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INTERFACES

The Newsletter of the Nebraska Center for Materials and Nanoscience
at the University of Nebraska-Lincoln

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From the Director

The end of the Spring Semester and beginning of the summer break allows us to catch our breath and reflect briefly on some events that encourage and gratify us as we contemplate the coming months. I note below a few developments that bode well for materials and nanoscience research here.

We are delighted that the new Physical Sciences Building is well into the planning and design stages. Professor Roger Kirby as Chair of Physics has been a major contributor to all aspects of this project, and has been the major "interfacer" (if not decider!) in getting the faculty and architects to converge on design of each laboratory, classroom, etc. The new building is scheduled for completion in mid 2009, and it will mean that all the condensed matter-materials physics faculty will be located on two floors of the new building, which will be situated across 16th Street from the Engineering College.

In addition, plans are underway to build a Nanotechnology and Materials Science Laboratory adjacent to the Physical Sciences Building. This will house seven Central or Core Facilities of NCMN, an additional Nanofiber Facility, headquarters offices for NCMN, offices for the Central Facility Specialists, and "hotel workspace" for postdocs, students and faculty using the Facilities. Several of the materials characterization facilities will go into space reserved for them in the basement of the Physical Sciences Building. This is a terrifically positive development for our research programs, and we are grateful to Vice Chancellor Prem Paul and Chancellor Harvey Perlman for their strong support and leadership in achieving it!

The Nanoscale Science and Technology Program of Excellence (NST POE), administered by NCMN, continues to provide major support to our activities. Thus far, eleven new faculty hires have been completed with support from NST POE, the latest being Dr. Axel Enders from Germany, who will join Physics this summer. Another hire is in progress for next Fall. Senior Vice Chancellor Barbara Couture and Deans Dick Hoffmann and David Allen have been most supportive of these advances.

Two additional hires are underway. One is an Assistant Director and Education/Outreach Coordinator for NCMN. This position is intended to operate and manage programs of NCMN, MRSEC, NST POE and others in order to help us recruit and retain graduate and undergraduate

students in all of the departments involved in NCMN. A major focus will be to help in efforts to boost our participation by underrepresented groups. The second hire is a Research Scientist/Specialist to operate our newest Central Facility (Nanofabrication) which is being developed temporarily in a room in the basement of Ferguson Hall. Major funding from the Nebraska Research Initiative is helping to equip this lab.

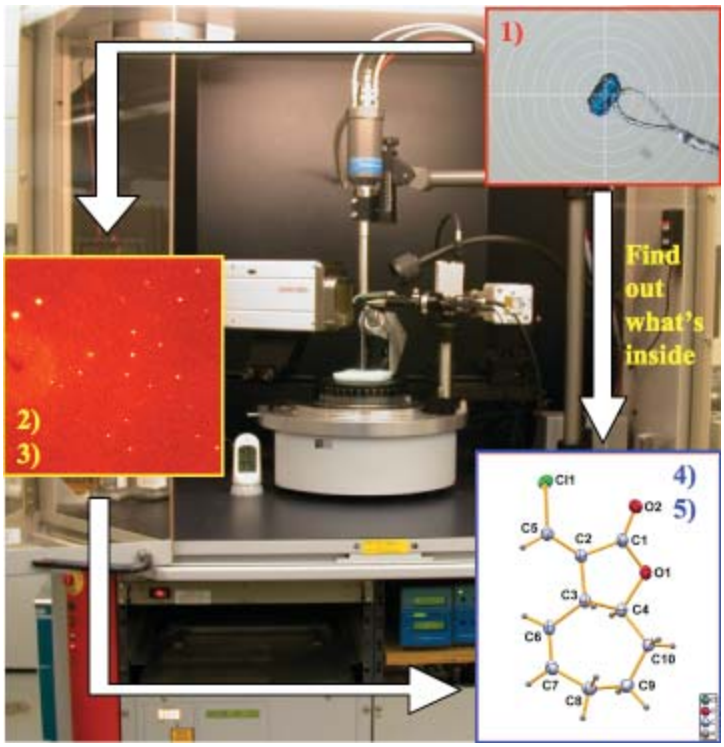
Finally, I want to mention the economic development activities of NCMN faculty. The University, under the leadership of Associate Vice Chancellor for Technology Development John Brasch, is expanding its efforts to promote tech transfer from research labs to Nebraska companies. A recent edition of the Palladian Digest, mentions five university spinoff companies, three of which evolved from our faculty: LNK ChemSolutions (Prof. Gustavo Larsen of Chemical Engineering), J.A. Woollam Co., Inc. (Prof. John Woollam of Electrical Engineering and Physics), and Rieke Metals, Inc. (Prof. Reuben Rieke of Chemistry). Other NCMN faculty with recent tech-transfer activities include Jody Redepenning (Chemistry, artificial bone), Steve DiMagno (Chemistry, imaging agents), Yongfeng Lu (Electrical Engineering, clean silicon wafers), Gerry Harbison (Chemistry, NMR detection of explosives). All of these faculty deserve great credit for taking their materials and nanoscience research to or towards commercialization, to the benefit of our state and nation.

David J. Sellmyer

Facility Focus: Crystallography

by Chunhua Hu

The Crystallography Central Facility at the Nebraska Center for Materials and Nanoscience (NCMN) provides single crystal X-ray diffraction analysis, the most powerful method known for obtaining the atomic arrangement in the solid state, based on a state-of-the-art Bruker-AXS SMART APEX CCD system. A typical experimental procedure to determine a crystal structure is shown in the figure below.



The standard procedure to obtain crystal structure: 1) Crystal Selection and Mounting, 2) Cell Determination and Data Collection, 3) Data Reduction and Correction, 4) Structure Solution and Refinement, 5) Result Presentation and Interpretation.

The SMART APEX CCD system includes the following hardware components:

- an X-ray source consisting of a high-stability 3kW X-ray generator, a molybdenum target ceramic X-ray tube, a tube shield with associated shutters, attenuators and safety interlocks, a single-crystal graphite monochromator, a higher brilliance MonoCap collimator, and a Haskris water chiller;
- a three-circle goniometer system D8, featuring stepper motors with optical encoders to ensure extremely precise angular values for sample alignment;
- a color video camera for aligning the crystal and indexing crystal faces;

- a SMART APEX CCD-based two-dimensional X-ray detector (big 62 x 62 mm Lockheed 4K CCD without the fiber-optic taper, 1:1 imaging, and faster readout time to allow even smaller or more weakly diffracting crystals to be measured), and an Neslab chiller (cool the detector);
- an Oxford Cryosystems 700 Cooler for cooling and heating the crystal during data collection with a temperature range of 80 – 400K;
- a microprocessor-based interface module that receives commands from a host computer and carries out all real-time instrument control functions to drive goniometer motors, monitor the detector system, open and close the shutter and monitor collision sensors and safely interlocks;
- a host PIII computer running Windows 2000, and diffractometer control programs to control the data collection and to send commands to the microprocessor.

The SMART APEX system incorporates a powerful software suite for instrument control and structure determination:

- SMART program controls the diffractometer to collect the experimental data used by the other programs in the system program suite;
- D8TOOLS software package helps users and service staff with maintenance, error diagnosis and correction of the diffractometer;
- VIDEO program controls the real-time video images from the video camera;
- RLATT program displays reflections in reciprocal space;
- GEMINI and CELL_NOW may index twins or split crystals;
- ASTRO and COSMO set up the data collection strategy;
- SAINT+ integrates the raw data to provide the best intensities for each indexed reflection;
- SADABS does absorption and other corrections;
- XPREP displays the indexed reflections in layers similar to Precession photographs, calculates the space group, performs face-indexed absorption corrections, and displays calculated Patterson sections;
- XS and XL perform structure solution and refinement, respectively;
- XP and XSHELL visualize molecular and crystal structure and plot diagrams;
- XCIF produces reports from standard CIF files.

In addition, the facility holds the licenses for molecular visualization programs ATOMS and DIAMOND and for the Cambridge Structural Database (CSD). There are also many freeware crystallography programs, which are maintained on the facility computers, such as PLATON, WINGX, and MERCURY.

Recent Achievements of Center Researchers

Awards, Honors

Peter Dowben received an Excellence in Graduate Education Award from UNL and a College of Engineering and Technology Multidisciplinary Research Award.
Craig Eckhardt was a Senior Fulbright Fellow in 2006.
Mathias Schubert, Associate Professor of Elect. Eng., received the 2006 Ludwig-Genzel-Prize for his contributions to generalized infrared spectroscopic ellipsometry and application to numerous problems in solid state science. The Ludwig-Genzel-Prize is awarded to a young scientist for exceptional contributions to the field of condensed-matter spectroscopy.
David Sellmyer received the Sigma Xi Outstanding Scientist Award in 2006 for "his international distinction in the study of magnetic properties."
Rodney J. Soukup was elected to the IEEE Education Society Administrative Committee.
John Woollam was named a fellow of the American Vacuum Society in 2006.

Patents

"Nano-crystalline, Homo-metallic, Protective Coatings," **Fereydoon Namavar**, Patent No.: US 7,048,767 May 23, 2006.

Outstanding Papers

The paper "Magnetoelectronics with Magnetoelectrics" by **Ch. Binek** and **B. Doudin**, published in J. Phys.: Condens. Matter 17, L39–L44 (2005), was selected as one of the best papers of 2005 in JPCM.

The paper "High-Resolution Thin-Film Device to Sense Texture by Touch" by Vivek Maheshwari and **Ravi F. Saraf** (Chem. Eng.) was published in the June 9 issue of Science.

In the paper "Tunneling Across a Ferroelectric," in the July 14 issue of Science, **Evgeny Tsymbal** (Physics) and collaborator Hermann Kohlstedt of the Research Center in Jülich, Germany, highlighted emerging research on ferroelectric tunnel junctions.

Xiao Cheng Zeng (Chemistry) and colleagues reported in the Proceedings of the National Academy of Sciences' online edition that they have found evidence of the first free-standing hollow cage structure composed of clusters of pure metal atoms, which they've dubbed golden hollow cages. Illustrations of their discovery can be found on the cover of the May 30 print edition of PNAS. It's believed to be the first UNL research featured on the journal's cover.

Student Awards and Honors

Justin Biffinger (Ph. D. Dec. 2005 Chemistry, S. DiMagno) received an NRC Research Associate Award ($120,000) and is currently working on biological fuel cells development at the

Naval Research Laboratory in Washington, D. C.
Satya Bulusu (Chemistry, X. Zeng) received the College Graduate Research Assistant Award 2006.
J. D. Burton (Physics, E. Tsymbal) received the Graduate Assistantships in Areas of National Need (GAANN) Fellowship, the UNL College of Arts & Sciences Outstanding Graduate Research Assistant Award, the Graduate Student Research Competition Prize at the UNL Research Fair and Best Poster Award at the 53rd Midwest Solid State Conference (all 2006).
The Chemistry Department awarded **Kausik Das** (Chemistry, A. Rajca) with the Graduate Teaching Award.
Danqin Feng (Physics, P. Dowben) received the Dorothy M. and Earl S. Hoffman Scholarship from the American Vacuum Society (2006) and the Fling Fellowship (2006-2007).
James Huguenin-Love (Electr. Eng., R. J. Soukup) was selected 2nd Place Poster at the 2006 UNL Research Fair.
Daniel Schmidt (Electr. Eng., M. Schubert) received the 2007 BOSCH-Prize for his outstanding Diplom-Thesis at the University of Applied Sciences Kaiserslautern carried out at Xaar plc, Cambridge, UK.
The poster "Piezomagnetism in Epitaxial Cr_2O_3 Thin Films" by **Yi Wang** (Physics, Ch. Binek) was selected as one of the best contributed presentations at the 53rd Midwest Solid State Conference in Kansas City.
Lu Yuan (Physics, S.-H. Liou) received the 2007 Lowe R. and Mavis M. Folsom Distinguished Doctoral Dissertation Award.

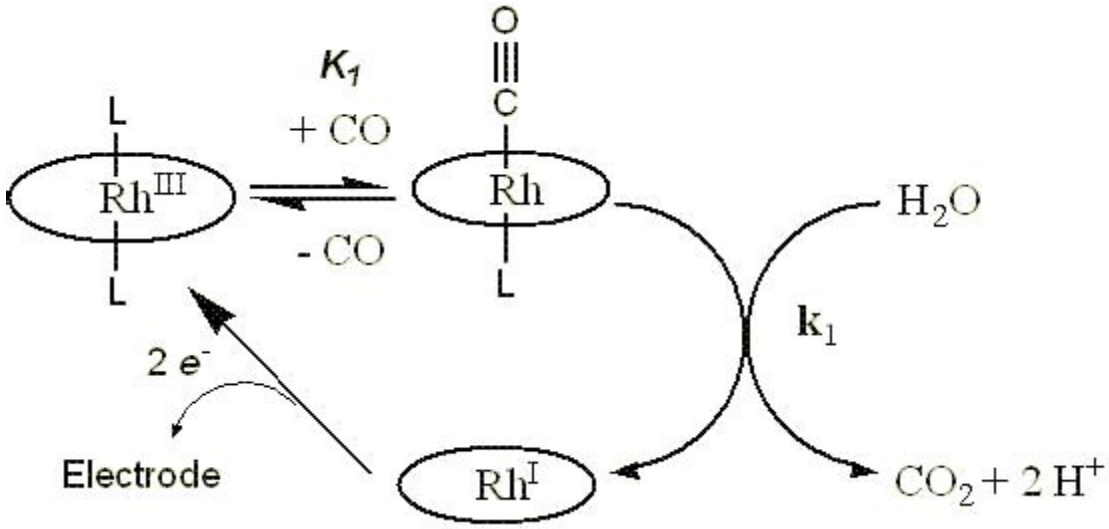
The following NCMN-affiliated students have earned their PhDs during the last year:
Sumit Mukherjee (Chemistry, A. Rajca), **Satya Bulusu** (Chemistry, X. Zeng).
The following NCMN-affiliated students have earned their M.S. degrees during the last year:
Jing Liu (Physics, P. Dowben), **Jie Xiao** (Physics, P. Dowben), **Ning Wu** (Physics, P. Dowben), **Shannon Fritz** (Physics, D. Leslie-Pelecky), **Thomas George** (Physics, D. Sellmyer), **Srinivas Polisetty** (Physics, Ch. Binek), **John D. Burton** (Physics, E. Tsymbal), **Yao Zhao** (Physics, D. Sellmyer), **Zhen Li** (Physics, D. Sellmyer and R. Kirby), Yushun Lin (Physics, S.-H. Liou), Xiaohui Wei (Physics, D. Sellmyer), **Rui Zhang** (Physics, S.-H. Liou), **Rama Valiveti** (Mech. Eng., Jeff Shield), **Yousseff Abdul-Mesih** (Mech. Eng., Jeff Shield), **Chad A. Kamler** (Electr. Eng., R. J. Soukup), **Noel T. Lauer** (Electr. Eng., R. J. Soukup).
The following NCMN-affiliated students have earned their B.S. degrees during the last year:
Peter Jacobson (Physics, P. Dowben), now at Tulane University.

Rhodium Porphyrin Preferential Oxidation (PROX) Catalysts For Carbon Monoxide Conversion

by Stephen DiMagno

One difficulty for the widespread implementation of hydrogen powered vehicles is the hydrogen storage problem. Since hydrogen is a gas that can only be liquefied with an energy penalty that is roughly 1/3 of the total energy content of the fuel itself, advanced hydrogen storage materials and liberation of hydrogen from liquid organic substances (such as alcohols) have been pursued as alternative, low cost strategies to cryogenic liquid hydrogen storage. Hydrogen fuel streams produced by hydrocarbon, alcohol, or biomass steam reforming are invariably contaminated with carbon monoxide (CO). Subsequent high temperature water gas shift (WGS) catalysis can reduce CO concentrations to the thermodynamic limit (20-50 ppm) in such hydrogen gas streams. However, the platinum anodes in current generation proton exchange membrane (PEM) fuel cells are poisoned by CO concentrations as low as 10 ppm. Our approach to this problem is to develop a catalyst or a catalytic reformer that can remove CO selectively at low temperature. Design requirements for such a catalyst are severe, since selective CO oxidation needs to be performed in the presence of hydrogen, carbon dioxide, and water prior to entry of the gas into the fuel cell.

Preferential oxidation of CO can be performed indirectly or directly. The advantage of the indirect approach (Scheme 1) is that CO's reducing equivalents can be captured at a fuel cell anode; such energy recovery is appropriate for gas streams containing high CO concentrations. In contrast, direct oxidation of CO with air or O_2 is an attractive option for scrubbing CO from streams produced by WGS catalysis. Because CO concentrations are already low in these gas streams, any potential energy recovery from CO oxidation is modest.



Scheme 1. Overall reaction pathway for the oxidation of carbon monoxide with rhodium porphyrins.

Group IX transition metal metalloporphyrins are known to be good catalysts for a wide variety of useful reactions, such as alkane activation and functionalization. The DiMagno group and others have studied intensively the impact of β–fluorination on porphyrin ring and metal redox potentials. Ligand fluorination alone can shift the formal potential for the rhodium(II)/rhodium(I)$^-$ reversible redox couple by 540 mV in nonaqueous solution. This shift in potential makes these complexes excellent oxidants for a wide variety of reductants, including CO.

We discovered homogeneous, room temperature aqueous carbon monoxide PROX catalysts based upon rhodium(III) salts of 5,10,15,20-tetrakis(4-sulfonatophenyl)-2,3,7,8,12,13,17,18-octafluoroporphyrin, **1**, and 5,10,15,20-tetrakis(2,6-difluoro-3-sulfonatophenyl)-2,3,7,8,12,13,17,18
-octafluoroporphyrin, **2**. The chemistry of these complexes was compared to the catalytically inactive, but structurally related benchmark compound 5,10,15,20-tetrakis(4-sulfonatophenyl)porphyrin **3** (Figure 1). The room activity of these complexes for carbon monoxide oxidation in water is unprecedented under such mild conditions.

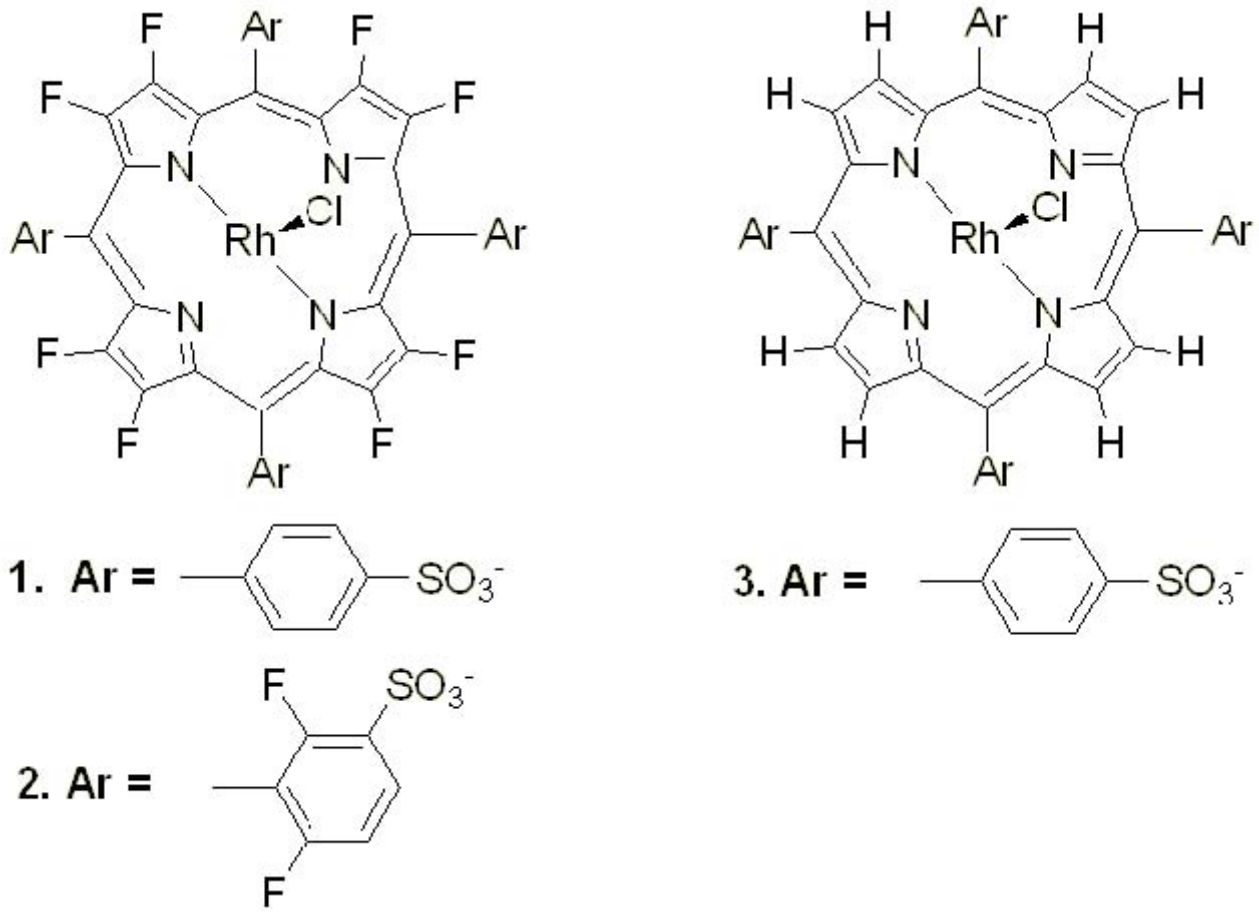


*Figure 1. Structures of compounds **1**, **2**, and **3**.*

To gather mechanistic information about PROX catalysis by these complexes, we studied the kinetics of individual steps in the process. The rate of reduction of **1**, **2**, and **3** to the corresponding RhI complexes by 1 atm of CO at 30°C under a variety of conditions and with various additives was examined. Generally, it was found that rates of CO oxidation increased with pH. For example, **2** was reduced to the corresponding Rh^I complex with the greatest rate observed ($140 \pm 13\ M^{-1}s^{-1}$) in 100 mM sodium hydroxide. The increased rate constant for **2** is consistent with the hypothesis that the most electron deficient porphyrin would increase the electrophilicity of the bound CO, which, in turn, increases the rate of nucleophilic attack. The rates of reduction of **1** and **3** are identical (within experimental error), and much slower than that of **2**. Unfortunately, at high base concentration significant decomposition of the metal complexes was observed, as was evidenced by the appearance of the signal for free fluoride in the ^{19}F NMR spectrum. We speculated that if the role of hydroxide could be filled by some nonbasic, non-nucleophilic additive, a reasonable PROX catalytic system would result.

An alternative explanation for the improvement in catalyst performance with increasing pH is that the five-coordinate hydroxo complex bearing an open coordination site for CO binding is the catalytically active species. Thus, we examined the impact of strongly-coordinating halide ions in the hope that they might also free an additional metal coordination site and thereby increase the turnover rate of CO oxidation. The association constants for the binding of halide ions (pH = 7) to **2** are shown in Table 1. The addition of halide ions led to CO oxidation rates in neutral or acidic (pH = 4) conditions that were comparable to those obtained under alkaline conditions, with the advantage that the ligand system is robust at neutral or acidic pH.

Table 1: Halide association constants with **2**.

Halide	K_{B1}	K_{B2}
Cl^-	45 ± 2	1
Br^-	11,000 ± 400	3
I^-	7,000 ± 200	8

To make the system catalytic, rather than stoichiometric, we sought regeneration systems compatible with O_2 as the terminal oxidant. The blue dye indigo carmine was found to be suitable for the reoxidation of reduced rhodium porphyrins. Moreover, rate constants for the redox reaction of indigo carmine with the porphyrin complexes are large, ensuring that the rate limiting step remains turnover of CO. The scrubbing of CO from a gas mixture by a 10^{-5} M solution of **2** in water is shown in Figure 2. The figure shows the bleaching of the indigo carmine upon reduction ($2H^+ + 2\ e^-$) and subsequent reoxidation of the dye by O_2 to form water. Importantly, the catalyst **2** does not have any hydrogen activity; CO can be removed from hydrogen gas mixtures without oxidizing hydrogen.

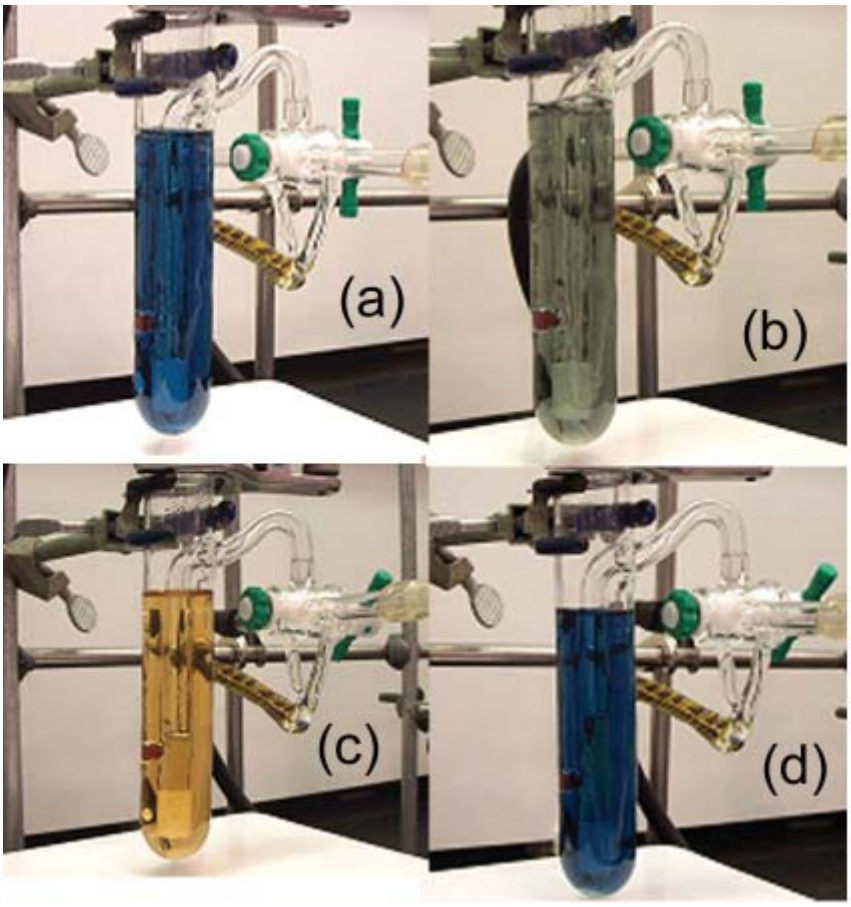


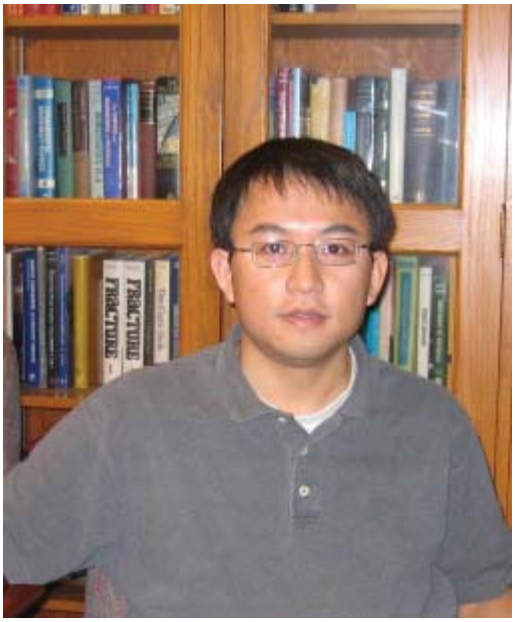
*Figure 2: Reaction of **2** with CO in the presence of 100 equivalents of indigo carmine at pH = 7. a) Initial, b) 15 min. after CO purge, c) after complete bleaching of the dye, d) immediately after exposure to air.*

These studies indicate that CO scrubbing by PROX catalysis is possible under exceptionally mild conditions. Current work in our laboratory is focused on converting these homogeneous catalysts to robust, supported heterogeneous catalysts.

Stephen DiMagno

NCMN Welcomes Li Tan

His expertise in polymer science was implemented during prior (2002-2003) post-doctoral work in the Solid-state Electronics Laboratory at the U. Michigan. Dr. Tan and his colleagues used nanofabrication processes, such as nanoimprint and contact lithography as tools for investigating novel geometry-dependent physical phenomena in polymer nanostructures. As a post-doctoral researcher at Davis (2003-2005), his experiences in chemistry and surface science were further enriched involving the development of single electron measurements and the advancement of the capabilities of high-resolution lithography.



His original work allowed him to be an Assistant Professor at the University of Nebraska-Lincoln in 2005. He and his group are currently developing a multidisciplinary program at the Department of Engineering Mechanics in the area of surface engineering, nanofabrication and material design.

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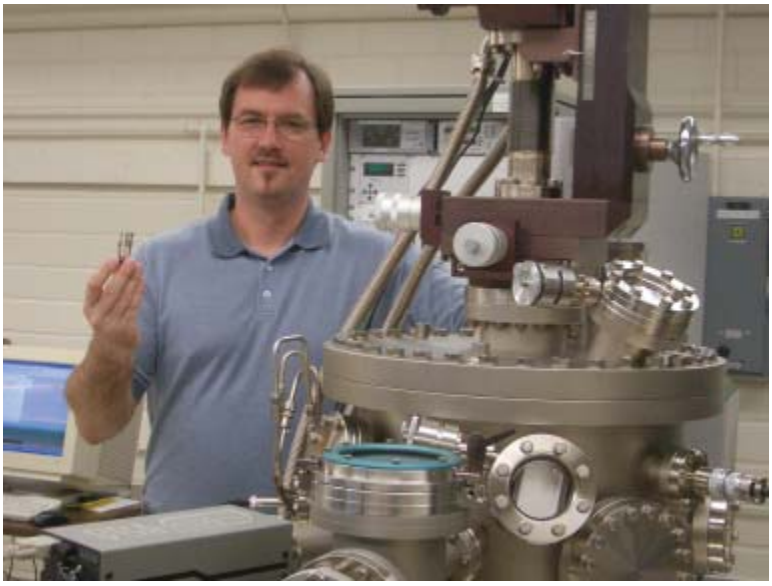
Particularly for the material design component, he is investing efforts to establish a material chemistry group using “bottom-up” approach to elucidate the structure of surfaces and interfaces. He is aiming at the following areas: synthesizing novel molecules for the preparation of self-assembly, including monolayers; creating fundamental frameworks to understand the bonding at interfaces; and incorporating enhanced functionalities, such as electrical or biological functions into thin films. This multidisciplinary program allowed them to work on a variety of research topics such as photo-responsive polymers and structures, combinatorial approach of micro fuel cells, as well as to develop an embossing/imprinting based nanolithography. These projects are supported by multiple funding sources such as NSF MRSEC Seed, Nebraska EPSCoR First

Award, Research Council and Nebraska Center for Energy Science Research (NCESR). With the opportunity of accessing a variety of polymer nanostructures, he is also extending his group's research capability into an important and untapped area: interpretation of polymer structure stability at nanometer scale. This activity should have a strong impact to the general nanomanufacturing community.

In addition to research, Dr. Tan strongly believes in the importance of teaching at universities, which is not only a great channel to pass on knowledge, but also critical to stimulate interests and motivate discoveries. He has been an undergraduate and graduate instructor and greatly enjoyed interacting with students. Starting from Spring 2007, he is offering a senior undergraduate/graduate class of "Structural, mechanical and chemical properties of nanostructures and nanomaterials" (ENGM 491/891).

Research Spotlight: Christian Binek



The research team of Christian Binek focuses on interface induced phenomena in magnetic heterostructures grown by molecular beam epitaxy, a state of the art thermal evaporation technique. Ultra high vacuum is a key prerequisite enabling low material deposition rates while keeping rest gas contamination of the samples at a minimum. Deposition at low flux and thermal energies allows growing ultrathin crystalline layers of magnetic materials. Chemical and structural composition is controlled down to the atomic scale and high-purity multilayers with interfaces close to atomic sharpness become feasible. Interfaces of materials in atomic proximity deviate significantly from individual bulk properties. Heterostructures of ultra-thin films can be dominated by interface phenomena and provide artificial materials with potentially novel physical properties. Dr. Binek's group focuses on those interface phenomena which are magnetic in origin.

Controlling materials on the nanoscale or below enables the fabrication of new and potentially useful artificial structures. An important part of Binek's work involves the investigation of multilayers combining magnetoelectric insulating antiferromagnets and metallic ferromagnetic thin films. Recently, a reversible electrically induced shift of the magnetic hysteresis loops along the magnetic field axis, known as electrically-controlled exchange bias, has been achieved by the team. Now they aim on realizing electrically controlled spin valves and tunneling magnetoresistance elements. This new family of spintronic devices uses thin films of magnetoelectric materials as key components. The electric field-induced magnetization of the latter allows switching magnetic states of exchange coupled layers by pure electrical means.

Research involving antiferromagnets as key components is in the tradition of Dr. Binek's scientific background. He was born and raised in Duisburg, Germany in the heart of the largest economic area of Europe. He earned his PhD in 1995 and received 7 years later his Habilitation and status as Privatdozent at the University of Duisburg-Essen. Throughout this time his research

interests involved antiferromagnets and their role as model systems in statistical physics and thermodynamics.

Dr. Binek's team of graduate students Xi He, Tathagata Mukherjee, Srinivas Polisetty and Yi Wang works together with postdoctoral researcher Sarbeswar Sahoo supported by undergraduate Keith Jones. Together they aim on the realization of spintronic devices combining memory and simple logical functions which ultimately may exceed the functionality of today's passive magnetoelectronics such as magnetic random access memories, magnetic field sensors and read heads.

Layered nanostructures which cannot be formed by chemical synthesis promise significant innovations in information technologies. At the same time this exciting field allows for fundamental studies in interface magnetism. Dr. Binek's interests in fundamental aspects of thermodynamics leads to further investigations of dipolar interacting magnetic nanoparticles and magnetic multilayers using antiferromagnetically interacting entities to realize advanced magnetocaloric materials for magnetic refrigeration applications. The former transdisciplinary activity takes place in collaboration with chemist Dr. Redepenning. The latter collaboration obtains theoretical and experimental input from Dr. Skomski and Dr. Sellmyer.

Dr. Binek's team uses magnetometry, magnetoresistance and magnetooptical methods to characterize nanoscaled magnetic systems. As a member of the Nebraska Center for Materials and Nanoscience (NCMN) and the Materials Research Science and Engineering Center (MRSEC) his group takes advantage of structural characterization techniques and opportunities for collaborations.

All aspects of Dr. Binek's work are subject to significant funding. The research on nanoscale spintronic systems is funded by NSF through an early career award. Collaborative work on Designing Materials for Electrodes in Spintronic Devices is done together with Dr. Dowben and Dr. Belashchenko and funded by the Nebraska Research Initiative (NRI). Studies on magnetocaloric materials are supported by the Nebraska Center for Energy Sciences Research (NCESR) in addition to support from NCMN and MRSEC where collaboration takes place on a broader scale.

LNK Chemsolutions receives funding for a two-year nanotechnology project

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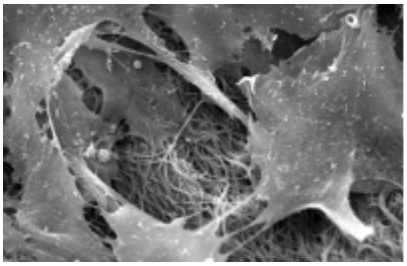
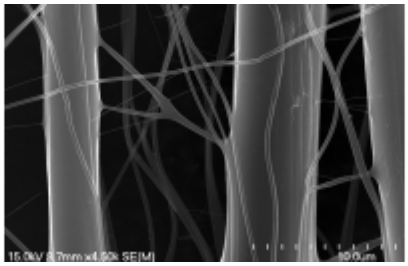
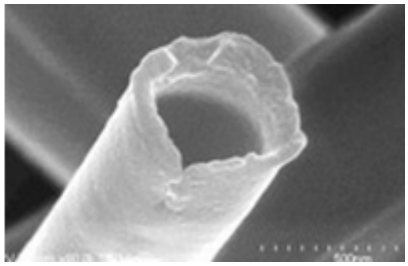
LNKChemsolutions has been awarded a two-year $725,150 Phase II Small Business Innovation Research (SBIR) grant from the U.S. Department of Energy. The funding will be used for the project called "Nano- and Micro-Encapsulation of Enzymes and Other Proteins in Their Native State."

Nanotechnology, the science of building electronic circuits and devices from single atoms and molecules, will be used in this project to make bio-catalysts for producing fine chemicals and protein drugs for use in possible cancer treatments. According to the National Nanotechnology Initiative, nanotechnology is the understanding and control of matter at dimensions of 1 to 100 nanometers (roughly 1/10,000 of human hair), where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling and manipulating matter at this scale.

Pictured left to right: cell growth and proliferation over ultrafine biopolymer fiber mats; aligned biopolymeric fibers with cross-linking; and inorganic nanotubes. The pictures correspond to other lines of research conducted by LNK Chemsolutions Owner and NCMN member Gustavo Larsen.

At the nanoscale, the physical, chemical and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology research and development is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

Any molecule of biological origin has to be treated very delicately in order for it not to break. The method that LNKChemsolutions is developing treats molecules much more gently than current technology allows, said Gustavo Larsen, the owner of LNKChemsolutions and professor of chemical and biomolecular engineering at the University of Nebraska-Lincoln.

The award brings current nanotechnology R&D expenditures at LNKChemsolutions to about $1 million a year. The company supplements its federally funded R&D with private service contracts with Fortune 500 companies. LNKChemsolutions is the only company in the Lincoln area focused completely on nanotechnology.

The company was founded in 2000 with core competencies in nanoparticle and nanofiber R&D for a variety of applications, such as toxicology, tissue engineering, encapsulation and controlled release. Food, biomedical and catalysis applications are among the many nanotechnology-based product lines being developed by LNKChemsolutions and its partners.

The company has received contracts from the U.S. Department of Agriculture, the U.S. Department of Energy, the National Science Foundation, the National Institutes of Health, and Kraft Foods to develop new nanotech products. They are housed in state-of-the-art laboratory facilities located at the University of Nebraska Technology Park.

The SBIR is a competitive threephase program that provides federal research funding to eligible small businesses. It is designed to stimulate technological innovation and research that addresses critical national priorities. For more information about LNKChemsolutions visit www.lnkchemsolutions.com

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