LeRoy Eyring Center for Solid State Science

Nate Newman, director

- **Established by ABOR on May 25, 1974**

encourage & support *interdisciplinary* research activities in solid state materials

- **Highlights of current status**

  *** >$2+ Million facility budget - 20% higher than our last year record value**

  *** >$32 M "touched-view" of research expenditures**

  *** >40 instruments available to ASU & outside research community including TEM, SEM, FIB, SQUID magnetometer, RBS, AFM, AES, XPS, thermochemical analysis**

  *** >200 current users, >70 P.I.s, >20 departments and >4 colleges**

  *** >Outreach- "*Science is Fun" program* reaches >20,000 K-12 students**

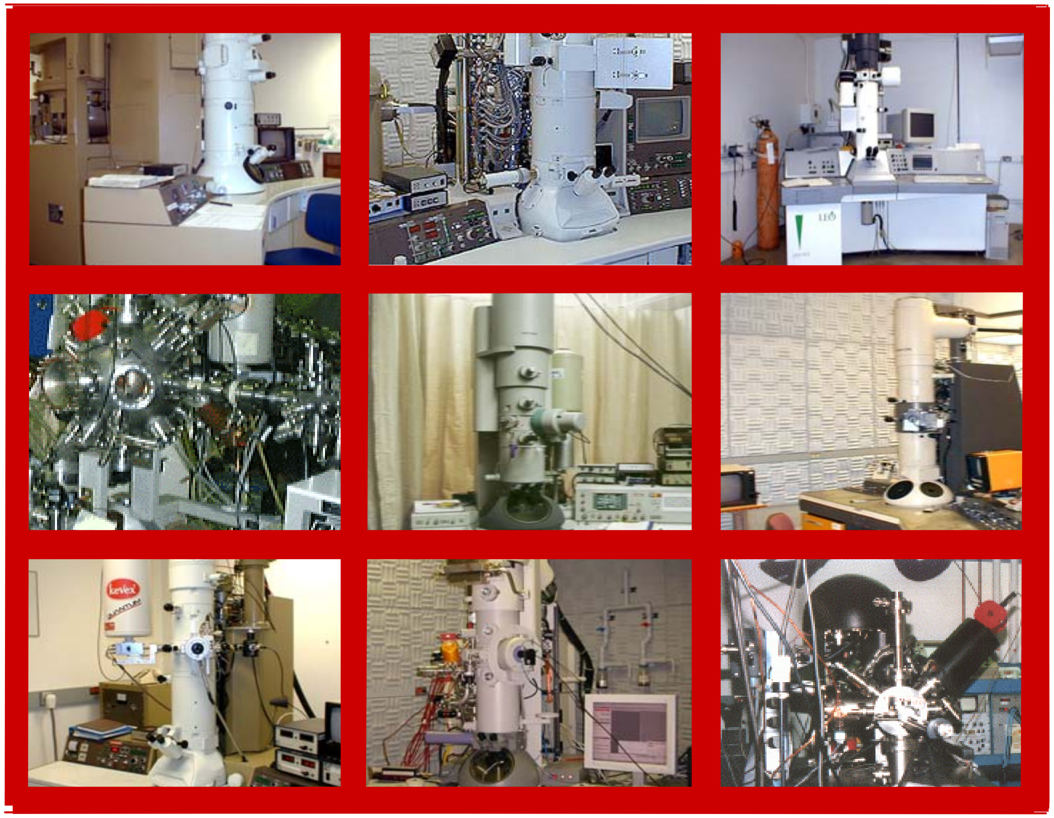
  *** > Members of IAP include Intel, Chevron, Monsanto, Dial, Freescale, …..**

- ***1200 users to-date, our most important "product"***

Major objectives of the Center are:

- to encourage and support interdisciplinary research activities in solid state science
- to operate & administer user-facilities for multidisciplinary research
- to support outreach activities ; and
- to provide a valuable resource for industry through industrial affiliates programs

Expensive Advanced Instrumentation



Milions $$$$ invested in instrumentation (unique)

Thousands of hours in associated expertise

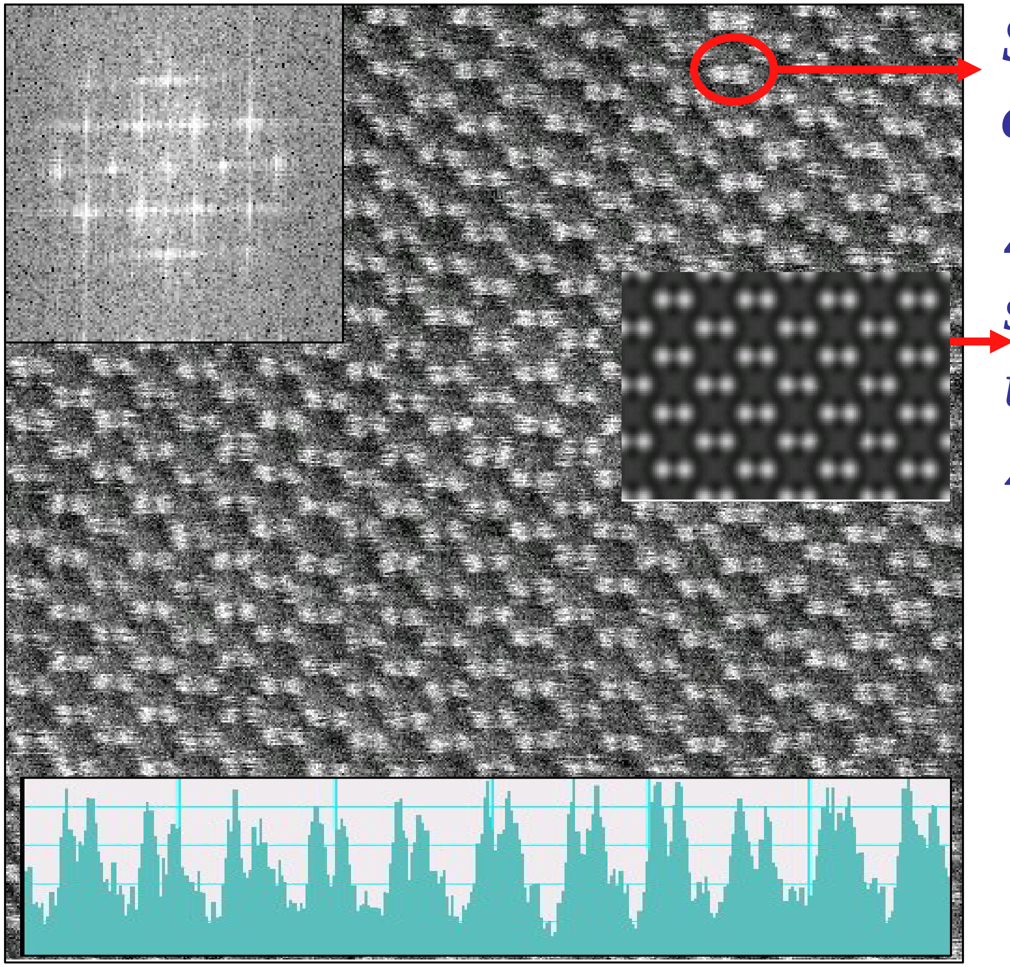
People who make it happen

LE-CSSS Staff

1984-present	**Karl Weiss,**	**23 years**
1985-present	**Renu Sharma**	**22 years**
1985-present	**Bonnie Mello**	**22 years**
1985-present	**David Wright**	**20 years**
1987-present	**Peter Crozier**	**20 years**
1987-present	**Paul Perkes**	**20 years**
1989-present	**Timothy Karcher**	**18 years**
1994-present	**Barry Wilkens**	**15 years**
2000-present	**Zhenquan Liu**	**7 years**
2000-present	**Jon Mull**	**7 years**
2002-present	**Grant Baumgardner**	**5 years**
2003-present	**Donalea Robertson**	**3/7years**
2003-present	**Joanne Ackerman**	**3/14 years**
2007-present	**Sisouk "Si" Phrasavath**	**1 year**
2007-present	**Roxanna montoya**	**3 days**

Atomic Resolution Z-Contrast Imaging

Z-contrast image of Si <110> orientation – atoms are white



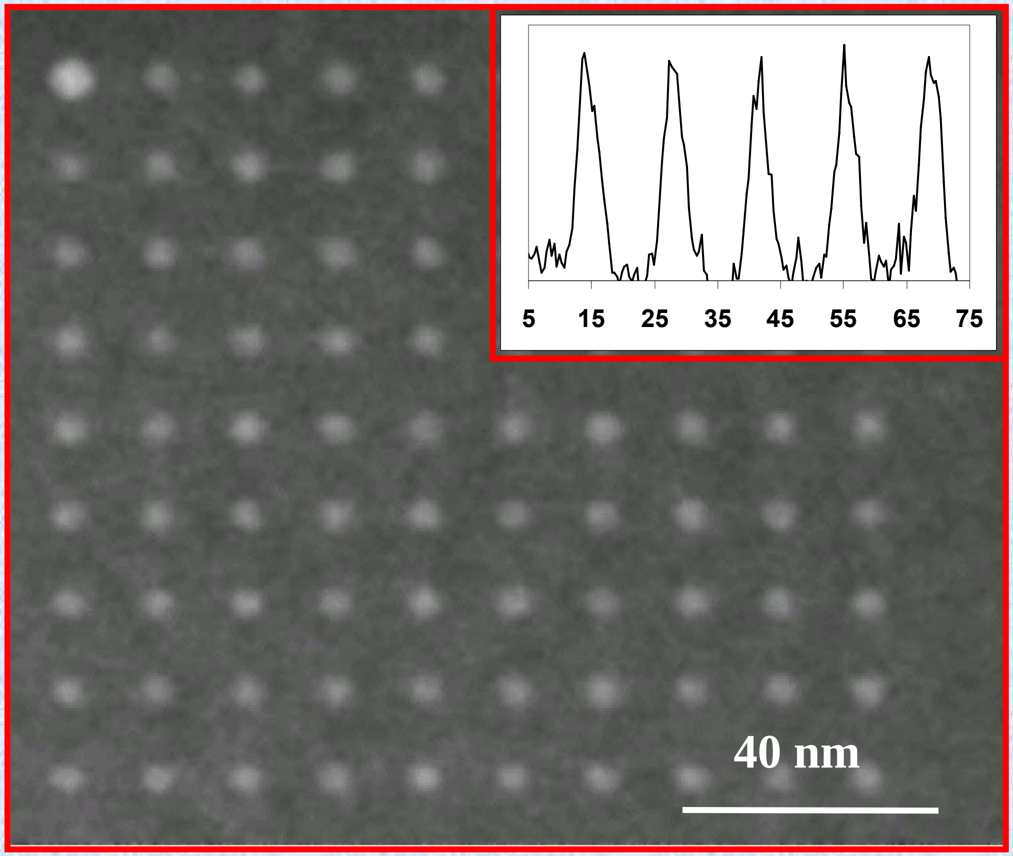
Separation of pair of Si atoms ~ 0.14 – 0.15nm

Z-contrast image simulation conducted using Kirkland codes Δf = 50 nm, t = 5 nm

E.J. Kirkland – Advanced Computing for Electron Microscopy 1998

For thin samples, focusing is unique no contrast reversals !

Ordered Arrays of GaN Dots on Si



- *10 x 10 array drawn from adsorbed layers*

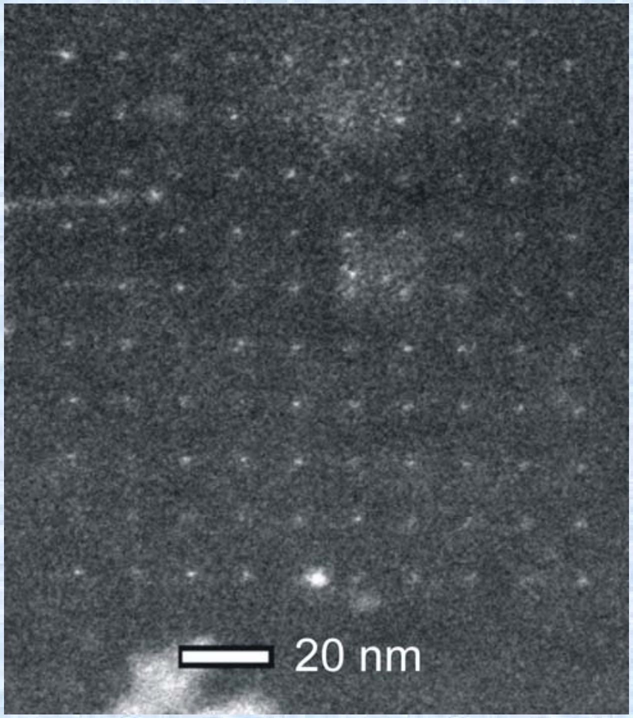
- *GaN dots are very regular and show uniform size with base width of 9 nm and FWHM of 4 nm.*

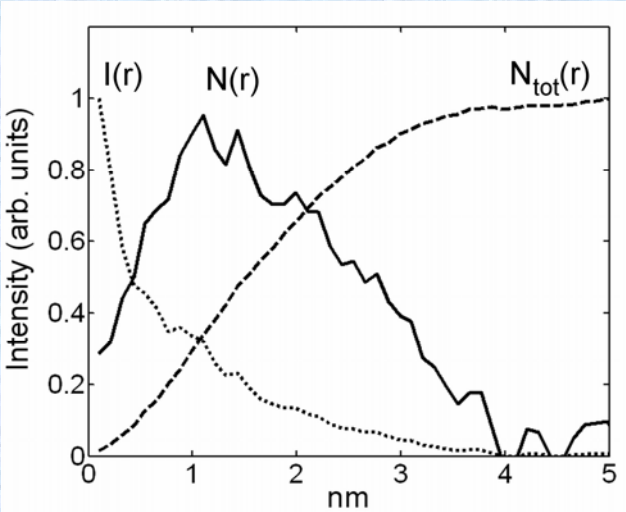
Decomposition of $W(CO)_6$

Array of <u>very</u> small W dots on Si_3N_4

Very few atoms in dot (~10 -15)

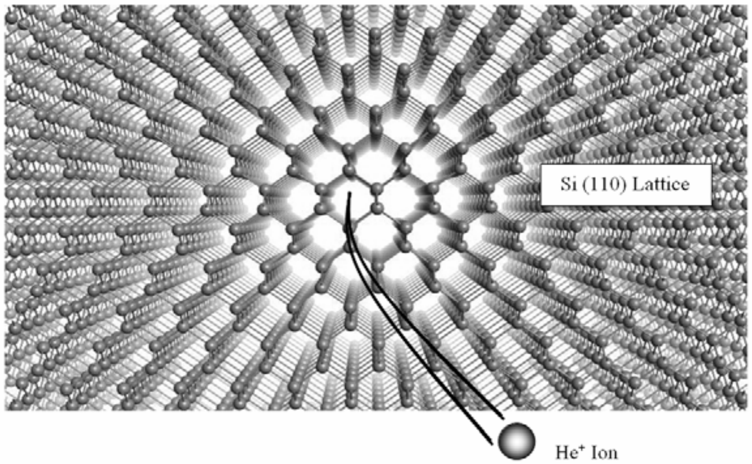
Shot noise leads to fluctuations



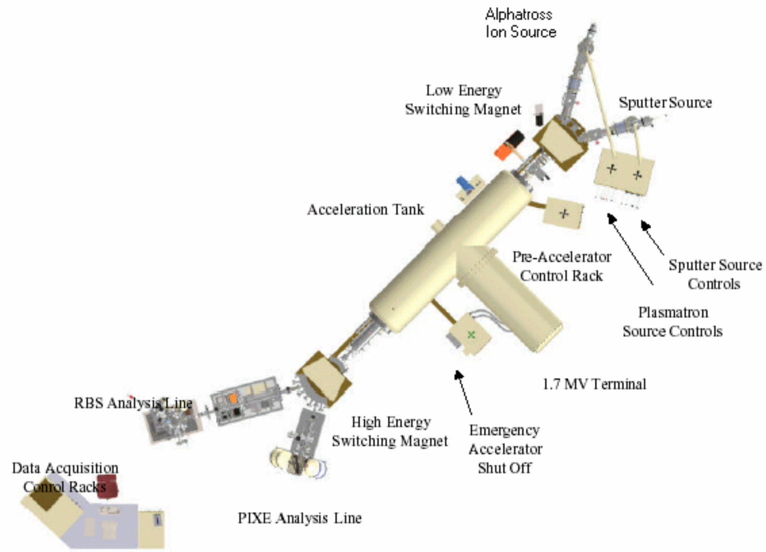


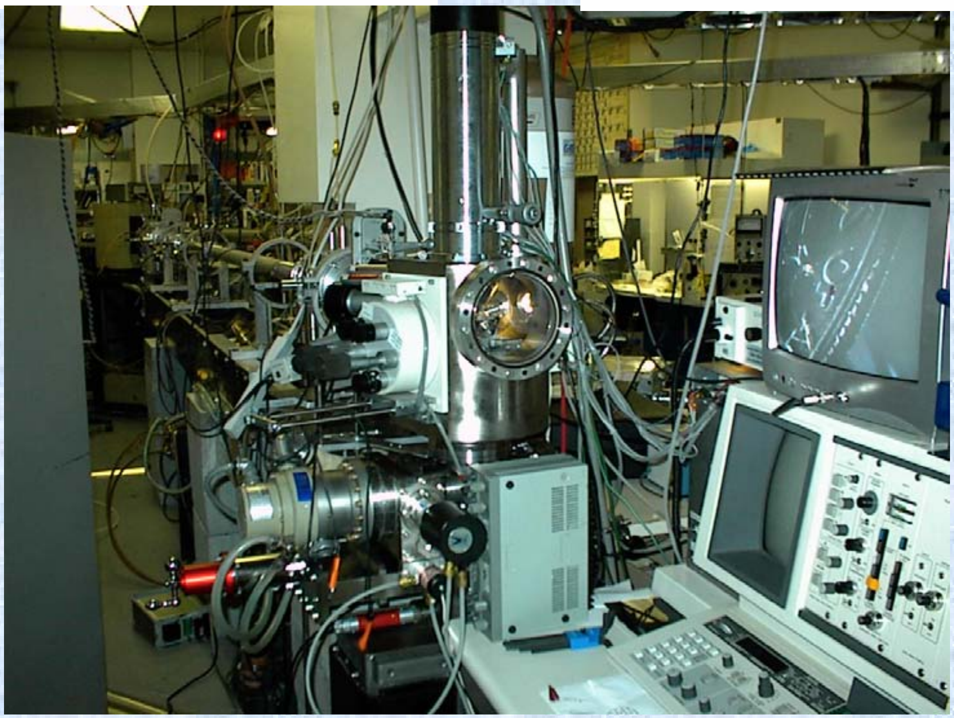
FWHM of average 1 nm - a world record for EBID !!!!
Smallest cluster is 0.7 nm
(submitted to Nanoletters)

Ion Channeling



Accelerator Overview

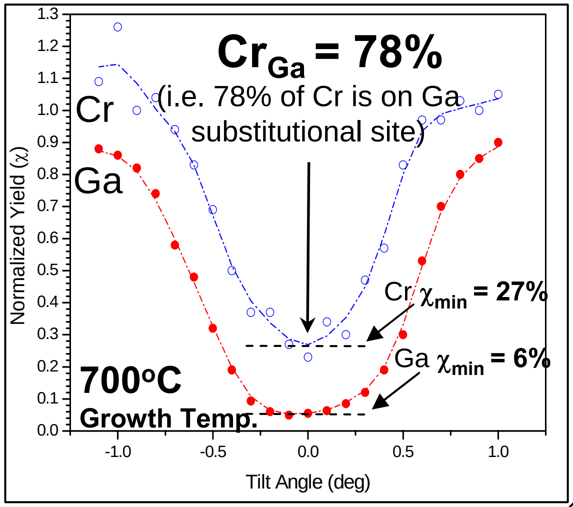


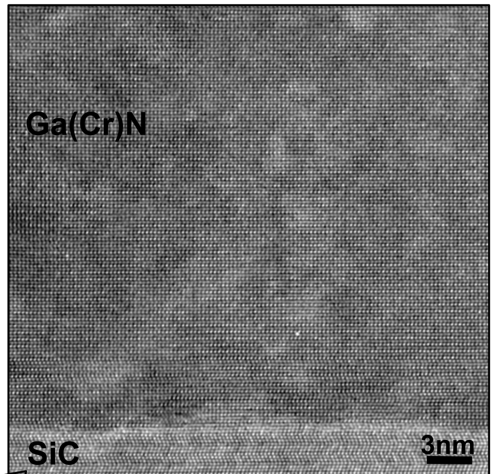


Ion-channeling RBS:

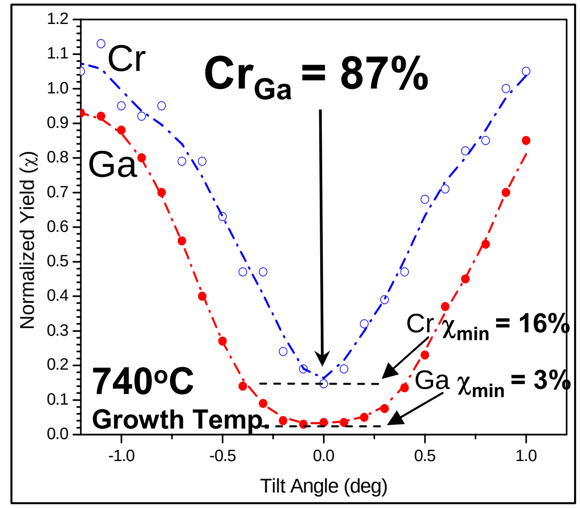
Measured Angular Distribution for 3% Cr-doped GaN

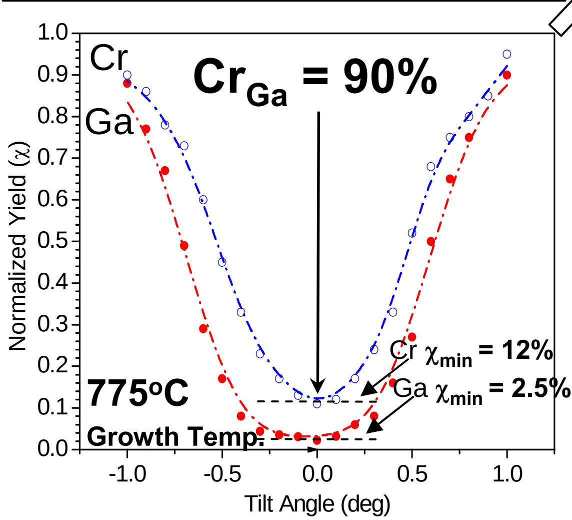
Low Ga χmin → excellent crystallinity; Low Cr χmin → high Cr_{Ga} (Cr on Ga substitutional site)

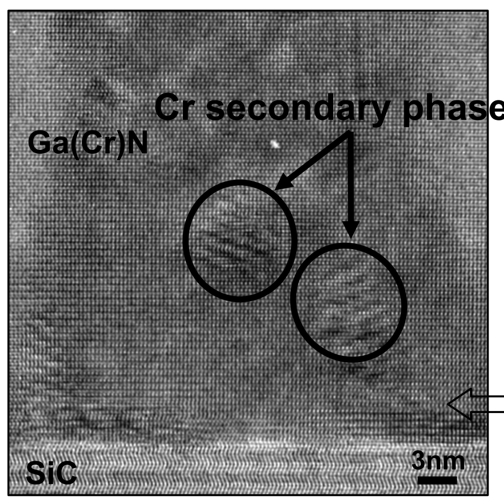


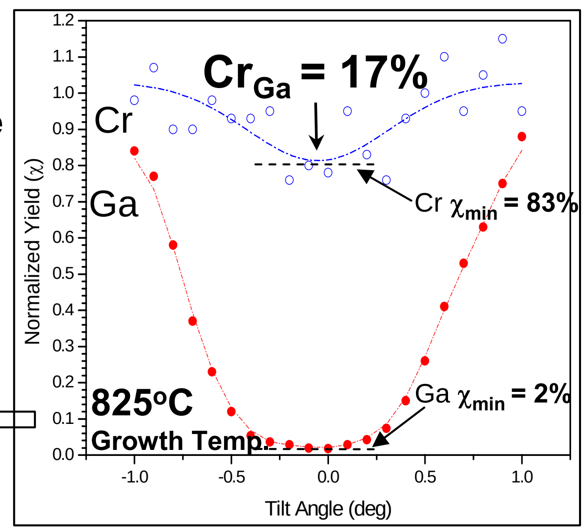


Uniform Cr distribution



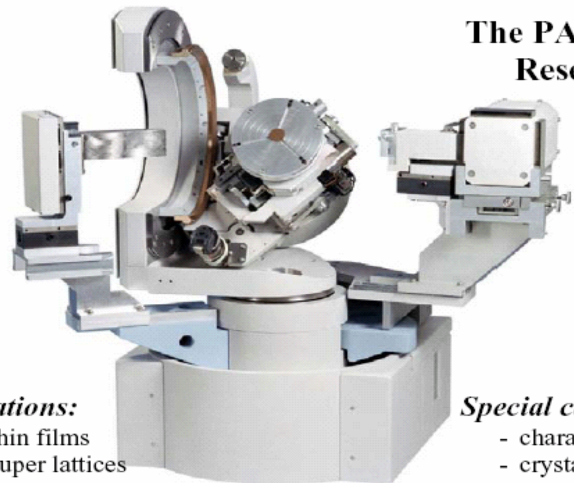






Cr segregation in sample grown at 825°C

NEW addition to LE-CSSS September 1st
New High resolution X-Ray Diffractometer



The PANalytical X'Pert Pro Materials Research X-ray Diffractometer.

Diffractometer for thin films, single crystals and powders from room temperature up to 900°C using CuKα radiations

Applications:

- thin films
- super lattices
- single crystals
- polycrystalline samples
- powders and amorphous materials
- air sensitive materials

Special capabilities:

- characterize primary and secondary phases
- crystal orientation
- degree of crystallinity
- stresses in the crystal structure
- spatial mapping (100 x 100 mm motion) of sample surfaces
- high speed wide angle x-ray diffraction and fast mode reciprocal space mapping

Thin film characterization:

- characterize epitaxial films and film stacks
- layer composition, relaxation, thickness, curvature, mismatch, mosaicity
- degree of off cut
- super lattice period
- x-ray reflectivity on layered structures (crystalline and amorphous)

Some technical details:

- 7 axis horizontal goniometer (Omega, 2Theta, Psi (Chi), Phi, X, Y, Z)
- flip focus Cu anode x-ray tube (line or point focus)
- high resolution: 5 arc sec in point focus mode / 19 arc sec in line focus mode
- low resolution 0.04 ° (Bragg Brentano slit optics)

Accessories:

- three sample stages:
  - standard 4" wafer mount
  - solid sample holder (also used for powders)
  - Anton Paar DHS 900 domed hot stage for data collection from RT up to 900 °C
- Incident beam optics
  - 5 arc sec Ge(440) point focus module (Bartels monochromator)
  - 19 arc sec hybrid (combination x-ray mirror + channel cut Ge(220) monochromator) line focus module
  - manual divergence slit line focus module
- diffracted beam optics
  - rocking curve receiving slit used with sealed Xe proportional detectors
  - 12 arc sec Ge(220) monochromator used with sealed Xe proportional detectors
  - manual anti scatter assembly used with X'Celerator high speed solid state linear array position sensitive detector

-ICDD PDF-2 XRD Database (2006-2007 version)

Contact Emmanuel Soignard (965 7242, emmanuel.soignar@asu.edu) for more information.

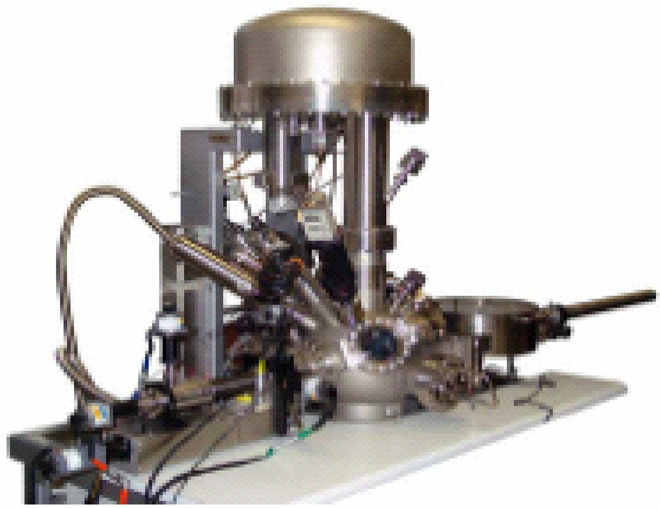
NEW addition to LE-CSSS, February 2008
Quantum Design MPMS SQUID magnetometer
& electrical test system, 0-5 T, 2 -400 K

•SQUID AC Susceptibility Measurement (*)
- 0.1 Hz to 1KHz
•sensitivity: 2 x 10^{-8} emu at 0 T
•Ultra-Low Field Capability (*) ±0.05 G
•Reciprocating Sample Option (RSO) - DC Magnetization absolute
•sensitivity: 1 x 10-8 emu @ 2,500 Oe
•Continuous Low Temperature Control/Temperature Sweep Mode (CLTC) -
•Sweep rate: 0.001 - 10 K/min.

Applications:
-Magnetic materials
-Superconducting materials
-Paramagnetic centers in semiconductors
and dielectrics

Contact Nate Newman (727 6934, nathan.newman@asu.edu) for more information.

New addition to LE-CSSS
VG ESCALAB 220i-XL



The LeRoy Eyring Center for Solid State Science announces the availability of the VG ESCALAB 220i-XL. (shown in its current location in Goldwater B10)
(donated to ASU by Intel Corp.)

It is expected to be fully operational/available for use on Sept. 1, 2007

Features:

- Standard XPS analysis.
- X-Ray Photoelectron imaging.
- SEM-style imaging.
- Video imaging.
- Small spot analysis: 100 micron, 50 micron, and 20 micron.
- XPS Depth-profiling in small spot mode.
- XPS Angle-Resolved analysis.

X-Ray sources:

- Monochromated Al K-alpha. Linewidth 0.8 eV.
- Twin anode Al/Mg K-alpha

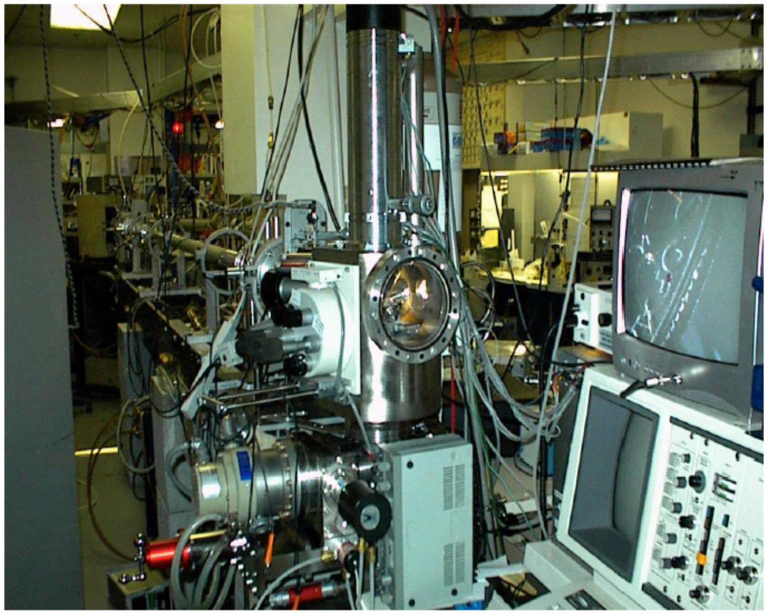
Sample handling:

- Standard multiple sample mount bar.
- 4" diameter and smaller wafer mount platform with rotation.
- Sample stage x-, y-, and z-motion.

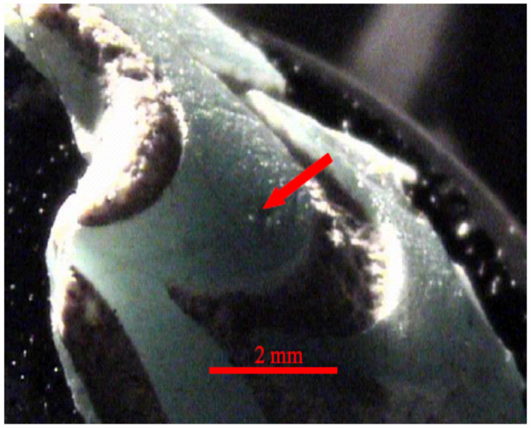
Please contact Tim Karcher at Tim.Karcher@asu.edu; GW B83; (480) 965-9070

Nuclear Microprobe Analysis

(Small Spot RBS and PIXE Analysis)



The capability of high spatial resolution PIXE and RBS analysis has been added to the IBeAM facility with the addition of a new beamline and focusing lens which provides a beam spot 100 – 500 X's smaller than the current 1 mm^2 spot size. The sample chamber incorporates an SEM (scanning electron microscope)and an optical microscope (with CCD camera) for small sample viewing and beam localization. Our anticipation is that the Nuclear Microprobe will find useful applications in a number of areas where improved spatial resolution in elemental analysis is required. Some examples would include: Geology (mapping grains and crystals), Physics and EE (elemental analysis of microstructures and devices) and Life Sciences (elemental mapping of cells).



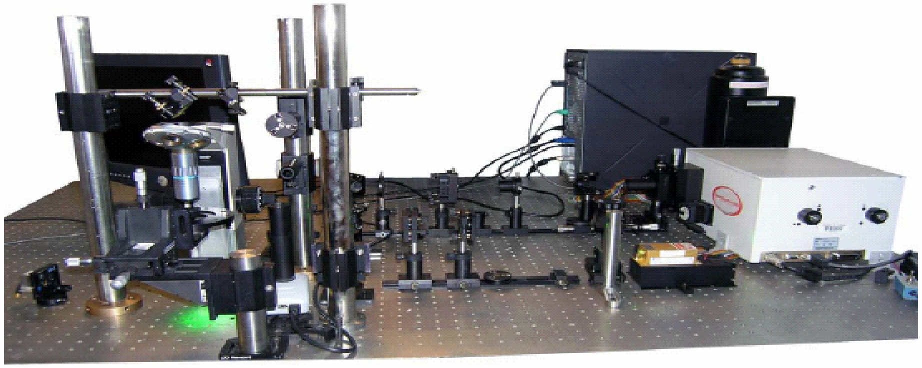
Optical image of a piece of ancient Egyptian decorated glass. Red arrow at left indicates location of 20 micron dia. proton beamspot.

It is fully operational and currently available for use.

Contact Barry Wilkens (barry.wilkens@asu.edu) for more information.

New addition to LE-CSSS
Raman spectroscopy facility

Instrument: custom System w/ 532 nm excitation wavelength
Currently available in Physical Science C37 (PSC 37)



State of the art custom-built notch filter based high throughput Raman system with an excitation wavelength of 532 nm.

- Maximum available power: 100 mW
- Special resolution: < 5 microns
- PI Liquid nitrogen cooled detector and Acton spectrometer
- Can collect down to ~ 100 cm^{-1}.

No or minimal sample preparation

- NON DESTRUCTIVE
- Works for most liquid, gas or solid
- pure phase, multi phases, glasses, single crystals…. and even artwork such as painting…

Some applications

- phase identification (compare to a published spectrum/ standard)
- investigate small chemical/structural
- strain/defects in some material
- sample mapping
- *in situ* characterization at high pressure and or temperature or within a medium

Some limitations:

- most metals are difficult / impossible to observe
- sample fluorescent
- symmetry of the material

Contact Emmanuel Soignard (965 7242, emmanuel.soignar@asu.edu) for more information.

Center for High Resolution Electron Microscopy

Electron Microscopy Methods for Advanced Materials

Arizona State University

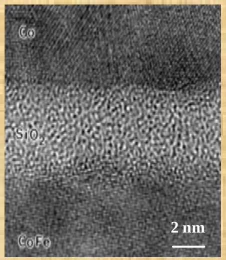
The purpose of the Center for High Resolution for Electron Microscopy is to promote the application of electron microscopy methods to problems of current scientific and technological importance.

The Center is a regional resource for applications involving imaging, microanalysis, electron diffraction, electron holography, and surface microscopy, as well as developments in methods and instrumentation.

Specific aims of the Center include:

- to provide access to advanced research tools;
- to provide advice on state-of-the-art techniques;
- to offer educational opportunities such as advanced schools and research workshops.

Transmission Electron Microscopy

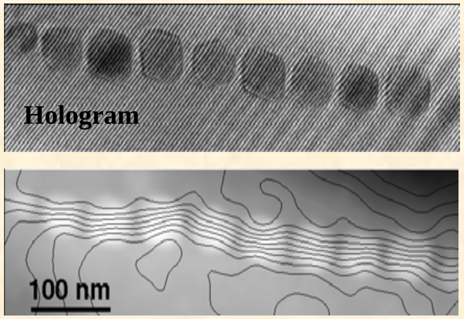


Cross-sectional TEM image revealing microstructure of Co/SiO_2/CoFe magnetic tunnel junction [1].

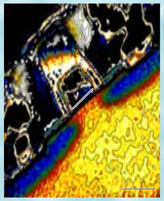
High-Resolution Electron Microscopy

Cross-sectional electron micrograph showing misfit dislocations at sapphire/AlN interface.

Electron Holography

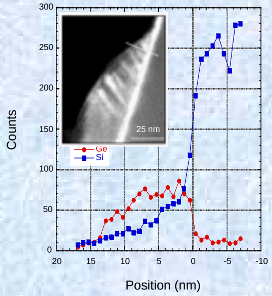


Two-dimensional imaging of magnetic field associated with tiny magnetite crystals in magnetotactic bacteria [2].



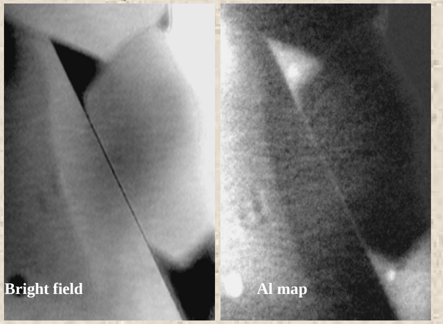
Electrostatic potential within 0.13micron transistor device quantified using electron holography [9].

Scanning Transmission E.M.



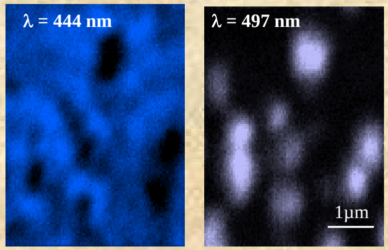
Energy-dispersive Xray analysis with sub-nm STEM probe reveals Si interdiffusion into epitaxial Ge island [3].

Energy Filtered Imaging



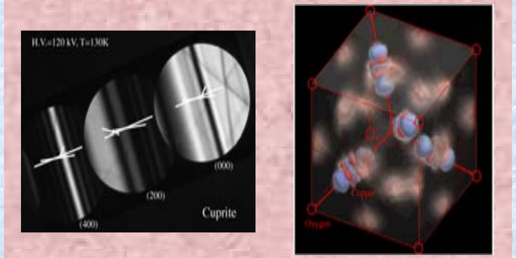
Grain boundary solute distribution in Si_3N_4/SiC ceramic densified with Y_2O_3/Al_2O_3 sintering aid [4].

Cathodoluminescence



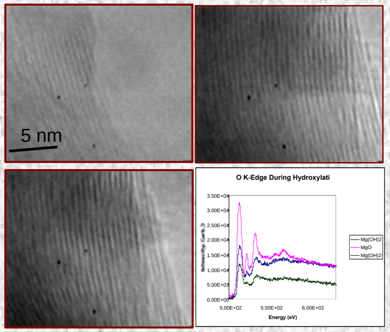
Plan-view CL images from InGaN used to correlate structural defects with light emission [5].

Convergent Beam Electron Diffraction



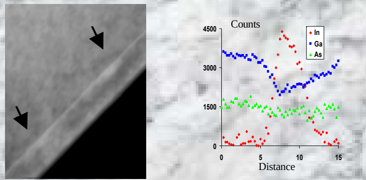
Quantitative CBED pattern yields charge density map showing d-orbitals in cuprite crystal [6].

Environmental Cell Microscopy

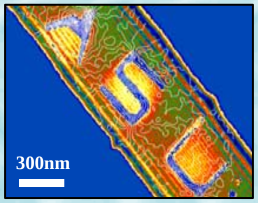


Progressive hydroxylation of MgO nanocrystal with associated change in EELS O_K -edge [7].

NanoSpectroscopy



Cross-sectional image of InGaAs quantum dots in GaAs matrix and EELS elemental profile [8].



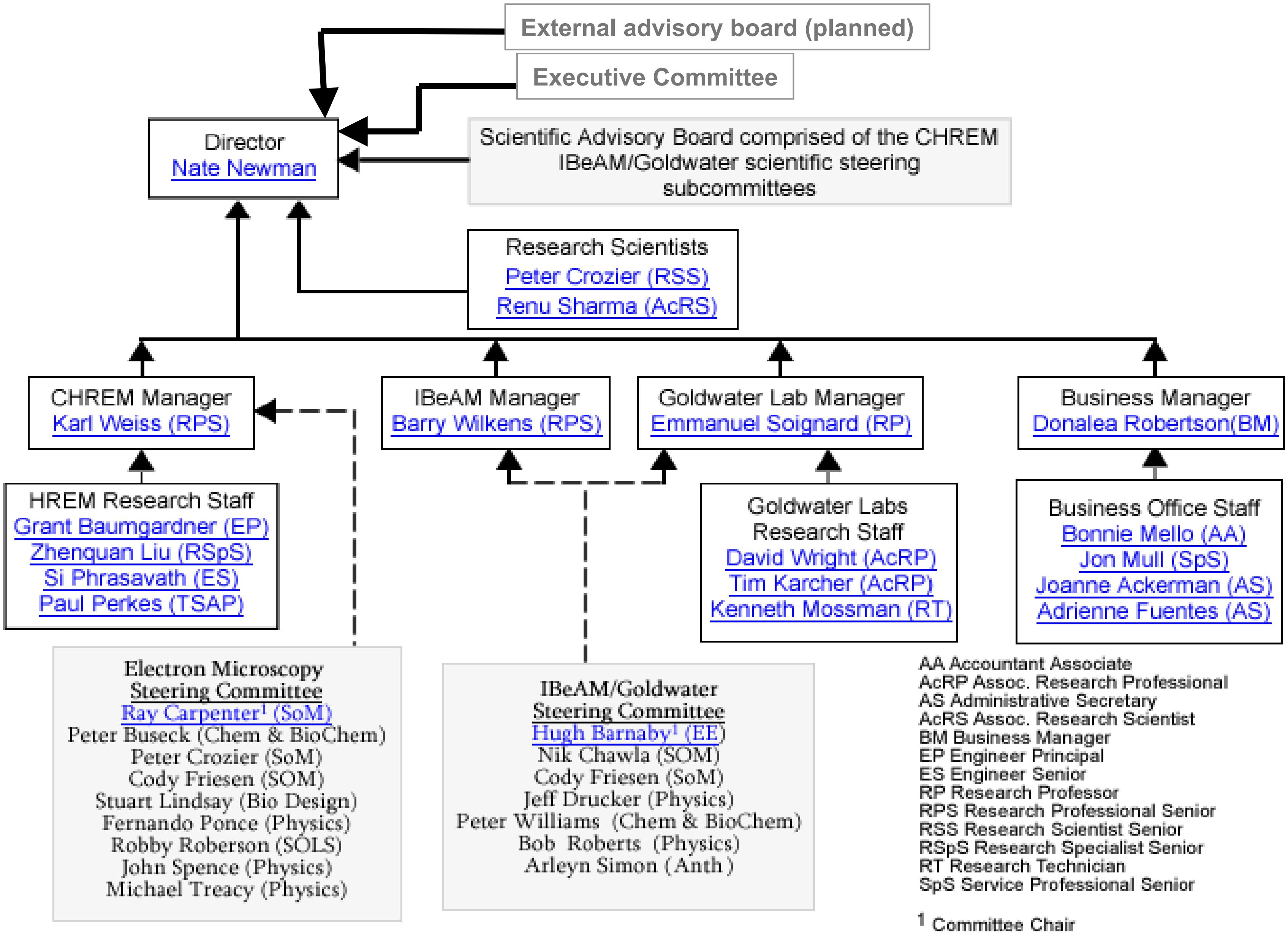
URL: http://www.asu.edu/clas/csss/chrem

References

[1] D. J. Smith, et al., J. Appl. Phys., 83 (1998) 5154.
[2] R. E. Dunin-Borkowski, et al., Science, 282 (1998) 1868.
[3] S. A. Chaparro, et al., Phys. Rev. Lett., 83 (1999) 1199.
[4] K. Das Chowdhury, et al., J. Amer. Cer. Soc., 78 (1995) 2579.
[5] S. Srinavasan, et al., Appl. Phys. Lett., 2001 (in press)
[6] J. M. Zuo, et al., Nature, 301 (1999) 49.
[7] M. J. McKelvy, et al., Chem. Mater., 13 (2001) 921.
[8] P. A. Crozier, et al., Appl. Phys. Lett., 2001 (in press)
[9] M. A. Gribelyuk, et al., Phys. Rev. Lett., 2001 (in press)

Major Instrument Acquisitions

1970 JEOL 100B2
1974 JEOL 100B4
1979 VG HB-5
1980 PHILIPS 400T
1980 JEOL 200CX
1981 PHILIPS 400T FEG*
1984 JEOL 4000 EX*
1986 PHILLIPS EM 300
1988 PHILIPS 430
1989 JEOL 2000FX*
1989 TOPCON 002B*
1990 VG HB-501
1992 RBS I-beam accelerator
1993 AES Physical Electronics 590
1993 XPS Kratos XSAM 800
1995 PHILIPS CM-200*
1996 LEO 912*
1997 JEOL 840*
1997 VG HB-501
2000 JEOL JSM 6300
2001 JEOL 2010F FASTEM*
2002 TECNAI F20*
2003 XL 30 ESEM FEG*
2004 Nova Nanolab FIB*
2006 VG-220i imaging XPS
2007 Panalytic high-res. X-ray diffractometer
2007 Quantum Design SQUID Magnetometer


External advisory board (planned)
Executive Committee
Director
Nate Newman
Scientific Advisory Board comprised of the CHREM IBeAM/Goldwater scientific steering subcommittees
Research Scientists
Peter Crozier (RSS)
Renu Sharma (AcRS)
CHREM Manager
Karl Weiss (RPS)
IBeAM Manager
Barry Wilkens (RPS)
Goldwater Lab Manager
Emmanuel Soignard (RP)
Business Manager
Donalea Robertson(BM)
HREM Research Staff
Grant Baumgardner (EP)
Zhenquan Liu (RSpS)
Si Phrasavath (ES)
Paul Perkes (TSAP)
Goldwater Labs Research Staff
David Wright (AcRP)
Tim Karcher (AcRP)
Kenneth Mossman (RT)
Business Office Staff
Bonnie Mello (AA)
Jon Mull (SpS)
Joanne Ackerman (AS)
Adrienne Fuentes (AS)
Electron Microscopy Steering Committee
Ray Carpenter[1] (SoM)
Peter Buseck (Chem & BioChem)
Peter Crozier (SoM)
Cody Friesen (SOM)
Stuart Lindsay (Bio Design)
Fernando Ponce (Physics)
Robby Roberson (SOLS)
John Spence (Physics)
Michael Treacy (Physics)
IBeAM/Goldwater Steering Committee
Hugh Barnaby[1] (EE)
Nik Chawla (SOM)
Cody Friesen (SoM)
Jeff Drucker (Physics)
Peter Williams (Chem & BioChem)
Bob Roberts (Physics)
Arleyn Simon (Anth)
AA Accountant Associate
AcRP Assoc. Research Professional
AS Administrative Secretary
AcRS Assoc. Research Scientist
BM Business Manager
EP Engineer Principal
ES Engineer Senior
RP Research Professor
RPS Research Professional Senior
RSS Research Scientist Senior
RSpS Research Specialist Senior
RT Research Technician
SpS Service Professional Senior
1 Committee Chair

Regional Aberration Corrected Microscopy Center (Ray Carpenter, chair)

Observations:

1. no aberration corrected electron microscopes in Southwest.
2. ASU is best qualified university in the US to construct and operate a regional center.

1. Personnel.

- 2 tenure track materials science/electron microscopy in SOM
- 2 permanent microscope researchers/operators
- 2 postdocs
- 1 computer support staff
- 2 microscope maintenance staff
- 1 center management staff

3. Equipment

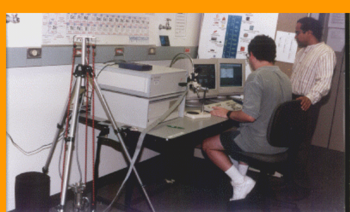
- aberration corrected STEM capable microscope
  - optimized for chemically sensitive imaging, electron and x-ray emission nanospectroscopy;
- aberration pre-and post-specimen corrected STEM (TEM/STEM)
  - for chemically sensitive imaging, HREM imaging, tomographic imaging, holography and nanospectroscopy
- TEM/STEM microscope with chromatic aberration corrector as well as spherical aberration corrector, cryostage, monochromator, and energy loss spectrometer
  - optimized for biomaterials nanocharacterization
- corrected microscope (TEM, TEM/STEM or DSTEM) with nanospectroscopic capability and ultra fast detection systems
  - for *in-situ* chemical reaction and phase transformation research.

INTEGRATED MATERIALS ANALYSIS & ADVANCED COMPUTATIONAL MODELING

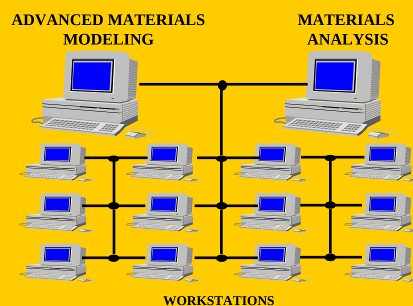
Optical Microscopy

Scanning Electron Microscopy

Scanning Probe Microscopy



Goldwater Materials Visualization Facility



Website: http://gmsl.eas.asu.edu/gmvf

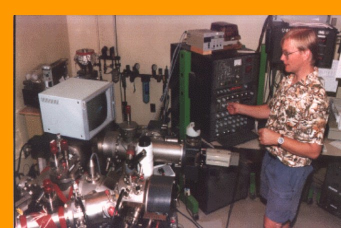
Ion Beam Analysis of Materials

Auger Electron Spectroscopy

X-ray Photoelectron Spectroscopy

X-ray Diffraction and Topography

Secondary Ion Mass Spectrometry



Science is Fun

- **Brings excitement of scientific discovery to K-12 classrooms via interactive, minds-on demonstrations & explorations**
- **100 schools, >20,000 students visited**
- **UNDERGRADUATE INTERNS / RESEARCH ASSISTANTS**
  - **enroll in 3-credit Science is Fun Service Learning Internship (UNI 484).**
  - **Trained & present science explorations at local schools throughout greater Phoenix metropolitan area.**
- http://www.asu.edu/clas/csss/scienceisfun/

Industrial Associates Program for Center for Solid State Science

Director, Dr. Renu Sharma

Renu.sharma@asu.edu

480 965-4541

Membership-Based Structure

- Industrial Associates Program (IAP) established in 1988 and membership based.

- Members over the past 5 years include Intel, Motorola, Monsanto, Delphi, Chevron, Heraeus, IBM, Nanostellar, Exxon,Dow Chemical (Union Carbide), Shell, Seagate, Ford, NanoTEM, HP, Agilent, AMD, Qynergy, Valence Technology.

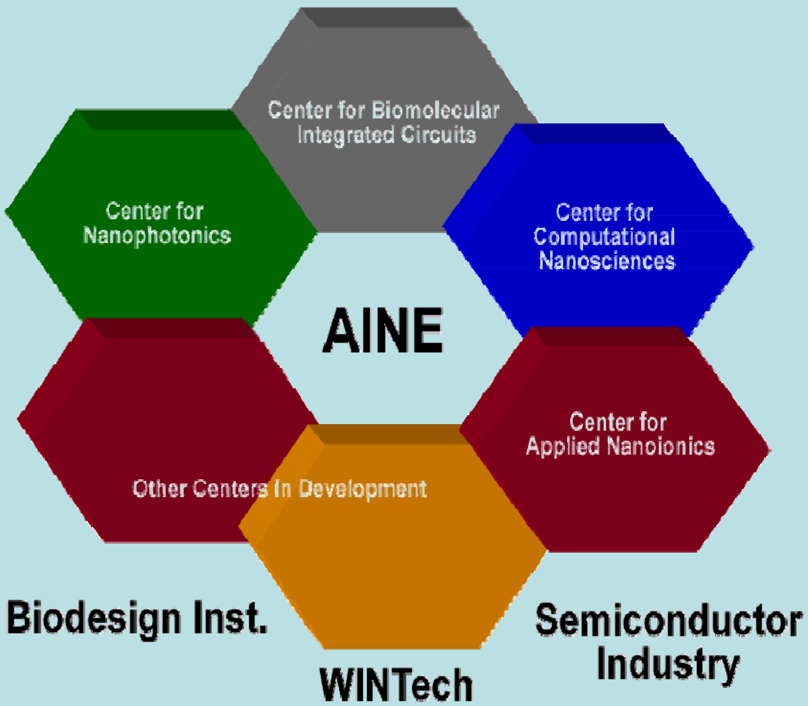
- Membership Categories:

Platinum	$40k/year
Gold	$10k/year
Silver	Hourly quotes

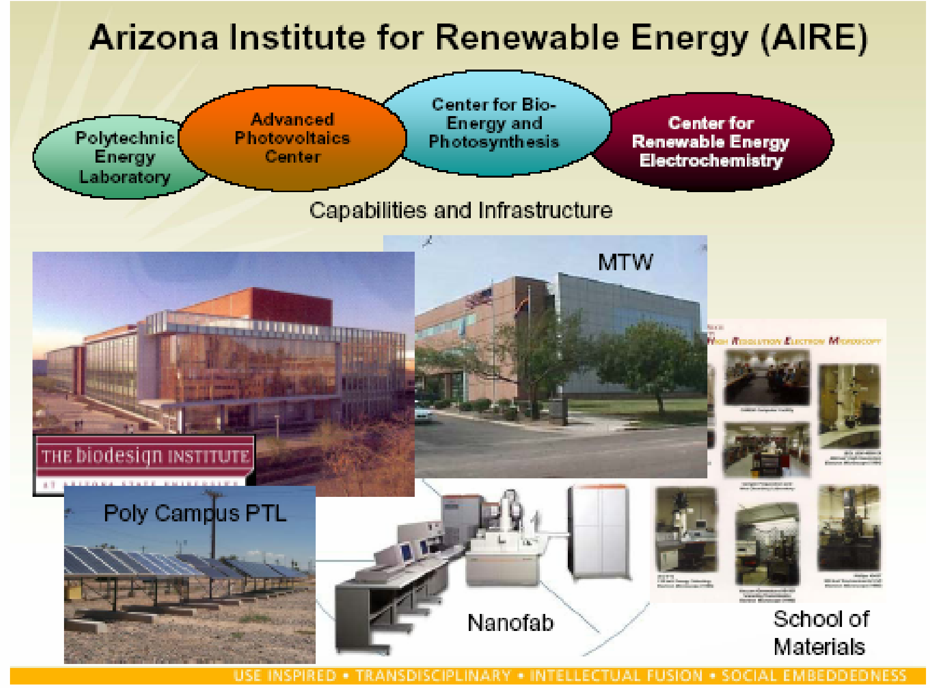
Aligning with major ASU initiatives, programs and projects

School of Materials Research areas

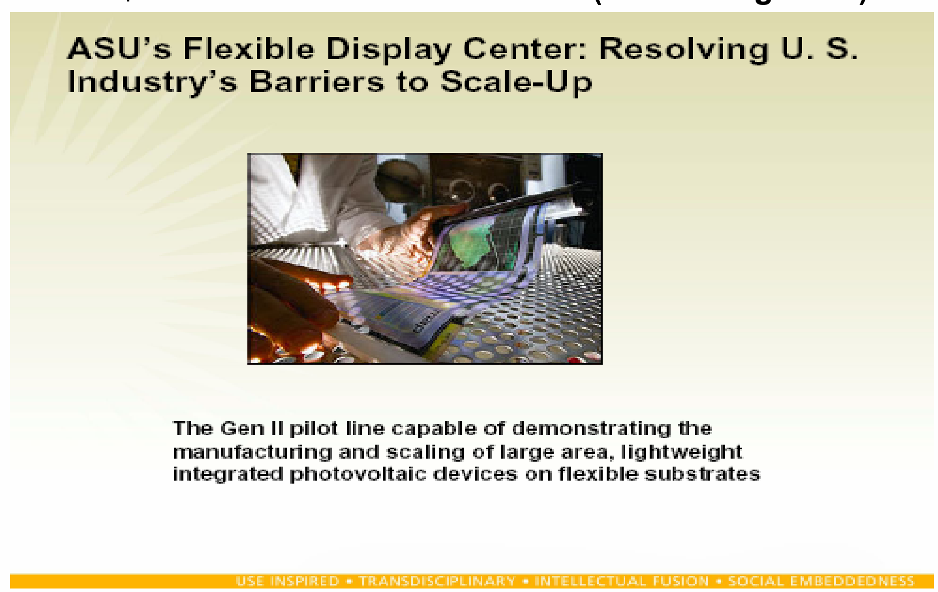
- ✓ ***Functional Materials***
- ✓ ***Computational Materials Science***
- ✓ ***Energy***
- ✓ ***Electron microscopy***
- ***Soft solids***



AINE – Approximately $1M in FY08



AIRE – Arizona Institute for Renewable Energy, ~$800K in FY08 & MRSEC effort (van Schilfgaarde)



Flexible Display Center- Multi-million dollar commitment per year in terms of 75% RID return and Building O&M/Debt Service

Integrated Materials- $200K in support for CEMAPS in 08