Particles 2007

Particle-Based Device Technologies

18-21 August 2007
Delta Chelsea Hotel, Toronto, Ontario, Canada

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General Program Schedule

Registration – Registration Desk (just outside of Mountbatten Halls)

Saturday, August 18
(1800 – 2000) – Opening Reception, Mixer, & Exhibition (Mountbatten A)

Sunday, August 19
(0830 – 1200) – General Session 1 (Mountbatten Hall B)
(1200 – 1400) – Luncheon/Exhibition (Mountbatten Hall A)
(1400 – 1730) – General Session 2 (Mountbatten Hall B)
(1800 – 2000) – Reception/Exhibition (Mountbatten Hall A)

Monday, August 20
(0830 – 1200) – General Session 3 (Mountbatten Hall B)
(1200 – 1400) – Luncheon/Exhibition (Mountbatten Hall A)
(1400 – 1730) – General Session 4 (Mountbatten Hall B)
(1800 – 1930) – Poster Session/Reception/Exhibition (Mountbatten Hall A)

Tuesday, August 21
(0830 – 1200) – General Session 5 (Mountbatten Hall B)
(1200 – 1400) – Luncheon/Exhibition (Mountbatten Hall A)
(1400 – 1730) – General Session 6 (Mountbatten Hall B)

Conference Ends
Map of Meeting Spaces

All Conference activities take place in Mountbatten Halls A and B on the second floor in the south tower. Registration commences Saturday morning, August 18th, at 9 am in the Mountbatten Prefunction area, Mountbatten Court. Registration opens at 8 am Sunday – Tuesday, 19-21 August.
Technical Program

Sunday, August 19, 2007, Morning

General Session 1 (Mountbatten Hall B)

Session Chair: James Adair, Pennsylvania State University

0835 1. Stephen Chamberlain, Invitrogen Corporation
Qdot® Nanocrystals in Biological Applications

0915 2. Iakov Kogan, Panisolar, Inc.
The Application of Nanostructured Composites for Energy Conversion with Dye Sensitized Solar Cells

0945 Break

1015 3. Mitch Winnik, University of Toronto
Polymers as Multidentate Ligands for Transferring Quantum Dots from Organic Solvents into Water

1100 4. Alain Perez, Universite Claude Bernard - Lyon1
Functional Nanostructures from Clusters

1130 5. Yoshitake Masuda, National Institute of Advanced Industrial Science and Technology, Nagoya
Self-assembly Patterning of Colloidal Photonic Crystals and Visible-Light-Emitting Oxide Particles for Next Generation Optical Devices

1155 6. Patrick Hole, NanoSight, Ltd.
Simultaneous Sizing of Nanoparticles by Individually Visualizing and Separately Tracking their Brownian Motion

1200 End of Session

Sunday, August 19, 2007, Afternoon

General Session 2 (Mountbatten Hall B)

Session Chair: Manijeh Razeghi, Northwestern University

1400 7. Heiko O. Jacobs, University of Minnesota
Nanoxerographic Printing and Fringing Field Directed Integration of Nanomaterial Building Blocks

1445 8. Lee Tutt, Eastman Kodak Company
Nanometals and Laser Patterning

1515 Break

1545 9. Ian Morrison, Cabot Corporation
Electrophoretic Display Technology

1630 10. Sameer Sapra, Technical University, Dresden
White Light Emission from Semiconductor Nanocrystals
1700 11. Luigi Martiradonna, Università del Salento
   Colloidal Nanocrystal Based Photonic Device Fabrication
1730 12. Wolfgang Parak, University of Marburg
   Quantum Dot-Based Devices as Cellular Sensors
1800 - End of Session

Monday, August 20, 2007, Morning

General Session 3 (Mountbatten Hall B)

Session Chair: Ian Morrison, Cabot Corporation

0835 13. Tadashi Kawazoe, University of Tokyo
   Nanoparticle-Based Nanophotonics
0915 14. Manijeh Razeghi, Northwestern University
   InAs Quantum Dots for High Performance Thermal Imaging Operating at High Temperature
0945 Break
1015 15. Sandy Asher, University of Pittsburgh
   Polymerized Colloidal Crystalline Array Glucose Sensing
1100 16. Sanjay Banerjee, University of Texas at Austin
   Flash Memory with Nanoparticle Floating Gates
1130 17. Nick Kotov, University of Michigan
   Molecular Assemblies of Nanoparticles: Surprising analogy with proteins and new Optical Properties
1200 End of Session

Monday, August 20, 2007, Afternoon

General Session 4 (Mountbatten Hall B)

Session Chair: Frank Koo, Minghsin University of Science and Technology

1400 18. Gregory Scholes, University of Toronto
   Organic Solar Cells and Challenges for Nanoscience
1445 19. Paul Braun, University of Illinois, Urbana
   Colloidal Crystal-Based Photonic Band Gap Waveguides
1515 Break
1545 20. Jeffrey Urban, University of Pennsylvania
   Designing Multifunctional Binary Nanocomposites for Direct Energy Conversion Applications
1630 21. Weijia Wen, Hong Kong University of Science and Technology
   Field-Induced Characteristics of Nanoparticles with Applications to Thin Film Displays
1700 **22. Hans-Gerd Boyen**, University of Hasselt, Diepenbeek  
Micellar Approach to Magnetic Ultra-high Density Data Storage Media  
1730 - **End of Session**

**Monday, August 20, 2007, Evening**

**Poster Session (Mountbatten Hall A)**  
Session Chair: **Melanie Martin**, Particles Conference  
1800-1930

32. **James H. Adair**, Pennsylvania State University  
Calcium Phosphate Nanocolloids for Bioimaging and Drug Delivery in Physiological Conditions

33. **Roberto Fenollosa**, Universidad Politécnica de Valencia and CISC  
Silicon Colloids

34. **Scott Harvey**, Ashland Specialty Chemical Company  
Aspects of Latex Particle Size Control for Improved Water Blush Resistance

35. **Chong-Tai Kim**, Korea Food Research Institute  
Preparation of Nanoemulsions and Nanoparticles as Delivery Systems for Bioactive Ingredients in Food

36. **Sang Man Koo**, Hanyang University  
Multi-Functional Hybrid Silica Particles for Nitrogen Chemosensors

37. **Wanjuan Lin**, University of Toronto  
Surface Modification of Lead Sulfide Nanocrystals with Poly(Acrylic Acid) through a Ligand Exchange Process

38. **Nadejda Krasteva**, Sony Deutschland GmbH  
Gold Nanoparticle/Organic Composite Chemiresistive Sensors: Vapor Sensitivity and Mechanism of Sensing

39. **Michael Papantonakis**, Naval Research Laboratory  
Laser-Assisted Deposition of Thin Layers of Functionalized Nanoparticles: A New Coating Technology

40. **Chantal Paquet**, National Research Council, Canada  
Multifunctional Nanostructured Composite Colloids Prepared Using a Miniemulsion Approach

41. **Andrew Parker**, Molecular Profiles Ltd.  
Adsorption of Protein Antigens onto PLG Microparticles Studied by X-ray Photoelectron Spectroscopy (XPS) and Time of Flight Secondary Ion Mass Spectrometry (ToF-SIMS)

42. **Marina A. Petrukhina**, State University of New York at Albany  
Different Synthetic Strategies toward CdSe Quantum Dot-Based Materials for Hydrocarbon Detection

43. **Sean Race**, XiGo Nanotools LLC  
A New Approach to Directly Measure the Surface Area of Nanoparticulate Disperions Using NMR
44. Lei Shen, University of Toronto
   Loading Quantum Dots into Thermoresponsive Microgels by Reversible Transfer from Organic Solvent to Water

45. Kanchana Somaskandan, National Research Council, Canada
   Water Soluble Superparamagnetic Iron-Based Core-Shell Nanoparticles as Cell Capture Probes

46. Matthew E. Staymates, National Institute of Standards and Technology
   Production of Polymer Microsphere Particle Standards Containing Trace Explosives Using Inkjet Printing and Co-Flow Nozzle Technology

47. John Texter, Eastern Michigan University
   Solvent Reversible Poration in Ionic Liquid Copolymers

48. Mingfeng Wang, University of Toronto
   Bright Water-Soluble Quantum Dots Passivated by Multidentate Block Copolymers

Tuesday, August 21, 2007, Morning

General Session 5 (Mountbatten Hall B)

Session Chair: Lee Tutt, Eastman Kodak Company

0835 23. Clinton Ballinger, Evident Technologies
   Product and Market Development in Quantum Dot Technologies

0915 24. Zhihao Yang, NanoMas Technologies
   Nanoparticle Inks for Printed Electronics and Displays

0945 Break

1015 25. Eugenia Kumacheva, University of Toronto
   From Multilayer Particles to Nanostructured Material for the Recording of Biometric Features

1100 26. Kristoffer Almdal, Risø National Laboratory
   Synthesis and Properties of Fluorescent Nanoparticles for Living Cell Metabolite Detection

1130 27. Seong Jin Koh, University of Texas at Arlington
   Large-Scale and Precise Nanoparticle Placement via Electrostatic Funneling for Data Storage and Devices

1200 End of Session
Tuesday, August 21, 2007, Afternoon

General Session 6 (Mountbatten Hall B)

Session Chair: John Texter, Eastern Michigan University

1400 28. Jan Sumerel, Fujifilm Dimatix
   Using Piezoelectric Printing to Pattern Nanoparticle Thin Films
1445 29. Horng-Show (Frank) Koo, Minghsin University of Science and Technology
   Nanoparticle Colorants and Inkjet Printing of Color Filters in TFT-Based Displays
1515 Break
1545 30. Tanya Kosc, University of Rochester
   Polymer Cholesteric Liquid Crystal Flakes: A Novel Medium for Electro-Optic
   Particle-Based Technologies
1615 31. Jason Clifford, University of Toronto
   High-Performance Colloidal Quantum Dot Optoelectronic Devices
1645 Panel Discussion - Sandy Asher, Clint Ballinger, Stephen Chamberlain,
   Iakov Kogan, Jan Sumerel, Zhihao Yang
   Discussion of Conference Issues, Bench to Market Tech Transfer
1730 End of Conference
Qdot bioconjugates enable life-science researchers to simultaneously image multiple biological targets with exceptional photostability. Studies of single biological molecules in live cells can be carried out with sensitivities and timescales previously impossible with traditional fluorescence techniques, yielding new information about biomolecules within cells. Qdot bioconjugates are gaining increasing popularity as important fluorescent probes for a variety of high-impact biological applications. The unique spectral properties of quantum dots allow simultaneous single-wavelength excitation and multiplexed detection at levels of sensitivity previously attained only with enzymatic amplification. Their photostability allows repeated analysis of samples from months to years. The application of commercially available Qdot bioconjugates to a variety of biological problems, including molecule trafficking in live cells over extended periods of time, in vivo animal imaging, and multicolor biomarker detection in cells and tissues will be presented, along with examples of other applications of the nanocrystal technology including Western blotting and flow cytometry.

The Application of Nanostructured Composites for Energy Conversion with Dye Sensitized Solar Cells

Iakov Kogan, Panisolar Inc, Etobicoke, ON, M9A 4M5, Canada, jacob@panisolar.com

Concerns about energy are greater today than at any time since the oil embargo of the 1970. The development of solar cells is the obvious strategy in the search of sustainable energy sources. One of the promising approaches is the application of dye sensitized solar cells (DSSC) relatively new and prospective devices. DyeSol, Konarka Technologies, Solaris Nanoscience and other companies are actively trying to develop and improve a new type of solar cell that achieves more than 11% conversion efficiency. A brief review of the latest development in the area of DSSC will be presented in this report. It will be discussed the charge separation at the interface of the titanium dioxide electrode and liquid electrolyte, the principles of design, and energy transfer from exited dye to titanium dioxide electrode. The application of nanostructured materials for DSSC was suggested by Graetzel group in 1991. According to the results of research a monolayer of dye deposited on the surface of titanium dioxide absorbs photon followed by electron transfer into the excited state. Then electron is injected into the conduction band of titanium dioxide. At the same time a positive charged dye molecule oxidizes a redox couple in electrolyte. The redox couple is regenerated at the counter electrode covered with a catalyst. DSSC is an excellent example of the dramatic effect of nanostructured materials on the performance of the energy conversion system. The conditions of
The synthesis of titanium dioxide nanoparticles and sintering techniques significantly influence the size, surface area, porosity and crystal structure of the nanocomposite electrodes, while these parameters in turn affect the solar cell performance. The natures of dye and nanocomposite oxide are also important to realize high efficient DSSC. The choice of electrolyte is another important factor that greatly affects the stability and efficiency of the dye solar cells. Quasi solid state DSSC with ionic liquid electrolyte demonstrated efficiency 6.6 %, gel and polymer semisolid electrolytes essentially improved the quality of the DSSC, their stability and flexibility. The application of crosslinked polyethylene oxide –co-propylene oxide trimethacrylate oligomers resulted in the formation of efficient devices (8.1 %) under AM 1.5 irradiation. The performance of DSSC depends on the kinetics of electron transfer. One of the major limiting factors of these cells is the back electron transfer from titanium dioxide to dye and redox couple in electrolyte.

**General Session 1**

3 POLYMERS AS MULTIDENTATE LIGANDS FOR TRANSFERRING QUANTUM DOTS FROM ORGANIC SOLVENTS INTO WATER

Mitchell A. Winnik, Department of Chemistry, University of Toronto, Toronto, Ontario Canada M5S 3H6; mwinnik@chem.utoronto.ca

The highest quality colloidal semiconductor nanocrystals (quantum dots, QDs) are prepared at high temperature in the presence of coordinating organic ligands such as trioctylphosphine or oleic acid. The QDs obtained are normally soluble in organic solvents but not in water. Most intended applications, such as biological imaging, require stable colloidal solutions in aqueous media. Thus one of the challenges is to be able to modify the QD surfaces to manipulate their compatibility with different media. Our approach envisions polymers as multidentate ligands, in which treatment of the QDs in organic solvents results in replacement of passivating ligands on the QD surface. These modified QDs can then be dissolved or dispersed in polar media such as alcohols or water. In this talk I will describe our work, in collaboration with my colleague Greg Scholes, on homopolymers and block copolymers polymers with 3° amine pendant groups as ligands for CdSe QDs and polymers with –COOH pendant groups as ligands for PbS QDs. I will also present recent work on ligand exchange with functional polymer microgels and discuss how these hybrid materials open the way to produce water-borne QD-inks and QD-paints.
General Session 1

4 FUNCTIONAL NANOSTRUCTURES FROM CLUSTERS

The Low Energy Cluster Beam Deposition technique (LECBD) is used to produce original cluster assembled nanostructures. This technique consists of depositing the very low energy neutral clusters produced in the gas phase using a combined laser vaporization-inert gas condensation source. In the typical cluster-size range considered in these experiments (from a few tens up to a few thousands of atoms corresponding to diameters from 1 to a few nm), low energy clusters are not fragmented upon impact on the substrate leading to a characteristic nucleation and growth process of the cluster-assembled nanostructures. Nanostructured systems of any kind of materials (metallic, covalent, oxides) are prepared by this technique, and both the characteristic LECBD-morphology and the memory effect of the original free cluster structures and properties are at the origin of their unique properties. After a brief review of techniques to produce, analyse, and deposit clusters in the LECBD regime, some specific aspects of the nucleation and growth process which governs the cluster-assembled nanostructure formation will be presented. Some characteristic examples of functionalized cluster-assembled materials prepared by LECBD will be also described: i.e. magnetic nanostructures from Co-based nanoclusters (i.e. Co-Pt, Co-Sm) for applications to high density memory devices and spintronics, and photoluminescent sesquioxide nanoclusters (i.e. Gd₂O₃:Eu³⁺) for applications to nano-optics. In the context of applications, recent results on the preparation of 2D-organized arrays of cluster-assembled nanostructures by LECBD on functionalized substrates in view to produce high integration-density devices (~Tbits/in²) will be reported.

General Session 1

5 SELF-ASSEMBLY PATTERNING OF COLLOIDAL PHOTONIC CRYSTALS AND VISIBLE-LIGHT-EMITTING OXIDE PARTICLES FOR NEXT GENERATION OPTICAL DEVICES.
Yoshitake Masuda, National Institute of Advanced Industrial Science and Technology (AIST), Moriyama, Nagoya, 463-8560, Japan; masuda-y@aist.go.jp

We developed self-assembly processes to prepare micropatterns of oxide particulate films and particle assemblies to contribute to development of particle-based device technologies. Site-selective deposition of UV- and visible-light-emitting ZnO crystals was successfully achieved in an aqueous solution at low temperature. Molecular recognition was effectively utilized for patterning of ZnO crystals on self-assembled monolayers (SAM). Crystalline ZnO was further controlled to have different morphologies such as cylindrical hexagonal rods, ellipses, or multineedle shapes by changing the solution conditions to improve the photoluminescence properties. All of the morphologies emitted strong photoluminescence in UV and visible regions with different
emission spectra. The novel process shows the high potential of solution processes for fabricating nano/microdevices constructed from crystalline materials for visible-light-emitting devices. A micropattern of europium-doped yttrium oxide thin films was further developed using a SAM. The thin film was transformed into the crystalline phase by annealing at 800 °C for 1 h. Europium-doped yttrium oxide films showed red emission (611 nm) due to photoluminescence excited by 266 nm. The deposition and micropatterning of visible-light-emitting europium-doped yttrium oxide was successfully realized in an aqueous solution under environmentally friendly conditions. Micropatterns of spherical particle assemblies were fabricated using two-solution method. Hydrophilic regions of a patterned SAM were covered with methanol solution containing SiO₂ particles and immersed in decalin to control the shape of droplets and gradually dissolve the methanol into decalin. Interfacing of methanol/decalin and shrinkage of methanol droplets were utilized to form spherical particle assemblies; additionally, its static solution system allowed precise control of the conditions. Particles were assembled to form spherical shapes on hydrophilic regions of an SAM and consequently, micropatterns of spherical particle assemblies were successfully fabricated through self-assembly.

**General Session 1**

**6**

**SIMULTANEOUS SIZING OF NANOPARTICLES BY INDIVIDUALLY VISUALIZING AND SEPARATELY TRACKING THEIR BROWNIAN MOTION**

Bob Carr, Jeremy Warren, and **Patrick Hole**, NanoSight Ltd, 2 Centre One, Old Sarum Park, Salisbury, Wiltshire SP4 6BU, UK; bob.carr@nanosight.co.uk; admin@nanosight.co.uk

The accurate analysis of nano-particulate suspensions, in terms of particle size, size distribution and particle concentration, is a pre-requisite for their successful application as the basis of surface coatings for sensors and other functional devices or as labels in (bio)diagnostic systems. A single nanoparticle tracking analysis system is described which allows nanoscale particles to be individually visualised (but not imaged) in liquids and from which higher resolution particle size distribution profiles can be obtained compared to other light scattering techniques. Sample pre-treatment is minimal requiring only dilution with a suitable solvent to an acceptable concentration range (between 10^5 and 10^10 per ml depending on sample type). Accurate and reproducible analyses can be obtained from video of only a few seconds duration and the results allow particle number concentration to be recovered. Given the close to real-time nature of the technique, particle-particle interactions are accessible as is information about sample aggregation and dissemination. All particle types can be measured and in any solvent type providing that the particles scatter sufficient light to be visible (i.e. are not indexed matched). The minimum detectable size measurable depends on particle refractive index but can be as low as 9-15nm for high refractive index materials such as colloidal silver. The technique is robust and low cost representing an attractive alternative or complement to higher cost and more complex methods of nanoparticle analysis such as photon correlation spectroscopy (PCS) or electron microscopy that are currently employed in a wide range of technical and scientific sectors. Finally, the technique uniquely allows the user a
simple and direct qualitative view of the sample under analysis (perhaps to validate data obtained from other techniques such as PCS) and from which an independent quantitative estimation of sample size, size distribution and concentration can be immediately obtained.

**General Session 2**

7  **NANOXEROGRAPHIC PRINTING AND FRINGING FIELD DIRECTED INTEGRATION OF NANOMATERIAL BUILDING BLOCKS**  
Chad Barry and Heiko O. Jacobs, Department of Electrical and Computer Engineering, University of Minnesota-Twin Cities, 200 Union St. SE, Minneapolis, MN 55455, USA; hjacobs@umn.edu

We report on a new gas phase printing approach to deposit nanomaterials into addressable areas on a surface with 50 nm lateral accuracy. Localized fringing fields that form around conventional resist patterns (PMMA and SiO2) with openings to a silicon substrate are used to direct the assembly of nanomaterials into the openings. Directed assembly was observed due to a naturally occurring inbuilt charge differential at the material interface which was further enhanced by corona charging to yield a field strength exceeding 1 MV/m in Kelvin Probe Force Microscopy (KFM) measurements. The assembly process is independent of the nanomaterial source and type - an evaporative, plasma, and electrospray source have been tested to deposit silicon and metallic nanoparticles. The results suggest a potential route to form nanolenses on the basis of charged resist structures - a 3 fold size reduction has been observed between the structures and the assembled particles. Applications range from the integration of functional nanomaterial building blocks to the elimination of lift-off steps in semiconductor processing.

**General Session 2**

8  **NANOMETALS AND LASER PATTERNING**  
Jin-Shan Wang, Lee W. Tutt, and Mitchell S. Burberry, Eastman Kodak Company, 1999 Lake Avenue, Rochester, NY 14650-2116, USA; lee.tutt@kodak.com

A variety of nanometals was synthesized by a typical reduction process that yields sizes of less than 10 nm. These nanoparticles are readily dissolved in ordinary organic solvents to form stable solutions. A variety of laser patterning processes was used on the nanometals to generate conductive micrometer-scale lines and spaces without etching. The line edge fidelity for silver lines from nanoparticles is shown to be excellent using a novel liftoff process.
Printing, coating, and painting are primarily particle-based technologies, because pigments have better color intensity and optical stability than dyes. These are reflective technologies with the light coming from illumination. Display technologies used for variable images are primary emissive processes with the light coming from electricity supplied to the device. These displays form images directly by electronic excitation (e.g. CRTs) or indirectly by backlight through a dye-based coatings (e.g. LCDs). If we could produce variable images with pigments then we might attain the advantages of printing: better color, stability, reflectivity, and lower power. One particle-based technology being aggressively developed by several companies is electrophoretic display technology: the control of particle position by particle motion in an applied electric field. Ideally this would be accomplished in the capacitive mode: particles move from one spot to another, neutralizing an applied electric field. (That is, ideally no net current should pass through the device.) For this mode, the particles must constitute a significant fraction of the free charge. Hence the particles are dispersed in fluids such as hydrocarbons where the concentration of free charges is extremely low. Our understanding of nonaqueous dispersions of charged particles is much weaker than aqueous dispersions. What we present in this talk is the series of ideas used to design stable dispersions of charged particles in hydrocarbons and how the quality of the image is scaled by the size, charge, and concentration of particles. Technical progress is faster than understanding so much art is involved, along with associated lively disagreements!

Solid state white light emitting devices would reduce the global electricity consumption by about 50%. Semiconductor nanocrystals (NCs) are highly fluorescent with fluorescence quantum efficiencies (Q.E.) as high as 80%, being thus ideal candidates for use in white light emitting displays. We will discuss four different types of nanomaterials that can be employed for white light emitting devices. The simplest method is to mix the red, green and blue emitting NCs to achieve a blend that gives white light emission. The second method takes advantage of the fact that the surface of nanocrystals is large and that emission through these electronic states spread throughout the mid-gap region could give rise to a broad emission spectrum. Then we focus on some novel structures that are dual emitters and a combination of the emission from the core and shell of the NCs could produce white light. Similarly, combination of the host emission and the impurity states from a doped NC gives an opportunity to synthesize white light emitting nanomaterials.
**General Session 2**

**11**  
**COLLOIDAL NANOCRYSTAL-BASED PHOTONIC DEVICE FABRICATION**

**Luigi Martiradonna**, Antonio Qualtieri, Tiziana Stomeo, Roberto Cingolani and Massimo De Vittorio; Scuola Superiore ISUFI, National Nanotechnology Laboratory (NNL) of CNR-INFM, Universita’ del Salento, via per Arnesano, Lecce, I-73100, Italy; martirad@iis.u-tokyo.ac.jp

Semiconductor colloidal nanocrystals (NCs) are wet chemical grown nano-objects whose optical and electronic properties are strongly governed by quantum-confinement effects. Similarly to epitaxially grown quantum-emitters, they show broad excitation spectra and narrow emission bands also at room temperature, tunable optical gain from the ultraviolet to the infrared spectral range, and a high photochemical stability, while requiring cheaper and higher-throughput growth facilities. Moreover, several critical drawbacks such as spectral shifting and blinking of the single-nanoparticle luminescence are nowadays deeply investigated and strongly reduced by improved engineering of their surface chemistry. Their potential as active materials for photonic devices is thus comparable or even higher than epitaxy-based devices. The most limiting factor is the lack of well established fabrication processes which can enable the realization of solid state devices based on emitters synthesized in liquid solution. In order to fully exploit colloidal nanocrystals it is thus important to fill up this technological limit by developing new fabrication processing or by engineering new devices totally oriented to this new cheaper and promising class of emitters. In this work we propose an approach for the fabrication of photonic devices based on the direct exposure to electron-beam or ultraviolet radiation of a resist layer embedding NCs. The core/shell configuration of nanocrystals allows high robustness and stability after the exposure to the radiation, so that their optical properties are not affected. Moreover, the sensitivity of the polimeric matrix is not lost, and the overall resolution of the lithographic process is only slightly reduced. By following this approach, several demonstrators are presented, such as DFB and DBR structures, bi-coloured bidimensional and tridimensional patterns on a micrometer scale, two-dimensional photonic crystal structures fabricated on suspended membranes. By exploiting the mechanical properties (flexibility, elastic deformation) of electron- and photo-resists, new classes of optical sensors and actuators based on NCs/resist composites can be engineered.
Three ideas for applications in which colloidal nanoparticles are used to interface cells are discussed.
1) A FRET-pair based on colloidal quantum-dot donors and multiple organic fluorophores as acceptors is reported. This approach allows for relatively small acceptor-donor distances, and thus for high energy transfer efficiencies, while simultaneously permitting high colloidal stability. The photophysics of the system is characterized and compared to similar systems which have been reported in literature.
2) Polyelectrolyte microcapsules have been loaded with a pH sensitive, high molecular weight SNARF-1-dextran conjugate. Upon ingestion of SNARF-1-filled capsules by breast cancer cells or fibroblasts, the pH change of the local capsule environment during transition from the alkaline cell medium to the acidic endosomal/lysosomal compartments could be observed. By incorporating magnetic and fluorescent colloidal nanoparticles into the capsule-shell a novel type of multiplexed sensor system was developed. Quantum dots allow for encoding of the capsules.
3) An assay to detect the adhesion of cell co-cultures on electrodes is reported.
conventional photonic device, its status is determined by the detector, which is outside of
the device. So, total device size becomes large and its integration is difficult. Thus, it has
been used only for data transmission usually. In the “true nanophotonic devices”, an
optical source and determination systems of the device status are included in the device
itself. Thus, its size becomes smaller like electronic devices and integration becomes
possible. Finally, it has obtained ability as highly functional devices.

**General Session 3**

14 INAS QUANTUM DOTS FOR HIGH PERFORMANCE THERMAL IMAGING OPERATING AT HIGH TEMPERATURE

M. Razeghi, H. Lim, S. Tsao, H. Seo and W. Zhang, Center for Quantum Devices, Department of Electrical Engineering and Computer Science, Northwestern University, Evanston, Illinois 60208, USA; razeghi@eecs.northwestern.edu

Self-assembled semiconductor quantum dots (QDs) have attracted much attention
because of their interesting properties and possible applications, such as quantum dot
infrared photodetectors (QDIPs). QDIPs can be building blocks of focal plane arrays
(FPAs) in infrared imaging systems which have been widely investigated for mid-infrared (3~5 μm) and long-infrared (8~12 μm) applications. QDIPs have several
potential advantages over conventional technologies and these advantages promise
infrared detectors with high-temperature operation and high performance. However, most
of the QDIPs reported so far in the literature have not met the expected high performance
and have been working at temperatures in the range 77 K~200 K. Here, we present a
high-performance, room temperature operating mid-infrared photodetector based on InAs
QDs embedded in Ga₀.₄₇In₀.₅₃As quantum wells (QWs) grown on top of Al₀.₄₈In₀.₅₂As
barriers on an InP substrate. We also report an FPA made from this kind of a QDIP. The
device structure was grown by low-pressure metalorganic chemical vapor deposition. The
growth temperature of the entire device structure was 590°C. The active region consisted
of 25 stacks of InAs QD/GaInAs QW layers with 29 nm-AlInAs barrier layers. The InAs
QDs on the AlInAs barrier layers were obtained by self-assembly based on the Stranski-
Krastanow epitaxial growth mode. We measured the spectral response at several
temperatures and applied biases by using a Fourier transform infrared spectrometer in the
normal incidence configuration without any optical coupling structures. In this device
structure, both the InAs QD layers and GaInAs QW layers are involved in the infrared
absorption process. In our device structure, we believe the initial state is not necessarily
from a localized “pure” quantum dot state but from a delocalized “mixed” state of the
quantum well and the quantum dot For all temperatures except room temperature, at an
applied bias of -5 V (-2 V for room temperature), the peak around 4.1 μm was dominant
in the spectral response. The strong sensitivity to the applied bias is an indicator that the
transition of the photo-excited electrons takes place between bound states of the QD/QW
hybrid. The peak responsivity increased with temperature from 120 K to 200 K and
started decreasing above 200 K. The peak responsivity was measured to be 822 mA/W at
150 K and a bias of -5 V. The specific detectivity (D*), which is calculated by
\[ R_p A^{1/2} S^{1/2} \], was obtained from the measured peak responsivity, the illuminated area of
the detector (A) and noise density spectrum (S). The maximum D* of \(2.8 \times 10^{11} \text{ cm Hz}^{1/2}/\text{W}\) was measured at 120 K. The room temperature detectivity was \(6 \times 10^{7} \text{ cm Hz}^{1/2}/\text{W}\). A high quantum efficiency of 35% was obtained in this device for normal incidence. This high quantum efficiency is due to the high oscillator strength for normal incidence light and also due to a higher number of carriers being available for absorption compared to conventional QDIPs where the number of photoactive carriers is limited by the number of QDs. Recently we achieved higher quantum efficiency of 48% by optimizing quantum dot condition and improving the infrared absorption. The focal plane array (FPA) was fabricated to test the capability for infrared imaging at high temperature. FPAs require the hybridization of the detector array and the Indigo ISC 9705 readout integrated circuit (ROIC). We could obtain imaging of a hot soldering iron up to 200 K. Imaging of human targets was possible up to around 150 K. Above 200 K the dark current of the detector became too high for imaging. We demonstrated a high performance InAs/InP quantum dot infrared photodetector which operates up to room temperature. A detectivity of \(4 \times 10^{10} \text{ cm Hz}^{1/2}/\text{W}\) and a quantum efficiency of 45% were obtained in this device at 150 K. A focal plane array fabricated from this material produced high quality images up to 200 K.

**General Session 3**

**15** POLYMERIC ZYLOIDAL CRYSTALINE ARRAY GLUCOSE SENSING  
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We developed a novel class of smart optical materials based on soft materials which are responsive to their environment and which can be actuated chemically or photonically. Highly charged, monodisperse colloidal particles will self assemble in water into crystalline colloidal arrays (CCA), which are either body centered or face centered cubic structures. We developed smart materials from these self-assembled structures, which utilize the highly efficient Bragg diffraction of light from the CCA periodicity. We polymerized these CCA into acrylamide hydrogels. These CCA-embedded hydrogels show the rich volume phase transition phenomena characteristic of these soft materials. These materials act as frequency agile optical filters. We have functionalized these hydrogels with dyes and photochromic molecules, as well as with molecular recognition agents which cause the hydrogel to change volume in response to either photons, or the presence of specific analytes (eg Pb\(^{2+}\), glucose etc). The resulting volume changes alter the array spacing, which causes the diffracted light wavelength to shift, or causes the diffraction efficiency to change. We will discuss the volume phase transition properties of these arrays and also describe the use of these arrays as chemical sensors, especially for use in _in-vivo_ tear fluid glucose sensing.
There is strong interest in enhancing conventional Si CMOS with heterogeneous integration of advanced memory devices. We have made high-density non-volatile flash memories using SiGeC or metal Self Assembled Quantum Dot (SAQD) floating gates with high-k gate dielectrics. These quantum dots in the floating gate act as electron charge storage sites, and program the bits “0” or “1” depending on the number of electrons stored, which determines the flatband and threshold voltage in these metal oxide semiconductor flash memories. One key advantage of such discontinuous quantum dot array floating gates over conventional continuous gate electrodes is that an electrical defect in the underlying tunnel oxide will not be able to discharge the entire array of dots, thereby leading to improved charge storage reliability. However, as the memory cells are shrunk in size, one ends up with a small number of dots in each memory cell, such that statistical variations in the number and spatial location of the dots cause unacceptably large manufacturing variations in the memory cell characteristics. We, therefore, focus on the growth of ordered arrays of SAQDs on high-k tunnel dielectric surfaces, employing chemical/physical vapor deposition or colloidal self-assembly using protein templates. We have recently demonstrated that a chaperonin protein lattice can be used as a template to assemble semiconductor and metal nanocrystal arrays for flash memory fabrication. Chaperonins are a group of molecular chaperones that have a large multimeric structure consisting of two stacked rings surrounding a central cavity within which the protein substrate binds. Chaperonins can be self-assembled into a crystalline lattice through non-covalent interactions between the proteins. The interior surface of the chaperonin’s central cavity is hydrophobic, which allows semiconductor or metal nanocrystals functionalized with hydrophobic molecules to be trapped site-specifically inside the cavities. Once PbSe or Co nanocrystals are trapped by the chaperonin template, the template is easily removed at 200 C by annealing in O2, leaving behind a nanocrystal assembly with uniform distribution and a high density of around 1×10^{12}/cm^2, and good spatial and size uniformity. Samples where dots are trapped by the protein and the protein is oxidized away, show significant electron storage, resulting in large flatband shifts which can delineate the “0” and “1” states. Control samples with just the proteins, or without proteins or dots show no charge storage.
MOLECULAR ASSEMBLIES OF NANOPARTICLES: SURPRISING ANALOGY WITH PROTEINS AND NEW OPTICAL PROPERTIES
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Physical properties of nanoparticles and nanowires are currently well understood. The next frontier is conceptualization of larger structures, such as nanoscale assemblies. This talk will discuss the two paradigms in this field: (1) spontaneous assemblies of nanoparticles and (2) quantum mechanical interactions of metallic and semiconductor building blocks in nanoscale assemblies. Anisotropic forces arising between nanocrystalline particles drive the self-assembly behavior of these colloidal particles. Interaction anisotropy between CdTe nanoparticles in solution leads to their spontaneous, template-free organization into free-floating sheets. Electrostatic interactions arising from a dipole moment and a small positive charge combined with directional hydrophobic attraction between the nanoparticles are the driving forces for the self-assembly, which we demonstrate by computer simulation. We found that nanoparticles show conceptual similarities with assembly of proteins. This supposition was recently confirmed by assembly of nanoparticles into spiral systems similar to those found in many biological systems. Electronic interactions in nanoparticle assemblies represent one of the fundamental problems of nanotechnology. Excitons and plasmons are the two most typical excited states of nanostructures, which were shown to produce coupled electronic systems. The concept of these interactions between the Au and CdTe nanoparticles and nanowires will be discussed in terms of quantum mechanical coupling of excited states and unusual optical effects. As such, in presence of dynamic component for excitons theory predicts that emission of coupled excitations in nanowires with variable electronic confinement is stronger, shorter, and blue-shifted. These predictions were confirmed with high degree of accuracy in molecular spring assemblies, where one can reversibly change the distance between the exciton and plasmon. The prepared systems were made protein-sensitive by incorporating antibodies in molecular springs. Modulation of exciton-plasmon interactions can serve as wavelength-based biodetection tool, which can resolve difficulties of quantification of luminescence intensity for complex media and optical pathways.

ORGANIC SOLAR CELLS AND CHALLENGES FOR NANOSCIENCE
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In this presentation attributes and applications of nanoscale excitons for organic solar cells will be described. What will nanoscience deliver in the future? Why are nanoscale materials interesting now? In one case study I will describe how natural systems harness solar energy. How is light captured and redistributed on the molecular scale... and what have we learnt by examining these ultrafast processes? A unique attribute of systems like nanocrystalline quantum dots is that the electronic levels can be modified by quantum
confinement. In the second case study of structure-function relationships, I will report how the energetics governing ultrafast photo-induced electron transfer in CdSe–CdTe nanorod heterostructures can be tuned. Relationships between size and energetics will be discussed, providing insights into the factors that determine photo-induced charge separation reactions in nanocrystalline composites, including the free energy changes, reorganization energy, activation barrier and adiabaticity. How are these systems new compared to supramolecular designs?

**General Session 4**

19  COLLOIDAL CRYSTAL-BASED PHOTONIC BAND GAP WAVEGUIDES  
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The self-assembly based fabrication of three-dimensional (3D) colloidal photonic crystals with the potential to show a complete photonic bandgap at optical wavelengths has been demonstrated. However for many applications, simple periodic structures are not sufficient. It remains unclear how to add function to such structures in an efficient fashion, be this introduction of aperiodic features, functional materials, or active components. Over the last few years, we demonstrated the use of two-photon polymerization to embed 3D features within self-assembled photonic crystals, however these preliminary structures were not designed to be optically active. We have dramatically improved the quality of the embedded features, and will also provide evidence that suggests successful waveguiding through straight and double-bend defects embedded within a 3D silicon-air inverse opal. The optical behavior of other features embedded in a self-assembled photonic band gap material, including planar defects and optical cavities will also be discussed.

20  DESIGNING MULTIFUNCTIONAL BINARY NANOCOMPOSITES FOR DIRECT ENERGY CONVERSION APPLICATIONS  
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The ability to synthesize quantum dots of desired size, shape, and chemical composition provides a rich family of nanoscale building blocks for the assembly of new solid thin films and devices. Self-assembly of different classes of these "artificial atoms" with distinct electronic, magnetic, and optical properties into composite solids provides access to new classes of multi-functional materials with fascinating and novel behavior. In this talk I will discuss the modular design of one class of binary nanocomposite (the PbTe/Ag2Te system) for potential thermoelectric applications. The development of
synthetic routes to size-tunable PbTe and Ag₂Te nanocrystals, along with their assembly into single-component solid thin films and nanocrystal transistors will be discussed. Subsequently, the self-assembly of these components into binary nanocrystal superlattices and multicomponent thin films will be presented. Investigations of the electronic and thermal properties of these PbTe/Ag₂Te binary nanocrystal composites, which represent the first studies of the collective physical properties of this new class of materials, have revealed exciting behavior. The electronic transport studies demonstrate synergism amongst the components which leads to a 100-fold enhancement in the p-type conductance over either individual nanocrystal building block. Studies of the thermal properties of these films have uncovered 5-10 fold reductions in thermal conductivity in comparison to the corresponding bulk crystals, which is promising for the development of thermoelectrics and materials for thermal management.

**General Session 4**

**21** FIELD-INDUCED CHARACTERISTICS OF NANOPARTICLES WITH APPLICATIONS TO THIN FILM DISPLAYS

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We present two kinds of nanoparticle-based displays. One of which is the manipulation of nanoparticles dispersed in an insulating liquid, the operative mechanism for the former is based on dielectric forces and electric field-induced dipolar interactions between neutral nanoparticles, leading to compact aggregates that change the optical characteristics. Owing to the hysteretic behavior, such displays can have either a diffusive scattering mode or a display storage mode, allowing for low-power operation. While another one is thermally-activated display fabricated from thermochromic nanoparticle composite and embedded conductive wiring patterns, shaped from mixture of metallic nanoparticles in polydimethylsioxane (PDMS) using soft lithography. Both displays exhibit good image qualities and ease of control with an external electric signal.

**General Session 4**

**22** A MICELLAR APPROACH TO MAGNETIC ULTRA-HIGH DENSITY DATA STORAGE MEDIA

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At the ultimate limit of magnetic recording, suitable storage media will consist of nanometer sized entities, each of which will carry one bit of information. Materials with a high magnetocrystalline anisotropy energy are required to warrant thermal stability of the ferromagnetic state at realistic operating temperatures. The face-centered-tetragonal (fct) $L1₀$ FePt alloy belongs to the promising class of materials, which offer the perspective of storing one magnetic bit per nanoparticle. Widespread activities have therefore arisen
worldwide targeting at novel strategies for both, the synthesis of suitable magnetic nanostructures as well as their organization into superlattices by means of parallel processes. Here, we present a new approach for the synthesis of size-selected $L1_0$ FePt nanoparticles based on the self-organization of spherical micelles formed by diblock-copolymers, thereby significantly extending a previous technique to produce large-scale arrays of elemental nanoparticles. Our approach allows overcoming typical drawbacks of current colloidal routes towards densely packed arrays of ferromagnetic FePt nanoparticles while still guaranteeing areal densities exceeding $1 \text{Tbits/inch}^2$.

**General Session 5**

23  **PRODUCT AND MARKET DEVELOPMENT IN QUANTUM DOT TECHNOLOGIES**

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Forming a new company around a new technology with new products that serve a variety of markets is difficult. Growing the company is even more difficult. There are many challenges to convert a nanotechnology into money-making products. This presentation will discuss the journey of one company, Evident Technologies, and the challenges faced with commercializing products based on quantum dot technology. Entrepreneurial scientists founded Evident Technologies, Inc. in 2000 and the same scientific, inventive culture prevails today. Evident is a leader in quantum dot product development, intellectual property, and the customizing of nanocrystal formulations for a range of applications and markets. Evident has invented and produces some of the world's most cutting edge materials for use in a number of the most promising application areas; such areas include LEDs, security inks, and the life sciences.

**General Session 5**

24  **NANOPARTICLE INKS FOR PRINTED ELECTRONICS AND DISPLAYS**

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Electronics manufacturers are continually striving to decrease costs and increase functionality of electronic devices and components. One emerging strategy for cost reduction is directly printing electronics onto low-cost plastic films using solution-based inks. NanoMas’s proprietary technologies have integrated the art of precision nano-scale engineering with mass production of nano-scaled functional materials, bringing high performance conductive and semi-conductive nanoparticle inks for the emerging Printed Electronics (PE) industry. NanoMas’s conductive nanoparticle inks have metal nanocrystals of ultra small particle size (2 to 10 nm) and narrow distribution, and possess the best performance in the conductive inks market; the printed patterns have the highest conductivity (comparable to that of bulk gold) at the lowest processing temperatures (70-150°C) and for the shortest processing time (less than 2 minutes).
From Multilayer Particles to Nanstructured Material for the Recording of Biometric Features

Hung Pham, Ilya Gourevich, James Jonkman, Eugenia Kumacheva

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In the last decade, development of new materials for the protection of identification documents, credit cards, and authentication labels against counterfeiting has been an active area of research. Photoactive materials have been successfully used as the recording media. Yet, these materials lack complexity and with rapid advances in laser and computer technologies become vulnerable to counterfeiting. We designed, synthesized and fabricated a polymer multiphase material that was used as a recording medium for biometric features. The material was derived from polymer multilayer particles comprising fluorescent dyes with distinct absorption and emission properties in different layers. Recording was achieved by selective photobleaching of the individual dyes. Two strategies were used for the ‘encryption’ of biometric features in the polymer material. In the first approach, we recorded full color (RGB) grey scale photographs. Alternatively, we recorded three spatially overlapping monochromatic biometric features in the same location of the material, without cross-talk between them. Each biometric feature (a photograph, a fingerprint, and a signature) was accessed only by irradiating the material at a specific well-defined wavelength. Finally, distinct biometric features were recorded in different planes of the polymer material.

Synthesis and Properties of Fluorescent Nanoparticles for Living Cell Metabolite Detection

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It is demonstrated how the segregation of amphiphilic molecules at an oil/water interface which leads to the formation of microemulsions can be utilized as a structured media in synthesis. A microemulsion is a thermodynamically stable solution which has structure at the nanometer length-scale. In microemulsions that consist of predominantly organic solvent with smaller but substantial amounts of surfactant and water present water droplets surrounded by a surfactant layer immersed in a continuous organic solvent domain is the equilibrium structure. These small water domains can be used as templates for synthesizing particles with sensor molecules embedded. Acrylamide gel particle with
embedded pH and phosphate sensor have been synthesized. The particles can subsequently be delivered into living cells and through optical microscopy report the value of some parameter, e.g. pH, or the concentration of a metabolite, e.g. phosphate in the cell. Advantages and limitation of fluorescent gel nanoparticles will be discussed.

**General Session 5**

**27** LARGE-SCALE AND PRECISE NANOPARTICLE PLACEMENT VIA ELECTROSTATIC FUNNELING

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The capability of placing nanoparticles on precise substrate locations is a key requirement for fabrication of future nanoparticle-based devices and sensors. For practical implementation, a placement technique must also be suitable for parallel processing, enabling simultaneous nanoparticle placement over a large area. Obtaining techniques satisfying both of these requirements has been one of the major efforts in the nanoscale science community. In this talk, we will present a new technique named “electrostatic funneling”, where charged nanoparticles in liquid medium are guided by electrostatic double-layer interactions and placed onto targeted substrate locations with nanoscale precision over a large area. The electrostatic guiding structures were formed using CMOS processing technology (lateral feature size in the ~100nm range), and the substrate surface was functionalized with self-assembled monolayers (SAMs) of organic molecules. Placement precision of ~5nm has been demonstrated over a large area (2cm × 2cm). The effectiveness of electrostatic funneling has been demonstrated with a variety of 0-, 1-, and 3-dimensional structures. In addition, the inter-particle and particle-substrate interactions were calculated using DLVO (Derjaguin, Landau, Verwey, and Overbeek) theory, which agrees well with the experiments. Based on this calculation, the inter-nanoparticle interactions were tuned by varying the ion concentrations in the Au colloid. This enabled single-particle placement, where only one nanoparticle is placed in the center of each circular template over a large area. This precise and large-scale nanoparticle placement via electrostatic funneling may be implemented into many applications including data storage, photonic devices, nanoelectronic devices such as single electron transistors, and growth templates for nanowires or carbon nanotubes.
Traditionally, spin coating systems have employed low boiling point solvent systems and centrifugal force, making it virtually impossible to pattern materials during deposition. Additionally, for many functional materials, the solvent systems are harsh fluid environments for the molecular structure that determines efficacy. These two limitations point towards the necessity of new processing methods. In our laboratory, we have shown that it is feasible to move towards ink jet printing as a processing step that replaces spin coating. We have used a piezoelectric ink jet printer that has a disposable cartridge system to produce patterned thinfilms. We have investigated the fluid formulation requirements and determined the operating parameters for the electronic pulse to the lead zirconate titanate that generates fluid drop ejection from a MEMS-fabricated nozzle. Furthermore, we have demonstrated the requisite substrate qualifications. While an individual droplet leaves the nozzle as a sphere, interaction with the substrate determines whether it develops into a cylinder or a torus. We will show these resulting pattern architectures including drop resolution and film thickness after drying. Interestingly, the critical part of this discussion will be how easy this processing step is and how adaptable it is to a variety of chemistries including electronic materials and biological materials.

The inkjet printing system for preparing color filters in the application of TFT-based LCD have been technically designed, assembled, operated and evaluated its performance. Three-primary colorant resist-based inks with nanoparticle pigments have been prepared by chemical route as well. The colorant resist inks with excellent characteristics are compatible to the piezoelectric heads with multi-channel inkjet nozzles, the colorant ink droplets are landing in the specified position of sub-pixel area on substrates. The self-design system with excellent performance in hardware and software is suitable to color filters technology with substrate size of 610x750mm², alignment accuracy of inkjet nozzle can achieve ±0.5μm. Organic colorant thin films have significantly been prepared on substrates by using resist-based colorant inks with nanoparticle pigments and inkjet printing process. The colorant inks synthesized by chemical route and its physical characteristics is suitable to the specifications of the modified print-heads in the inkjet printing system. The results exhibit that physical characteristics of as-printed thin films in optical transmittance, surface morphology, and chromaticity are excellent, comparing to the conventional color filters.
Polymer cholesteric liquid crystal (PCLC) flakes make a unique medium for particle-based applications. The motion of PCLC flakes suspended in a host fluid is controlled with an electric field, whereby the flakes reorient to align parallel with the applied field. A PCLC device easily switches from a bright state, selectively reflecting light of a given wavelength and polarization to a dark, non-reflective state. The device is returned to a bright state when flakes relax to their original orientation after removal of the applied field. Progress has been made in addressing several key device issues: the need to switch flakes back to a reflective state quickly, the development of bistability, the ability to produce flexible devices, the necessity to produce high brightness and contrast ratio. Improvements in the technology have been made by addressing the optical, mechanical, chemical, and electrical features and characteristics of the PCLC flake – host fluid system. The manufacture of custom flakes produces shaped flakes with improved reflectivity and response times along with the ability to respond to both AC and DC fields. Specially designed driving waveforms provide a new measure of flake motion control. PCLC flake micro-encapsulation allows for the possibility of flexible and potentially bistable devices. Here we report on the wide variety of approaches toward improving PCLC flake devices and their results. The potential for using PCLC flake technology for flexible displays and electronic paper is evident, but additional applications for electro-optics devices abound.

Lead sulfide colloidal quantum dots (CQDs) have recently demonstrated exceptional capabilities as the foundation of optoelectronic devices optimized for detection, energy conversion, and lasing. CQD photodetectors leverage the very high photoconductive gain obtainable in lead sulfide materials and quantum size effect in order to obtain normalized detectivities of greater than 1e13 at room temperature, which exceeds the performance of traditional crystalline semiconductor materials. These devices are sensitive to near-IR light, and are thus suitable for applications in optical communications and sensing.
traditionally requiring costly epitaxial materials. CQD photovoltaics have the potential to exceed the efficiency organic solar cells by absorbing light in the near-IR as well as the visible. Monochromatic internal quantum efficiencies > 10% and external quantum efficiencies >1% are obtained by optimizing carrier transport within films of CQDs in order to achieve carrier extraction prior to recombination. These devices have the potential to access nearly 50% more energy than those limited to visible absorption, while maintaining all of the cost and manufacturing benefits of organic photovoltaics. The observation of lasing at 1.53 μm in CQD films shows the potential of these materials for development of optical communication components capable of direct integration with silicon signal processing electronics. These temperature sensitivity of these devices, 0.03 nm/K, is an order of magnitude lower than that of current semiconductor quantum well lasers.
CALCIUM PHOSPHATE NANOCOLLOIDS FOR BIOIMAGING AND DRUG DELIVERY IN PHYSIOLOGICAL CONDITIONS

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A new bioimaging and drug delivery system has been developed using calcium phosphate nanocomposite colloids. These nanocolloids (dia. ~ 30-50 nm), known as Molecular Dots (M-Dots), can encapsulate both fluoroprobes and chemotherapeutics within the calcium phosphate matrix of the nanocolloid for delivery to cells or tissues. Encapsulated fluoroprobes exhibit enhanced stability and fluorescent properties. The M-Dots are colloidally stable in physiological solution (phosphate buffered isotonic saline) and in various cell culture media at 37°C. As examples of the general potential for M-Dots in medical research, we have used them to image acutely isolated sympathetic neurons, vascular smooth muscle, and cancer cells without significant toxicity. Furthermore, ceramide, a bioactive, but physiologically insoluble, experimental anti-cancer lipid was delivered within M-Dots to melanoma and breast adenocarcinoma cells, resulting in significant cytotoxicity and apoptosis. Our findings indicate that M-Dots have the potential to increase the efficacy of physiologically insoluble drugs in vivo as well as provide enhanced bioimaging.

SILICON COLLOIDS

Roberto Fenollosa, Francisco Meseguer, Michal Tymczenko, Unidad Asociada CSIC-UPV, Universidad Politécnica de Valencia, Avda Tarongers s/n, 46022, Valencia, Spain, and Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas (CSIC), C/ Sor Juan Inés de la Cruz, 3, 28049, Madrid, Spain; rfenollo@ter.upv.es

We report on a method for obtaining silicon colloids with diameters from 0.5 μm to 5 μm. Because of their spherical shape and smooth surface, they work as optical microcavities with well-defined resonating modes in the near-infrared range. Silicon colloids may facilitate development of high quality factor optical microcavities with strong light confinement effects, allowing integration of fundamental electronic devices such as a p-n junction into a single system. Silicon colloids have also been used as the building blocks of a new microstructured material formed by tree-like arrangements of polydisperse microspheres. We call this material 'photonic sponge' because it can scatter
light strongly over a wide range of wavelengths. We expect applications of these materials in the fields of photovoltaic cells, chemical sensors, and light detectors and emitters. Silicon colloids may also find applications in other fields like medicine, cosmetics, etc.

**Poster Session**

### 34 ASPECTS OF LATEX PARTICLE SIZE CONTROL FOR IMPROVED WATER BLUSH RESISTANCE

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Latex films have a tendency to blush when exposed to water. The swelling of trapped hydrophilic material, resulting in pockets with different refractive indices is proposed as a possible model for blushing. A pressure sensitive latex was developed based on this model. The blush was improved by choice of surfactant and control of particle diameter. The resulting latex has an unusual particle growth behavior, during polymerization. The particle size distribution was characterized by dynamic light scattering (DLS), methods of electron microscopy (SEM/TEM) and with the help of atomic force microscopy (AFM). AFM data are in a good agreement with our growth model. A possible explanation, based on competitive growth of dissimilar particle diameters is proposed.

**Poster Session**

### 35 PREPARATION OF NANOEMULSIONS AND NANOPARTICLES AS DELIVERY SYSTEM FOR BIOACTIVE INGREDIENTS IN FOOD

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There are many types of delivery system has been utilized to encapsulate functional ingredients, including simple solution, associated colloids, emulsions, biopolymer matrices, and so on. One of above delivery system, nanoemulsions are transparent or translucent systems mostly covering the size range of 50-500 nm, and it is only kinetically stable. Nanoemulsions also can be classified as associated colloids, nanostructured multiple emulsions, nanostructured multilayer emulsion and biopolymeric nanoparticles depending on the types of surfactants, cosurfactant, oils, polyelectrolytes, biopolymers and emulsification methods. Meanwhile, many nanoemulsion systems are not dilutable, so it easily may be broken down at increased water concentration. This is the reason why the application of food nanoemulsions still not be used widely in food systems. The objectives of this study are to investigate the optimum condition of nanoemulsion formation to solubilize oleoresins, to analysis the characteristics of nanoemulsions such as the size of nanoemulsion and stability, to study the structural information of nanoemulsions characterized by AFM. Chitosan and alginic acid were used as nanoparticle polymers and Tween 40, 60, 80 were used as surfactants.
Nanoemulsions could be obtained with particles sizes of 20-450 nm depending on the emulsification parameters such as the concentration of polymers and the ratio of surfactant to dispersion polymers. Nanoemulsions were stable after thermal treatment and storage for 14 days. In addition, the stability of nanoemulsions were maintained as a dry state and showed a good redispersibility. We might be confirmed that the AFM images of nanoemulsions gives a structural information in nano scale.

**Poster Session**

**36** MULTI-FUNCTIONAL HYBRID SILICA PARTICLES FOR NITROGEN CHEMOSENSORS  
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In the last decade there has been an increasing interest in the development of optical chemosensor for covalent interactions with target molecules. Among the various types of sensory materials, functionalized organic-inorganic hybrid particles have received great attention due to their easy preparation, detection mobility, and signal amplification. However, as demands on multiplex detecting, simultaneous targeting/separation, and etc. arose recently, the development of multifunctional materials has been the center of leading research topics. In this study, we have prepared multi-functional hybrid silica particles for simultaneous targeting, detecting, and anchoring to various substrates. In addition, the surface property of this hybrid particles can be adjusted to hydrophilic or hydrophilic just by changing one of functional groups in the particle. Using modified sol-gel process multi-functional hybrid silica particles with phenyl/vinyl, thiol, and amine functionalities were synthesized first. In order to endow substrate binding ability, the amine functional groups on the surface of hybrid particles were then converted to carboxylic acid moieties through surface reaction with glutaric anhydride. Thiol groups on the surface of hybrid particles were also modified with o-phthaladehyde(OPA) for the detection of amine groups. By monitoring fluorescence spectrum of isoindole product resulting from covalent bonding between OPA on the surface of hybrid particles and external amine groups, the sensing characteristics of multi-functional hybrid silica particles have been studied.

**Poster Session**

**37** SURFACE MODIFICATION OF LEAD SULFIDE NANOCRYSTALS WITH POLY(ACRYLIC ACID) THROUGH A LIGAND EXCHANGE PROCESS,  
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Lead sulfide (PbS) QDs absorb and emit light in the near-infrared region, making them potentially useful for telecommunication and biotechnological application. The PbS QDs
with the highest photoluminescence quantum efficiency (PLQE) are normally prepared by an organometallic route. QDs as prepared are capped with oleic acid (OA) on their surface and not soluble in polar solvents. The challenge to transfer the QDs into polar solvents is overcome by a ligand exchange process after synthesis. My work shows that poly(acrylic acid) (PAA) can substitute the OA on the surface of the PbS QDs and transfer the QDs into polar solvents like methanol and water. PAA was synthesized by RAFT polymerization. The ligand exchange process was studied by various techniques including solubility tests, transmission electron microscopy, dynamic light scattering, and absorption and emission spectroscopy. I also explored the effects of pH on the absorption and emission of QDs in water.

Poster Session1

38 GOLD NANOPARTICLE/ORGANIC COMPOSITE CHEMIRESISTIVE SENSORS: VAPOR SENSITIVITY AND MECHANISM OF SENSING

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During the last decade metal nanoparticle/organic composite films have gained remarkable attention as sensitive coatings for chemiresistor sensors. In such films the nanoparticles provide electric conductivity and the organic component provides sites for the interaction with analyte molecules, while at the same time ensuring the mechanical stability of the film. The sensing properties of these materials can be tailored by varying the size, structure, or the composition of the organic component. The conductivity of the metal constituent ensures a simple and straightforward electrical signal transduction. We report here on the self-assembly fabrication of nanocomposite films comprising Au-nanoparticles and alkylene dithiol or dendritic polymer linkers, their characterization and application as chemiresistive vapor sensors. AFM measurements revealed films with well-controlled nanometer range thickness and granular structure. Charge transport measurements were consistent with an activated tunneling mechanism. The chemical sensitivity of the films was probed by exposing them to solvent vapors while measuring the film resistance. In parallel the analyte uptake was monitored with quartz crystal microbalances covered with the sensitive material. Our results show, that the analyte sorption and the selectivity of the films is governed by the chemical nature of the organic component. The sorption-induced increase in film resistance scaled linearly with the amount of analyte sorbed in the films. The response of the films to equal uptake of analytes decreases with increasing the dielectric constant of the analyte. This trend is qualitatively in agreement with the assumption that an analyte induced increase in the permittivity of the organic component in the film may reduce the energy barriers for charge transport and thus may counteract the increase in resistance due to film swelling. The high sensitivity (< 5 ppm), the fast response (few seconds), and the well-controlled chemical selectivity make such Au-nanoparticle/organic films promising candidates for sensor applications.
LASER-ASSISTED DEPOSITION OF THIN LAYERS OF FUNCTIONALIZED NANOPARTICLES: A NEW COATING TECHNOLOGY

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We report a new technique for controlled deposition of layers of functionalized nanoparticles using resonant infrared laser-assisted nanoparticle transfer (RIR-LANT) from a bulk frozen target. RIR-LANT (1) exhibits a high degree of control over the thickness of the particle layers, (2) is generally applicable to particles with any organic moiety, (3) can be used with masks to pattern particles on the receiving substrate, (4) and can be combined with other deposition techniques – or repeated applications of RIR-LANT – to create multi-layered coatings containing several functional materials. In RIR-LANT, a dilute solution of functionalized nanoparticles is flash-frozen, introduced into a vacuum chamber and subsequently irradiated with a pulsed infrared laser. The ejected particles are collected on a proximate substrate while the solvent is pumped away by the vacuum, creating a high surface area layer. One example of this technique involved the transfer of 170 nm silica spheres synthesized with a rhodamine dye in the core of the nanoparticle and a fluorescein dye located on its surface. Photoluminescence measurements performed on a deposited film of these particles show no significant alteration of the emission properties of either dye, suggesting that no damage occurred to either one during the ablation process. Because the process is solvent-free on the receiving substrate, the particles are more evenly distributed than when using most solvent-based techniques, an important criterion both for patterning on devices in the latter stages of assembly and for preserving patterns in multilayered applications. The selection of a resonant infrared laser wavelength is critical to producing an even coating of material and preserving nanoparticle functionality. Deposition through shadow masks and deposition of multilayer structures turned out to be straightforward using this technique, suggesting its potential utility in preparing designer sensor structures using functionalized nanoparticles.
**Poster Session**

**40** MULTIFUNCTIONAL NANOSTRUCTURED COMPOSITE COLLOIDS PREPARED USING A MINIEMULSION APPROACH

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Colloidal nanostructures with magnetic and luminescent functionalities are potential candidates for diagnostic tools, such as cell capture and detection based on an optical readout. In this presentation, I will discuss how miniemulsion methods are used to generate colloidal clusters of luminescent quantum dots and magnetic iron-based nanoparticles. The colloidal clusters are subsequently functionalized with carboxylic acid groups by polymerizing a layer of poly(acrylic acid) around the clusters. The surface carboxylic acid groups provide aqueous dispersibility and sites for surface modification where small molecule probes, DNA or antibodies can be anchored to the colloid surface. The miniemulsion conditions that yield colloidal architectures with enhanced cell capture and detection capabilities (i.e. high photoluminescence and rapid magnetic response) will be presented.

**Poster Session**

**41** ADSORPTION OF PROTEIN ANTIGENS ONTO PLG MICROPARTICLES STUDIED BY X-RAY PHOTOELECTRON SPECTROSCOPY (XPS) AND TIME OF FLIGHT SECONDARY ION MASS SPECTROMETRY (TOF-SIMS)

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Polymer micro-particles have become an attractive vehicle for the delivery of protein antigens in the treatment of numerous diseases. Previous approaches have been to encapsulate the antigen within the microparticle however more recent methods have shown that surface adsorption is a more appropriate method of delivery since the structural integrity of the protein is maintained. The aim of this current study is the identification and quantification of protein adsorbed at the surface of such microparticles through *in situ* chemical analysis. Poly (lactide-co-glycolide) microparticles were synthesised by an oil and water emulsification method in the presence of varying concentrations of dioctylsulfosuccinate (DSS) surfactant. The HIV envelope glycoprotein (gp120), recombinant meningococcal protein (Mb1), and two model proteins (Lysozyme and Ovalbumin) were adsorbed on the microparticle surfaces. The efficiency of this process was studied by X-ray photoelectron spectroscopy (XPS) and Time of flight secondary ion mass spectrometry (TOF-SIMS). TOF-SIMS confirmed the presence of protein at the surface of all microparticles on the basis of the identification of specific
amino acid fragment ions. XPS was able to quantify the amount of protein present at the surface of the microparticle and characterise the efficiency of the adsorption process. Generally it was shown that protein concentration at the surface decreased with increasing DSS surfactant concentration. XPS and TOF-SIMS can identify and quantify the levels of different proteins detected at the surface of PLG microparticles following surface adsorption.

**Poster Session**

42 DIFFERENT SYNTHETIC STRATEGIES TOWARD CdSe QUANTUM DOT-BASED MATERIALS FOR HYDROCARBON DETECTION
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Our interests are focused at the development of the CdSe nanoparticle-based sensing materials that have the ability to provide multiple levels of selectivity toward aromatic hydrocarbons through the tailored design of both the host matrix and the surface-functionalized nanoparticles. To synthesize the latter we have adapted colloidal synthetic chemistry procedures to attach a combination of stabilizing and sensing groups to the surface of semiconducting CdSe quantum dots (QDs). The sensing groups are designed and utilized to achieve the first level of selectivity toward detection of the target hydrocarbons. To attain the second level of selectivity, we developed three synthetic strategies that allow different organization of QDs within a host matrix for sensing applications. The first strategy is based on drop-casting of mixtures of QDs with poly(methyl methacrylate) to afford thin hybrid films of QD/polymer nanocomposites. Such dispersion of QDs in soluble polymers produces not uniform films and may yield particle aggregation and subsequent luminescence quenching. To avoid these effects, we developed an approach, in which thick polymer films are built by in-situ polymerization of QDs with different methacrylate monomers, such as hexyl, lauryl, stearyl and behenyl methacrylates. Long side hydrocarbon chains of these polymethacrylates allowed uniform dispersion of QDs within a polymeric host and preserved their luminescence. The final strategy utilizes the covalent attachment of QDs to glass or Si wafers by different silane-coupling agents that is followed by diisocyanate binding to form multiple QDs layers. This approach allows one to avoid the use of polymers, which affect the sensing capabilities of embedded QDs, and leaves the QD-surface unshielded by a matrix. Sensing properties of the resulting QD-based nanocomposite materials will be discussed and compared.
**Poster Session**

**43**

A NEW APPROACH TO DIRECTLY MEASURE THE SURFACE AREA OF NANOPARTICULATE DISPERSIONS USING NMR

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The need to determine the surface area of powders is well established; it influences many aspects of product performance. The most widely employed technique is that of (BET) gas adsorption. However, the overwhelming majority of manufactured products involve suspensions of particulate materials in some fluid, either in the final state or at some stage of their production. Gas adsorption is not well suited to such systems; drying takes time and will promote aggregation. Thus, while gas adsorption is useful to test incoming dry powder raw materials, it cannot provide information about the powder when dispersed in a liquid. To date this has not been possible other than to estimate the surface area from particle size measurements, from time-consuming adsorption isotherm measurements or by titration, none of which are routine. We describe a revolutionary instrument designed to measure the surface area of nanoscale particles or droplets dispersed in a liquid. This new (patent pending) technique is based on nuclear magnetic resonance (NMR) and it offers many advantages in comparison with conventional surface area instrumentation. The technique is based on the fact that the NMR relaxation time of bound versus bulk liquid is markedly different: the relaxation time of the latter is much longer. There are no assumptions made about the sample particle size (distribution) or shape in the determination of the surface area; it is measured directly. One very useful practical consequence is that the instrument can also readily measure the volume fraction of solids. Suspensions and emulsions can be measured non-invasively, without dilution. The upper limit in concentration is essentially unlimited; the lower limit is about 1-2%. The theory underpinning this new approach to surface area measurement will be discussed and examples given to illustrate its wide applicability.

**Poster Session**

**44**

LOADING QUANTUM DOTS INTO THERMORESPONSIVE MICROGELS BY REVERSIBLE TRANSFER FROM ORGANIC SOLVENTS TO WATER

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Several microgel compositions have the interesting property that they form stable colloidal solutions both in water, in which they are synthesized, and in polar organic solvents. Examples include poly(N-isopropyl acrylamide) and poly(N-vinyl caprolactam-co-acetoacetyl methacrylate). We report that microgels with this basic composition that include functional co-monomers such as N-vinylimidazole or acrylic acid, once transferred to tetrahydorfuluan solution, can incorporate TOPO-coated CdSe or oleic acid-
coated PbS quantum dots (QDs) prepared by traditional high temperature methods in organic media. The microgels, synthesized in water, retained their colloidal stability during the transfer from water to THF; and the QD-microgel hybrid particles retained their colloidal stability during transfer from THF to water. QD binding to the microgel takes place by a ligand exchange process, which leads to strong binding of the QDs to the microgel network. Small differences in behavior were noted and attributed to the different internal morphologies of these microgels. The QDs incorporated into the microgels remained photoluminescent, both in THF and in water. The hybrid microgels retained their temperature-sensitive properties in aqueous solution, but the presence of the QDs shifted the volume phase transition to lower temperatures. We believe that this new approach can be used for the loading of a broad range of nanoparticles into microgels and can also lead to the design of novel multifunctional materials.

**Poster Session**

45 WATER SOLUBLE SUPERPARAMAGNETIC IRON BASED CORE-SHELL NANOPARTICLES AS CELL CAPTURE PROBE

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The use of superparamagnetic nanoparticles both in vivo or within tiny microfluidic channels is beneficial because the small nanoparticles have very long sedimentation rates, and hence will not be excreted by the body, nor clog a microfluidic device. In general, coating small nanoparticles with silica can improve the biocompatibility; help prevent aggregation and degradation; and decreases the clearance from cell by endoplasmic reticulum (ER) system. Another advantage of using silica is its ease of functionalization for binding of drugs or other molecules depending on the intended use. One of the important in vitro applications of magnetic nanoparticles is their use in diagnostics. Currently, solid phase extraction (SPE) provides a means by which pathogens or cells can be isolated from a sample matrix. However, this technique is time consuming when large volume of sample is used. Therefore, speeding up the process in an efficient manner needs more attention. This suggests that the incorporation of magnetic nanoparticles in the existing SPE technology will be promising. Our goal is to design a superparamagnetic material with the proper surface functionality allowing its use within a rapid and efficient biomolecule detection scaffold. For this purpose, highly magnetic zero-valent iron nanoparticles coated with inert iron oxide shell have been prepared via a high temperature colloidal route. In order to use these nanoparticles for biomolecule capture, they are post-coated with a shell of silica and modified with amine or carboxylate groups. These nanoparticles can be utilized to capture polystyrene (PS) beads (i.e. cell/pathogen mimics) and investigate what factors affect the capture efficiency, such as nanoparticle concentration, viscosity of the suspension medium, etc. In addition, the analogous experiments were performed with commercially available ferrofluid particles coated with silica and a number of commercially available magnetic particles (Dynal and Ademtech beads). In this work, synthesis and properties of uncoated, coated, and functionalized magnetic nanoparticles will be discussed along with the findings obtained during the capturing experiments.
Poster Session

46 PRODUCTION OF POLYMER MICROSPHERE PARTICLE STANDARDS CONTAINING TRACE EXPLOSIVES USING INKJET PRINTING AND CO-FLOW NOZZLE TECHNOLOGY
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Increases in United States Homeland Security measures have led to a substantial deployment of trace explosive detection systems within the United States and US embassies around the world. One such system is described as a walk-through portal which aerodynamically screens people for trace explosive particle. Another system is a benchtop instrument that can detect explosives from swipes used to collect explosive particles from surfaces of luggage, clothing, and other articles. Well characterized test materials are essential for validating the performance of these systems. Particle size, chemical composition, and detector response are particularly important. Here, we explain two methods for producing monodisperse polymer microspheres encapsulating explosives and explosive simulants by using inkjet printing technology or a sonicated co-flow Berkland nozzle. It was found that inkjet printing works well, but has practical limitations such as low particle yield and difficulty of use due to frequent clogging of the small orifice diameter. By comparison, the Berkland nozzle produces very high particle yields and does not easily clog. Issues such as particle size, particle uniformity and levels of analyte composition will be discussed.

Poster Session

47 SOLVENT REVERSIBLE PORATION IN IONIC LIQUID COPOLYMERS
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Microemulsions comprising methyl methacrylate (MMA) and a polymerizable ionic liquid (IL)-based surfactant, 1-(2-acryloyloxyundecyl)-3-methylimidazolium tetrafluoroborate (IL-BF₄), water and cosurfactant, 1-propanol, have been polymerized via thermal initiation. Nanolatexes or gels are obtained; the products depend on starting composition (phase space position). The resulting polymer hydrogels can be transformed to porous polymers by anion exchange of BF₄ by PF₆ in the IL moiety. The pore size of the polymer varies with crosslinker content in the precursor microemulsions. The converted porous polymers can be transformed to solvogels by imbibing solvents such as dimethyl sulfoxide (DMSO), dimethyl formamide (DMF) and alcohols. These polymer solvogels can be reversibly transformed to porous polymers again by treatment with water. The basis for this reversible poration process appears due to spinodal decomposition of the solvogel composition into the open cell nanoporous material, induced by addition of a poor solvent (e.g., water) for the ionic liquid surfactant blocks of the copolymer.
Colloidal quantum dots (QDs) are semiconductor nanocrystals capped by an organic layer around the surfaces. As a kind of unique photoluminescent probes, QDs have several advantages over organic dyes. For instance, they have broad and continuous absorption with high molar extinction coefficients, a narrow and symmetric emission, often with a high photoluminescence (PL) quantum yield (QY), as well as a strong resistance to photobleaching. Many of these applications, for example biological imaging, require QDs that form stable colloidal solutions in water. Herein, we present an approach for transferring trioctylphosphine oxide-stabilized CdSe and core/shell CdSe/ZnS semiconductor nanocrystals from toluene into water through a ligand exchange process with a poly(ethylene glycol-b-2-N,N-dimethylaminoethyl methacrylate) (PEG-b-PDMA) diblock copolymer. In this polymer, the DMA units serve as multidentate ligands for the QD, while the protruding PEG layer is to enhance the water-solubility of the polymer/QD adduct. We compared the optical properties of the polymer/QD adduct before and after the transfer from toluene to water. We further examined the effect of ionic strength, photoactivation, temperature and addition of small water-soluble ligands on the PL of the polymer/QD in water.
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Symposium D. FEOL & BBOL Advanced Processing: topics include substrate material science, cell isolation; high-k dielectrics and metal gate; shallow junction formation; source drain contacts (silicide/silicide); conductive interconnects (PVD, ALD, ECP, Electroless); dielectrics (stress layer, low-k, diffusion barriers/etch stops, caps, ARC layers); siliced silicon technology, millisecond spike anneal technology, etc; clean and process module development and integration.

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Sessions and Organizers
(1) Soft Matter at Interfaces
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Jan Genzer, Jan_Genzer@ncsu.edu

(2) Self-Assembly of Surfactants and Biomolecules
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(3) Life Science Applications
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(4) Nanoscale Synthesis
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(5) Nanoscale and Microscale Engineering
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(6) Electrokinetic Phenomena and Microfluidics
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(7) Rheology of Colloids and Interfaces
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(8) Environmental Applications and Natural Colloids
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(9) Surface Science and Catalysis
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(10) General Papers in Colloid Science
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(11) Poster Session
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