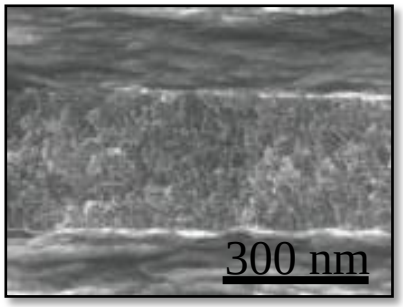
d - Distance between planes

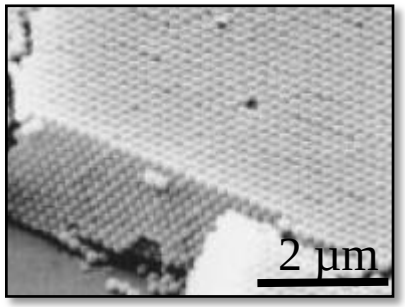


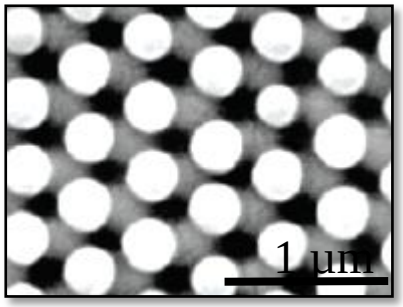
Key Requirements:

1. Particle Spacing < 1 μm
2. Long-Range Periodic Structure

Clay/ TiO_2 Composite **Convective Assembly** **Spin-Coating**





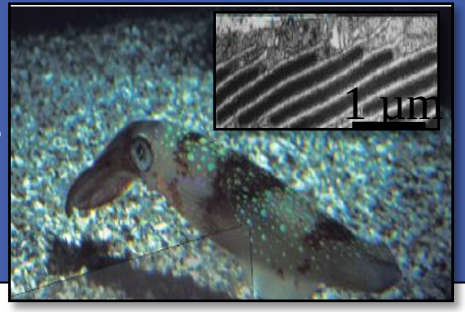


Ozin, G. et al, *Adv. Mater.* (2008)

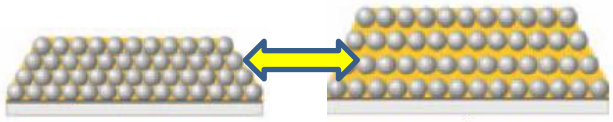
Jiang, P. et al, *Chem. Mater.* (1999)

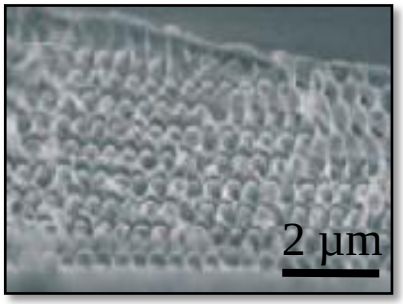
Jiang, P. et al, *J. Amer. Chem. Soc.* (2004)

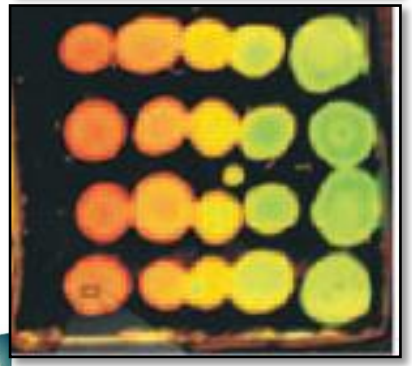
Color Tunable Displays



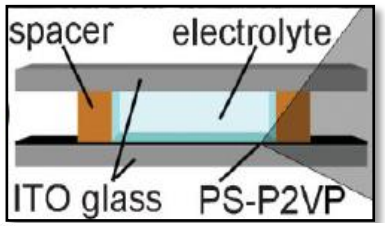
Solvent Swelling **Electrochemical Reaction** **Magnetic Force**

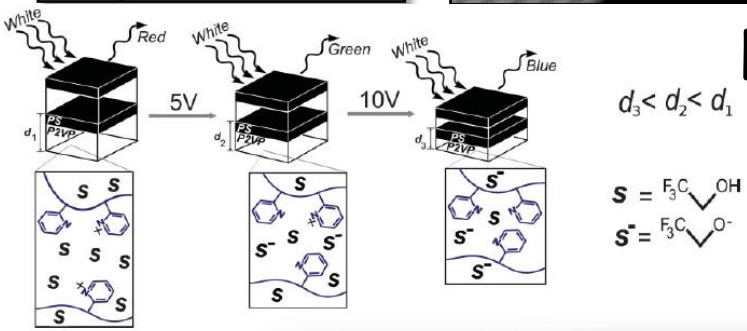


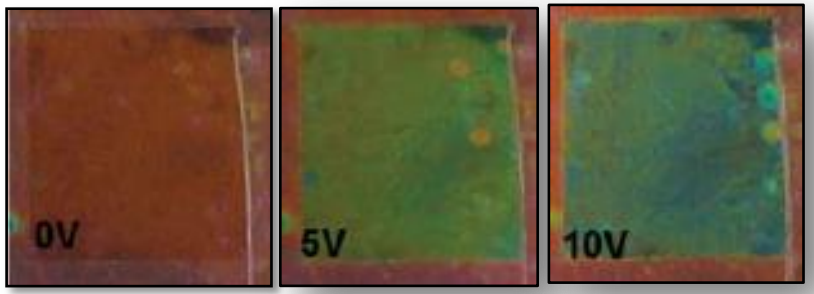




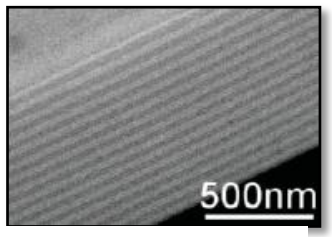
Ozin, G. et al., *Nat. Mater.* (2007)

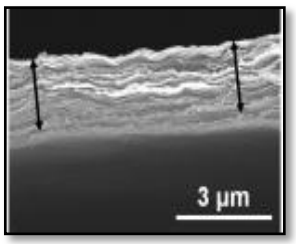




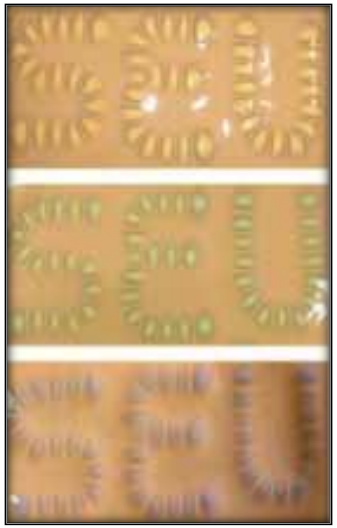


Thomas, E. et al., *Adv. Mater.* (2009)





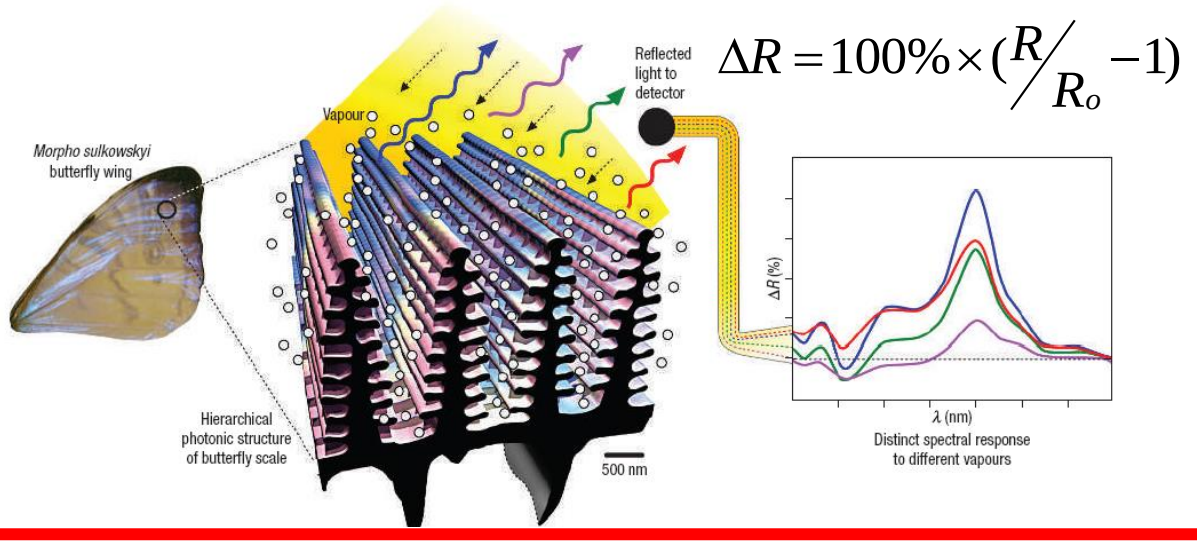
Fe_3O_4/PS Composite



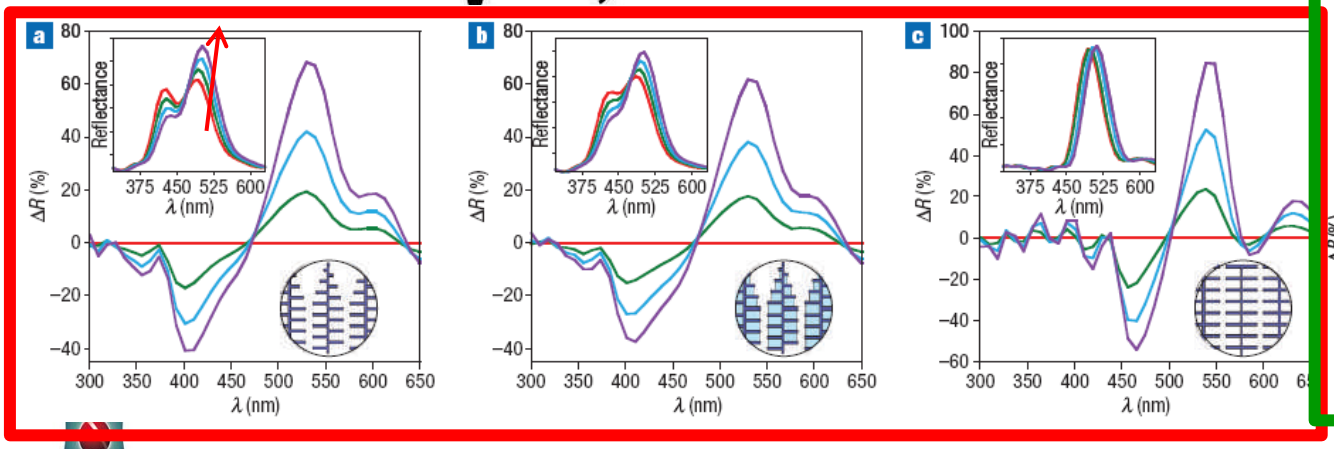
Gu, Z. et al., *Macro. Rapid Comm.* (2009)

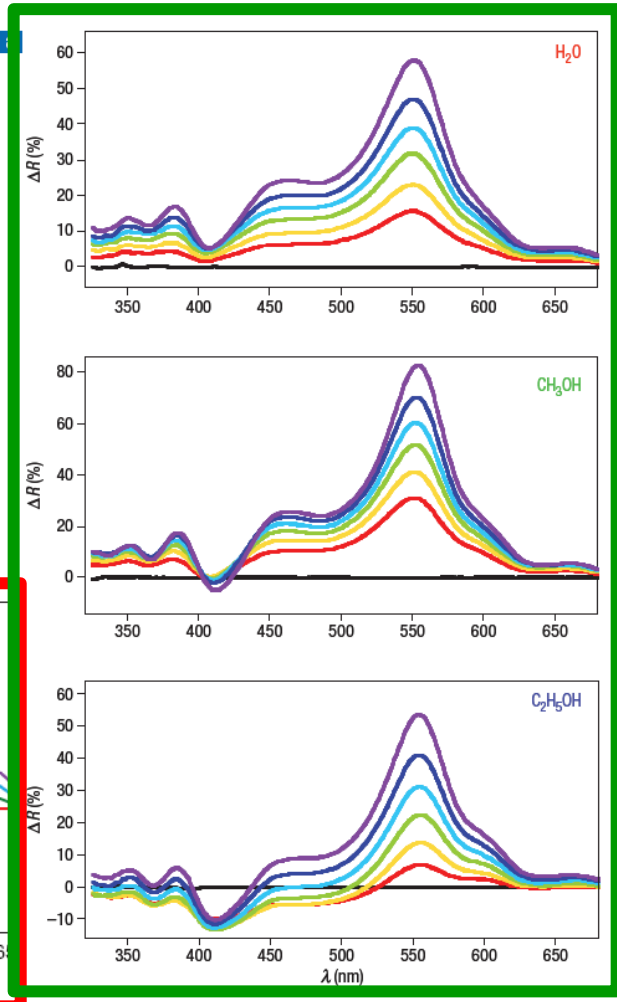
Commercial / Alarm Signs

Butterfly Wings in Chemical Vapors



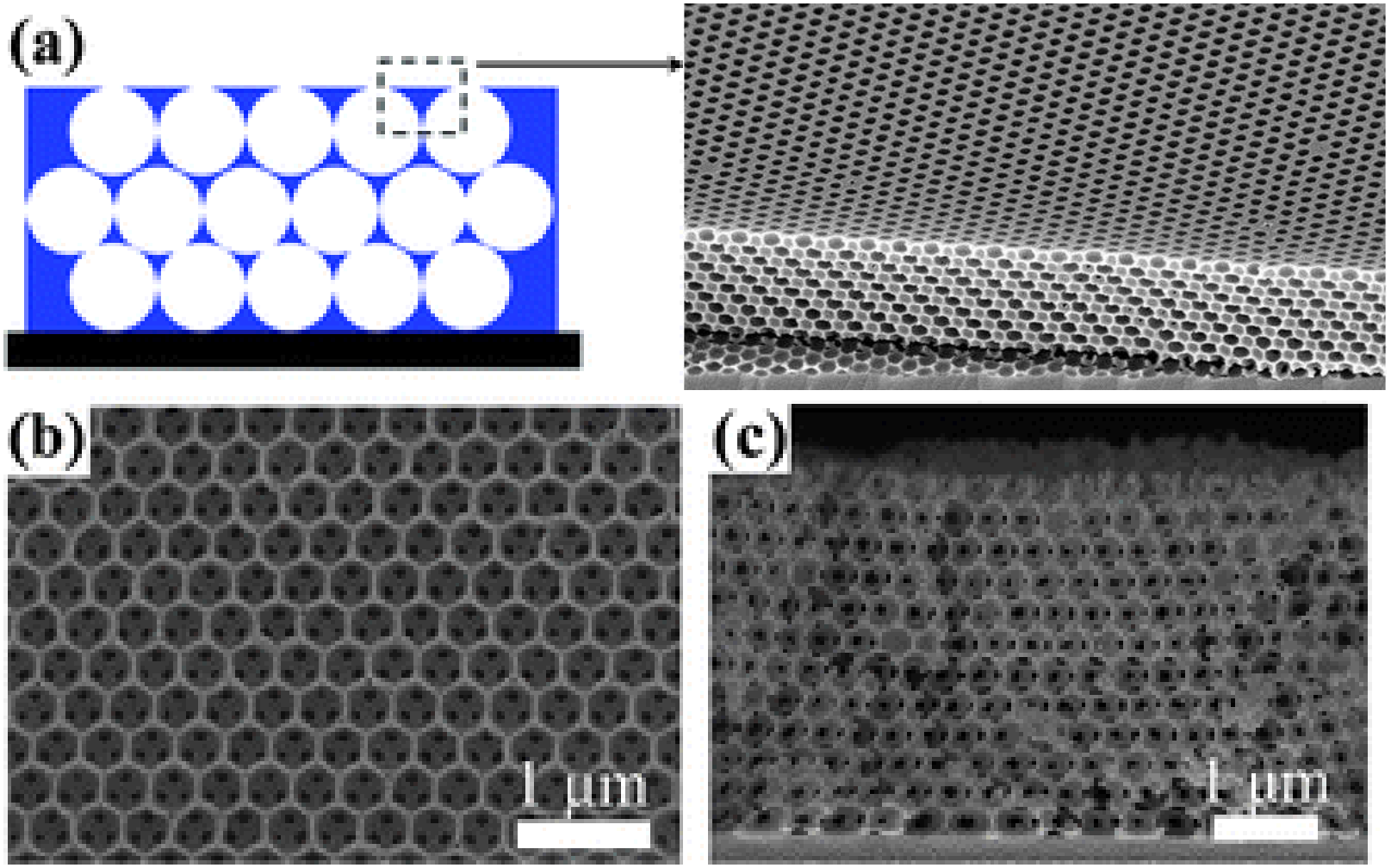
$$\Delta R = 100\% \times (R/R_o - 1)$$





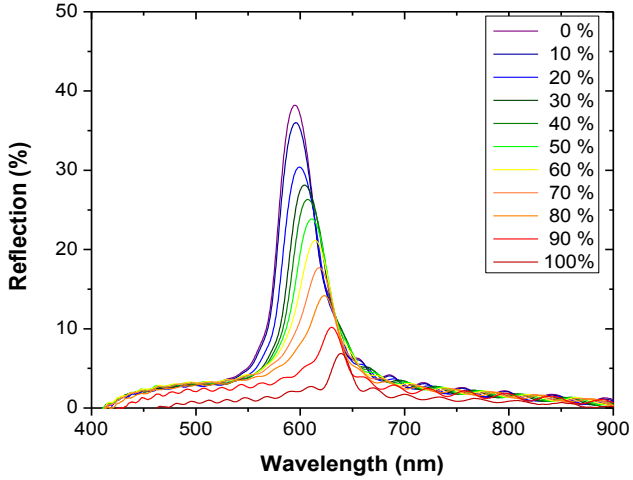
Potyrailo, R. A. et al., *Nature Photonics* (2007)

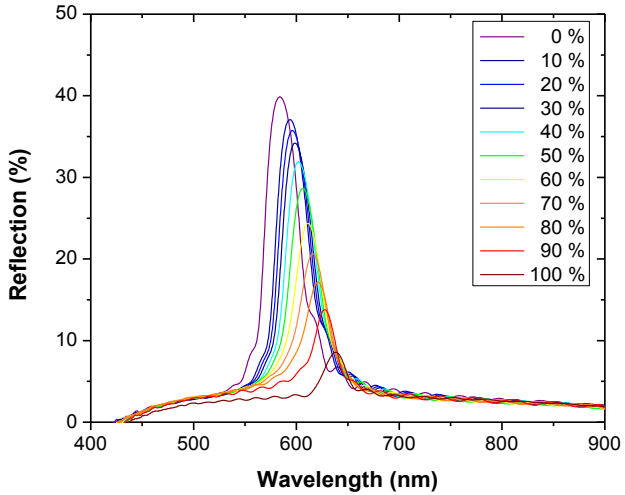
Polymeric Photonic Crystals

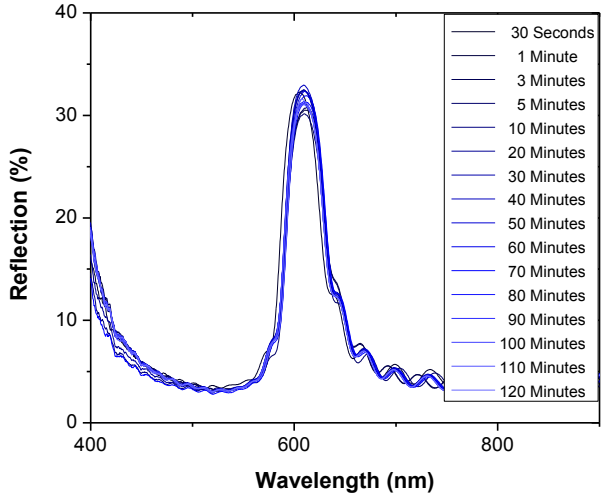


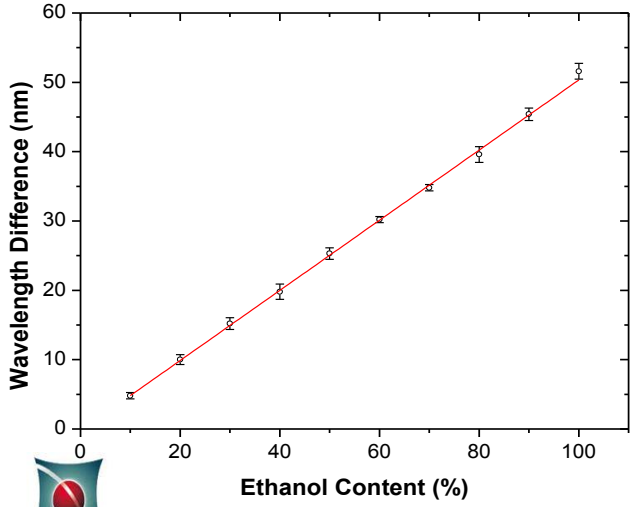
H. Yang et al., *Langmuir*, 26, 12598 (2010)

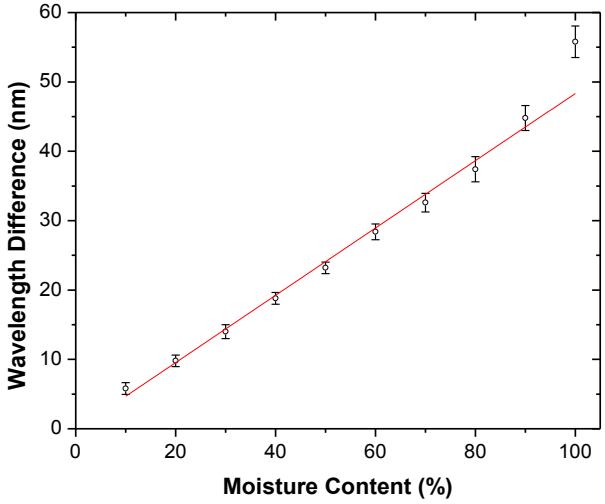
Photonic Crystals in Chemical Vapors

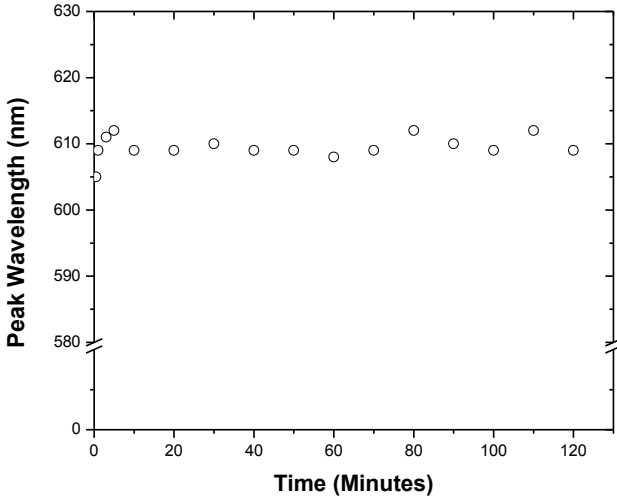








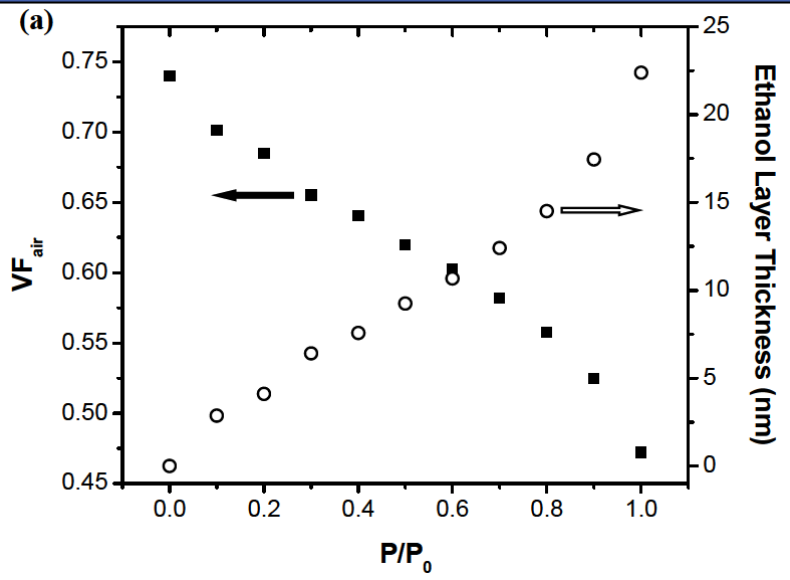


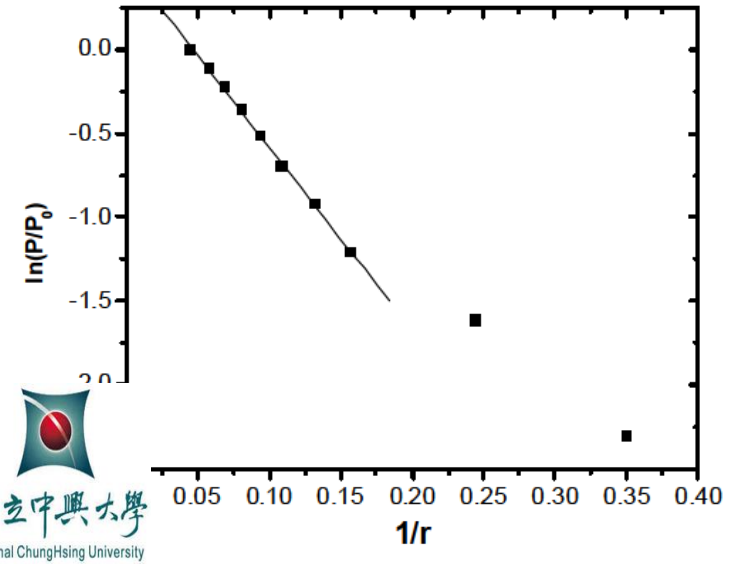


Ethanol **Water**

H. Yang et al., *Appl. Phys. Lett.*, 98, 011104 (2011)

Kelvin's Equation

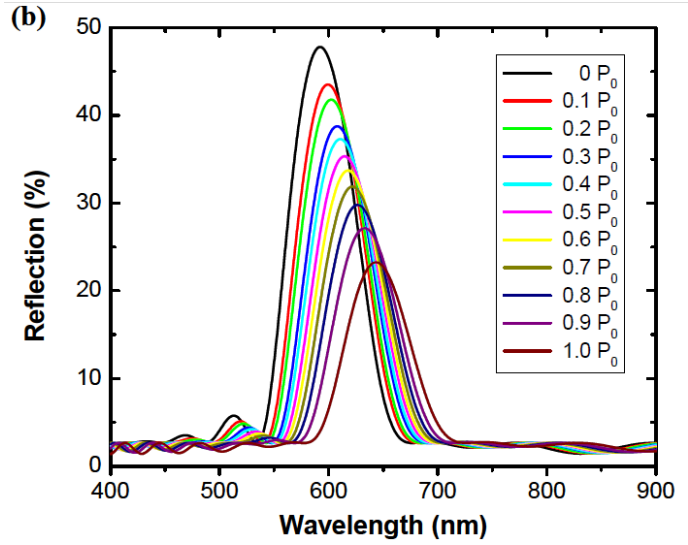




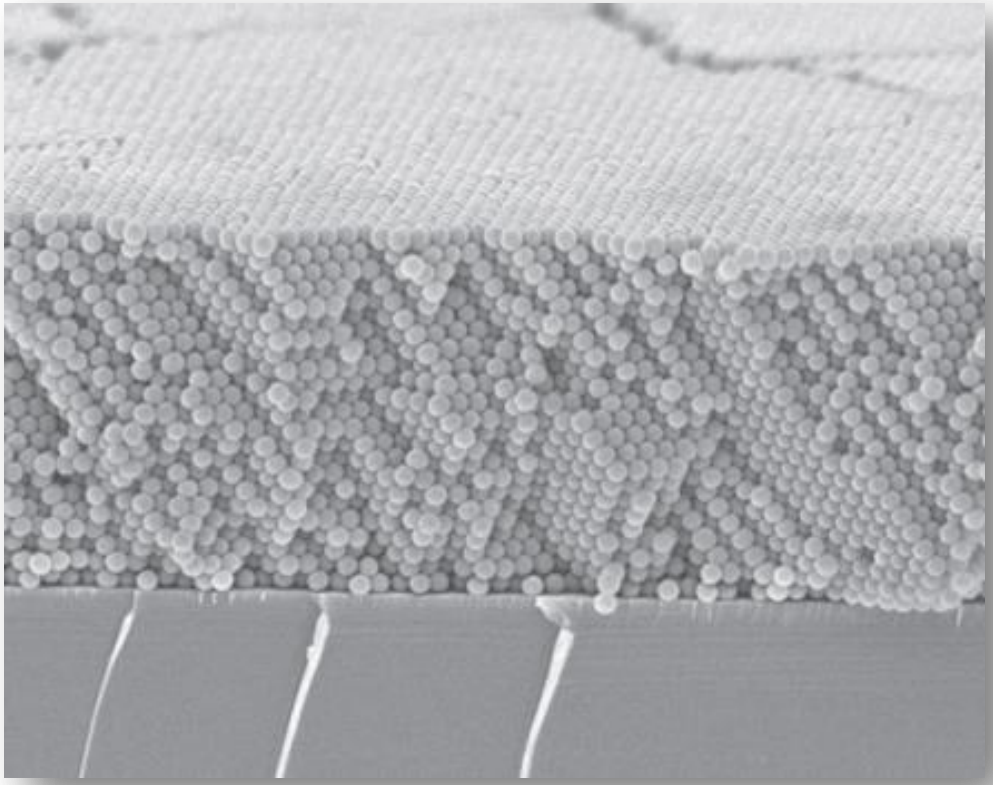
Kelvin's Equation

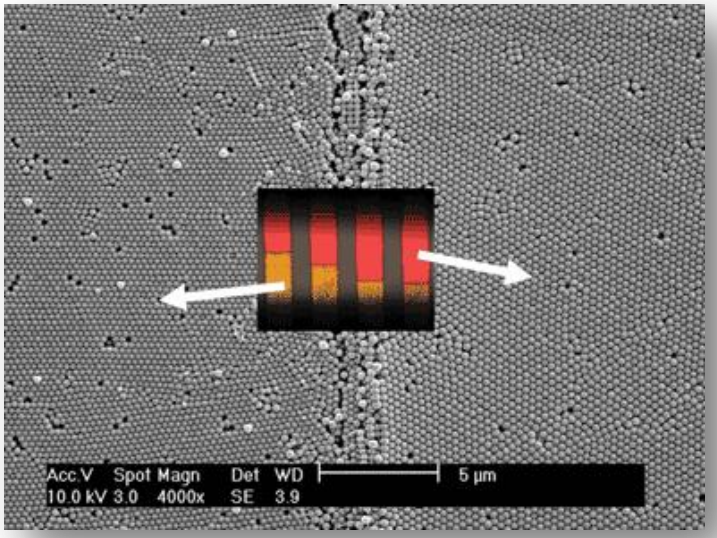
$$ln\frac{P}{P_o} = -\frac{2\gamma V_m}{rRT}$$

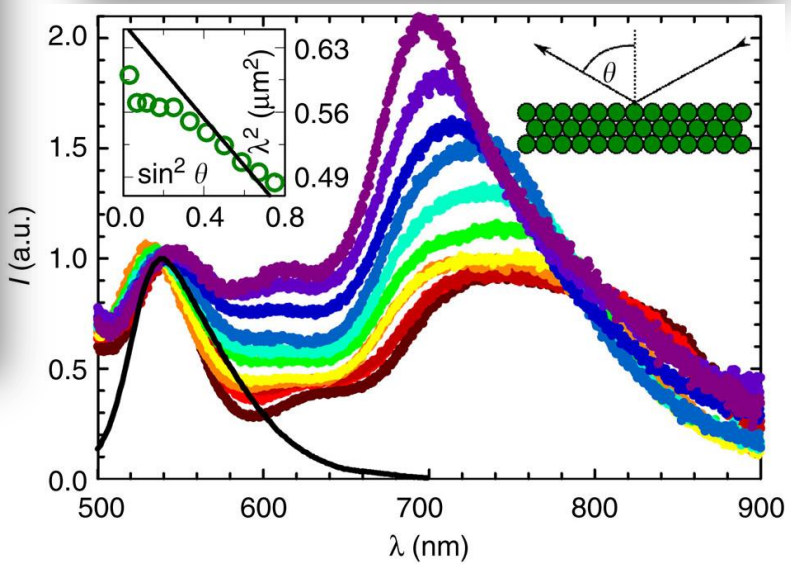
P - Vapor Pressure
Po - Saturated Vapor Pressure
γ - Surface Tension
Vm - Molar Volume
R - Gas Constant
r - Radius of the Cavity
T - Temperature (K)



Silica Colloidal Crystals







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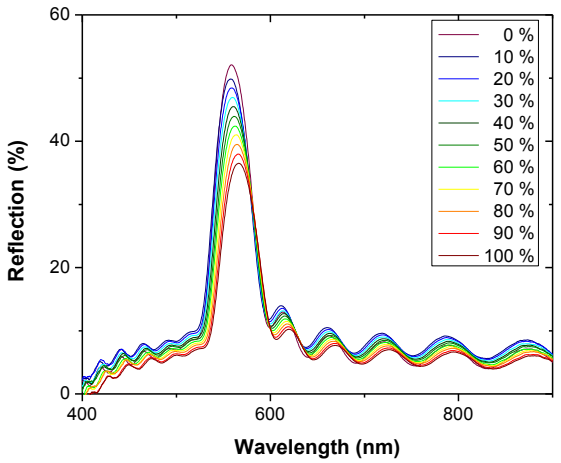
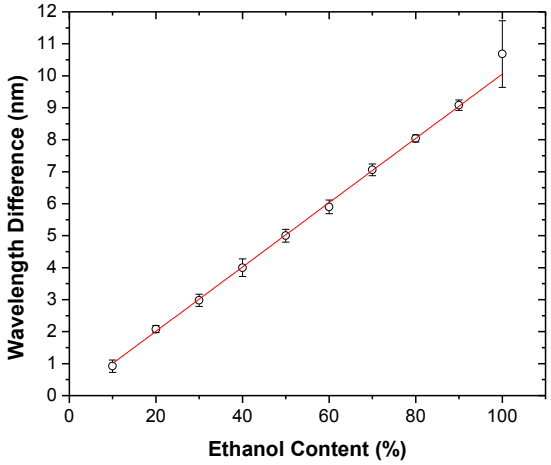
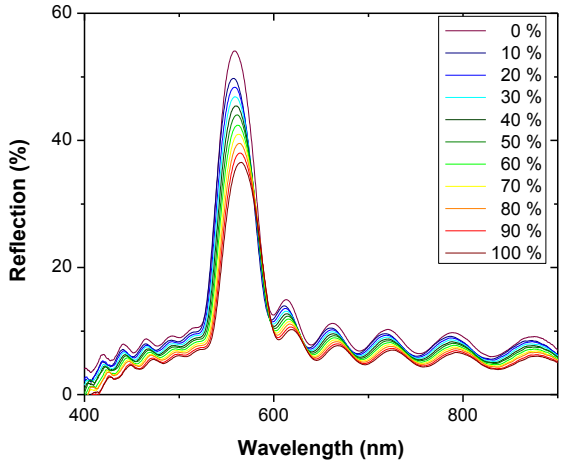
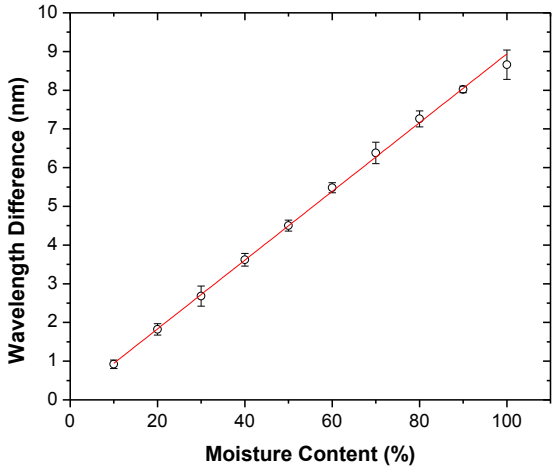
Colloidal Crystal-Based Vapor Detectors



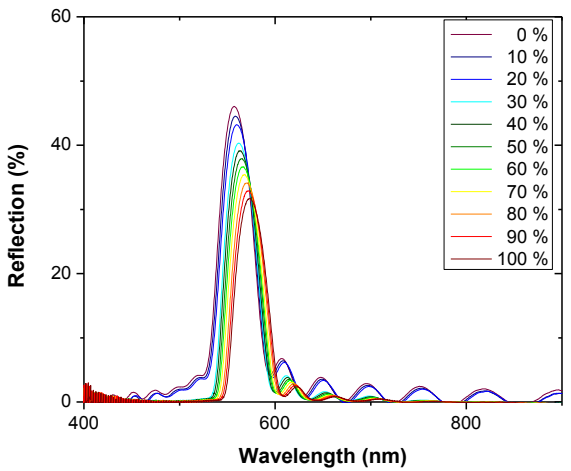


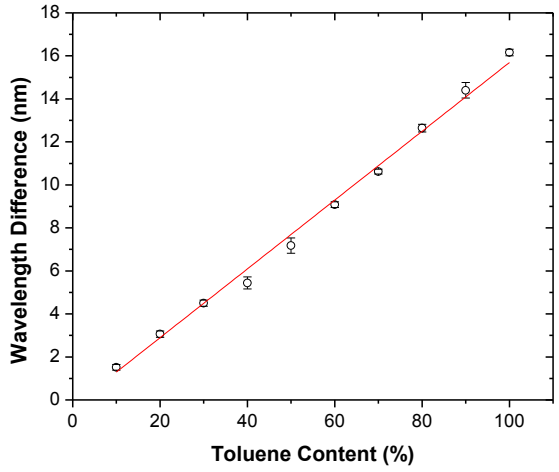
Ethanol





Water





Toluene

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Yang, H. et al., *J. Colloid Inter. Sci.* 370, 11 (2012)

Vapor Detector Applications