NNIN
www.nnin.org
Nanoscale Science Engineering & Technology

UNIVERSITY OF MINNESOTA

NANOTECHNOLOGY NEWS FROM THE UNIVERSITY OF MINNESOTA

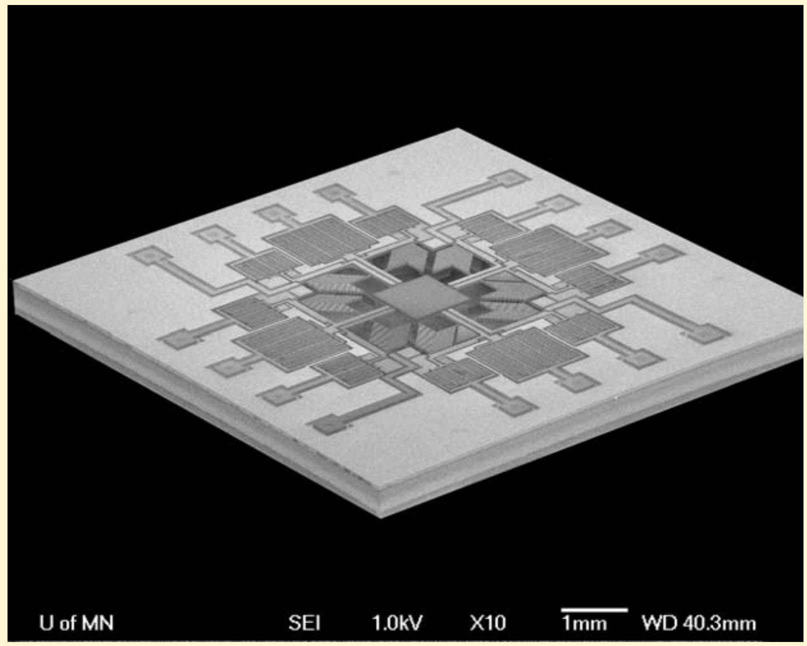
SUMMER 2008

Welcome to the summer 2008 issue of our newsletter. The University of Minnesota is now in the fifth and final year of support from the National Science Foundation under the National Nanotechnology Infrastructure Network program. Cornell, the network lead, has asked Minnesota to participate in the renewal, however, the scope of the renewal excludes the types of characterization services provided by the Characterization Facility. We will update you on the outcome of the NNIN renewal in the next issue.

This issue continues our recent format, offering the opportunity for Center for Nanostructure Applications sponsored groups to provide a glimpse of their work. In this issue Professor Uwe Kortshagen (Mechanical Engineering) discusses the project that he leads. This group involves faculty from Mechanical Engineering, Physics, and Chemical Engineering & Materials Science. The work concerns the development of doped nanoparticles for photovoltaic and thin film devices.

Finally I want to put in a plug for our web site, www.nano.umn.edu. In addition to funding opportunities and an overview of University-based nano research, we have now introduced the NNIN-sponsored open textbook on nano. While some sections are still incomplete, the open text provides excellent, introductory material for people wanting to learn more about many areas of nano.

SUMMER 2008 NANO IMAGE



A Novel MEMS Angle Sensor

This sensor measures inertial angle instead of angular rate

Photo courtesy of Neng Piyabongkarn, Serdar Sezen and Prof. Rajesh Rajamani, Mechanical Engineering University of Minnesota

Reminder: If your work uses CharFac, NFC, or PTL, please add the following in the acknowledgements section of any publication: "Parts of this work were carried out in the Minnesota (Characterization Facility, Nanofabrication Center, or Particle Technology Lab) which receives partial support from NSF through the NNIN program."

Nanotechnology News from the University of Minnesota is published by the University of Minnesota's Center for Nanostructure Applications and made possible by:

NSF
OVPR
INSTITUTE OF TECHNOLOGY
engineering | physical sciences | mathematics

Low-Cost High-Efficiency Silicon and Germanium Quantum Dot Solar Cells

Uwe Kortshagen, PhD, Mechanical Engineering
James Kakalios, PhD, Physics
Eray Aydil, PhD, David Norris, PhD, and Dan Frisbie, PhD, Chemical Engineering & Materials Science

Even by conservative estimates of the projected increases in global population and economic activity, the world's need of primary energy is expected to roughly double by 2050, reaching a level of ~30 Terawatt (TW). If this is to be achieved while stabilizing the atmospheric CO_2 level at 550 ppm—twice the pre-industrial level—15 TW of carbon-free energy will be required [1] —the equivalent of ~15,000 1-GW nuclear power plants. Achieving this daunting task will likely require developing a mix for carbon-free and renewable energy sources including wind energy, biomass, and solar energy. Solar-to-electric energy conversion, known as photovoltaics, is expected to play a significant role in the carbon-free energy mix. As the earth receives roughly 100,000 TW of power from the sun, converting just a miniscule fraction of this energy could make a significant contribution toward the world's need for carbon-free power production. Unfortunately, current photovoltaic technologies are significantly more expensive than electricity produced by burning fossil fuels. Hence the dramatic expansion of solar technologies witnessed over the last few years has mainly been fueled by government subsidies and is not a reflection of the current economic viability of solar technology.

While a range of materials are being investigated for photovoltaic devices (solar cells), about 90% of all currently available cells are based on silicon, the second most abundant element in the earth's crust. Silicon's appeal is based on its abundance, its non-toxic nature, and the fact that a significant knowledge base on silicon manufacturing has been assembled by the microelectronics industry over the past four decades. Silicon finds use in solar cells either in the form of single- or poly-crystalline wafers or as thin, amorphous (non-crystalline) silicon films deposited with vacuum techniques. While the cost of crystalline silicon solar cells is

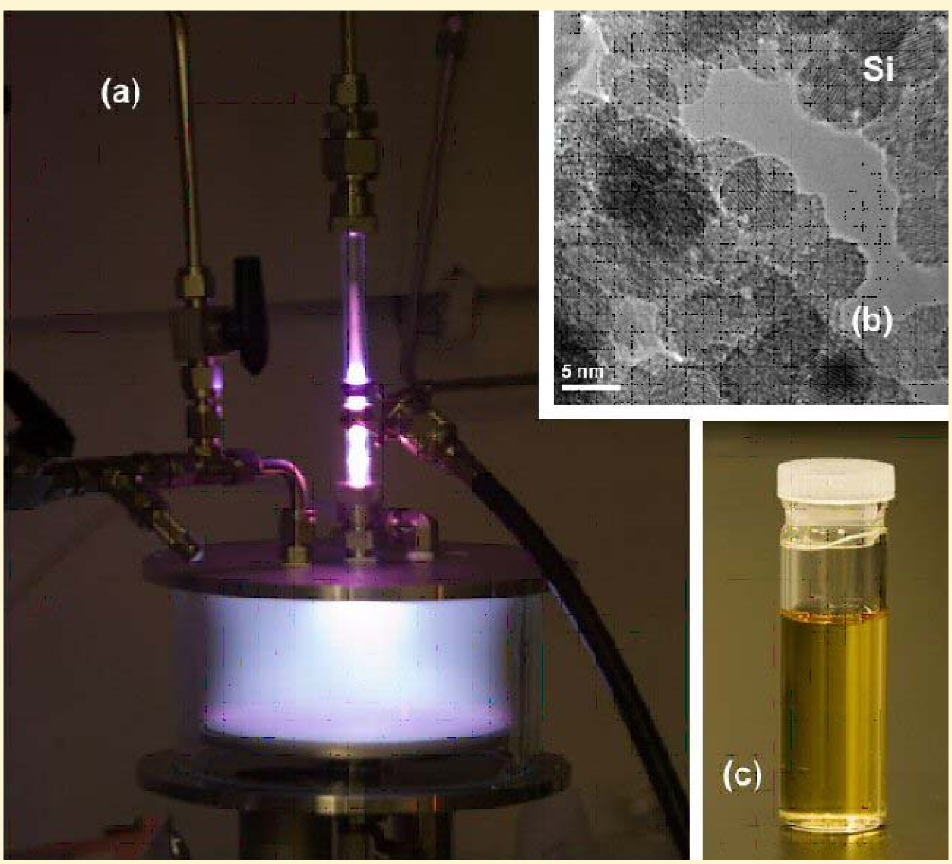


Figure 1: The figure shows a low pressure plasma reactor for the synthesis and surface functionalization of silicon nanocystals **(a)**. Silicon crystals are produced in the upper, narrow processing reactor. At low pressure, a gaseous silicon precursor (silane, SiH_4) is broken down and silicon atoms form nuclei through chemical clustering. Within a few millisecond, silicon crystals of several nanometers in size form. Some of these crystals are shown in **(b)**. While still in flight, the silicon crystals are injected into a second plasma, in which they are exposed to a vapor of an organic surfactant precursor (dodecene). Dodecene molecules are activated and attach to the surface of the silicon crystals, enabling to form stable colloidal solutions of silicon crystals **(c)**.

generally higher than that of amorphous silicon devices, their solar-to-electric conversion efficiency is also significantly higher, which ultimately levels the advantages of both technologies.

With this research project the Minnesota group aims at developing silicon solar cells that combine the high efficiency of crystalline silicon devices with the cost advantage of amorphous silicon cells. The group explores novel schemes to manufacture solar cells from nanocrystals, also called quantum dots, of silicon and germanium. The latter element shares many of the advantages of silicon but provides a better absorption of radiation in the red and infra-red range of the solar spectrum. The group pursues two parallel tracks. In the first track, thin films of silicon or germanium quantum dots are assembled using solution-phase techniques. The quantum dots in these films retain their individual optical characteristics which can be modified via the nanocrystal size. An advantage of such quantum dot films is that the absorption properties can be tailored to the solar spectrum by adjusting the nanocrystal size without changing the materials composition. However, as producing solutions of quantum dots requires functionalizing their surfaces with some kind of organic surfactant which often is an obstacle to charge carrier transport, obtaining good electrical conductivities from nanocrystal films is one of the important challenges addressed by this project. In the second track, the group investigates thin films in which silicon quantum dots are used as a key component to improve the films' functionality. Thin film materials studied consist of multiple phases of the same material and benefit from the synergistic enhancement of the materials properties of the different phases. The model material investigated by the Minnesota group is that of amorphous silicon with embedded silicon nanocrystals. Incorporating varying fractions of silicon quantum dots of different sizes presents an appealing strategy for tailoring the optical absorption of the material, its stability under solar irradiation, and its transport properties for the produced electrical carriers.

The Minnesota team combines a wide range of expertise to address the important problems from the synthesis of the materials, to the characterization of electronic and optical properties, to the integration into functional solar cells, and the characterization of their device performance. Kortshagen's group has developed synthesis techniques that enable the gas phase production of monodisperse silicon and germanium quantum dots, Figure 1 [2]. Since both materials have high melting points, low-pressure plasma synthesis has proven to be a useful tool, in particular, since it enables the simultaneous surface functionalization of the quantum dots with organic surfactants [3]. Norris's expertise is in the area of doping of nanocrystals [4, 5]. Similar to bulk semiconductors, where doping is crucial to achieve the desired functionality of the material in a device, the doping of semiconductor quantum dots is expected to play a central role in the development of solar cells. Together with Frisbie, Kortshagen, and Aydil, he works on the solution phase assembly of quantum dot films. Frisbie's expertise in characterizing electronic properties of films by integrating them into field effect transistor structures is crucial to the understanding of the performance of the quantum dot films. On the parallel track, Kakalios and Kortshagen work on the characterization of amorphous silicon films with embedded silicon quantum dots. Techniques developed in Kakalios's lab provide information about the absorption characteristics, the density of defect and trap states in the material, and the stability of the films' electronic qualities under extended exposure to solar radiation. On the devices side, Aydil has significant expertise in the assembly of quantum dot solar cells and the characterization of their performance under simulated solar conditions [6]. Initial results obtained under this project have already resulted in two "spin-off grants" funded by the National Science Foundation and Xcel Energy.

1. Hoffert, M.I., K. Caldeira, A.K. Jain, E.F. Haites, L.D.D. Harvey, S.D. Potter, M.E. Schlesinger, S.H. Schneider, R.G. Watts, T.M.L. Wigley, and D.J. Wuebbles, *Energy implications of future stabilization of atmospheric CO2 content*. Nature, 1998. **395**(6705): p. 881-884.
2. Mangolini, L., E. Thimsen, and U. Kortshagen, *High-Yield Plasma Synthesis of Luminescent Silicon Nanocrystals*. Nano Letters, 2005. **5**(4): p. 655-659.
3. Mangolini, L. and U. Kortshagen, *Plasma-assisted synthesis of silicon nanocrystal inks*. Advanced Materials, 2007. **19**: p. 2513-2519.
4. Erwin, S.C., L. Zu, M.I. Haftel, A.L. Efros, T.A. Kennedy, and D.J. Norris, *Doping semiconductor nanocrystals*. Nature, 2005. **436**(7047): p. 91-94.
5. Norris, D.J., A.L. Efros, and S.C. Erwin, *Doped Nanocrystals*. Science, 2008. **319**(5871): p. 1776-1779.
6. Leschkies, K.S., R. Divakar, J. Basu, C.B. Carter, U.R. Kortshagen, D.J. Norris, and E.S. Aydil, *Photosensitization of ZnO Nanowires with CdSe Quantum Dots for Photovoltaic Devices*. Nano Letters, 2007. **7**(6): p. 1793-1798.

UPCOMING NANO EVENTS

Microscopy Camp 2008
July 14 – 18, 2008
Characterization Facility and Departments of Chemistry and Curriculum & Instruction at the University of Minnesota

In this camp, Secondary Science Teachers will learn about atomic structure imaging and curriculum implementation for their classrooms as well as explore and work in a research laboratory. Participants will see and use state-of-the-art characterization microscopes at the Characterization Facility, including: Atomic Force Microscopy (AFM), High-Resolution Transmission Electron Microscopy (HRTEM), and Scanning Electron Microscopy (SEM). We will also synthesize and characterize nanocrystalline gold and magnetite.

Join us in exploring Science, Technology, Engineering & Mathematics (STEM) issues under the framework of Nanotechnology Education and examine curriculum that can immediately be employed in middle school and high school life and physical science classrooms.

Aerosol and Particle Measurement
August 18 - 20, 2008
Organized & Offered by the Particle Technology Lab and Mechanical Engineering Department at the University of Minnesota in cooperation with TSI Incorporated

This course includes material on air pollution, industrial hygiene, and nanoparticle technology as well as aerosol sampling and measurement for bioaerosol, cleanroom and contamination control. The course covers both fundamentals and applications to meet the growing demand of professionals for training in the aerosol field. The course objective is to provide theoretical and practical training for individuals with a need for knowledge of the behavior of airborne particles and skills to sample, measure, and characterize airborne particulate matter for cleanroom, contamination control, air pollution, bioaerosol, and industrial hygiene studies.

Air and Gas Filtration
August 21 - 22, 2008
Organized & Offered by the Particle Technology Lab and Mechanical Engineering Department at the University of Minnesota in cooperation with TSI Incorporated

This course provides training for industrial and university personnel interested in the fundamentals of air and gas filtration and its applications to air and gas cleaning for nuclear, microelectronics, automotive/gas turbine, respiratory protection, building ventilation, indoor air quality, hospital air purification, and other applications.

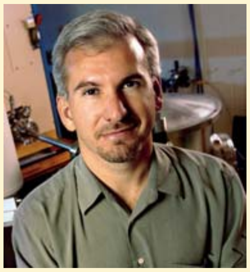
For complete information about the Aerosol & Particle Measurement and the Air & Gas Filtration Short Courses, visit: http://www.cce.umn.edu/conferences/aerosol/

4th Annual Nanotechnology Conference
November 11 - 13, 2008
Radisson Hotel, University of Minnesota

Save the date! Our annual Nanotechnology Conference is coming up this Fall. This year's event will offer discussions of various fields of nano including: medicine, energy, devices, sensors and materials. As always, we will feature speakers from around the country and from the University of Minnesota who are leaders in their fields. The Conference will also host poster sessions in these areas so researchers and conference visitors may connect one-on-one.

CHARACTERIZATION FACILITY NEWS

CHARFAC DIRECTOR'S MESSAGE

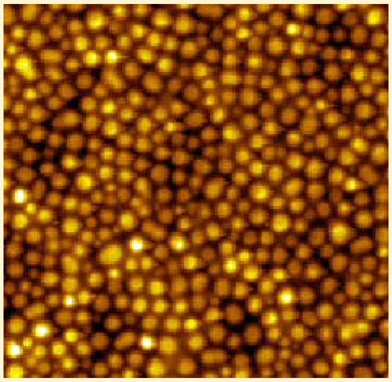


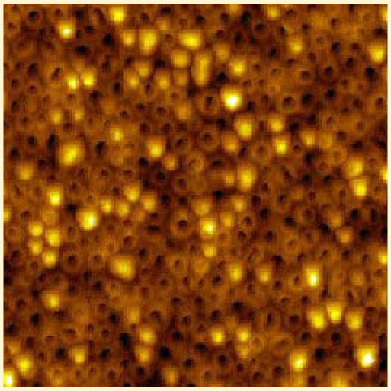
CharFac Director, Greg Haugstad

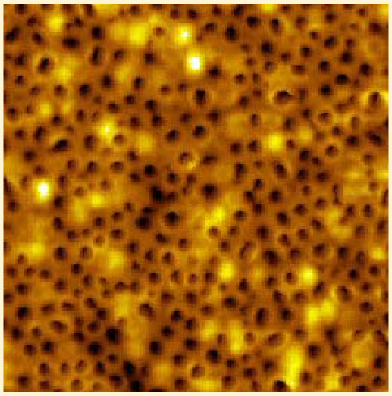
The CharFac announces a new TEM PicoIndenter (Hysitron), capable of nanomechanical testing inside of a transmission electron microscope (TEM). CharFac is one of only two facilities in the world with this capability. With the PicoIndenter, quantitative force-displacement curves can be time correlated to the corresponding TEM movie of the stress-induced deformation processes. The combination of CharFac's high-end FEI TEMs and this analytical tool will enable researchers to witness the nanoscale structural changes corresponding to observed force and displacement transients. Some example applications are direct observation of depth-sensing indentations, quantitative compression testing, and defect formations such as dislocations, stacking faults, twins, etc.

The CharFac is offering expanded analytical services utilizing environmental atomic force microscopy (AFM). We are rapidly developing know-how in imaging and analysis under variable humidity (1-95%) and temperature (-30 to 200ºC) as well as liquid immersion. Recent uses center on drug-eluting coatings and other biomedical applications. Staff members can conceive analytical approaches in discussion with clients, say to seek specific changes under liquid immersion or to identify temperatures that will yield structural transitions.

Here we show one example, the elution of the drug dexamethasone from a 50:50 spin-coated film of dexamethasone/poly(butyl methacrylate). The top image (5x5 microns) is topography showing protruding circular domains attributed to drug. (Heating above the polymer glass transition increased the stickiness during tip pull-off only in regions *outside* of these circular domains). The bottom two images show the topography after immersion in deionized water for 10 minutes (left) and 2.5 hours (right), comparing the same 5x5 micron region. Many protrusions in the as-cast film immediately become holes which grow with passing time; some protrusions remain intact initially only to disappear later, while still others remain intact over the longer time frame. Implications for "burst" versus long-time drug release are suggested.







CHARFAC AT THE UNIVERSITY OF MINNESOTA

12 Shepherd Labs
100 Union Street SE
Minneapolis, MN 55455

www.charfac.umn.edu
Main telephone: 612-626-7594
Fax: 612-625-5368

Greg Haugstad, Director

NANOFABRICATION CENTER NEWS

NFC DIRECTOR'S MESSAGE

NFC Director,
Steve Campbell

We have one minor capability addition to report this period. Using National Nanotechnology Infrastructure Network (NNIN) support, the Nanofabrication Center has licensed the Coventor software suite for designing and simulating MEMS devices. The lab acquired a single-seat one year license to Architect and the Designer/Analyzer tool (www.coventor.com/mems/support/index.html). The software can be downloaded to your computer and you can use the license file that we have loaded on an Electrical & Computer Engineering department server. If you have an interest in using this tool for academic research, please contact the lab for help with setting it up.

I ask for your patience this summer as the University changes to a new accounting system. Assefa, Greg, Sherri, and I have all been taking classes in how this system will operate. Although it looks reasonable now, it would be fairly remarkable if we do not run into significant problems with lab billings as it comes on line on July 1st. We will do everything that we can to eliminate problems and to make sure that your billing is done on time.

SOFT LITHOGRAPHY CAPABILITY

Soft lithography refers to a group of non-photolithographic methods that can be used to fabricate or replicate structures, using polymers such as polydimethylsiloxane (PDMS). Examples include micro contact printing, replica molding, micromolding in capillaries and microtransfer molding. Many of these techniques were developed by George Whitesides at Harvard University. Applications include fabrication of microfluidic devices, patterning on non-planar surfaces, fabrication of complex optical surfaces, and stamps for selective application of biological materials.

At the Nanofabrication Center we are establishing a soft lithography capability centered around SU-8 molding of PDMS. SU-8 is a commonly used molding material for PDMS, and can be formed into structures of a wide range of sizes and shapes. These masters can be made with nanoscale feature sizes using our electron beam lithography system, or with larger sizes using conventional photolithographic processing. We are also working to put in place the equipment necessary to do the PDMS molding as well. Please contact us if you are interested in learning how we can help you with soft lithography.

NANOFABRICATION CENTER AT THE UNIVERSITY OF MINNESOTA

1-165 Electrical Engineering/Computer Science
200 Union Street SE
Minneapolis, MN 55455

www.nfc.umn.edu
Main telephone: 612-624-8005
Fax: 612-625-5012

Steve Campbell, Director
Greg Cibuzar, Lab Manager

SAFETY TRAINING

NFC is offering safety training for new users twice each month. On the first Thursday of every month, the training sessions begin at 1:15PM, and on the third Thursday of the month sessions begin at 10:00AM. The training includes watching our safety video and taking a brief quiz. Also, a NFC staff member provides a tour showing some of the safety related equipment and the gowning process used for the NFC cleanroom. Finally, there is training on using the Coral lab software. The safety training takes about two hours to complete, and must be done before users will be granted access to NFC facilities.

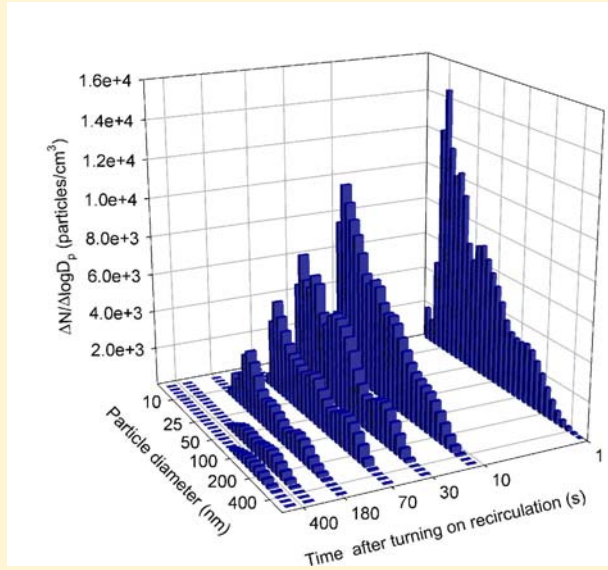
PARTICLE TECHNOLOGY LAB NEWS

PTL DIRECTOR'S MESSAGE

Distinguished McKnight University Professor, David Y.H. Pui

NNIN-PTL is receiving a great deal of attention on its filtration research and facility. David Pui and Jing Wang presented two papers at the 10th World Filtration Congress in Leipzig, Germany in April on agglomerate filtration and nanofiber filtration. We received many inquiries on our methodology and facility. In particular, many companies expressed interest in testing filters in our ASHRAE 52.2 tunnel. Another topic of significant interest to nanotech companies is our Recirculating Air Filtration study. We have recently published two papers in Environmental Health Perspectives and in Environmental Science and Technology (online edition for both are available). We found that filters are effective in removing nanoparticles and thereby reducing nanoparticle exposure. Recirculating air filtration in car-cabins and workplaces is especially effective in reducing exposures to nanoparticles for commuters and workers, respectively. The following figure shows the nanoparticle size distributions at 1, 10, 30, 70, 180, and 400 seconds from turning on recirculating air in a car-cabin on a freeway. In 3-4 minutes, the nanoparticles are removed by the cabin air filters and the particle concentration decreases to lower than that in a typical office. Similar results

(continued, top right)



are observed for workplace air recirculation. This may be a low cost solution to reduce workers' exposure to nanoparticles in workplaces.

In May, NNIN-PTL will host the visit of Dr. Jason Scott from Professor Rose Amal's group at the University of New South Wales from Australia. Under the support of the Australian Research Council, we are developing a joint test facility to evaluate VOC oxidation by doped TiO_2 nanoparticles synthesized in Amal's lab. We would like to incorporate these specialized nanoparticles in cabin air filters to remove VOC from the recirculating air. Once the test facility is set up, it will be made available to the NNIN users.

During August 18-20, NNIN-PTL will again organize the Aerosol and Particle Measurement Short Course for the 33rd offering. Each year, 50-80 registrants attend this short course, most of them from industry. We have found the course helps us network with industry. Over the years, we have attracted over 1,900 attendees for this course. This year, we will offer a back-to-back Air and Gas Filtration Short Course, August 21-22 for the 11th offering. Registrants will then have the opportunity to review the fundamentals in Aerosol Measurement and attend the specialized filtration course. Please review the following website for more details: http://www.cce.umn.edu/aerosol.

PARTICLE TECHNOLOGY LAB AT THE UNIVERSITY OF MINNESOTA

Mechanical Engineering 3101
111 Church Street SE
Minneapolis, MN 55455

www.me.umn.edu/labs/ptl
Main telephone: 612-624-2368
Fax: 612-625-6069

David Y.H. Pui, Director
Jing Wang, Lab Manager

Center for Nanostructure Applications

The primary mission of the Center for Nanostructure Applications is to seed interdisciplinary nano research projects that will go on to attract external support. Active nanostructures include applications of nano as diverse as energy conservation and production, large area displays and lighting, printed electronics, smart fabrics, electronic noses, drug delivery, cancer therapy, and new types of medical imaging.

These applications often require significant participation across traditional disciplines and the Center is designed to foster the cross-disciplinary research necessary to bolster the nano applications area at the University.

The Center also organizes workshops, speaker series, and short courses, as well as serving as a focal point for nano at the University.

For more information, visit http://www.nano.umn.edu/

The Minnesota Nanotechnology Cluster

MiNTeC is an umbrella organization of three labs at the University of Minnesota that support the development of nano technology: the Characterization Facility, Nanofabrication Center, and Particle Technology Lab. As a node in NSF's National Nanotechnology Infrastructure Network (NNIN), MiNTeC provides access to advanced multi-user facilities to both industry and academic researchers, the latter at a subsidized rate. The MiNTeC facilities are at the University of Minnesota's Minneapolis campus.

For more information, visit http://www.mintec.umn.edu/ and www.nnin.org

Nanotechnology News from the University of Minnesota
Published by the University of Minnesota's Center for Nanostructure Applications
and the National Nanotechnology Infrastructure Network.
Comments and suggestions are welcome! Would you like to be added to or removed from our distribution?
Contact: Becky von Dissen at vondi001@umn.edu or 612-625-3069

Nanotechnology News from the University of Minnesota
1-165 Electrical Engineering & Computer Science Bldg.
200 Union Street SE
Minneapolis, MN 55455