MONT
Montana Nanotechnology Facility

An NSF NNCI Node in the Northern Rocky Mountain Region

Year 1 Activities Snapshot

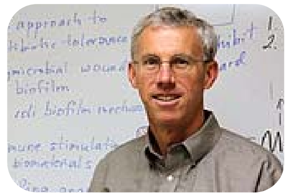
David Dickensheets

NNCI Annual Conference, January 17-18, 2017

Our Team:

David Dickensheets

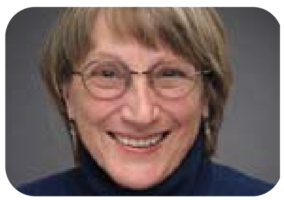
Recep Avci
ICAL



Phil Stewart
CBE

Mark Young
CBIN / VPR

Dave Mogk
Geology / E&O



Carolyn Plumb
Assessment

Phil Himmer
MMF Manager

Nancy Equall
ICAL Manager

MONTANA
STATE UNIVERSITY
Mountains and Minds

Sean Fox

Education Specialist

Carleton College
Science Education
Resource Center

CARLETON COLLEGE
NORTHFIELD, MINN. EST 1866

Our Vision

The Montana Nanotechnology Facility (MONT) promotes nanotechnology discovery, education and outreach by providing access to shared-use instruments, expert training on their safe and effective use, and broad-based education about nanoscale science and technology for teachers and learners who come from diverse communities.

Overview and Core Facilities

Coordinated access to and training on shared equipment housed in 5 campus facilities:

- Montana Microfabrication Facility
- Imaging and Chemical Analysis Lab
- Center for Biofilm Engineering
- Center for Bio-Inspired Nanomaterials
- Metabolomics, Proteomics and Mass Spectroscopy facility

MMF
MONTANA STATE UNIVERSITY
MONTANA MICROFABRICATION FACILITY
ICAL
MPMS
CBIN
CBE

Core Fabrication

CBE

- Processes set up for 4 inch wafers and pieces
  - Wet benches
  - Spinners – pos, neg photoresists, ebeam resists, lots of SU-8 work
  - Patterning – contact litho; FE-SEM with NPGS, Dip-Pen nanowriting
  - Thermal processing – oxidation and anneal; solid source diffusion
  - PVD - Angstrom Engineering sputter, e-beam evap, thermal evap
  - Dry etching – cryo ICP; RIE; O2 ash;

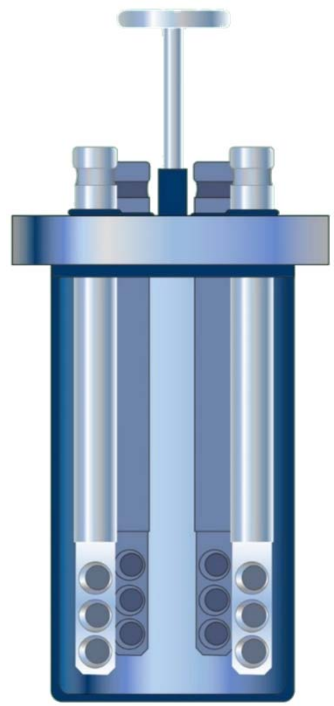
Core Characterization

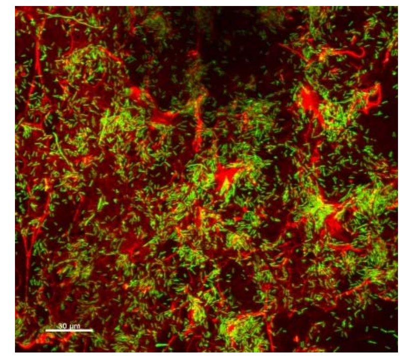
MONTANA MICROFABRICATION FACILITY ICAL CBE CBIN MPMS

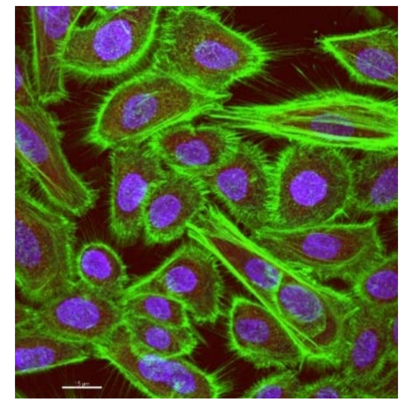
- **Thin films**: Ambios profilometer, Nanospec, resistivity probes
- **Device characterization**: probe stations, SPA, wire bonders
- **Imaging**: Metrology and stereo microscopes, fluorescence microscopes, SEMs, AFMs, TEM
- **Spectroscopy**: Auger, TOF-SIMS, XPS, EBSD, EDX, and Mass Spec capabilities spanning small to large molecules

CBE CBIN Unique Capabilities for Bio + Nano

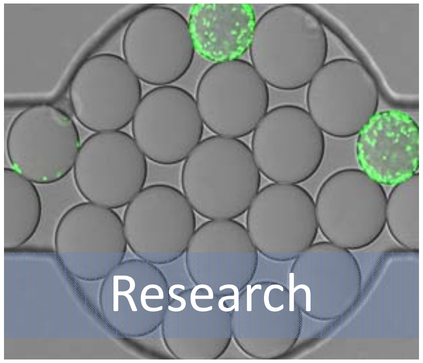
- Center for Biofilm Engineering
  - Incubation capabilities for biofilms, mammalian cells and thermophiles
  - Chromatography and spectroscopy tools
  - Genetic sequencing
  - Advanced confocal and fluorescence imaging – live cell imaging





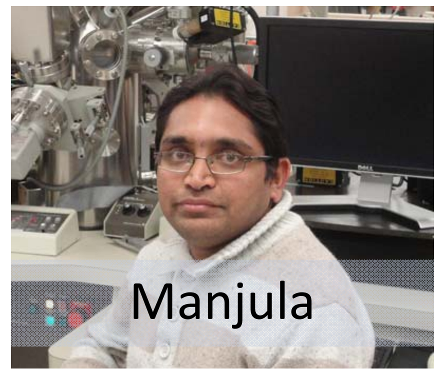


Year 1 Highlights



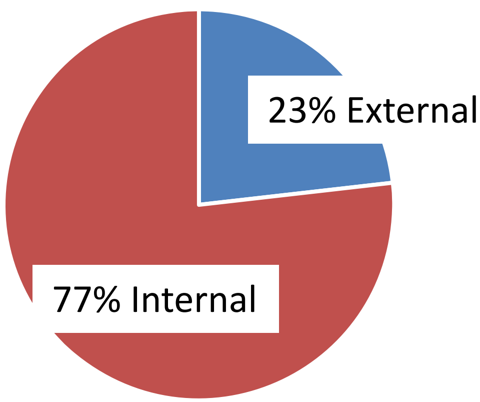
Facility Enhancement

- Added Staff: litho/microfluidics, characterization, user liaison
- New Equipment: NanoAuger (PHI 710), EVG aligner, Filmetrics

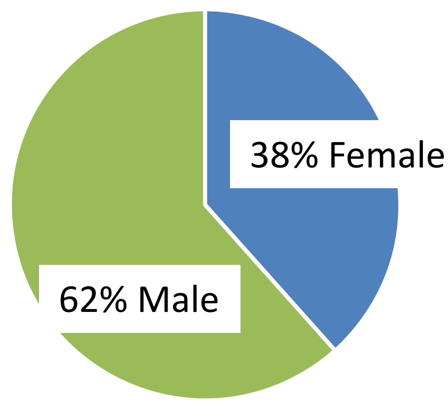


Users

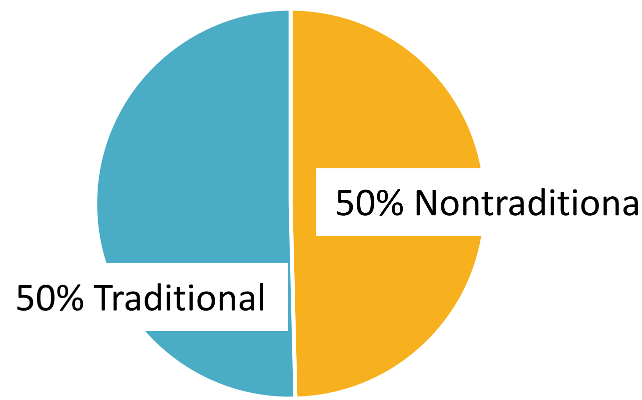
125 Total Users in Y1



External Users

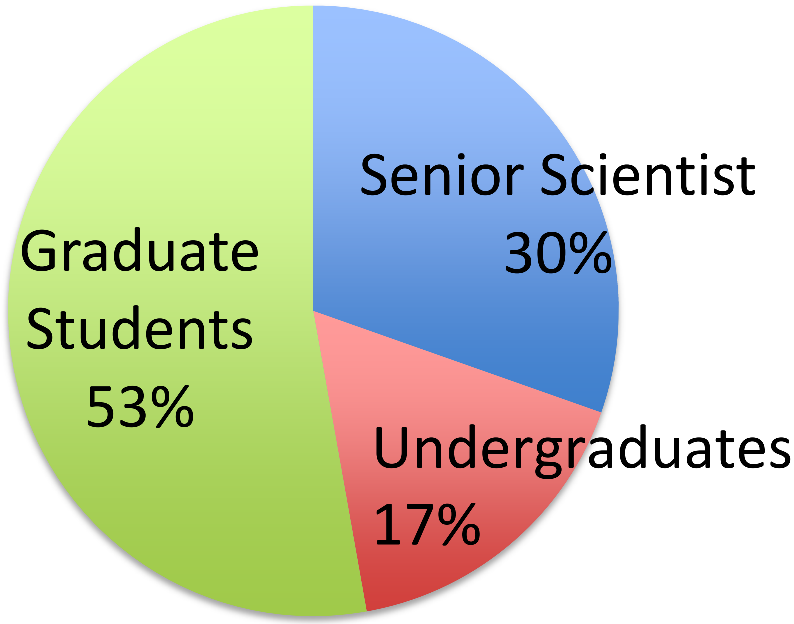


Gender

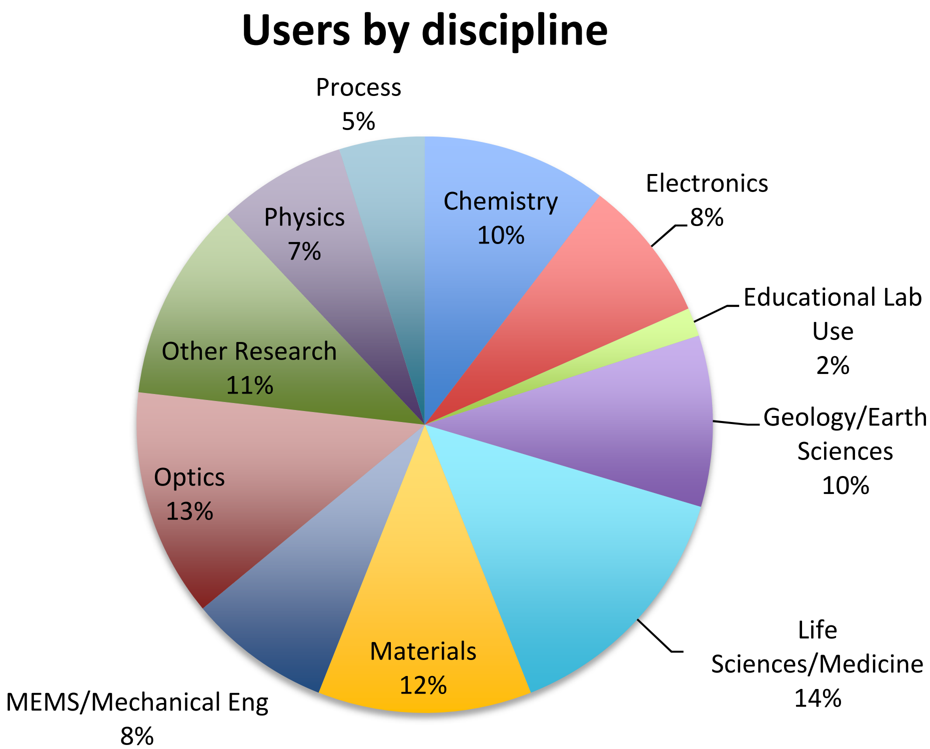


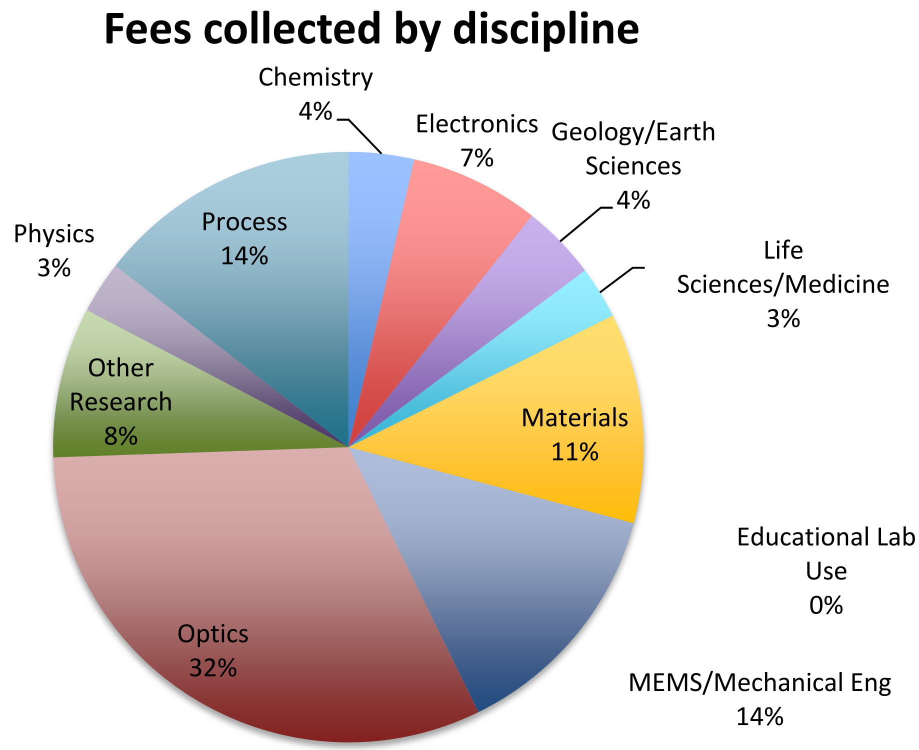
Non-Traditional

Users – Academic Rank



Users – Discipline Breakdown





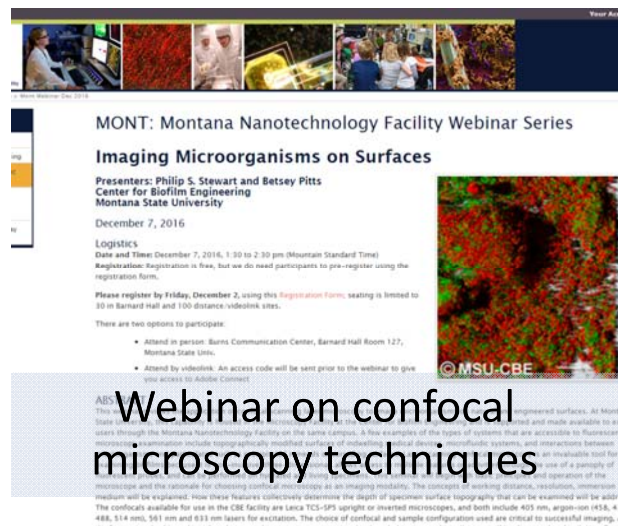
User-Driven New Directions

Proposals pending for new space and new equipment to support “Soft Lithography” and 3D printing for microfluidics research and training.

Education and Outreach

- **70 undergraduates** used MONT for courses on Microfabrication and Photovoltaics
- Photovoltaics summer course for **secondary science teachers** (>60 so far)
- **Summer REU** in 2017, cooperatively with ECE department
- **Industry workshop**: Nanotech for Biofilms
- **Webinars**
- **K-12 Outreach**: Nanodays, Shadow an Engineer

MSSE teachers in MONT facility, June 2016



Webinar on confocal microscopy techniques

Education and Outreach

- In cooperation with Carleton College Science Education Resource Center (SERC):
  - Web-based educational and instructional resources
    - Important nanotechnology processes (http://serc.carleton.edu/18410)
    - Nanotechnology applications
    - Ethics and societal impacts of nanotechnology
    - Teaching resources – integrating discussion of ethics and society into all of our educational activities http://serc.carleton.edu/geoethics/index.html
  - – Web-based outreach
    - http://serc.carleton.edu/8640

Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS)

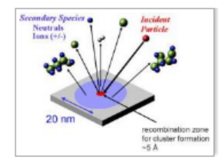
David W. Mogk, Montana State University

What is Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS)

Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) is a surface-sensitive analytical method that uses a pulsed ion beam (Cs or microfocused Ga) to remove molecules from the very outermost surface of the sample. The particles are removed from atomic monolayers on the surface (secondary ions). These particles are then accelerated into a "flight tube" and their mass is determined by measuring the exact time at which they reach the detector (i.e. time-of-flight). Three operational modes are available using ToF-SIMS: surface spectroscopy, surface imaging and depth profiling. Analytical capabilities of ToF-SIMS include:

- Mass resolution of 0.00x amu. Particles particles with the same nominal mass (e.g. Si and C_2H_4, both with amu = 28) are easily distinguished from one another because as Mr. Einstein predicted there is a slight mass shift as atoms enter a bound state.
- Mass range of 0-10,000 amu; ions (positive or negative), isotopes, and molecular compounds (including polymers, organic compounds, and up to ~amino acids) can be detected.
- Trace element detection limits in the ppm range.
- Sub-micron imaging to map any mass number of interest.
- Depth profiling capabilities; sequential sputtering of surfaces allow analysis of the chemical stratigraphy on material surfaces (typical sputtering rates are ~100 A/minute).
- Retrospective analysis. Every pixel of a ToF-SIMS map represents a full mass spectrum. This allows an analyst to retrospectively produce maps for any mass of interest, and to interrogate regions of interest (ROI) for their chemical composition via computer processing after the dataset has been instrumentally acquired.

Fundamental Principles of Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS)



▶ Show caption

ToF-SIMS uses a focused, pulsed particle beam (typically Cs or Ga) to dislodge chemical species on a materials surface. Particles produced closer to the site of impact tend to be dissociated ions (positive or negative). Secondary particles generated farther from the impact site tend to be molecular compounds, typically fragments of much larger organic macromolecules. The particles are then accelerated into a flight path on their way towards a detector. Because it is possible to measure the "time-of-flight" of the particles from the time of impact to detector on a scale of nano-seconds, it is possible to produce a mass resolution as fine as 0.00X atomic mass units (i.e. one part in a thousand of the mass of a proton). Under typical operating conditions, the results of ToF-SIMS analysis include:

1. a mass spectrum that surveys all atomic masses over a range of 0-10,000 amu,
2. the rastered beam produces maps of any mass of interest on a sub-micron scale, and
3. depth profiles are produced by removal of surface layers by sputtering under the ion beam.

ToF-SIMS is also referred to as "static" SIMS because a low primary ion current is used to "tickle" the sample surface to liberate ions, molecules and molecular clusters for analysis. In contrast, "dynamic" SIMS is the method of choice for quantitative analysis because a higher primary ion current results in a faster sputtering rate and produces a much higher ion yield. Thus, dynamic SIMS creates better counting statistics for trace elements. Organic compounds are effectively destroyed by "dynamic" SIMS, and no diagnostic information is obtained.

Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) Instrumentation – How Does It Work?

ToF-SIMS instruments typically include the following components:

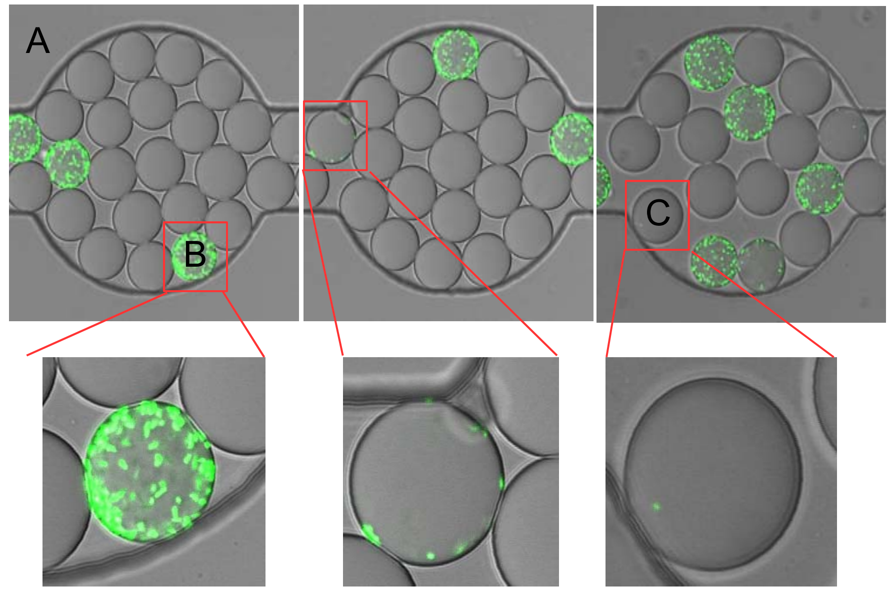
- An ultrahigh vacuum system, which is needed to increase the mean free path of ions liberated in the

Research Highlights - Microfluidics

“Droplet Engineering” to Study Single Bacteria Cells

Prof. Connie Chang
Chemical and Biological Engineering,
Center for Biofilm Engineering

C.B. Chang, J.N. Wilking, S.H. Kim, H.C. Shum, D. A. Weitz. “Monodisperse Emulsion Drop Microenvironments for Bacterial Biofilm Growth” *Small* (2015)



Examples of cell resuscitation of individual *P. aeruignosa* bacteria within 15 µm diameter oil microdroplets. Maximum Projection images from CLSM.

Research Highlights – Nonlinear Optics

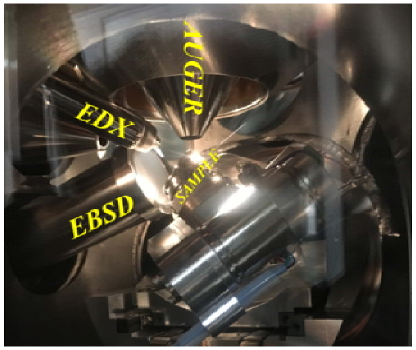
Industrial user AdvR., Inc. of Bozeman uses MONT to build laser wavelength converters

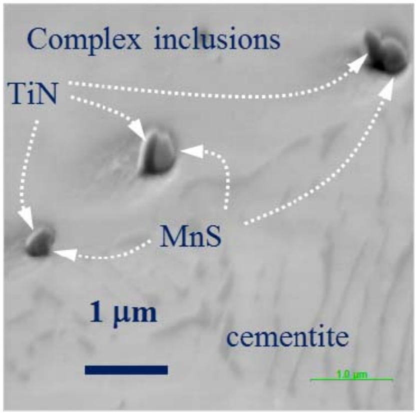
AdvR uses the MMF/MONT facilities to fabricate waveguides in nonlinear optical materials such, as KTP, LN, and Mg:LN.

These waveguides can be periodically poled in various configurations and used to generate second harmonic generation, sum frequency generation, downconversion, difference frequency generation, Bragg stabilization, and phase modulation.

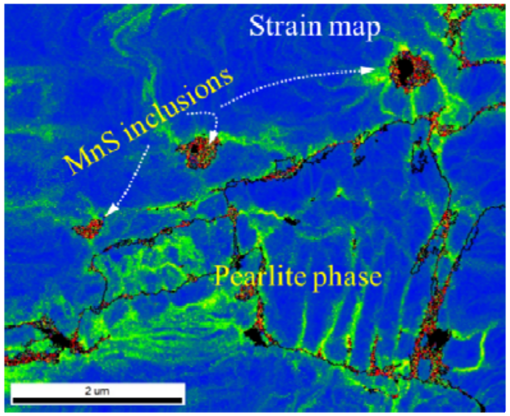
Research Highlights – PHI 710 NanoAuger

Hybrid Auger system combines a field emission Auger nanoprobe with an EDX and an EBSD system.
This enables analysis of morphology, surface and bulk composition, structural, crystallographic orientation and phase at the same area at the nanoscale resolution.





SEM image of MnS, TiN inclusions and cementite lamella in carbon steel.



Overlayed strain map of the same region obtained using EBSD.

The role of nano-defects in the localized corrosion of low carbon steel (a USD 1.1 Trillion annual problem).

MONT Had a Successful NNCI Y1!

- **Significant facility enhancement and new hires; excellent leveraging of NSF funds to grow State/Private investment**
- **Growth in user numbers and diversity**
- **Strong E & O portfolio, locally and on the web in partnership with Carleton College's SERC**
- **Exciting new research directions, both academic and industrial**