Synthesis and Applications of Colloidal Crystals

Lucas B. Thompson Materials Literature Seminar October 14, 2004

Colloids have long been a crucial part of materials chemistry and are an important part of everyday life from paints to ceramic precursors to cosmetics[1]. Recently colloids have taken on a new importance in the fields of catalysis[2,3], sensors[4-6], and optical displays[7-9]. In 1987, Yablonovitch[10] and John[11] both theorized that a regular three-dimensional array of colloidal spheres would show interesting photonic properties. These regular arrays of colloidal spheres have since been termed colloidal crystals (Figure 1). Colloidal crystals can also be backfilled and then removed to form an inverse opal structure (Figure 2)

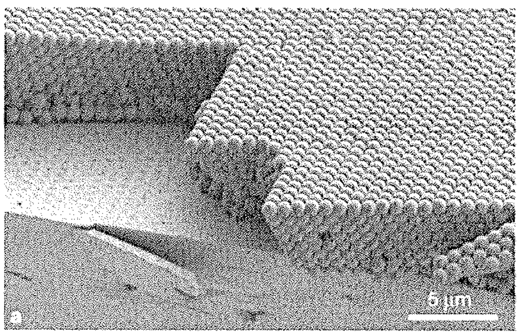

Figure 1

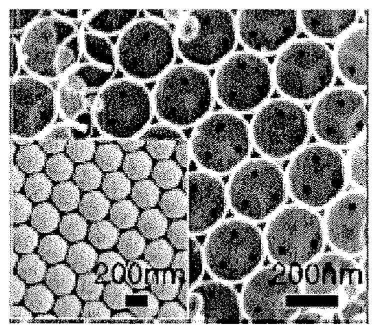

Figure 2

Most of the current research in the realm of colloidal crystals is focused on the assembly and properties of the crystals that are formed. Typically the focus of the colloidal crystal films over large areas. Although research devoted to the assembly of the colloidal crystals has been broad and encompassing there are still a myriad of problems involved in producing a colloidal crystal with sufficiently low defect density to exhibit a full photonic band gap in the visible region, which is needed for use in optical computing and telecommunications devices.

When colloidal crystals were first theorized the functions in mind were directly related to optical computing and telecommunications. Recently, the realization that colloidal crystals might not be the best way to fabricate devices that function in this realm has prompted researchers to look for new applications for these colloidal crystals. These applications lie in the areas of sensors, catalyst supports and optical displays.

One of the applications that is especially interesting is the ability for the colloidal crystals to be used as biosensors in high ionic strength environments that mimic the body[4-6]. These biosensors are able to detect a wide variety of analytes such as lead[5], creatine[6], and glucose[4] in solution based on the changes in lattice spacing of the colloidal crystals due to the swelling or contraction of the polymer or hydrogel that the colloidal crystal array is embedded in. The changes in lattice spacing will shift the wavelength of reflected light based on Bragg's law. Since regular arrays of colloids display extreme iridescence it is not surprising that research has been directed towards making these into optical displays. These optical displays also function by the swelling or contraction of the polymer that the colloidal crystal is embedded in[7-9]. Another application that relies on the ability to back fill the open spaces in the colloidal crystal with another material is the fabrication of catalysts supports (Figure 2)[2,3].

References:

1. Xia, Y.; Gates, B.; Yin, Y.; Lu, Y. "Monodispersed colloidal spheres: Old Materials with New Applications" *Adv. Mater.* **2000**, *12*, 693-713.

2. Al-Daous, M.A.; Stein, A. "Preparation and Catalytic Evaluation of Macroporous Crystalline Sulfated Zirconium Dioxide Templated with Colloidal Crystals" *Chem. Mater.* **2003**, *15*, 2638-2645.

3. Yu, J-S.; Kang, S.; Yoon, S.B.; Chai, G. "Fabrication of Ordered Uniform Porous Carbon Networks and their Applications to a Catalyst Supporter" *J. Am. Chem. Soc.* **2004**, *124*, 9382-9383.

4. Alexeev, V.L.; Sharma, A.C.; Goponenko, A.V.; Das. S.; Lednev, I.K.; Wilcox, C.S.; Feingold, D.N.; Asher, S.A. "High Ionic Strength Glucose-Sensing Photonic Crystals" *Anal. Chem.* **2003**, *75*, 2316-2323.

5. Reese, C.E.; Asher, S.A. "Photonic Crystal Optrode Sensor for Detection of Pb^{2+} in High Ionic Strength Environments" *Anal. Chem.* **2003**, *75*, 3915-3918.

6. Sharma, A.C.; Jana, T.; Kesavamoorthy, R.; Shi, L.; Virji, M.A.; Finegold, D.N.; Asher, S.A. "A General Photonic Crystal Sensing Motif: Creatine in Bodily Fluids" *J. Am. Chem. Soc.* **2004**, *126*, 2971-2977.

7. Fudouzi, H.; Xia, Y. "Colloidal Crystals with Tunable Colors and their Use as Photonic Papers" *Langmuir* **2003**, *19,* 9653-9660.

8. Arsenault, A.; Fournier-Bidoz, S.; Hatton, B.; Miguez, H.; Tetreault, N.; Vekris, E.; Wong, S.; Yang, S.M. Kitaev, V.; Ozin, G.A. "Towards the synthetic all-optical computer: science fiction or reality?" **J. Mater. Chem**. **2004**, *14*, 781-794.

9. Arsenault, A.; Miguez, H.; Kitaev, V.; Ozin, G.A.; Manners, I. "A Polychromic, Fast response Metallopolymer Gel Photonic Crystal with Solvent and Redox Tunability: A Step Towards Photonic Ink (P-ink)" *Adv. Mater.* **2003**, *15*, 503-507.

10. Yablonovitch, E. "Inhibited Spontaneous Emission In Solid State Physics and Electronics" *Phys. Rev. Lett.* **1987**, *58*, 2059-2062.

11. John, S.; Strong Localization of Photons in Certain Disordered Dielectric Superlattices" *Phys. Rev. Lett.* **1987**, *58*, 2486-2489.

12. Stober, W.; Fink, A.; Bohn, E.; "Controlled Growth of Monodispersed Silica Spheres in the Micron Size Range" *J. Colloid. Int. Sci.* **1968**, *26*, 62-69.

13. Wong, S.; Kitaev, V.; Ozin, G.A. "Colloidal Crystal Films: Advance in Universality and Perfection" *J. Am. Chem. Soc.* **2003**, *125,* 15589-15598.

14. Hoogenboom, J.P.; Derks, D.; Vergeer, P; van Blaaderen, A. "Stacking Faults in Colloidal Crystals Grown by Sedimentation" *J. Chem. Phys.* **2002**, *117*, 11320-11328.

15. Hoogenboom,; Retif, C.; de Bres. E.; van de Boer, M.; Van Langen-Suurling, A.K.; Romijn, J.; van Blaaderen, A. "Template-Induced Growth of Close Packed and Non-Close-Packed colloidal Crystals during Solvent Evaporation" *Nano Lett.* **2004**, *4*, 205-208.

16. Vlasov, Y.A.; Bo, X.; Sturm, J.C.; Norris, D.J. "On-chip Natural Assembly of Silicon Photonic Bandgap Crystals" *Nature*, **2001**, *414,* 289-293.

17. Lee, W.; Chan, A.; Bevan, M.; Lewis, J.A.; Braun, P.V. "Nanoparticle-Mediated Epitaxial Assembly of Colloidal Crystals on Patterned Substrates" *Langmuir*, **2004**, *20*, 5262-5270.