Overview of Current Research

Further information is available @

http://www.me.gatech.edu/MITf-Lab

Chemical Microsystems & Fuel Cells
Slides 2-9

Bioanalytical Instrumentation & Sensors
Slides 20-29

Thermal Management of Electronics
Slides 14-19

Nanomanufacturing & Materials Processing
Slides 10-13
CHAMP Fuel Processing Technology for Scalable Hydrogen Production with CO₂ Capture

Liquid synthetic fuels carry renewable energy to the transportation sector (recycled CO₂ provides the carbon energy carrier)

Steam Reforming power plant: Liquid fuel converted to hydrogen (for power) with byproduct carbon dioxide (greenhouse gas) pre-concentrated and captured

CHAMP (CO₂/H₂ Active Membrane Piston) fuel processor (compact, scalable, transient, efficient, robust)

Lead Researcher: David L Damm, PhD Candidate (started Fall’03, MSME’05)

Financial Support: GT “Creating Energy Options” Grant
CHAMP reactor: performance enhancement

Basic Embodiment: Piston/Cylinder, batch operation, methanol steam reforming
- Variable volume, residence time
- Integrated H₂ membrane separation
- Exhaust recycle (w/ CO₂ capture)

→ Dynamic control of volume for improved rate of hydrogen production (enhanced rxn and separation process)

→ Regenerative fuel processing (100% fuel utilization with minimal increase in system size) and zero carbon emissions

Publications:

Lead Researcher: David L Damm, PhD Candidate (started Fall’03, MSME’05)

Financial Support: GT “Creating Energy Options” Grant
Direct Droplet Impingement Planar Microreactor for Hydrogen Generation from Liquid Fuels

**Lead Researcher:** Mark Varady, PhD student (started Fall’04)

**Collaboration:** Prof. Degertekin (GT ME)

**Financial Support:** NASA Grant #UG03-0050
Direct Droplet Impingement Planar Microreactor for Hydrogen Generation from Liquid Fuels

Hydrogen production by a droplet impingement reactor via steam reforming of methanol


Fuel atomization by ultrasonic MEMS atomizer

Lead Researcher:  Mark Varady, PhD student (started Fall’04)

Collaboration: Prof. Degertekin (GT ME)  
Financial Support: NASA Grant #UG03-0050
Figure 1: Fabricated composite membrane. (A) Membrane x-section showing vertical sidewalls from DRIE etch and thin SiO$_2$ Pd/Ag membrane (top surface) (B) Array of 30 µm pores which constitutes the support superstructure. (C) Single pore cross-section showing 930nm thick Pd/Ag membrane

**KEY IDEAS**

- Pd alloys absorb large amounts of H$_2$ with virtually infinite selectivity to all other gases
- H$_2$ pressure gradient across membrane drives solid-state diffusion resulting in hydrogen separation
- On-demand and on-site purification of hydrogen is enabling technology for utilization of liquid fuels

**Figure 2: Hydrogen permeation results**

**Lead Researcher:** Logan McLeod  
**PhD Candidate (started Fall’03)**

**Collaboration:** Prof. Degertekin (GT ME)

**Financial Support:** NASA Grant #UG03-0050
Microstructure Effects on H₂ Permeation Rate through Pd-Alloy Membranes

- Thin film deposition methods result in highly non-equilibrium film microstructure with nanometer grain size.
- Film release and subsequent annealing causes coalescence and growth of grains to minimize surface area associated with grain boundaries (see figures (a), (b), (c), and (d) below).
- Since grain boundaries act as hydrogen “traps” during diffusion, increasing grain size results in enhanced hydrogen permeation.

![Microstructure Images](a) (b) (c) (d)

**Lead Researcher:** Logan McLeod  
**PhD Candidate (started Fall’03)**


**Collaboration:** Prof. Degertekin (GT ME)

**Financial Support:** NASA Grant #UG03-0050
Photocatalysis Using TiO2 Nanostructures for Renewable Energy Applications

- Photocatalysis uses photon energy to generate an electrochemical potential difference in a semiconductor.
- As opposed to photovoltaic devices, this potential difference then drives surface electrochemical redox reactions.

**Lead Researcher:** Andrew Ogden, PhD student (started Fall’06)

**Collaboration:** Prof. Gole (GT Physics)

**Financial Support:** NSF NIRT Grant CBET 0608896
Photocatalysis Using TiO2 Nanostructures for Renewable Energy Applications

Traditional:
Hydrogen Generation from Water Electrolysis
- Problems of low yield tied to carrier recombination and high bandgap

Recently demonstrated:
Direct Hydrocarbon Synthesis from CO₂ and Water solution
- Aqueous environment limits reaction rate because of weak CO₂ solubility and methanol mineralization

Our approach:
Indirect Hydrocarbon Synthesis from CO₂ and Water splitting intermediate products


Lead Researcher: Andrew Ogden, PhD student (started Fall’06)

Collaboration: Prof. Gole (GT Physics)  
Financial Support: NSF NIRT Grant CBET 0608896
Nanomanufacturing by Electron Beam Chemical Vapor Deposition

- **Project Goal:** Development of a novel nanofabrication technique through physics-based models and supporting experiments
- **EB-CVD Advantages:** One step process, increased spatial resolution, complex 2D and 3D structures possible

![Diagram of Electron Beam and Precursor Interaction]

- **Adsortion**
- **Diffusion/advection**
- **Desorption**

Precursor

Secondary electrons
- generation
- scattering

Substrate

Primary electrons
- elastic/inelastic scattering
- Heating

Lead Researcher: William White, PhD student (started Fall’04)

Collaboration: Prof. Lackey (GT ME), Prof. Orlando (GT Chem)

Financial Support: NSF NIRT Grant DMI 0403671
Nanomanufacturing by Electron Beam Chemical Vapor Deposition

- Rarefied gas flow in chamber modeled using the Direct Simulation Monte Carlo (DSMC) technique

- Carbon and platinum deposits made using computer-controlled beam patterning system

- Publications:
  - Fedorov, Rykaczewski, White, “Transport issues in focused electron beam chemical vapor deposition” *Surface and Coatings Technology*, v 201, n 22-23, Sept. 2007, p 8808-8812

**Lead Researcher:** William White, PhD student (started Fall’04)

**Collaboration:** Prof. Lackey (GT ME), Prof. Orlando (GT Chem)

**Financial Support:** NSF NIRT Grant DMI 0403671
Electron Beam Induced Deposition (EBID) of Nanostructures Using Residual Hydrocarbons

EBID can be either a contamination problem or can provide a basis for 3-D nanofabrication and nanoscale metrology. In this process a solid deposit is formed at the point of impact of the electron beam due to the decomposition of adsorbed precursor gas on the solid substrate. It has been demonstrated that with appropriate control of the electron beam deposit three dimensional nanostructures with the spatial resolution down to $\sim 5\text{nm}$ can be formed.

Physical Phenomena of FEB-CVD

\[ \frac{\partial [C_i]}{\partial t} + \nabla [C_i] = \nabla (D_i \nabla [C_i]) + S_i \]

Lead Researcher: Konrad Rykaczewski, PhD student (started Fall’05)

Collaboration: Prof. Lackey (GT ME), Prof. Orlando (GT Chem)

Financial Support: NSF NIRT Grant DMI 0403671
Our work focuses on development and experimental validation of a comprehensive mass transport, electron transport, and reaction model of EBID to both enhance the fundamental understanding of the process and development of EBID into a reliable nano-scale manufacturing tool.


**Lead Researcher: Konrad Rykaczewski, PhD student (started Fall’05)**

**Collaboration:** Prof. Lackey (GT ME), Prof. Orlando (GT Chem)

**Financial Support:** NSF NIRT Grant DMI 0403671
Perspiration NanoPatch for Hot Spot Cooling in Electronics

Lead Researcher: Shankar Narayanan, PhD student (started Fall’06)

Key Ideas

Efficient vapor removal from interface

Jet impingement/streaming of high velocity dry gas

Sustaining a thin liquid film

Capillary confinement of fluid by hydrophobic nanoporous membrane

Collaboration: Prof. Joshi (GT ME)

Financial Support: MARCO/DARPA Interconnect Focus Center
Perspiration NanoPatch Cooling Performance

- Heat flux $>500$ W/cm$^2$ can be dissipated with $\{\delta_{\text{memb}} & \delta_{\text{film}}\} < 1$ µm and $V_{\text{jet}} > 100$ m/s
- Experiments conducted on a large-scale using H$_2$O as coolant show $q'' > 50$ W/cm$^2$
- The required flow rate (~10-25 ml/min) and pumping pressure head (~10-100 kPa) offer the possibility for simultaneous cooling of multiple hot spots
- Various commercially available membranes are currently being analyzed for performance


**Lead Researcher:** Shankar Narayanan, PhD student (started Fall’06)

Financial Support: MARCO/DARPA Interconnect Focus Center

**Collaboration:** Prof. Joshi (GT ME)
A thermal management solution for next generation integrated circuits with a focus on integrating hotspot and background heat flux cooling

**Lead Researcher:** Craig Green, PhD student (started Fall’06)

**Financial Support:** MARCO/DARPA Interconnect Focus Center

**Collaboration:** Prof. Joshi (GT ME)
**Key Idea #1**

Utilize the most optimal coolant to efficiently meet demands of each chip domain (e.g., fluid #1 for hot spot & fluid #2 for background cooling)

**Key Idea #2**

Enable intimate thermal interaction between fluids #1 and #2 (e.g., hot spot coolant regeneration) via common HX interface within the heat sink


**Lead Researcher:** Craig Green, PhD student (started Fall’06)

**Financial Support:** MARCO/DARPA  
Interconnect Focus Center

**Collaboration:** Prof. Joshi (GT ME)
Evaporation-Enhanced Dynamically-Adaptive Air Cooled Heat Sink

Lead Researchers: J. Mark Meacham, PhD’07 & Aaron Powers (GT UG)

Collaboration: Prof. Degertekin (GT ME)

Financial Support: ONR (Pending)
Evaporation-Enhanced Dynamically-Adaptive Air Cooled Heat Sink

Maximum heat sink temperature decreases significantly upon droplet injection into an air stream --> 20-50 % improvement in power dissipation by heat sink!


**Lead Researchers:** J. Mark Meacham, PhD’07 & Aaron Powers (GT UG)

**Collaboration:** Prof. Degertekin (GT ME)

**Financial Support:** ONR (Pending)
AMUSE (Array of Micromachined Ultrasonic Electrospray) Ion Source for High Throughput, Multiplexed Bioanalytical Mass Spectrometry

**Lead Researcher:** Thomas P. Forbes, PhD student (started Fall’06)

AMUSE Ion Source has potential to provide a unique multifunctional interface between liquid chromatography and mass spectrometry for high throughput, ultra-sensitive, and multiplexed analysis of biomolecules.

**Design Features:**
- Utilize acoustic wave focusing fluid horn for ejection
- DC signal – electrochemical ionization, AC signal – drive piezoelectric transducer
- Utilize cavity resonances for power-efficient ejection
- MEMS batch fabrication for low-cost manufacturing

**Multiplexed Device Design:**
- On-demand ejection and ionization of different analyte streams
- Interfacing with multiple LC streams with independent sample injection

**Financial Support:** Grant # R21 RR021474-01A1

**Collaboration:**
- Prof. Degertekin (GT ME)
- Prof. Fernandez (GT Chem) and Muddiman (NCSU Chem)
Multiplexed AMUSE Device

- Synchronized ejection of sample(s) and internal standard for quantitative results and mass calibration
- ANSYS Device Simulation
  - Successful isolation of driving signal, piezoelectric actuation, and acoustic focusing

- Experimental Multiplexed Operation
  - Successful isolated ejection from individual domains and simultaneous ejection from both.

Relevant Publications


Lead Researcher: Thomas P. Forbes, PhD student (started Fall’06)

Financial Support: Grant # R21 RR021474-01A1

Collaboration: Prof. Degertekin (GT ME)
Prof. Fernandez (GT Chem) and Muddiman (NCSU Chem)

National Center for Research Resources (NCRR) of the National Institutes of Health (NIH)
ElectroSonic Microarray for DNA/Drug Delivery

1st Fluid Cavity Resonance: $f = 1.02$ MHz

Droplets with DNA transfected cells

Medium +Cells+DNA

PIEZOELECTRIC TRANSDUCER

AC Drive Signal

ANSYS: Acoustic pressure field within a single 3D nozzle

FLUENT: velocity field (m/s) within a single 3D nozzle

**Lead Researchers:** J. Mark Meacham, PhD’07 & Allison Connolly (REU)

**Collaboration:** Prof. Degertekin (GT ME), Prof. Hao (Emory), Prof. Payne (GT Chem)

**Financial Support:** NSF & NIH (pending)
MITf-Lab @ GT
http://www.me.gatech.edu/MITf-Lab

**Lead Researchers:** J. Mark Meacham, PhD’07 & Allison Connolly (REU)

**Collaboration:** Prof. Degertekin (GT ME), Prof. Hao (Emory), Prof. Payne (GT Chem)

**Financial Support:** NSF & NIH (pending)

**Cell**
- Drug molecules, Imaging agents, DNA/RNA
- Cell treatment
- Cell response
- Bioeffects

**Electrical or Mechanical Stimuli**
- Drug uptake
- Cell death

Dynamics of Spontaneous Relaxation of Fused Giant Vesicles

Lead Researcher: Marmar Mehrabadi, PhD student (started Fall’06)

Motivation

- Membrane fusion is an important mechanism involved in many life processes such as secretion via exocytosis
- Pore expansion velocity plays a key role in regulation of secretion pore processes

Haluska, C. K. et al., PNAS, 2006

Financial Support: Grant # RO1 EB000508-01A1
National Institute of Biomedical Imaging & Bioengineering of the National Institutes of Health (NIH)

Collaboration: Dr. Kottke, Prof. Mizaikoff, Dr. Kranz (GT Chem)
Modeling and Numerical Solution:

- Bilayer is modeled as two fluid monolayers with inclusion of friction at the interlayer interface in addition to resistance to curvature
- Governing equations are discretized using finite difference method, and the Interface shape is captured by cubic splines

Model can be used to:

- determine the time scales of the different stages of vesicle fusion
- estimate pore expansion velocity in exocytosis
- study the effects of bilayer composition, initial (stalk) shape, inclusion of lipid flip-flop and variation in normal stresses (by inclusion of a granule matrix) on fusion dynamics

Lead Researcher: Marmar Mehrabadi, PhD student (started Fall’06)

Financial Support: Grant # RO1 EB000508-01A1

National Institute of Biomedical Imaging & Bioengineering of the National Institutes of Health (NIH)

Collaboration: Dr. Kottke, Prof. Mizaikoff, Dr. Kranz (GT Chem)
AFM/SECM for Imaging & Cell Signaling

Lead Researcher: Peter A. Kottle, PhD, Research Engineer II (2005-2007)

Development of theoretical understanding and simulation tools for interpretation of AFM-based Scanning Electrochemical Microscopy (SECM) of biological interfaces


Financial Support: Grant # RO1 EB000508-01A1

National Institute of Biomedical Imaging & Bioengineering of the National Institutes of Health (NIH)

Collaboration: Prof. Mizaikoff and Dr. Kranz (GT Chem)
AFM-Integrated Scanning Mass Spectrometry (AFM-SMS) Probe for Biochemical Imaging

*Lead Researcher: Peter A. Kottle, PhD, Research Engineer II (2005-Present)*

**NEW SOFT IONIZATION TECHNOLOGY FOR IN SITU MS IMAGING**


**Financial Support: NIH/NCRR Grant # K99 RR023758-01**

(Career Development Grant to Dr. Kottle)

**NSF MRI Grant IPDT 0722812**

(Mass spec instrumentation award)

**Collaboration: Dr. Kottke (GT ME) & Prof. Degertekin (GT ME)**
DRILL: DRy Ion Localization & Locomotion
Interface between Ion Source & Mass Spectrometer

We develop a novel device and method (DRILL: DRy Ion Localization & Locomotion) which utilize the converging vortex flow in combination with electrodes for confining (localizing) and guiding charged droplets/particles/ions from the ion source to the MS inlet. Advantages of DRILL originate from unique distribution of axial, tangential and radial velocities, resulting in optimal flow path followed by charged droplet/ions.

Lead Researchers: J. Mark Meacham, PhD’07 & Amod Jane (IIT UG)
Financial Support: Grant # R21 RR021474-01A1

Collaboration: Prof. Degertekin (GT ME)
Prof. Fernandez (GT Chem) and Muddiman (NCSU Chem)
**DRILL: DRy Ion Localization & Locomotion**

**Interface between Ion Source & Mass Spectrometer**

+ Trajectories of water droplets and size evolution (coded as color map)
+ Converging (helical) vortex flow streamlines (isometric view)


**Lead Researchers:** J. Mark Meacham, PhD’07 & Amod Jane (IIT UG)

**Financial Support:** Grant # R21 RR021474-01A1

**Collaboration:** Prof. Degertekin (GT ME)
Prof. Fernandez (GT Chem) and Muddiman (NCSU Chem)