INDUSTRIAL PARTNERSHIP
FOR RESEARCH IN
INTERFACIAL AND MATERIALS ENGINEERING

Research Highlights

2013

I’PRIME
### Biocatalysis and Biotechnology (BB)

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Department</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ping Wang</td>
<td>BBE</td>
<td>Enzymology, membrane and interfacial catalysis, bioactive materials and coatings, bioelectrochemical processing, biosensors.</td>
</tr>
<tr>
<td>Mark Distefano</td>
<td>Chem</td>
<td>Organic and biochem., protein conjugates for therapeutic and biotechnology applications.</td>
</tr>
<tr>
<td>Romas Kazlauskas</td>
<td>Biochem</td>
<td>Biocatalytic synthesis of chemical intermediates and biofuels. Enzyme modification for new reactions.</td>
</tr>
<tr>
<td>Michael Sadowsky</td>
<td>SWC</td>
<td>Enzymes for bioremediation and bioenergy, enzyme discovery, functional and metagenomics</td>
</tr>
<tr>
<td>Claudia Schmidt-Dannert</td>
<td>Biochem</td>
<td>Biosynthetic pathway engineering, metabolic engineering, gene discovery.</td>
</tr>
<tr>
<td>Friedrich Srienc</td>
<td>CEMS</td>
<td>Cell population dynamics, metabolic engineering, synthesis of polymers.</td>
</tr>
<tr>
<td>Lawrence Wackett</td>
<td>Biochem</td>
<td>Microbial catabolic enzymology, functional genomics.</td>
</tr>
<tr>
<td>Kechun Zhang</td>
<td>CEMS</td>
<td>Synthetic biology, metabolic engineering, protein engineering, biofuels, renewable chemicals.</td>
</tr>
</tbody>
</table>

*Program Leader*

Fine and specialty chemical production; Biofuels and biosensors; Bioremediation; Bioactive compounds; Enzyme Evolution, Biodegradable polymers and biocoatings, Pathway engineering
Biocatalysis and Biotechnology at Different Scales

Enzyme and Protein Chemistry

Pathway Engineering

Biocatalyst and Reaction Design

Bioprocessing Technologies
Enzyme Engineering, Discovery and Manipulation

Reconstructing ancestral enzymes to discover new catalytic activities

- Soil Metagenomes – search for enzymes in soil microbiomes
- Minnesota Mississippi Metagenome Project (M3P)
- Human Intestinal Metagenomes – Cures for human GI Diseases

Michael Sadowski
Pathway Engineering for Biosynthesis

Claudia Schmidt-Dannert
Bioproducts Innovations

Chemical process: Unsustainable, wasteful, low yield, expensive

Fermentation process: Renewable, cost-effective, environmentally-friendly

Ping Wang and Kechun Zhang
BIOPROCESSING
Biotechnology Resource Center
A service provided by the Biotechnology Institute

Fermentation/Cell Growth
• Cultivation of bacteria, yeast & algae
• Process development & optimization
• Pilot-scale production

Recombinant Protein Expression
• *E. coli* & other bacterial expression systems
• *Pichia pastoris* & *S. cerevisiae*

Downstream Processing
• Recovery and purification of proteins & small molecules

GMP Capabilities
• Fully established quality system
• Production of Phase I and Phase II clinical trial material

Facility
The 4,700-square-foot facility is located on the University of Minnesota’s St. Paul campus. Equipment includes:
• 14 fermenters with volumes of 6L, 10L, 20L, 75L, 300L, and 550L
• 5 x 20L light-ring photobioreactors
• batch and continuous-flow centrifuges
• microfluidizer, high-pressure homogenizer, & French press
• bench- to pilot-scale ultra-filtration units
• bench- to pilot-scale chromatography
• freeze dryer

Mike Sadowsky
Phone: (612) 624-2706
Email: Sadowsky@umn.edu
Biomedical and Pharmaceutical Materials (BPM)

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Department</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ron Siegel (Director)</td>
<td>Phm(^1)/BME(^2)</td>
<td>hydrogels, biosensors, drug delivery systems, microfabrication</td>
</tr>
<tr>
<td>Effi Kokkoli</td>
<td>CEMS(^3)</td>
<td>bioadhesion and drug targeting</td>
</tr>
<tr>
<td>Jayanth Panyam</td>
<td>Phm</td>
<td>multifunctional nanodelivery vehicles</td>
</tr>
<tr>
<td>Wei Shen</td>
<td>BME</td>
<td>bioactive materials</td>
</tr>
<tr>
<td>Calvin Sun</td>
<td>Phm</td>
<td>drug crystal and particle engineering</td>
</tr>
<tr>
<td>Raj Suryanarayanan</td>
<td>Phm</td>
<td>solid state properties of drugs, stability of drug/biomaterial formulations</td>
</tr>
<tr>
<td>Bob Tranquillo</td>
<td>BME/CEMS</td>
<td>fabrication characterization of bioartificial artery, cardiovascular valve, myocardial patch</td>
</tr>
<tr>
<td>Chun Wang</td>
<td>BME</td>
<td>bio-molecular materials, polymer-based DNA and drug delivery, protein-based tissue scaffolds</td>
</tr>
</tbody>
</table>

**Affiliated Investigators:** Chris Macosko (CEMS), Marc Hillmyer (Chem\(^4\)), Theresa Reineke (Chem), Tom Hoye (Chem), Victor Barocas (BME)

\(^1\)Pharmaceutics; \(^2\)Biomedical Engineering; \(^3\)Chemical Engineering and Materials Science, \(^4\)Chemistry

- **Biomaterials for drug delivery, medical device coatings, and tissue engineering**
- **Drug/medical device combinations, characterization of drug/materials interactions**
- **Cell-based fabrication of bioartificial tissues**
- **Novel tissue mechanical testing and analysis methods**
Inert Biodegradable Surfaces with “Artificial Mucus”

Ron Siegel + Chun Wang: Wenshou Wang, postdoc

Biodegradable matrix (PCL)

Active nanostructured particles

Biocompatible surface coating

Medical device surface

Hydrophilic core (HA)

Hydrophobic graft (PCL)

1 week

TCP

PCL

PCL/(1% HA-g-PCL)

PCL/(3% HA-g-PCL)

Cell count

1 week

4 weeks

TCP

PCL

PCL/(1% HA-g-PCL)

PCL/(3% HA-g-PCL)
**PR_b Targeted Delivery to Cancer Cells**

PR_b-functionalized pH-sensitive stealth liposomes show increased binding and intracellular uptake by colon cancer cells compared to non-targeted pH-sensitive stealth liposomes and inert (targeted or non-targeted) formulations.

**PR_g Peptide-Amphiphile Hydrogels for Tissue Engineering**

PR_g gels outperform PEG gels functionalized with fibronectin (FN) protein and commercially available peptide hydrogels (PuraMatrix) in terms of cell adhesion and other cellular phenomena.
(1) Synthetic and biomimetic materials to define cell microenvironments for regulation of cell fate.

Integrin ligand
Growth-factor-mimetic
Enhance endothelial differentiation

UCB-derived CD34+ cells

Biomimetic substrate

Cell

α β

A B

Cys Cys Cys Cys

Integrin ligand
Growth-factor-mimetic

(2) Modular assembly of cell-laden porous hydrogels for tissue regeneration.

Perfusable construct having interconnected pores.

Crosslinker

Weishi Shen
Crystal structure
Mechanical properties
Tableting performance

Calvin Sun
CryEngComm, 2010
# Coating Process Fundamentals — CPF

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorraine F. Francis*</td>
<td>Solidification, stress development, microstructure, properties</td>
</tr>
<tr>
<td>Satish Kumar*</td>
<td>Transport processes, interfacial phenomena, microfluidics</td>
</tr>
<tr>
<td>Marcio S. Carvalho**</td>
<td>Fluid mechanics, rheology, numerical methods</td>
</tr>
<tr>
<td>Alon V. McCormick</td>
<td>Curing, thermodynamics &amp; kinetics, NMR, stress development</td>
</tr>
<tr>
<td>Michael Tsapatsis</td>
<td>Zeolite and particulate coatings, membranes, separations</td>
</tr>
<tr>
<td>Chris W. Macosko</td>
<td>Rheology, polymer processing</td>
</tr>
<tr>
<td>Bill Gerberich</td>
<td>Nanomechanics</td>
</tr>
<tr>
<td>Wieslaw Suszynski***</td>
<td>Coating process experiments, apparatus, flow visualization</td>
</tr>
</tbody>
</table>

*Program Co-Leaders

**Pontificia Universidade Catolica, Rio de Janeiro

***Research Engineer and Coating Process and Visualization Laboratory Manager
Goal: Understand the roll of inertia and wettability on gravure cavity emptying

Method: Solve the Navier-Stokes equations for a 2D axisymmetric liquid bridge using the finite element method

Results:
- Inertia drives interface into cavity, which increases liquid transfer to the web
- If web wettability is high enough, this can produce a second breakup point and a satellite drop
- Cavity shape/wettability do not strongly affect satellite formation

Simplify the system by considering the emptying of a single axisymmetric cavity

Shawn Dodds
(Kumar, Carvalho)
High-Speed Wetting in Confined Coating Flows

Objective: Understand the effect of meniscus confinement on high-speed wetting behavior

1) Measure the critical speed of wetting failure, $U_{\text{crit}}$, as a function of coating gap, $H$, using an experimental coating system
2) Develop computational models to study wetting hydrodynamics

Results:

- $U_{\text{crit}}$ systematically increases with confinement ($\downarrow H$)
- High-speed wetting models require accurate fluid stress calculations; however, computational cost limits 2D models
- A hybrid (1D/2D) FEM model provides efficiency and closely estimates experimental results
The distribution of particles through the thickness of a drying particulate coating is influenced by soluble polymer binder: sedimentation and diffusion slow while evaporation is not affected.

Slower sedimentation demonstrated by cryoSEM

**Magnetic Microrheology of Coatings during Drying**

**Goal:** Measure coating viscosity during drying, characterize spatial gradients

**Method:** Track motion of micron sized magnetic particles in coating under magnetic field gradient, develop experimental set-up, determine local

\[
\begin{align*}
\frac{m_p}{\rho_p} \frac{dv}{dt} & \approx F_m + F_{\text{drag}} \\
0 & = MV \frac{dB}{dx} / \mu_0 - 6\pi \eta R v_p \\
\eta & = \frac{2MR^2 (dB/dx)}{9\mu_0 v_p}
\end{align*}
\]

Iron oxide particle in PVA coating, drying at 28 °C

**Jin-Oh Song (Francis)**

Particulate Films by Forced-Convection-Assisted Drag-out

**Forced-Convection-Assisted Drag-out:**

*A coating method in which evaporation, viscous, and capillary forces direct film growth.*

**APPLICATIONS** of nanoscale particulate coatings

- Seeded growth of zeolite membranes
- Optical circuits from photonic crystals
- Functional catalyst and electrode materials

**TARGETS** of current research

1) Scaleable coating process for low-defect coatings
2) Fundamentals of particulate coating flows

Coating experiments, visualization, and computation complement one another

---

Damien Brewer (Tsapatsis, U. Minn.)

Capillary pressure and solvent flow within the interstitial spaces may be critical to microstructure

Evaporation-assisted dip coating allows control of colloidal film thickness and microstructure
# Magnetic Heterostructures (MH)

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Department</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paul Crowell</td>
<td>PHYS</td>
<td>Magneto-optics/transport studies</td>
</tr>
<tr>
<td>E. Dan Dahlberg</td>
<td>PHYS</td>
<td>Thin film magnetism, transport, MFM</td>
</tr>
<tr>
<td>Chris Leighton*</td>
<td>CEMS</td>
<td>Magnetic films/heterostructures, transport</td>
</tr>
<tr>
<td>Bethanie J. H. Stadler*</td>
<td>ECE</td>
<td>Magneto-optical materials, thin films</td>
</tr>
<tr>
<td>Randall Victora*</td>
<td>ECE</td>
<td>Theory/modeling of magnetic materials</td>
</tr>
<tr>
<td>Jian-Ping Wang*</td>
<td>ECE</td>
<td>Magnetic materials and spintronics</td>
</tr>
<tr>
<td>Renata Wentzcovitch</td>
<td>CEMS</td>
<td>Electronic structure calculations</td>
</tr>
</tbody>
</table>

**Collaborators**

- Chris J. Palmstrøm  ECE, UCSB  MBE, CBE, thin film characterization

* Develop a fundamental understanding of interfaces in magnetic heterostructures, with a focus on spin transport and dynamics

* Also with the Center for Micromagnetics and Information Technology:  www.ece.umn.edu/~MINT/
New Technologies:

• Magnetic Random Access Memory
• Magnetic tunnel junction sensors
• Patterned media
• Semiconductor spintronics
• Highly polarizable materials

Field sensing (medical devices, security)
Formation of CoS$_2$ by \textit{ex-situ} sulfidation of Co on GaAs

\textit{Leighton, Palmstrom, Mkhoyan}

Transfer of spin polarization across interfaces
New heterostructures for spin transport
Manipulation of electronic structure to engineer magnetic and transport properties

GaAs(001) / CoS$_2$(68 nm)
$T_S = 325$ C, 8 h

Lateral spin valves
\textit{Crowell, Leighton}
Spin dynamics

Spin transfer torque detection of ferromagnetic resonance

Wang

Noise in magnetic nanostructures

Dahlberg, Victoria
Magnetic Nanostructure Arrays

- For bit patterned media and magnetic random access memory
- Monolithic arrays of magnetic sensors

Ultra-low resistivity nanowire arrays

Stadler, Victoria

Highly ordered monodisperse arrays of ~20 nm diameter permalloy nanomagnets

Hillmyer, Leighton
# Microstructured Polymers (MP)

<table>
<thead>
<tr>
<th>Investigator</th>
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<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marc A. Hillmyer*</td>
<td>CHEM</td>
<td><em>Polymer synthesis and characterization</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>(Director: Polymer Synthesis Facility)</em></td>
</tr>
<tr>
<td>Frank S. Bates</td>
<td>CEMS</td>
<td><em>Thermodynamics, scattering, synthesis</em></td>
</tr>
<tr>
<td>Timothy P. Lodge</td>
<td>CHEM/CEMS</td>
<td><em>Polymer dynamics, solutions, scattering</em></td>
</tr>
<tr>
<td>Chris Macosko</td>
<td>CEMS</td>
<td><em>Rheology, processing</em></td>
</tr>
<tr>
<td>David C. Morse</td>
<td>CEMS</td>
<td><em>Theory and modeling</em></td>
</tr>
<tr>
<td>Theresa Reineke</td>
<td>CHEM</td>
<td><em>Biomedicine, Diagnostics, Targeted Delivery</em></td>
</tr>
</tbody>
</table>

**Collaborators include:**

Ed Cussler (CEMS), Lorraine Francis (CEMS), Dan Frisbie (CEMS), Tom Hoye (CHEM), Efie Kokkoli (CEMS), Chris Leighton (CEMS), Ron Siegel (PHRM), Bill Tolman (CHEM)

*Program Leader*

Synthesis, characterization, dynamics, processing, properties, and theory
Stabilization of cocontinuous blends via nanoclays

polyethylene (PE) +

polyethylene oxide (PEO) +

organo-modified nanoclay (Cloisite 10A)

Extruded Film

Solvent Extraction (in water)

Porous PE + clay

Trifkovic, Hedegaard, Houston, Sheikhzadeh, Macosko, Macromolecules, 2012, 45, 6036-6044.
High Toughness, High Conductivity Ion Gels by Sequential Triblock Copolymer Self-Assembly and Chemical Cross-linking

Ion gels – physical networks formed by self-assembly of ABA copolymers in ionic liquids – have shown great promise as gate dielectrics in printable plastic electronics and in CO₂ separation. In order to improve ultimate toughness, we have designed a system in which the “A” micellar cores can be chemically crosslinked after assembly.

Crosslinking leads to 5x improvement in toughness, with no loss of conductivity.

Yuanyan Gu, Sipei Zhang, Luca Martinetti, Keun Hyung Lee, Lucas D. McIntosh, C. Daniel Frisbie, and Timothy P. Lodge, submitted for publication.
Nanoporous polymers are important for advanced applications such as catalysis, templating, and separations. We recently discovered a simple way to prepare nanoporous polymers with percolating porous space, precise pore dimensions and mechanical integrity. Microphase separation into a bicontinuous phase was achieved by controlled in situ block polymer formation and the structure was arrested by simultaneous crosslinking. Nanoporous polymers with a continuous network of sub-10 nm pores were readily obtained by etching of a sacrificial segment (e.g., polylactide). Versatile chemistry available for block polymer synthesis will allow for broader applications of bicontinuous nanoporous materials using this method.

Hillmyer and Seo
Basic mechanism for block copolymer toughened epoxy

4% wt. BCP

rubbery core Glassy core

Damaged Epoxy/corona

Carmelo Declet-Perez, Erica Redline, Lorraine Francis and Frank S. Bates (ACS Macro Letters 2012)
Do we understand the basics of block polymer micellization?

It is generally expected that the critical micelle concentration (CMC) for surfactants and block polymers will decrease exponentially with the length of the solvophobic block, i.e., $\text{CMC} \sim \exp(-N)$

Recent pyrene fluorescence measurements on poly(styrene-$b$-ethylene oxide) diblocks in the ionic liquid $\text{[EMI][TFSI]}$ do not follow the expected scaling.

Comparison with literature CMC data for many different systems shows an as yet unexplained crossover to $\text{CMC} \sim \exp(-N^{1/3})$.

Michelle M. Mok, Maritza Flores, Raghu Thiagarajan, David C. Morse and Timothy P. Lodge (Macromolecules 2012)
Nanostructural Materials and Processes (NMP)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Alon McCormick</td>
<td>CEMS</td>
<td><em>Materials and Emulsions Synthesis; Spectroscopy and CryoMicroscopy</em></td>
</tr>
<tr>
<td>C. Daniel Frisbie</td>
<td>CEMS</td>
<td><em>Molecular Materials and Interfaces; Molecular Electronics</em></td>
</tr>
<tr>
<td>Wayne Gladfelter</td>
<td>CHEM</td>
<td><em>Materials Chemistry; Inorganic Chemistry; Scanning Probe Microscopy</em></td>
</tr>
<tr>
<td>Greg Haugstad</td>
<td>CHAR FAC</td>
<td><em>AFM Scanning Probe Microscopy</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Director, Characterization Facility)</td>
</tr>
<tr>
<td>R. Lee Penn</td>
<td>CHEM</td>
<td><em>Environmental Solid State Chemistry</em></td>
</tr>
<tr>
<td>Ilja Siepmann</td>
<td>CHEM</td>
<td><em>Molecular simulation and theory</em></td>
</tr>
<tr>
<td>Andreas Stein</td>
<td>CHEM</td>
<td><em>Solid State Chemistry of Porous Materials</em></td>
</tr>
<tr>
<td>Michael Tsapatsis</td>
<td>CEMS</td>
<td><em>Materials Synthesis, Structure Elucidation</em></td>
</tr>
<tr>
<td>Joe Zasadzinski</td>
<td>CEMS</td>
<td><em>Microscopy of Complex Fluids</em></td>
</tr>
</tbody>
</table>

*Program Coordinator*

**Associated Investigators:** Frank Bates, Lorraine Francis, Bill Gerberich, Eric Kaler, Chris Macosko, David Norris, Wei Zhang

*synthesis, phase behavior, structure, and performance of surfactants and self-assembled molecular and colloid systems*
Tsapatsis Research Group and Collaborators
DOE (Carbon Capture and CCEI-EFRC), NSF (CBET, NIRT, EFRI), Iprime (CPFP and NMP), ARPA-E, Industrial sponsors

NANOSHEET ZEOLITE CATALYSTS AND MEMBRANES

AFM Thickness = 34 Å

Micropore: 0.52 nm
Mesopore: 2-7 nm

$p$-/o-x Separation Factor >30 (@150° - 200°C)
$p$-xylene > $10^{-7}$ mol/m²sPa

Stein Group: Nanostructured Energy Storage Materials

www.chem.umn.edu/groups/stein

Lithium ion batteries

Electric Double-Layer Capacitors

Xu, Chem. Rev. 2004, 104, 4303

High energy density and high power density!
Characterizing the dynamics of aggregation in reactive systems (PENN)

CRYO-TEM images of nanoparticles in liquid media.

WATER: after aging.
Yuwono, Burrows, Soltis, Penn (JACS, 2010)

Yuwono, Burrows, Soltis, Penn (Faraday Trans 2012)

Burrows, Talmon, Penn; submitted

pH 3.5

pH 5.5

Isopropanol

Tetrahydrofuran
Cryo-EM monitoring material and emulsion processes (McCormick)

1. Cryogenic Transmission Electron Microscopy (Cryo-TEM)

   AgSt Formation: reaction ~30 s
   NaSt + AgNO3 → AgSt


   In preparation, Hanseung Lee w/ McCormick group

2. Cryogenic Scanning Electron Microscopy (Cryo-SEM)

   Cross section of a drying /consolidating latex coating


   In preparation, Hanseung Lee w/ McCormick group
Sensing “interphase” domains in silicone/silica nanocomposite

Darker domains: greater tip-sample energy dissipation ($E_{dis}$) under a dynamic “tapping” interaction

Reflect confined conformations that exhibit more viscoelastic (VE), compared to Elastic, behavior.

primary particle: 10-20 nm
Aggregate: 120-250 nm
Agglomerate: >750 nm-2 µm

$E_{dis} \approx \frac{2\pi}{Q} \left( \sqrt{2} kA_0^2 \right) \sin \varphi - A/A_0$

Haugstad and Coggio (Cabot Industrial Fellow)
## Organic Optoelectronic Interfaces (OEI)

<table>
<thead>
<tr>
<th>Faculty Member</th>
<th>Department</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Daniel Frisbie</td>
<td>CEMS</td>
<td>Organic transistors, <em>SPM</em></td>
</tr>
<tr>
<td>David Blank</td>
<td>CHEM</td>
<td>Ultrafast spectroscopy</td>
</tr>
<tr>
<td>Jean-Luc Brédas</td>
<td>CHEM (GA Tech)</td>
<td>Computation of electronic structure</td>
</tr>
<tr>
<td>Chris Douglas</td>
<td>CHEM</td>
<td>Organic synthesis</td>
</tr>
<tr>
<td>Russell J. Holmes</td>
<td>CEMS</td>
<td>Organic optoelectronics, solar cells</td>
</tr>
<tr>
<td>P. Paul Ruden</td>
<td>ECE</td>
<td>Device modeling, transport theory</td>
</tr>
</tbody>
</table>

*Program Leader*

Organic synthesis, thin film growth and characterization, optoelectronic devices, transport, spectroscopy, computation
Science and technology of organic semiconductors

Organic Electronics and Optoelectronics

New applications in OLEDs, displays, lighting, solar cells, sensors, photodetectors, OFETs, printed circuitry, optically pumped lasers

Older applications in xerography, photography

- π-electron rich, van der Waals solids
- Processable at low temperature
- Absorb, emit in the visible
- Carrier mobility $10^{-3} - 10$ cm²/Vs
- Tunable electronic properties

In devices, interfaces are crucial!

Poly(3-hexylthiophene)  phthalocyanine

Printed electronics  OLED lighting

Sony OLED TV
Rubbery, High Capacitance, Fast Response Ion Gels

Lodge (IRG 1), Frisbie (IRG 2) co-advised students Sipei Zhang, Keun-Hyung Lee

Objective: Make new fast response polymer electrolytes

Block polymer

Ionic Liquid

Capacitor Test Structure

Physically crosslinked, rubbery network swollen with ionic liquid

Low polymer fraction (5-10%)
Tunable mesh size (10-100 nm)

$C \sim 10 \mu F/cm^2$

$RC \sim 1 \mu s$ for 1 \mu m thick film....FAST!

Fast, Low Voltage Circuits on Plastic

Frisbie (IRG 2), Lodge (IRG 1)
grad student Mingjing Ha & Optomec, Inc.

Objective: Develop fast, low voltage, printed electronics on plastic

Switching times of 5 µs achieved at supply voltages < 3V

Efficient, Single Layer OLEDs

Holmes & grad student Nick Erickson

Key Idea: High efficiency in single-layer OLEDs
– optimize charge/exciton confinement with
graded composition emissive layer (G-EML)

Compare performance of G-EML to other
“simple” OLEDs:

Result & Significance

Single-layer G-EML efficiency approaches
the intrinsic limit of ~20%

Renewable Energy Materials (REM)

Eray Aydil* Thin film solar cells, nanoparticle solar cells, dye-sensitized solar cells, photocatalysis, lithium ion batteries

Uwe Kortshagen* Plasma synthesis of semiconductor nanoparticles, silicon and silicon nanoparticle solar cells, thermoelectrics

Aditya Bhan Catalysis & biomass routes to fuels & chemicals

Daniel Frisbie Organic electronics and solar cells

Russ Holmes Organic electronics and solar cells

Kechun Zhang Synthetic biology, metabolic engineering, protein engineering, biofuels, renewable chemicals.

*Program Leaders

Mission: Develop materials and systems for renewable energy applications
Plasma Processing of Nanocrystals for Electronic and Optoelectronic Devices

Patented UMN NC synthesis

Precursors

RF

Si, Ge NCs

Disperse in solvents

Ligand

Impaction

Device

Coating

Coating


Hypervalent surface interactions for colloidal stability and doping of silicon nanocrystals

Wheeler, Neale, Chen and Kortshagen (2013) submitted & in review
All Gas Phase Nanocrystal LEDs

- Si NC synthesis in nonthermal plasma
- Gas-phase capping with dodecyl chains
- Film creation via impaction
- Device efficiency 0.02%

Rebecca J. Anthony, Kai-Yuan Cheng, Zachary C. Holman, Russell J. Holmes and Uwe R. Kortshagen
*Nano Letters, 12* (6), 2012
**Cu$_2$ZnSnS$_4$ Thin Films from Nanocrystal Dispersions:**

**CZTS Thin Films from CZTS Inks**

- Cu$_2$ZnSnS$_4$ (CZTS) is a promising solar cell absorber for thin film solar cells.
- CZTS nanocrystals sterically stabilized with oleylamine ligands and dispersed in nonpolar organic liquids or CZTS nanocrystals electrostatically stabilized in polar liquids were used to make thin films for solar cells.

University of Minnesota Characterization Facility

• ~$18 million of equipment (replacement value):
  ❖ Electron microscopy (TEM/SEM/analytical/cryo)
  ❖ X-ray scattering (wide and small angle)
  ❖ Proximal probes (AFM/profilometry/nanoindent.)
  ❖ Surface analytical (XPS/Auger/contact angle)
  ❖ Chemical spectroscopy (Raman/FTIR/+3D)
  ❖ Thin film analysis (RBS & related, ellipsometry)

• 13 experts, analytical methods & sample prep
• ~600 research users/yr, ~100 external
• 130 faculty users from ~35 UMN departments/units
• >250 students/yr, for-credit classes & short courses
• 40-50 companies per year
• 20-25 external academic institutions per year

❖ Hard & soft materials, liquids, biological
❖ Expert analytical services
❖ Custom methods
❖ Industry collaborations
❖ Workshops & short courses

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Asahi Kasei

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