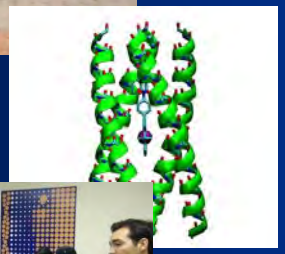
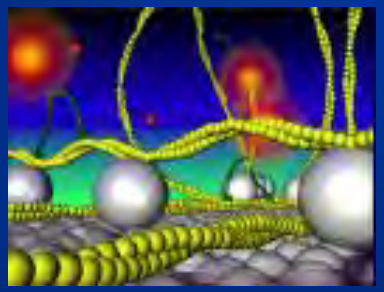
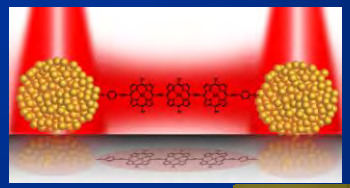
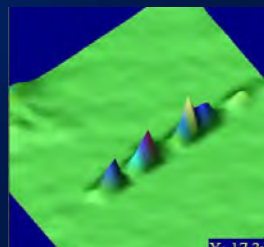
Nano/Bio Interface Center

The Nano/Bio Interface Center research establishes the foundation for understanding the interface of physical and biological systems.





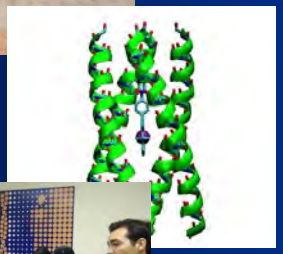


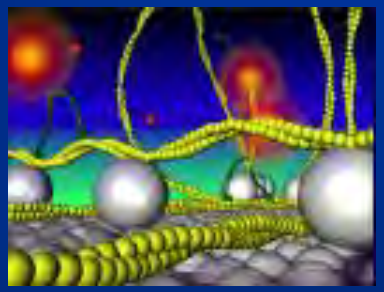


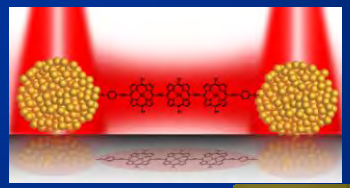
NANO / BIO INTERFACE CENTER

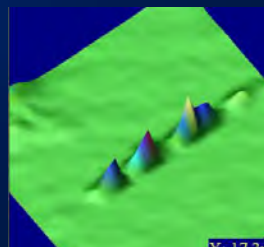
Nano/Bio Interface Center

It advances fundamental understanding that enables technology solutions in the areas of sensors and probes; educates the next generation of scientists and innovators in bio/nanotechnology; and develops infrastructure platforms that support the next 2 decades of cutting edge research.



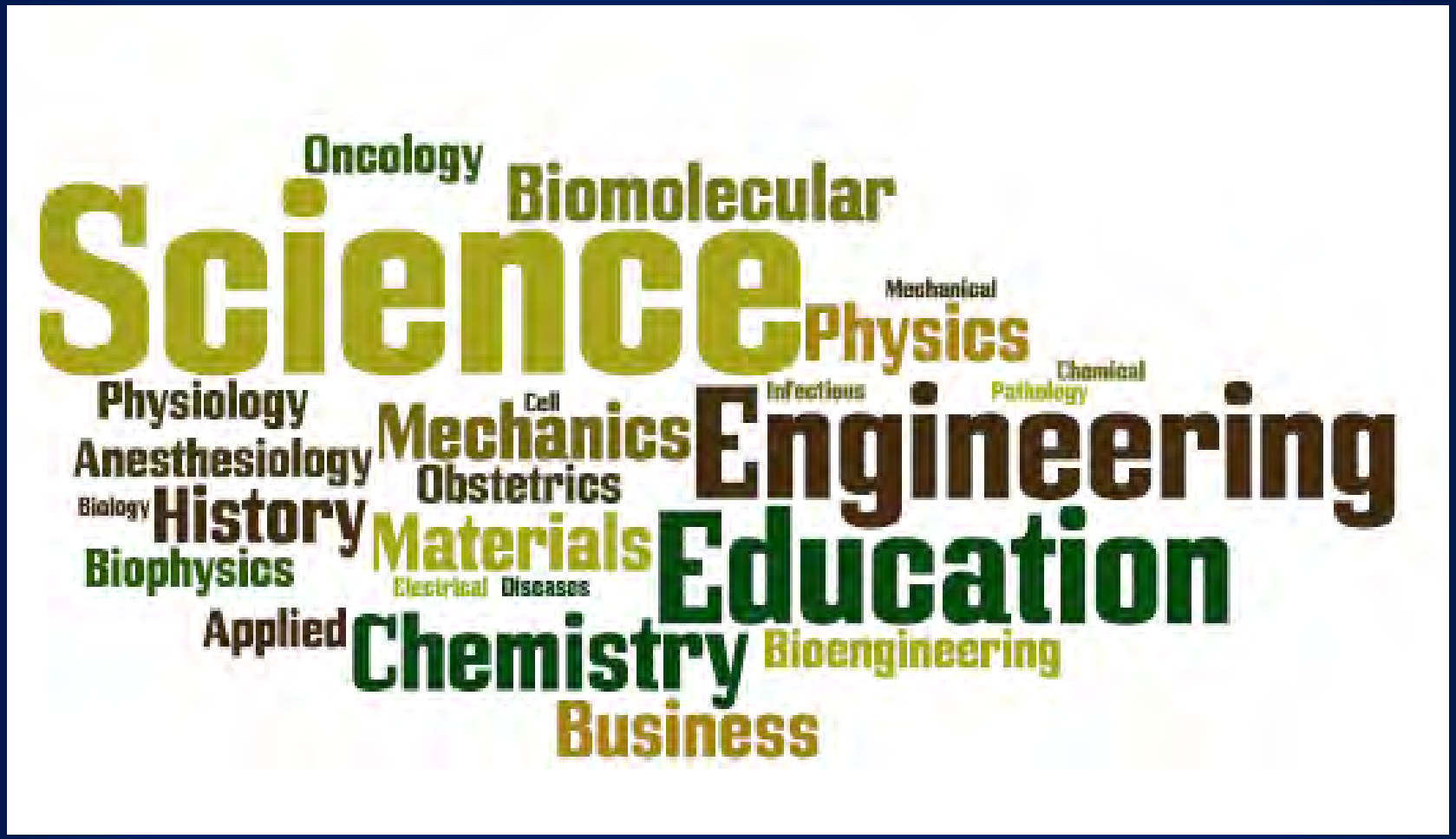






NANO / BIO INTERFACE CENTER

Nano/Bio Interface Center



NANO / BIO
INTERFACE
CENTER

Nano/Bio Interface Center

Participating in Research

- 50 Penn faculty members of 17 departments
- 4 faculty members of partner institutions
- 87 students and post docs

Participating in Education, Outreach, and Community

- 90% of faculty research participants
- 90% of student/post doc research participants
- 8 faculty members of partner institutions
- 113 additional students, post docs, teachers

A vibrant community of ~260

NANO / BIO INTERFACE CENTER

NBIC Partnering for Impact

Nano/Bio Interface Center

Single Molecule Probes

Biomolecular Opto Electronics

Molecular Motions

education

societal implications

facilities

industry interactions

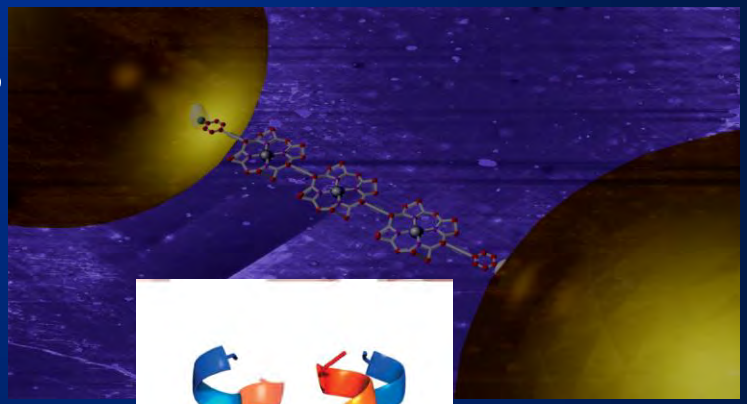
diversity

NANO / BIO
INTERFACE
CENTER

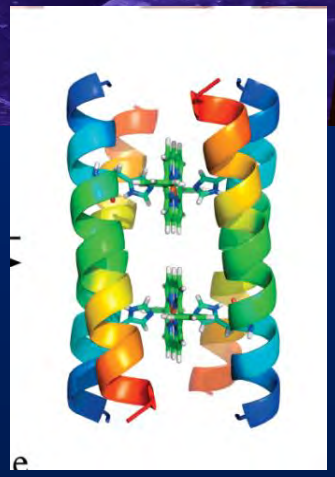
RT1: Bio-electronic and –optoelectronic Systems

A. T. Johnson, Jeffery G. Saven, William F. DeGrado, Dawn Bonnell, J.Kent Blasie, Bodhana Discher, Christopher Murray, Marija Drndic, So-Jung Park,

Exploring frontier of interfaces between **proteins and nanostructured materials** (surfaces, nanoparticles, carbon nanostructures)



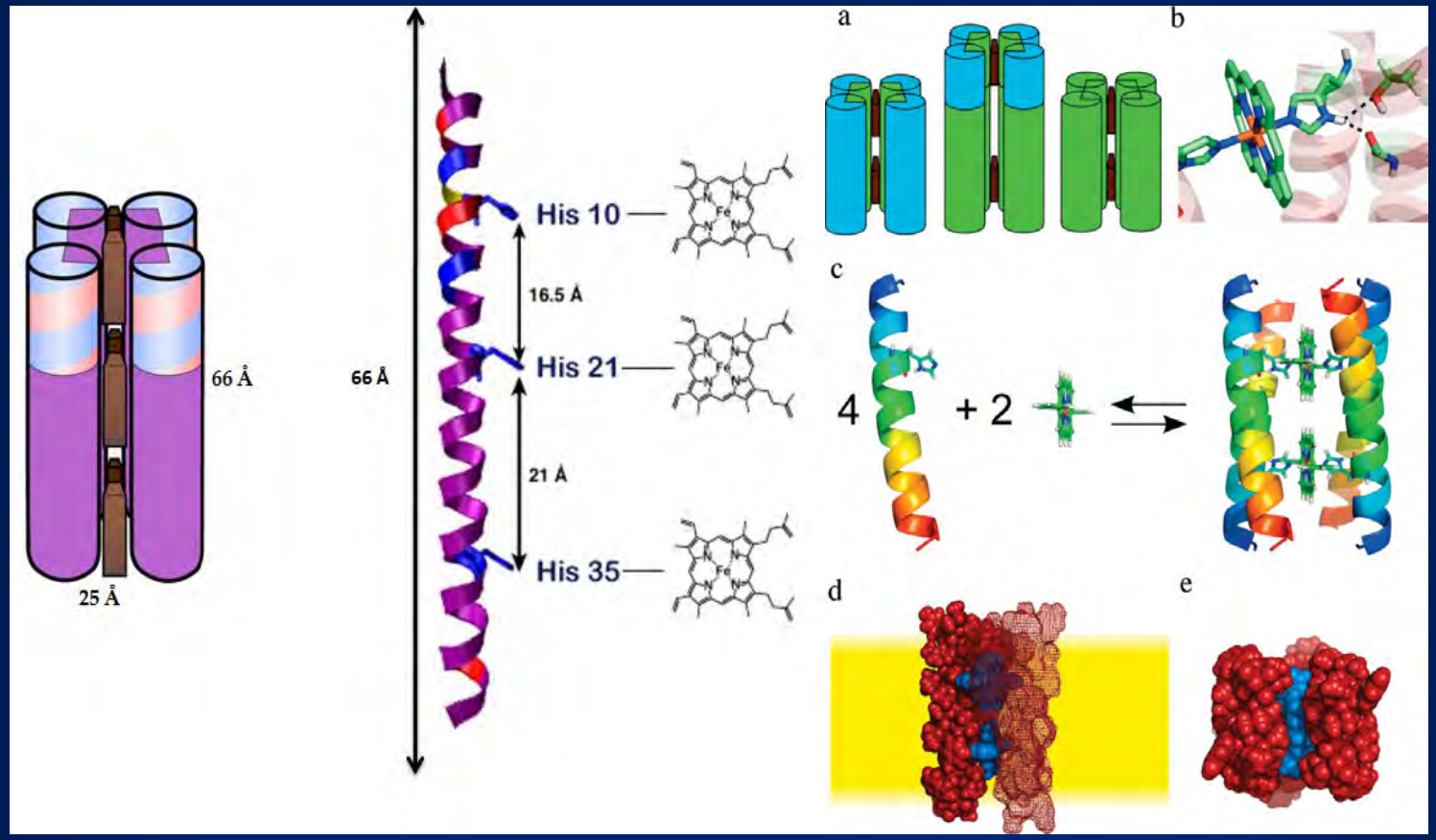
Designed protein structure and self-organization



Protein-enabled nanosystems with new electronic and optoelectronic activities

NANO / BIO INTERFACE CENTER

Engineered Proteins for Device Function



B Discher, W. DeGrado

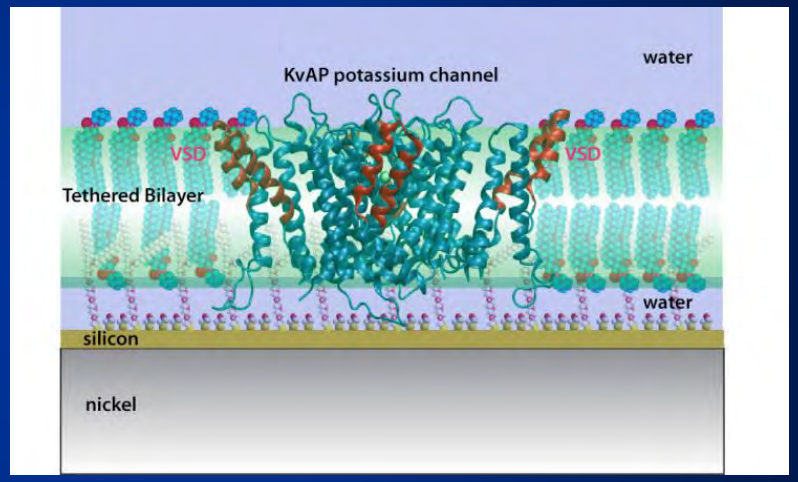
Structural Response of Membrane Sensor Proteins via "Pump-Probe" Time-Resolved X-ray/Neutron Interferometry

A. Tronin, J. Strzalka, I. Kuzmenko, D. Worcester, V. Lauter & J. Kent Blasie

NSEC DMR08-32802

Voltage-sensor proteins have been vectorially-oriented in single lipid bilayer membranes at the liquid-gas and solid-liquid interfaces. The dependence of their profile structures on the transmembrane voltage has been investigated with time-resolved x-ray and neutron interferometry techniques analogous to the classic "pump-probe" approach employed in transient spectroscopies. This approach utilizes repeated cycles of excitation/relaxation, here via step-wise changes in the transmembrane voltage, followed by signal-averaging to provide data arising from the excited and relaxed states of the protein with the desired signal-to-noise level. The investigations were carried out at the Advanced Photon Source (ANL), and the Spallation Neutron Source (ORNL). A full 3-D atomic level view of the structural changes so-detected will be provided by molecular dynamics simulations of the tethered membrane system employing the experimental profile structure results as key constraints.

Tronin, A., Chen, C-H., Gupta, S., Worcester, D., Lauter, V., Strzalka, J., Kuzmenko, I. and Blasie, J.K. Structural Changes in Single Membranes in Response to an Applied Transmembrane Electric Potential Revealed by Time-Resolved Neutron/X-ray Interferometry. *Chem. Phys.* (in press: http://dx.doi.org/10.1016/j.chemphys.2013.01.016)



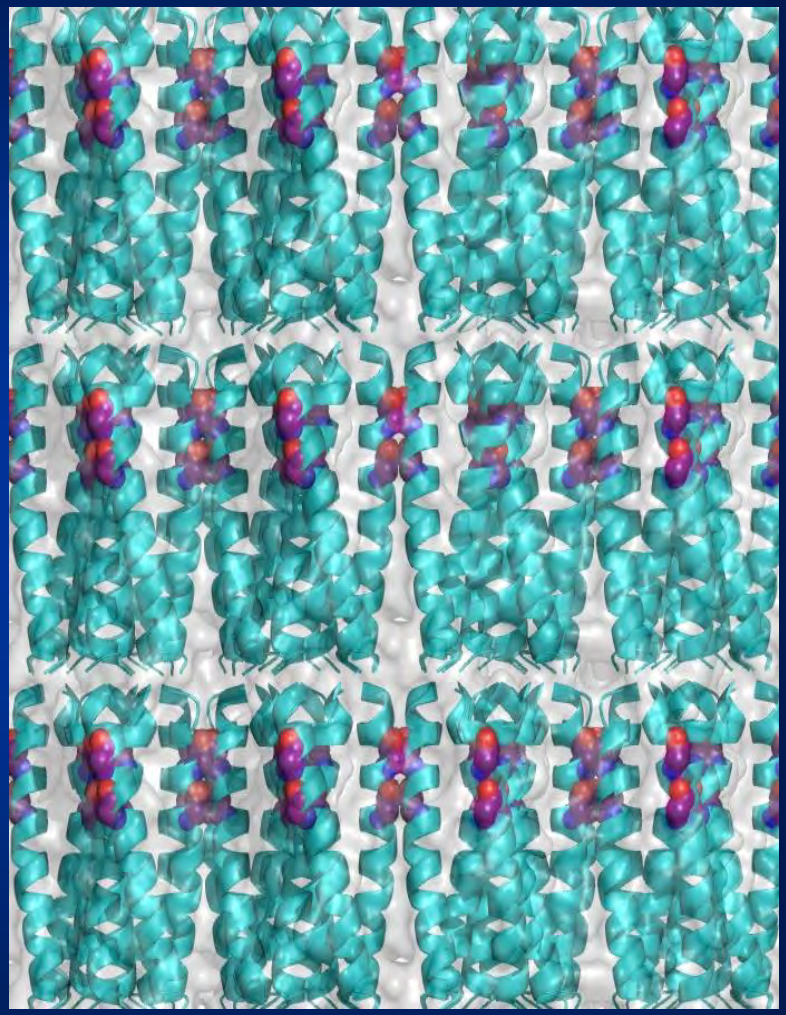
The voltage sensor domain (VSD) itself and the tetrameric voltage-gated K^+ channel have each been vectorially-oriented in a single-membrane at the solid-liquid interface (above). The profile structure of the VSD at 0mV and voltage-dependent *difference* profile structure for +100mV – 0mV (below).

NANO / BIO INTERFACE CENTER

Computational Design of a Protein Crystal

Christopher J. Lanci, Christopher M. MacDermaid, Seung-gu Kang, Rudresh Acharya, Benjamin North, Xi Yang, X. Jade Qiu, William F. DeGrado, Jeffery G. Saven *DMR 0425780*

Protein crystals have materials applications and are central to efforts in structural biology. Designing predetermined crystal structures is subtle, however, given the complexity of both proteins and the interactions that govern crystallization. De novo protein design provides an approach to engineer highly complex nano-scale molecular structures, and often the positions of atoms can be programmed with sub-Å precision. The careful design of molecular structure and properties can potentially be used to specify macroscopic order and assembly. A computational approach is has been developed for the design of proteins that self-assemble in three dimensions to yield macroscopic crystals. This approach to crystal design has potential applications to the de novo design of nano-structured materials and to the modification of natural proteins to facilitate x-ray crystallographic analysis.



[In press at *Proc. Natl. Acad. Sci 2012*.]

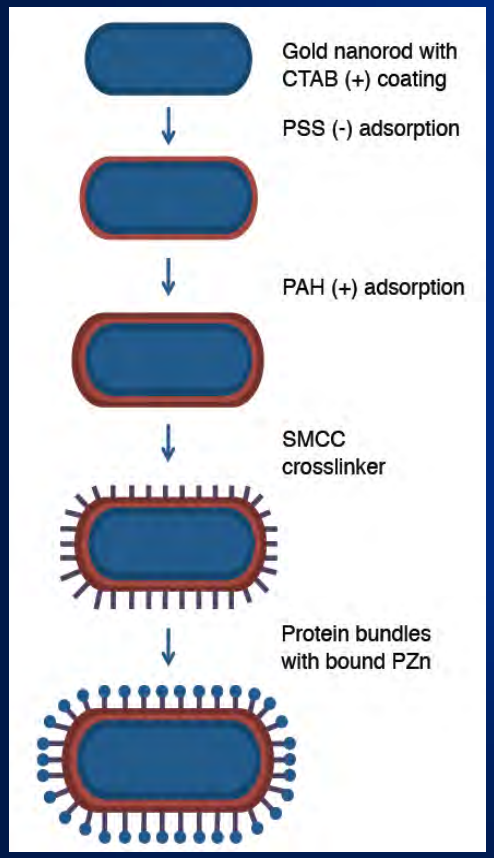
NANO / BIO INTERFACE CENTER

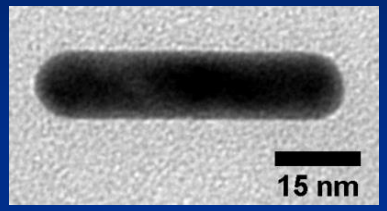
Coupling Gold Nanorods and Computationally Designed Protein Bundles for Plasmonic Fluorescent Enhancement

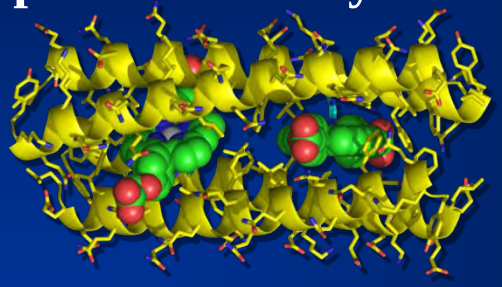
Thomas R. Gordon, Dahlia R. Klein, Xingchen Ye, Christopher J. Lanci, Matthew Eibling, Jeffrey G. Saven, Christopher B. Murray

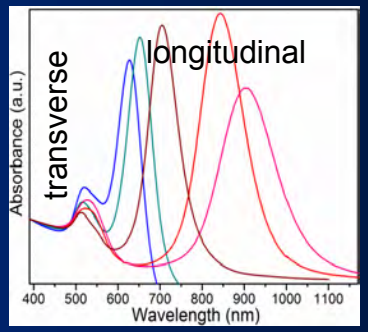
NSEC DMR08-32802

Nanorod Coating Procedure

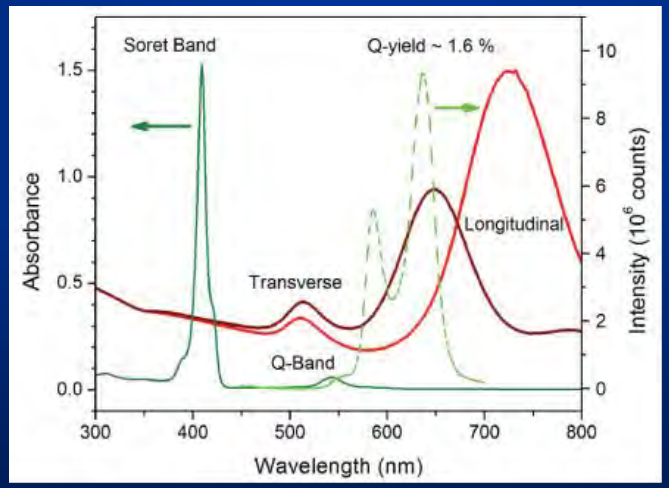




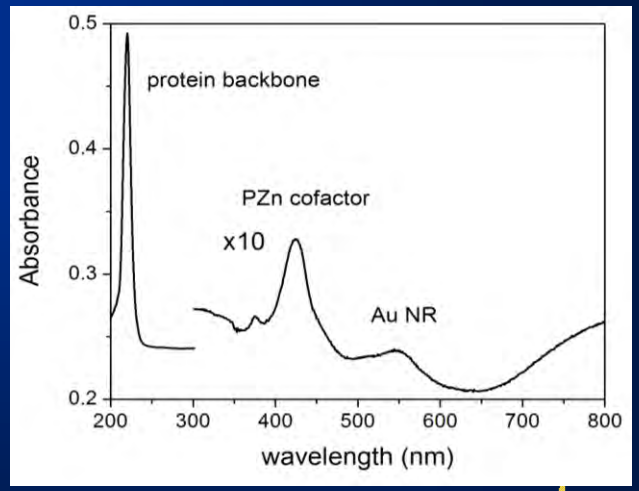




Fluorescent chromophores are positioned on gold nanorods with tunable aspect ratio using computationally designed proteins, aim to enhance photoluminescence quantum yield.



Longitudinal plasmon resonance of Au nanorods can be tuned based on aspect ratio to overlap with zinc porphyrin cofactor emission.



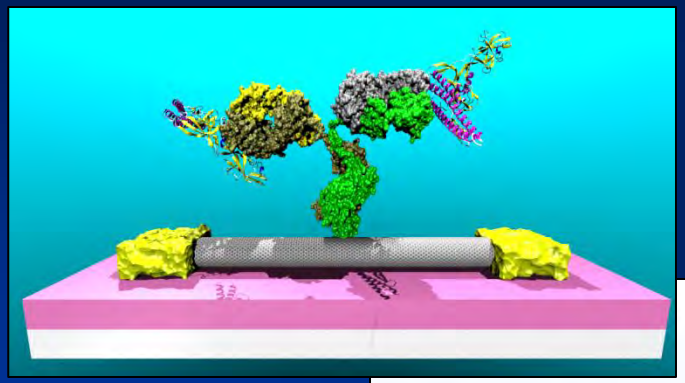
Optical absorption of buffer-soluble nanorod/protein heterostructure. Optimization required to ensure overlap of LSPR with cofactor emission.

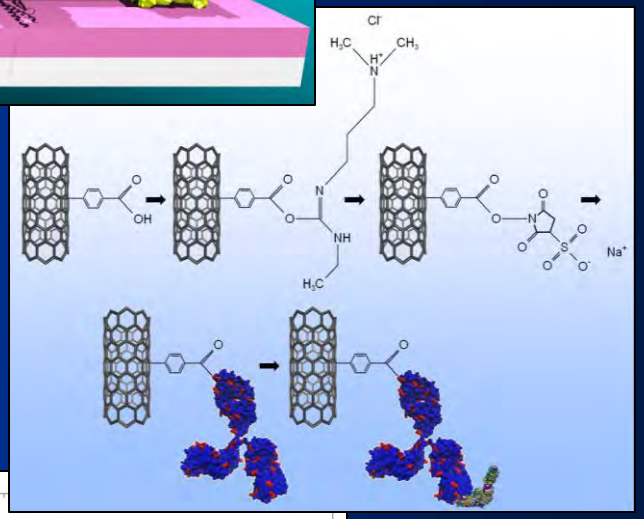
NANO / BIO INTERFACE CENTER

Detecting Lyme Disease Using Antibody-Functionalized Single-Walled Carbon Nanotube Transistors

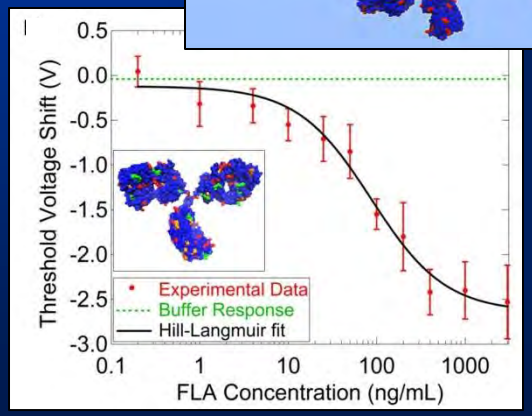
Mitchell B. Lerner, Jennifer Dailey, Brett R. Goldsmith, Dustin Brisson, A.T. Charlie Johnson DMR 0832802

Carbon nanotubes (NTs) are a one-dimensional electronic system, making them extremely sensitive to the local electrostatic environment. NT transistors were coupled to antibody proteins to yield highly sensitive and selective biosensors for Lyme disease.





The antibodies bound their target protein, p41 flagellar antigen (FLA), as they would *in vivo*. This led the antibodies to change their conformation, so charged amino acids on the antibody surface present a new electrostatic field to the NT device. This induced measurable, concentration-dependent shifts in the transistor characteristics. The shifts were detected at an antigen concentration as low as 1 ng/mL.



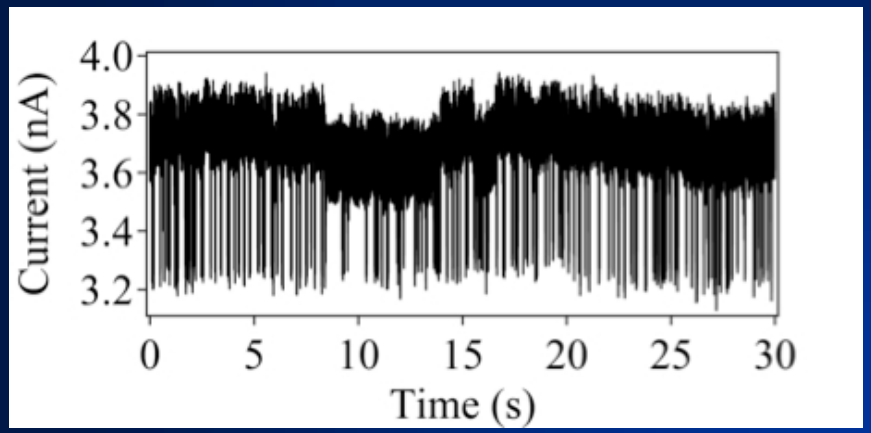
The chemistry may be used for any protein, so this work opens a pathway to create a sensor array to detect multiple diseases in parallel. The rapidity and ease of use of this sensor is superior to traditional immunoassays, suggesting its utility as a point-of-care diagnostic tool.

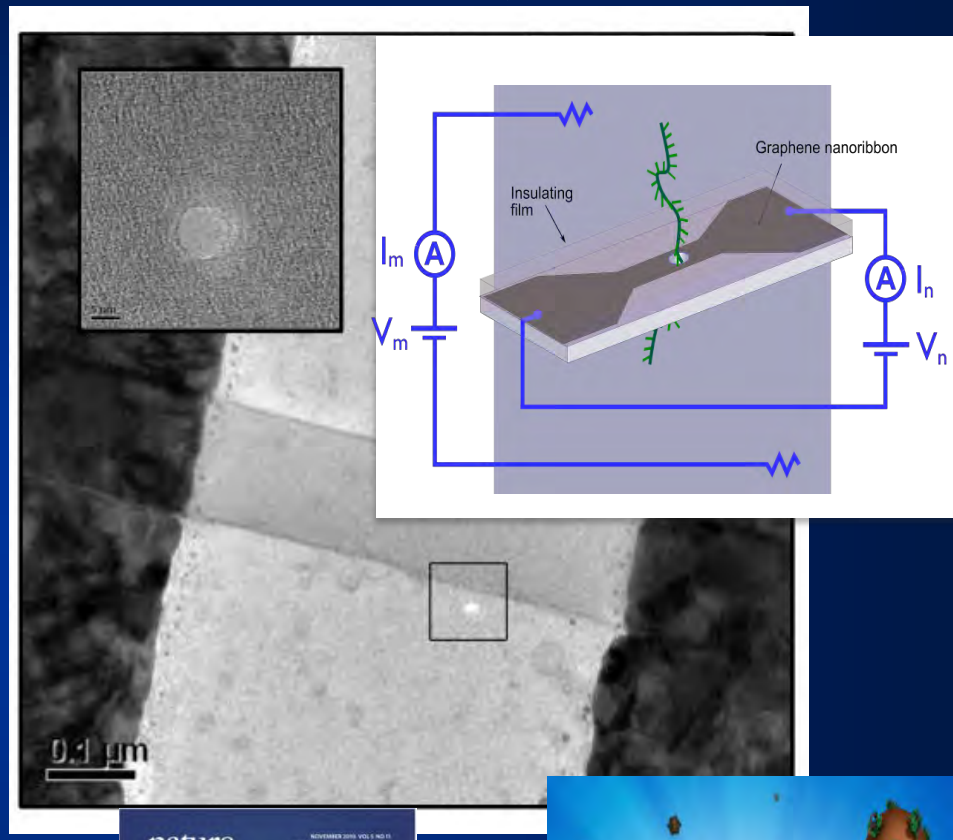
NANO / BIO INTERFACE CENTER

Lerner et al., Biosensors and Bioelectronics (2013)

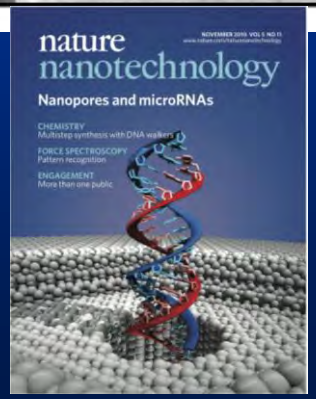
Graphene nanoribbon-nanopore devices for detection of biomolecules (Drndic)

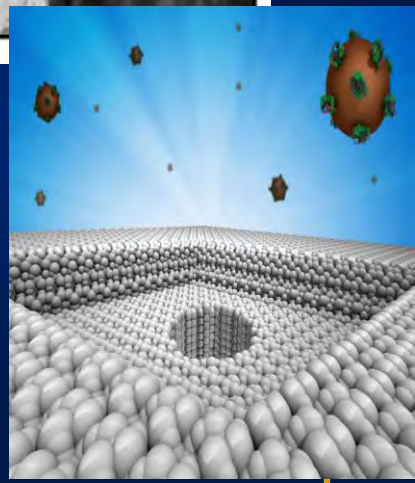
NSEC DMR08-32802





A graphene nanoribbon is positioned on a silicon nitride membrane with a nanopore drilled in the vicinity. Voltage applied to solution bath drives DNA molecules through the nanopore. The graphene ribbon current is measured by a separate electronic circuit to detect the modulations induced by the DNA as it passes through the nanopore.





NANO / BIO INTERFACE CENTER

Exploiting Plasmon Induced Hot Electrons in Molecular Electronics

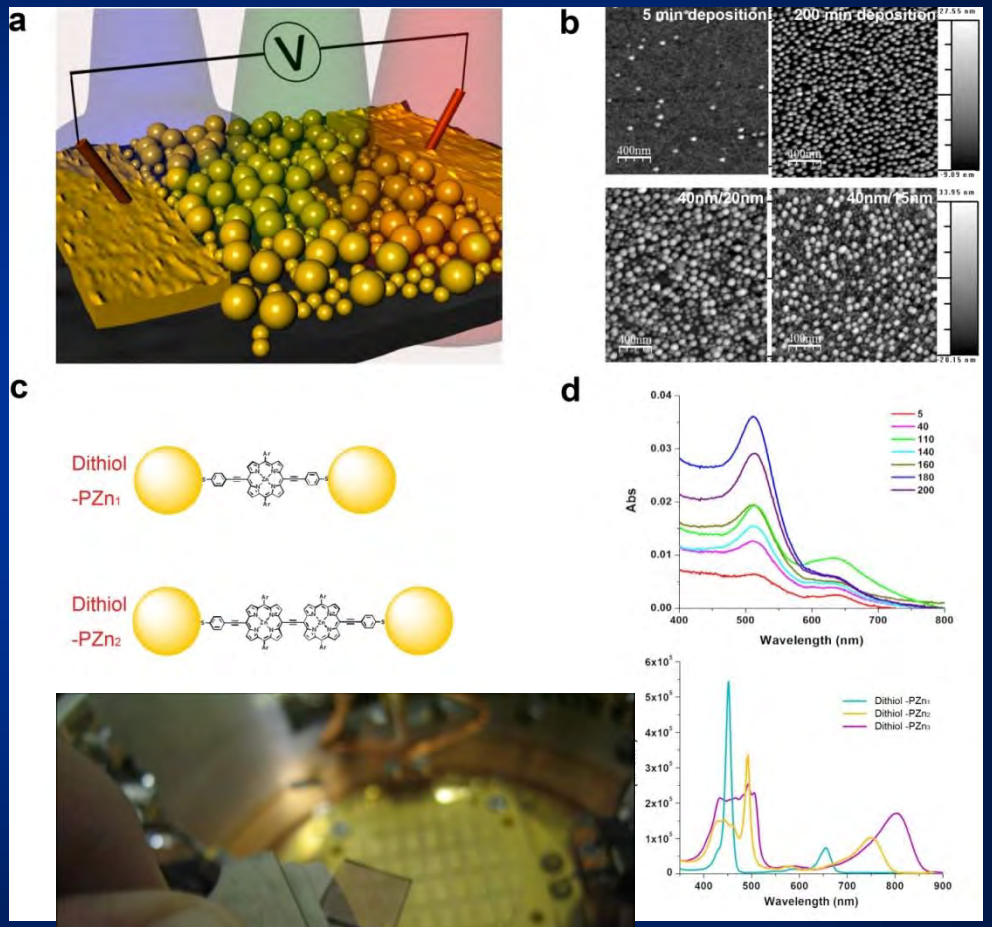
D. Conklin, S. Nanayakkara, T-H Park, J. Stecher, M. Therien, D.A. Bonnell

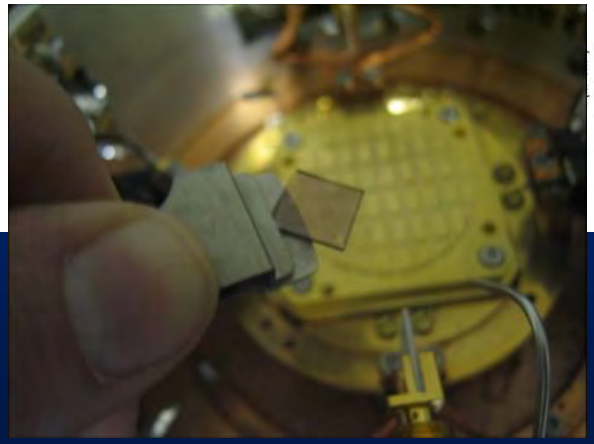
NSEC DMR08-32802

A family of hybrid optoelectronic devices consisting of Au plasmonic nanoparticles linked with photoactive, thiophenylethynyl-terminated metalloporphyrin structures is designed. This platform allows systematic variations in the optical absorption of the molecules and the plasmon resonances through which the mechanisms of photocurrent can be systematically investigated.

We demonstrate that hot electrons can be extracted from plasmons and exploited in molecular electronic optoelectronic devices. This mechanism has the potential to revolutionize energy harvesting and optoelectronic circuit design, since hot electron generation is more efficient than exciton generation.

Conklin et al ACS Nano 2010, Nano Letters 2012, ACS Nano 2013





NANO / BIO INTERFACE CENTER

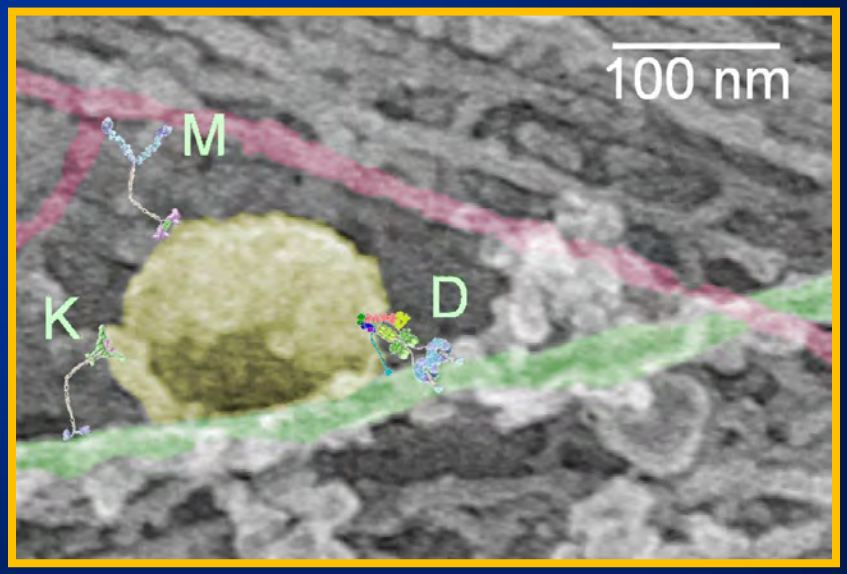
RT 2 *Building Biological Complexity: One Molecule at a Time*

The RT2 team strives to obtain a better understanding of biological systems by applying tools of nanotechnology to:

- **pattern and functionalize surfaces,**
- **position and manipulate macromolecules,**
- **measure forces acting on molecules,**
- **assess force-modulated conformational changes, and**

construct systems of biological components with gradually increasing complexity.

Nam Bau, Rob Carpick, Composto, Denis Discher, Yale Goldman, Howard Hu, Phil Nelson, Prashant Purohit



A nano-landscape we don't build

NANO / BIO INTERFACE CENTER

NSF

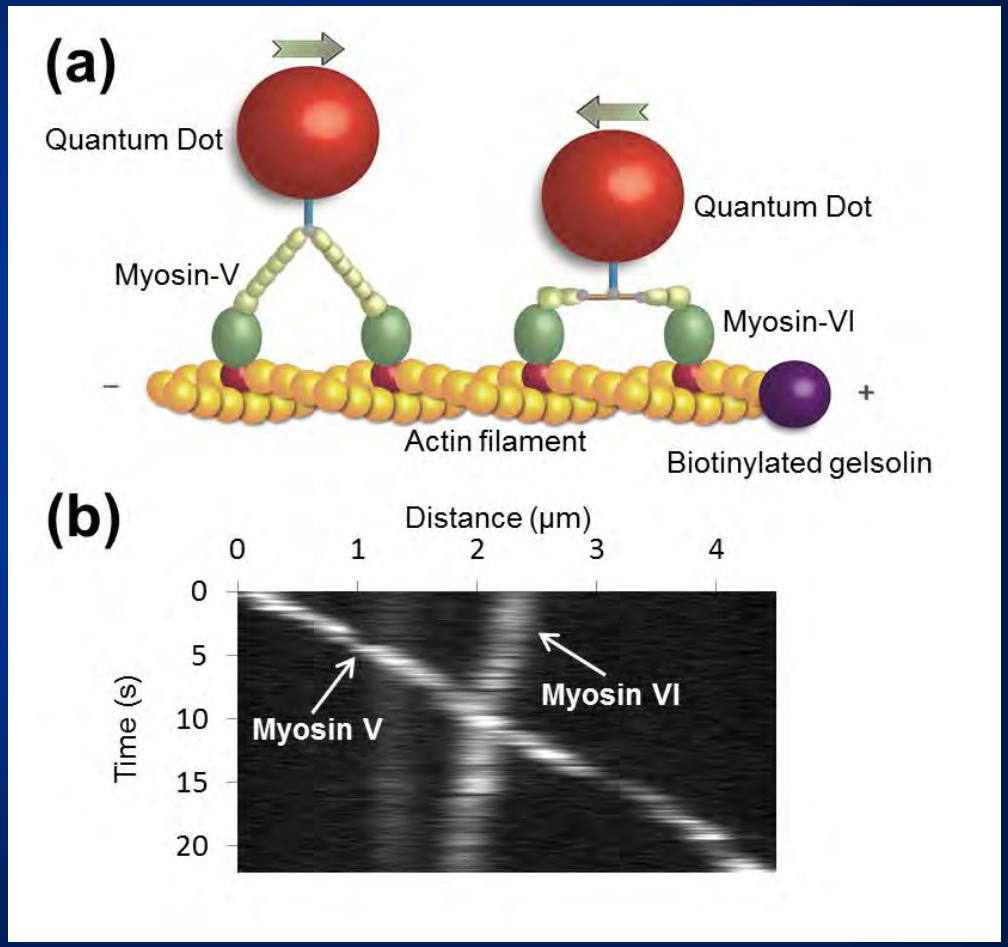
Motor Crossing

Myosin V and VI can pass each other when travelling along a single filament

Jinzhou Yuan, Yale E. Goldman, and Haim H. Bau

NSEC DMR08-32802

When myosin V and VI motors pass each other while walking in opposite directions along the same filament. A typical time-space-plot (kymograph) of such a event is shown in (b).



Yuan, Jinzhou; Pillarisetti, Anand; Goldman, Yale; Bau, Haim, 2013, Orienting Actin Filaments for Directional Motility of Processive Myosin Motors, Nano Letters 13 (1), 79-84.

NANO / BIO INTERFACE CENTER

Towards Synthetic Devices that Utilize Molecular Motors as Shuttles:

Directional Motility of Myosin Motors Along Uniformly Polarized Actin Filaments

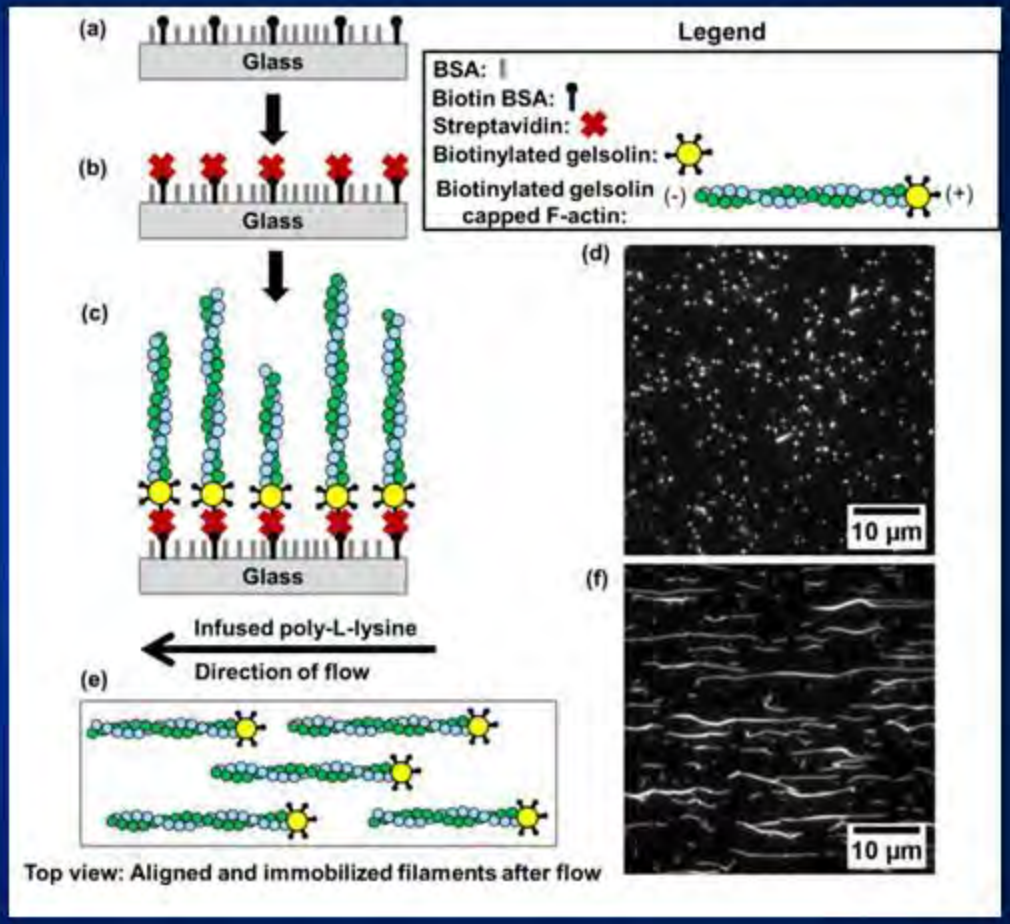
Jinzhou Yuan, Yale E. Goldman, and Haim H. Bau

NSEC DMR08-32802

We study biological complexity by adding molecules, one at a time, to the system. Here, we describe a molecular motor-driven device for transporting cargoes in a predetermined fashion. The system requires structural alignment of actin filaments.

DIRECTIONAL ALIGNMENT OF ACTIN FILAMENTS (Polarized Assay)

Actin filaments were aligned by forming (a) a specific end-on attachment between the biotinylated gelsolin-functionalized "plus" end of the filament and biotinylated BSA via streptavidin linkage followed by (b) side-on attachment along the length of actin filaments via electrostatic attraction between the polylysine-treated surface and the actin filaments.



Yuan, Jinzhou; Pillarisetti, Anand; Goldman, Yale; Bau, Haim, 2013, Orienting Actin Filaments for Directional Motility of Processive Myosin Motors, Nano Letters 13 (1), 79-84.

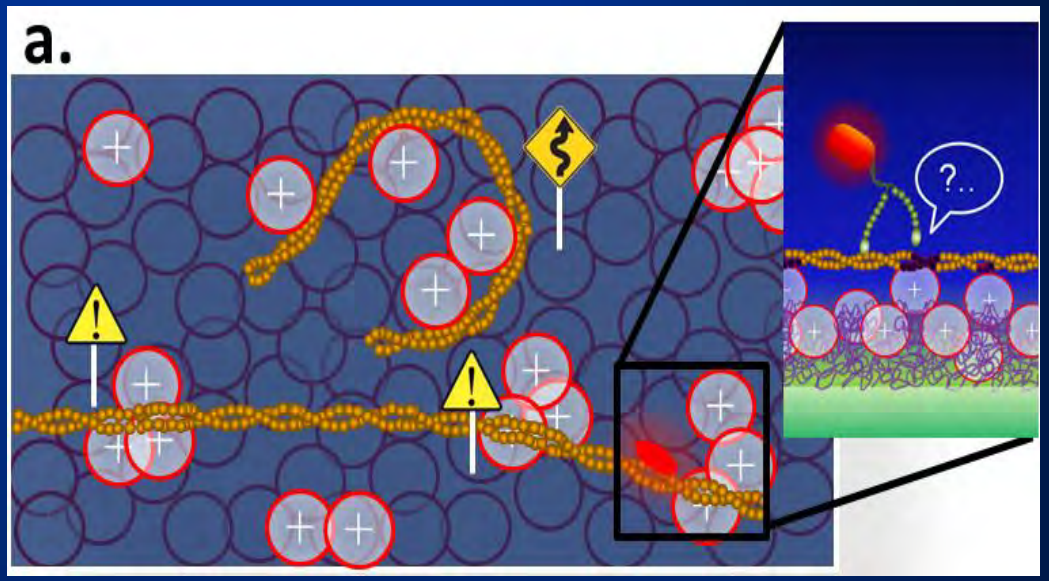
NANO / BIO INTERFACE CENTER

Nanoscale Engineered Surfaces for Tuning Acto-Myosin Networks

M. A. Caporizzo, Y. Sun, Y. E. Goldman, and R. J. Composto
UPenn NSEC 0832802

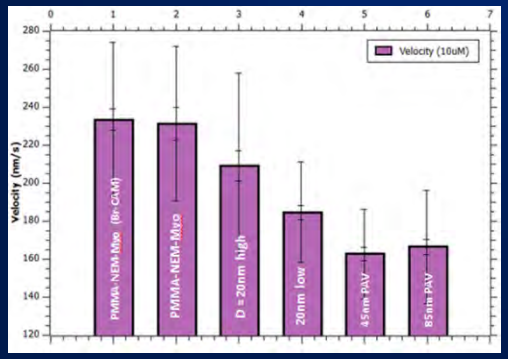
Aim:

- Nano engineer surfaces in controllable and scalable fashion to elucidate the mechanism by which topography modulates the adhesion of actin filaments and motor motion on bound filaments.



Results:

1) Individual steps of myosin V motion IS imaged using super-resolution fluorescence spectroscopy.
2) Myosin V velocity and run length are reduced on nanoparticle grafted surfaces compared to control studies In contrast to native behavior, Myosin V exhibits back steps near regions of actin bound to NPs



Motor Velocity as function of nanoscale topography. The velocity on control surfaces is ~ 230nm/s. Velocity decreases with increasing long range surface roughness for 20nm, 45nm and 85nm NPs

Conclusions :

1. Non-specific binding of actin to nanoparticles can alter mechano-enzyme interactions such as myosin translocation along actin.
2. These studies provide guidelines for one of the overarching goals of RT2, namely to build devices approaching cellular complexity using a materials science approach that requires the assembly of biomolecules at the nano-bio interface.

Caporizzo, M.A., *Langmuir*, **2012.**

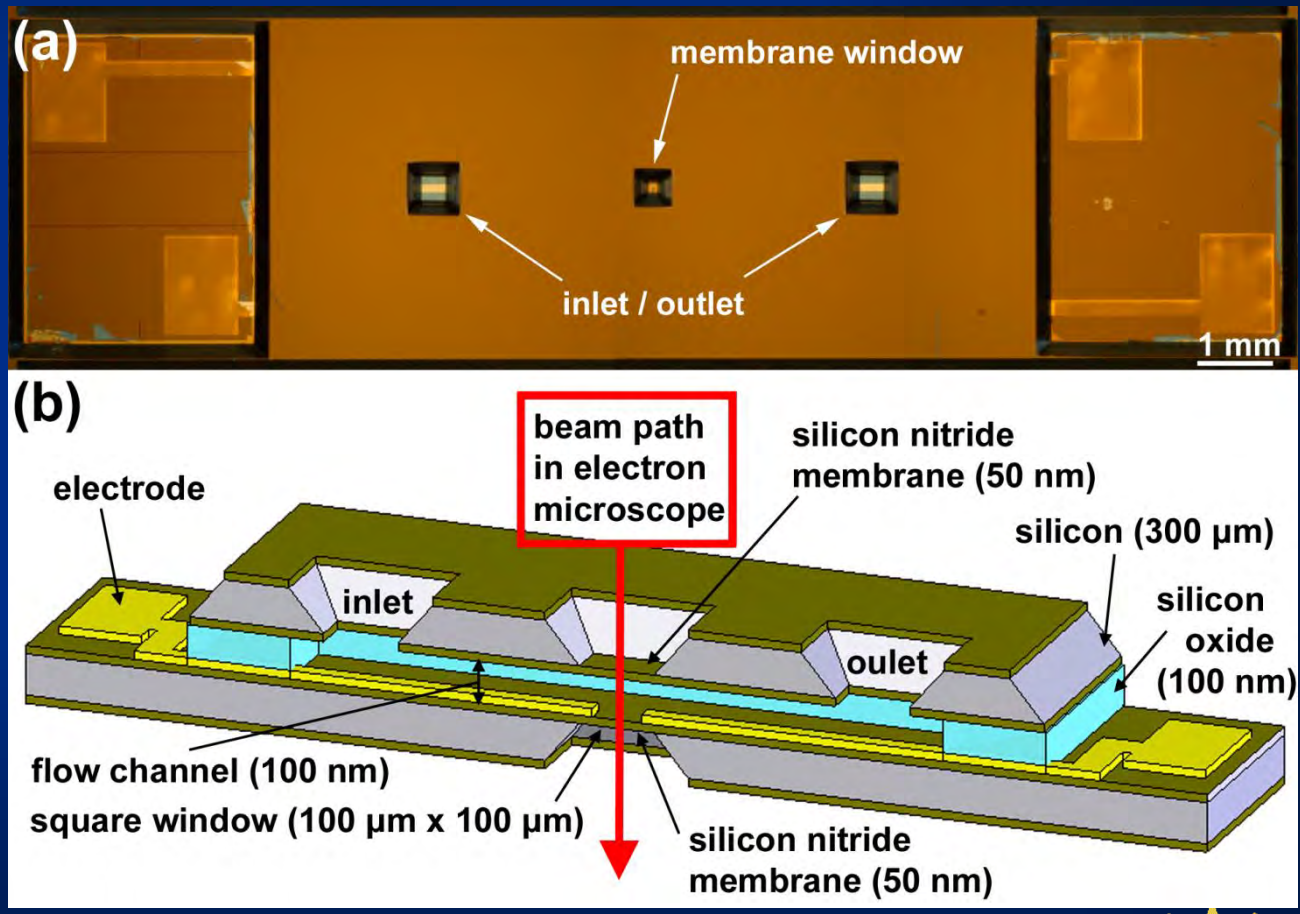
NANO / BIO INTERFACE CENTER

The Nanoaquarium: A Platform for In Situ Transmission Electron Microscopy in Liquid Media

Joseph M. Grogan and Haim H. Bau

We have developed a microfabricated chip, dubbed the nanoaquarium, for *in situ* direct observation of dynamical processes in liquid media in a transmission (TEM) or scanning transmission (STEM) electron microscope.

The nanoaquarium consists of a flow cell with a height of tens of nanometers, sandwiched between two thin silicon nitride membranes. The sample cross section is extremely thin to minimize electron scattering by the suspending medium, and the device is hermetically sealed and leak-proof to prevent sample evaporation in the high vacuum microscope chamber. The cell is equipped with electrodes for actuation and sensing.



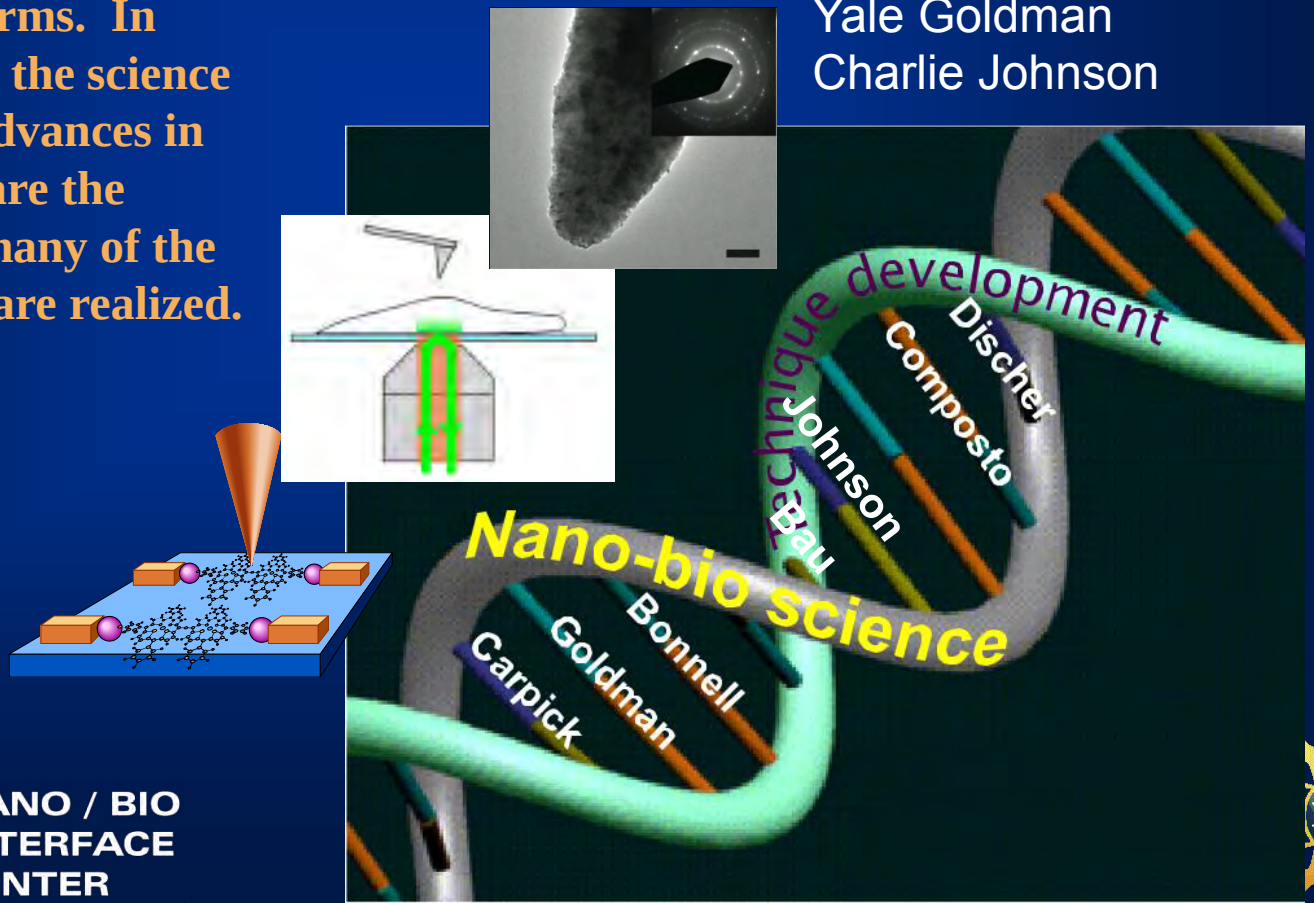
The nanoaquarium. (a) Top-view photograph featuring the silicon nitride observation window and inlet/outlet ports. (b) A schematic of the cross-section.

NANO / BIO INTERFACE CENTER

CCI *Single Molecule and Advanced Probes*

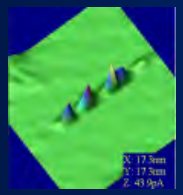
This cross cutting initiative invents the next generation of high spatial resolution probes based on optical, electromagnetic and force detection and implements them in a suite of instrumentation platforms. In addition to forwarding the science of local phenomena, advances in this probe technology are the mechanism by which many of the goals of RT1 and RT2 are realized.

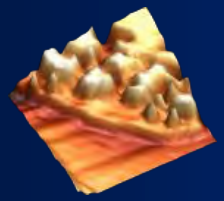
Haim Bau
Dawn Bonnell
Robert Carpick
Russ Composto
Dennis Discher
Yale Goldman
Charlie Johnson



NANO / BIO INTERFACE CENTER

Advances in Local Probes of Complex Properties





- 4th Harmonic Scattering Near Field Optical Microscopy
- Scanning Impedance Microscopy
- High Resolution Scanning Capacitance 2end Harmonic
- Dual Frequency Piezo Force Microscopy
- Torsional Resonance Nano Impedance Microscopy/Spectroscopy
- SPM Tip Design for Mechanical and Chemical Stability
- Combined Near Field Optical/Raman Spectroscopy/ AFM
- In Situ High Temperature Scanning Probe Microscopy
- Microwave Frequency Scanning Probe Spectroscopy
- TIRF/AFM with Parallax (3-D) and High Speed Detection

NANO / BIO INTERFACE CENTER

Direct Probe of Molecular Polarization in de novo Protein-Based Devices

K. Kathan-Galipeau, S Nanayakkara, P O'Brien, M. Nikiforov, X. Chen, B M. Discher, D. A. Bonnell

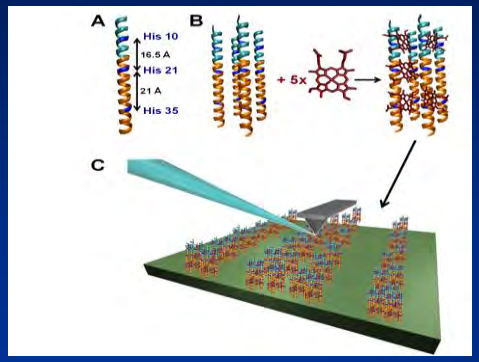
DMR08-3280

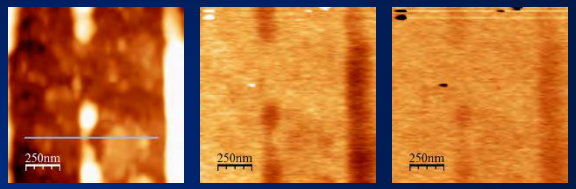
A novel approach to energy harvesting and biosensing devices would exploit optoelectronic processes found in proteins that occur in nature. In order to design such systems the proteins need to be attached to electrodes and the optoelectronic properties in non-liquid (ambient) environments must be understood at a fundamental level.

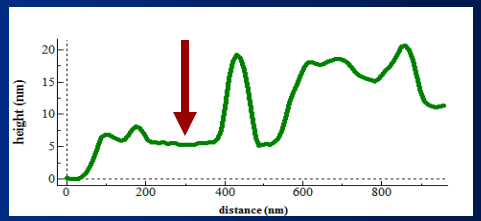
Here we report the simultaneous detection of electron transport and the effect of optical absorption on dielectric polarizability in oriented peptide single molecular layers.

The combination enables a quantitative comparison of the change in polarization volume between the ground state and excited state in a single molecular layer.

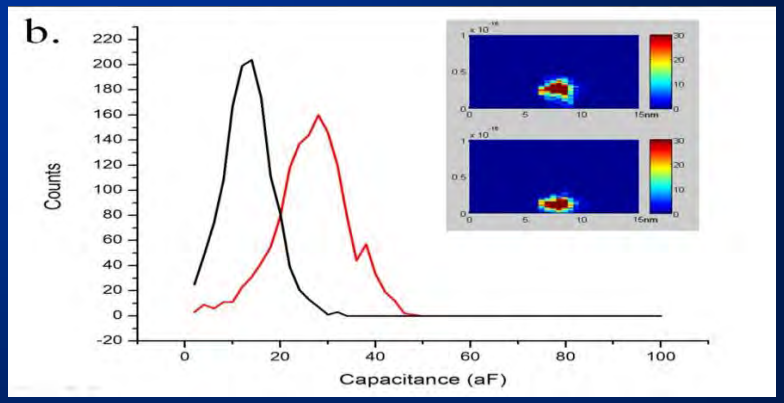
ACS Nano 2012







Proteins patterned on an electrode, (left), ZnPP maquette design. Right (a) topography, (b) x-component of impedance, (c) y-component of impedance (d) profiles of ZnPP maquettes. Red arrow indicates region of ~6.6 nm, which are one monolayer in height.



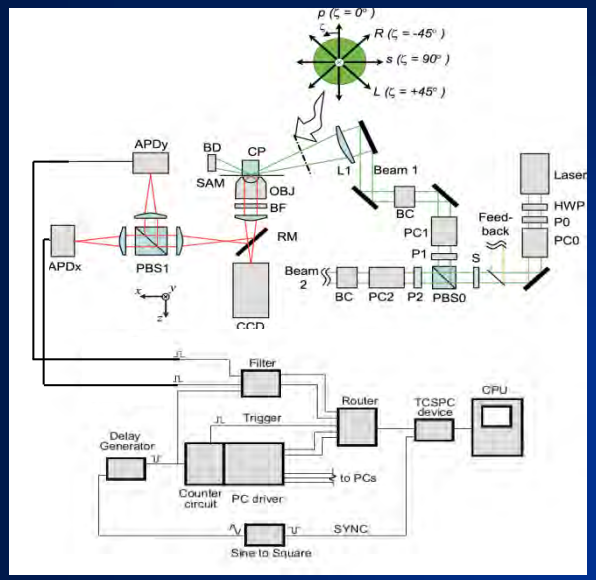
The increased capacitance on illumination with 425 nm light corresponds to a 117% - 267% increase in polarization volume. This is attributed to the fact that the excited state exciton resides in a more delocalized orbital.

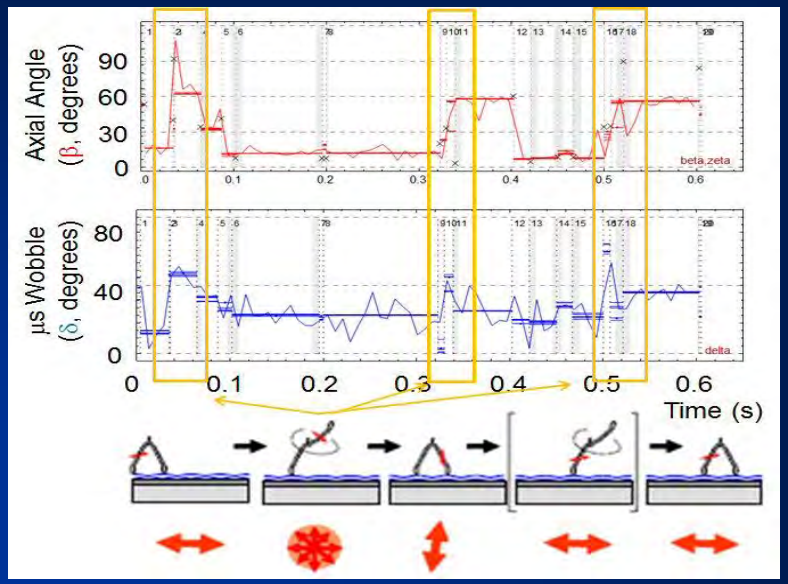
NANO / BIO INTERFACE CENTER

NSF

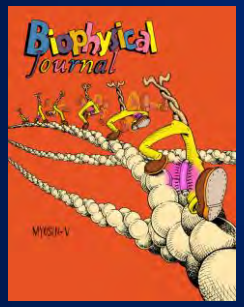
High-Speed Fluorescence Polarization Measurements of Single Myosin V Molecules

John F. Beausang, Deborah Shroder, Philip C. Nelson, Yale E. Goldman *DMR 0425780*





Ultra high-speed (0.8 ms) polarized-TIRF microscope for measuring 3D orientation and dynamics of macromolecules.



β = axial angle of probe relative to the actin filament

δ = half-angle of μs motions

Note the short-lived, high wobble state between two stable dwell periods when β increases (every other step). These results show that myosin V uses thermal motions to stretch out to a correctly oriented actin filament when it steps, thereby extending its reach.

NANO / BIO INTERFACE CENTER

Time (s)

Atomic-Scale Wear of Diamond-like Carbon and Silicon Nitride at Single Asperity Repetitive Contacts

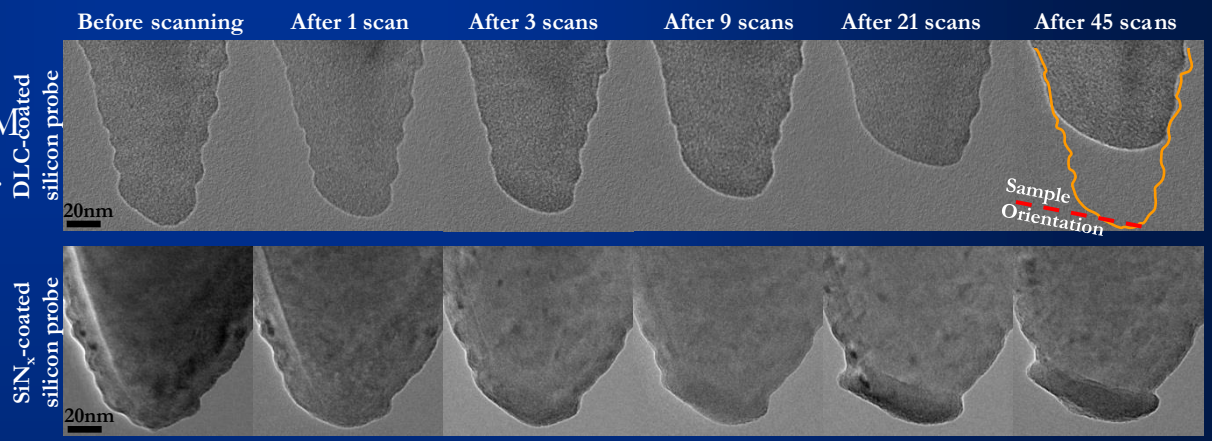
V. Vahdat, D.G. Grierson[1], K.T. Turner, & R. W. Carpick

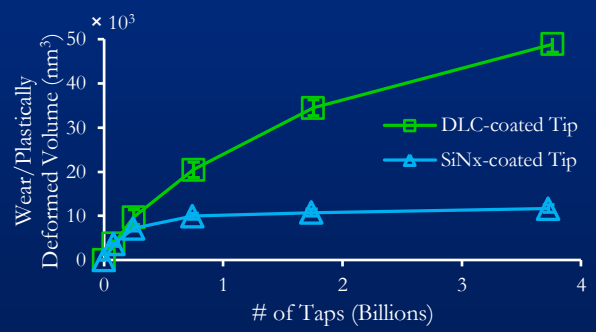
NSEC DMR 08-32802

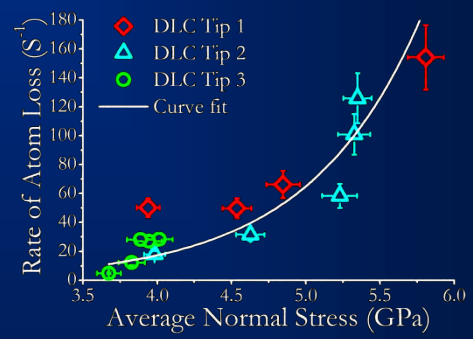
[1]UW-Madison; currently with systeMECH, LLC

Motivation:

- Tip wear limits the performance of AFM probes in all modes, including AM-AFM.
- Increasing probe lifetime (decreasing wear) is critical for applications that demand high reliability, repeatability, and throughput.
- The process is generally not understood.
- Here, we explore the wear behavior and mechanisms of DLC and SiN_x coated silicon probes used to image ultrananocrystalline diamond (UNCD) samples using AM-AFM.







Conclusions:.

- A contact mechanics solution for the adhesive contact of an arbitrary punch shape is used to numerically calculate the average normal stress.
- The mean normal stress is greatly affected by the evolution of the tip geometry.
- Wear of DLC occurs by gradual atom-by-atom removal, while plastic deformation and removal of clusters of atoms dominate for SiN_x.

NANO / BIO INTERFACE CENTER

Single Molecule and Advanced Probes: Accomplishments

DoS in Nanowires and tunneling through dielectric films (2nd harmonic EFM) (Bonnell and Johnson) 2005, 2011

Dielectric polarization of single molecular layers, excited state delocalization (Bonnell) 2011

3-D Optical Tomography at sub wavelength (100nm) resolution : NSOM (Schotland) 2005, 2006, 2007, 2008, 2009

Real and imaginary component of dielectric function of single molecular layers (scattering NSOM) (Bonnell, Eng, Engheta) 2009

Combined TIRF/AFM of a single ribosome (Discher, Goldman)
Beta site for Veeco 2006, 2007

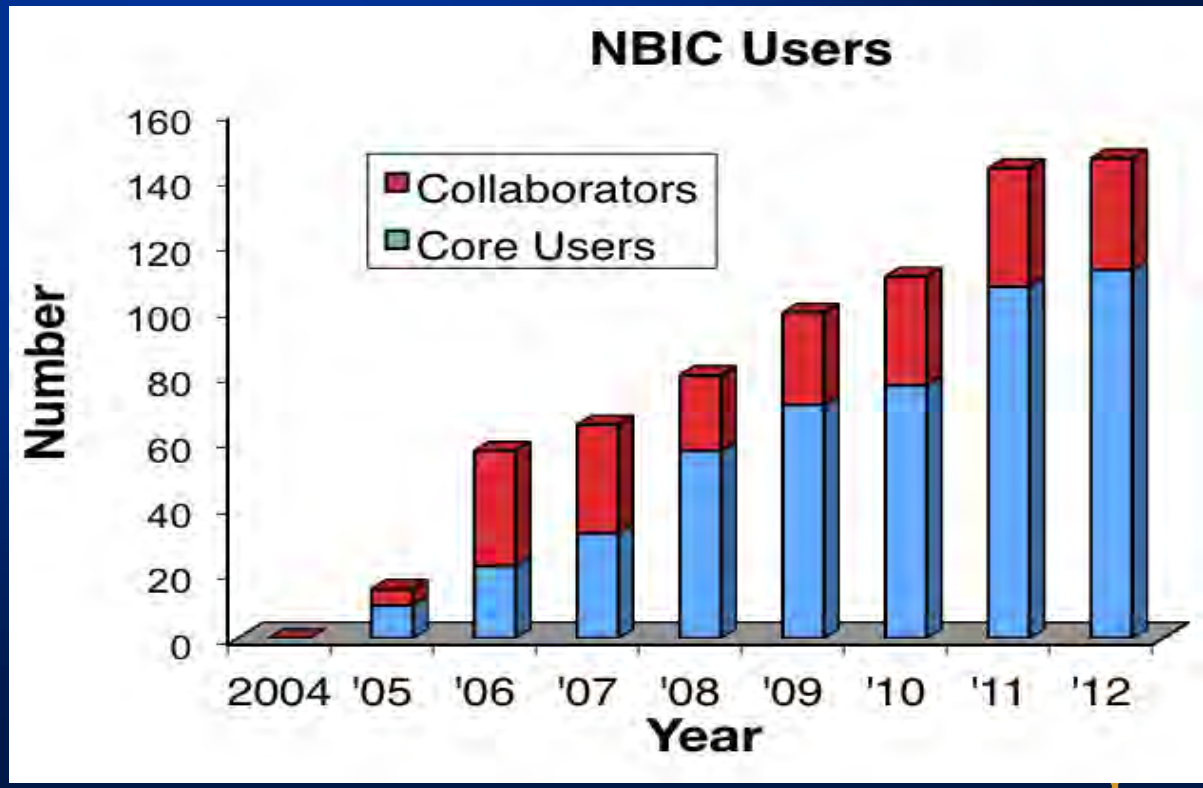
Chemically functionalized silicon and diamond probes and wear (Carpick, Yamakoshi, Composto) 2009, 2012, 2013

Determined the helical path of myosin on actin: 3-D mapping
TIRF on suspended fibers (Goldman, Bau, Nelson, Purohit) 2005, 2007, 2008, 2009, 2012

NBIC Scanning and Local Probe Facility

Nine instrumentation platforms with advanced probes of local properties that enable fundamental research, proof-of-concept testing, and characterization at the micro and nanoscale.

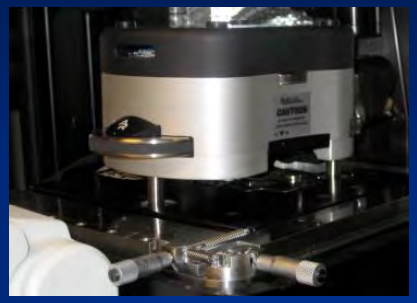
The facility currently:
serves over 140 users/year, facilitates K-12 outreach programs, supports graduate and undergraduate courses



NANO / BIO INTERFACE CENTER

Nine Instrumentation Platforms for Advance Local Probes

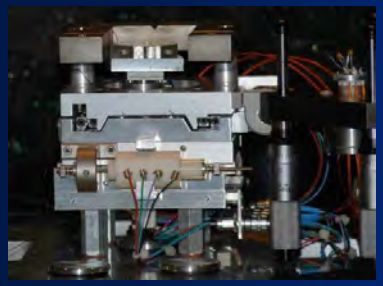
TIRF-AFM combines fluorescence microscopy with force spectroscopy



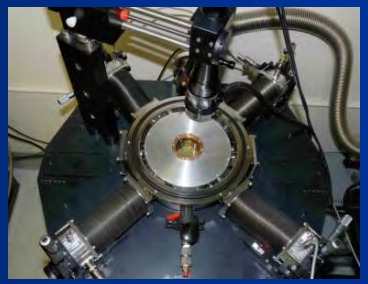
AFM: microwave imaging, dual freq, piezo response

Environmental AFM, closed-loop and pulsed-force imaging

AFM: Scanning impedance, nano-impedance, photo conduction, and multiple frequency modes



Interfacial force microscope for stiffness and friction



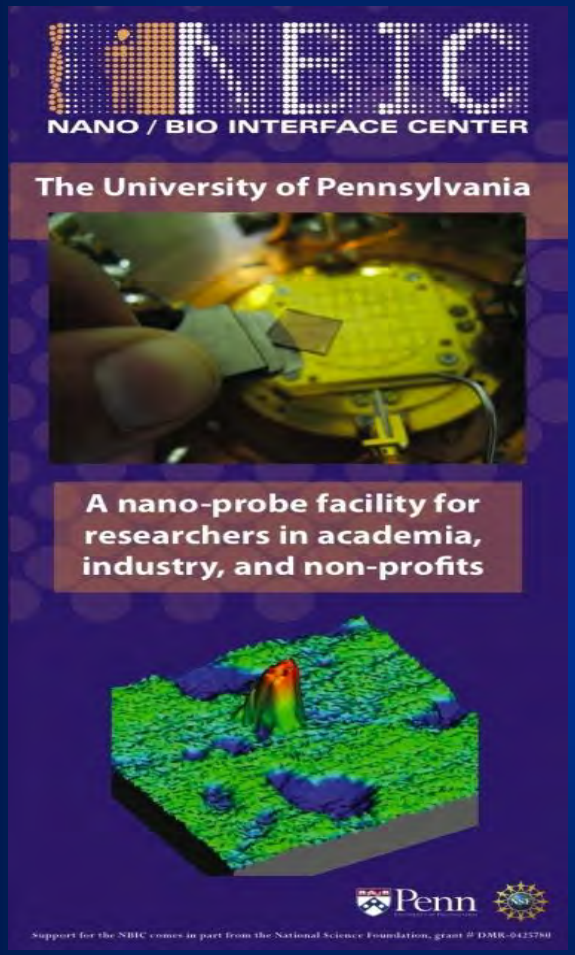
Cryogenic / ambient microwave frequency probe station with optical sources

Raman / NSOM with laser spectroscopy

VT tunneling microscopy with laser junction excitation

UHV-AFM/STM with nc and contact capacitance, conductance spectroscopy, scanning gate imaging

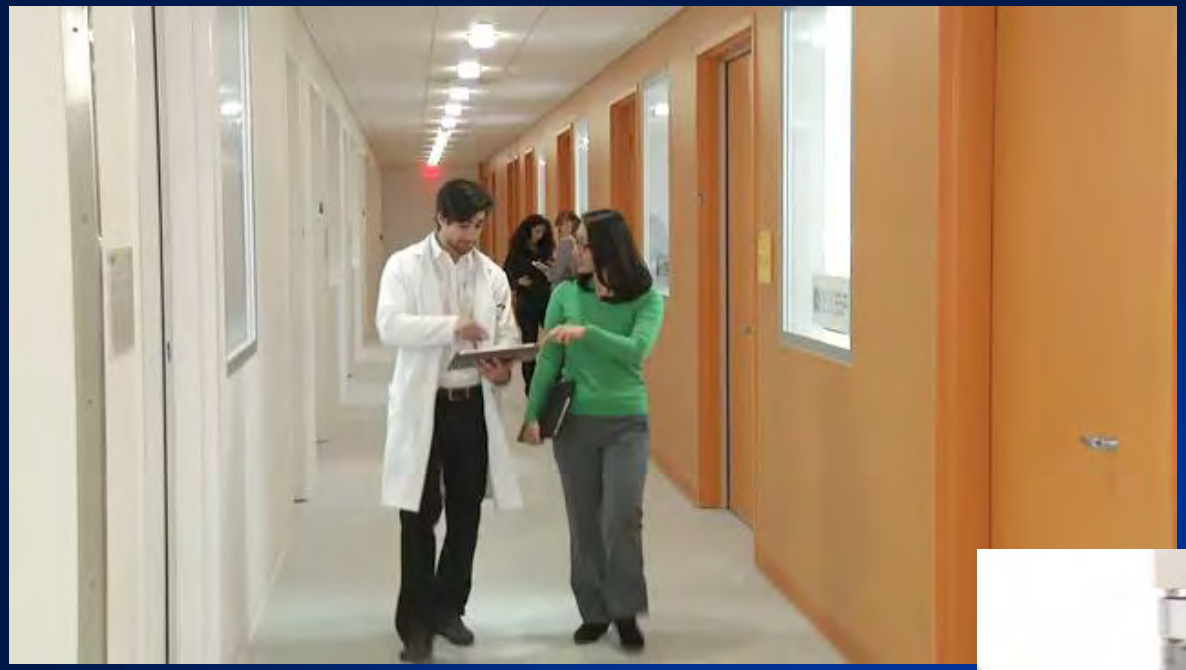
Nano/Bio Interface Center



NANO / BIO INTERFACE CENTER

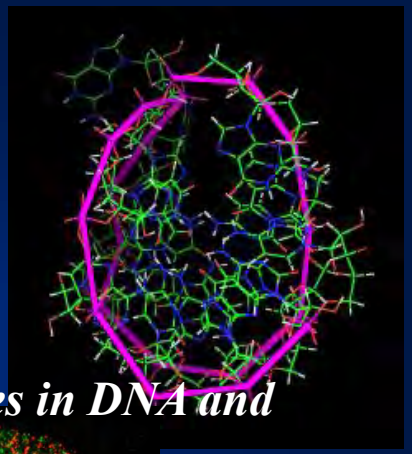
Singh Nanotechnology Center

$90M, 90,000 sq ft
10,000 sq ft clean room
NBIC Scanning and Local Probe Facility
Electron Microscopy facility

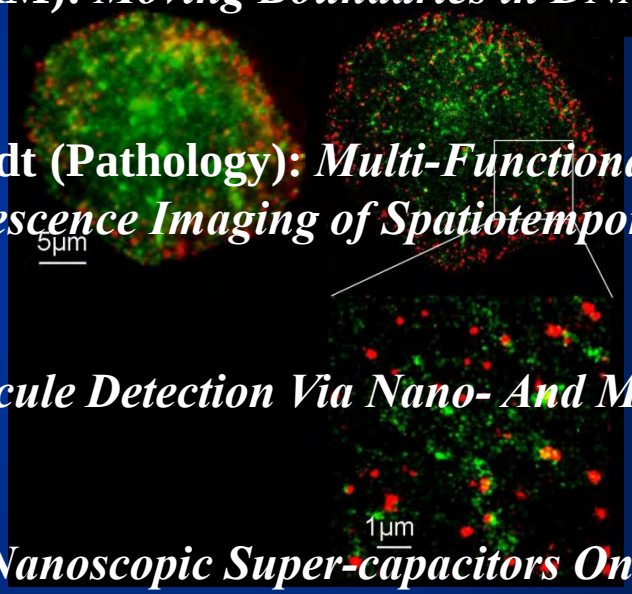


Recent Innovation Awards

Competitive program solicits proposals from across campus 50 Awards to date

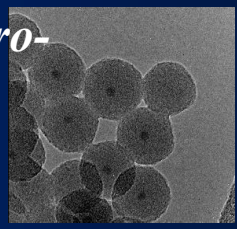


Ritwik Raj (MEAM) & Prashant Purohit (MEAM): ***Moving Boundaries in DNA and Coiled Coils Control Mechanical Response***



Tobias Baumgart (Chemistry) & Janis Burkhardt (Pathology): ***Multi-Functional Nano-particles and Patterns for Nano-resolution Fluorescence Imaging of Spatiotemporal and Mechanical Aspects of T-cell Stimulation***

Feng Gai (Chemistry) : ***Enhancing Single-molecule Detection Via Nano- And Micro-Confinements***



Jorge Santiago (ESE): ***Implantable Micro- And Nanoscopic Super-capacitors On Batteries (Hybrids)***

NANO / BIO INTERFACE CENTER

Nano/Biotechnology Impacting Society

Sociology, Medicine and the Environment

Social Science of nanotechonlogy: paramedia interactions, process of interdisciplinarity, architecture and interaction

Nanoscience in Oncology

Nanotoxicology Alliance

CEET
CENTER OF EXCELLENCE IN ENVIRONMENTAL TOXICOLOGY
NANO / BIO INTERFACE CENTER
ITMAT
Ben Franklin Technology PArtners
25TH ANNIVERSARY

NANO / BIO INTERFACE CENTER

NSF

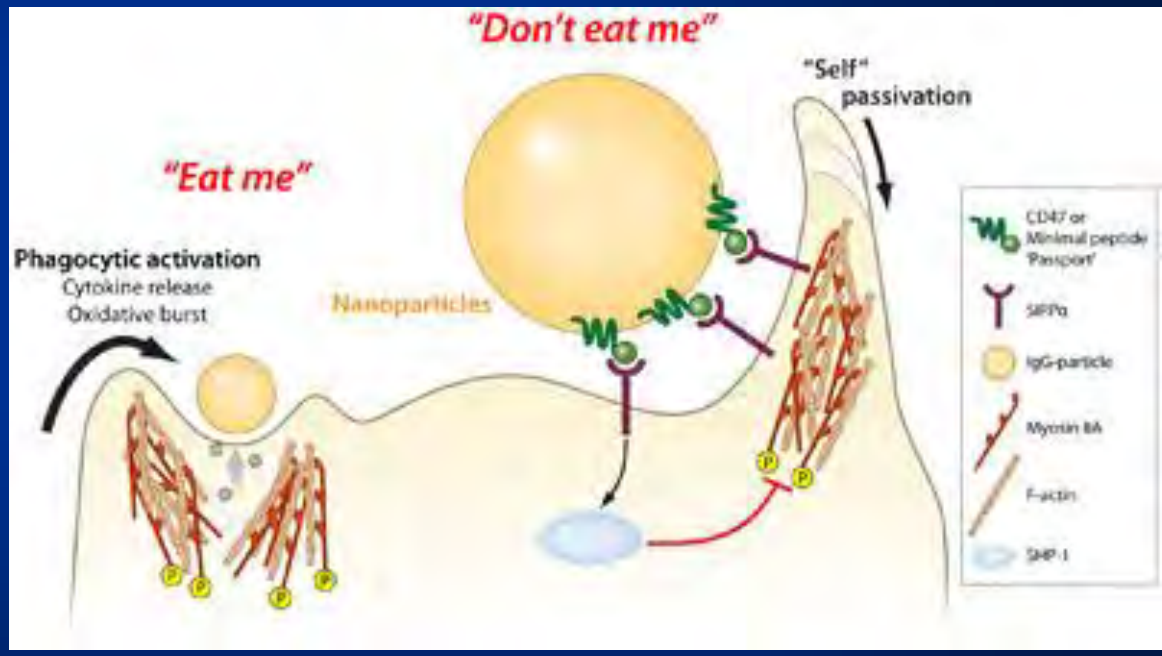
Protein 'Passport' That Help Nanoparticles Get Past Immune System

P.A. Rodriguez, T. Narada, D.A. Christian, D.A. Pantano, R.K. Tsai, and D.E. Discher

NSEC DMR08-32802

This NBIC Seed co-supported work grew out of efforts to deliver drugs and dyes with nanoparticles, but too many of such particles are 'eaten' by immune cells. The sketch shows particles +/- a designed 'Self' peptide that signals to the cytoskeleton of an immune cell called a Macrophage. This inhibits cytoskeletal organization and membrane curvature near the particle's surface, ultimately suppressing uptake by the cells. The particles can thus deliver their payload to other cell types.

- *Science* 2013



NANO / BIO INTERFACE CENTER

Outstanding Research Accomplishments

566 publications

30 Nano Letters
15 ACS Nano
11 Nature (Reviews/Nanotechnology/Materials)
5 Science
9 Physical Review Letters
13 Proceedings of the National Academy
15 Langmuir
2 Physics Today
5 Adv. Materials
2 Cell
+9 from facilities

22% of total in high impact journals
~35% of papers since 2008 co authored by NBIC PIs

NANO / BIO INTERFACE CENTER

Technology Transfer

Patents filed 72
Patents awarded to date 10
Companies formed 3 direct; 2 indirect

Graphene Frontiers
Adamant

Anima Cell Metrology
Advanced Diamond Technologies

NANO / BIO INTERFACE CENTER

Workforce Development

NBIC Graduates	
BSE	80
MSE	35
PhD	78
Post Docs	20

Placements	
NBIC participating firms	9%
Other firms	25%
Government	11%
Academic Institutions	55%

NANO / BIO INTERFACE CENTER

NSF

Educational & Outreach
Program Goals

Teacher development in content knowledge with emphasis on pedagogical skills and impact on local science curriculum

Diversity in the workforce through integrated high school and undergraduate programs

Nanotechnology courses and degree programs for undergraduate and graduate students

International experience for undergraduate and graduate students to support the global science ecosystem

Engaging the local community

NANO / BIO
INTERFACE
CENTER

NanoDay @ Penn: Annual Public Outreach

NanoDay@Penn introduces the excitement of nanoscale science research to the Penn community, neighborhood schools, community members, and the news media.

Impact:

- 800+ high school visitors
- 205 HS research projects
- 160 graduate research posters
- 7 graduate research awards
- 8 national research excellence awards
- News media workshop
- Career panel discussions
- Scanning probes conference in 2011 for international community

NANO / BIO INTERFACE CENTER

NanoDay @ Penn

NanoDay introduces visitors to cutting edge research and brilliant insight into the future of nanoscale science and technology through the annual Research Excellence in Nanotechnology Award.

Nano/Bio Interface Center

Research Excellence in Nanotechnology

Recipients

HORST STORMER (2005)
Columbia University

STEVEN M. BLOCK (2006)
Stanford University

CHRISTOPH GERBER (2007)
Univerity of Basel

CHARLES M. LIEBER (2007)
Harvard University

NAOMI J. HALAS (2008)
Rice University

HAROLD G. CRAIGHEAD (2009)
Cornell University

ANGELA BELCHER (2010)
Massachusetts Institute of Technology

DON EIGLER (2011)

Toshio Ando (2012)
Kanazawa University

UNIVERSITY *of* PENNSYLVANIA

NANO / B
INTERFACE
CENTER

NSF

NBIC research is disseminated through a diverse network of professional development programs and collaborations

RET-NANO

SCHOOL REFORM COMMISSION
THE SCHOOL DISTRICT OF PHILADELPHIA, PA

ITEST-NANO
small things considered

TEACHERS

Hundreds of teachers experience hand-on and curriculum-oriented professional development with NBIC partners that include Drexel University and the Graduate Schools of Education. Many teach in the School District of Philadelphia.

In turn, thousands of students are impacted through their science curriculum or by participating in out-of-school time activates co-managed or offered by NBIC.

LULAC

NanoDays

STUDENTS

MBA
Mariana Bracetti Academy
CHARTER SCHOOL

NBIC NANO / BIO INTERFACE CENTER

NSF

High School Teacher Professional Development

Research Experience for Teachers (RET-Nano)

The NBIC and Drexel University develop substantive connections with science teachers helping integrate nanoscale science and technology with local curriculum within the School District of Philadelphia (SPD) and other regional schools.

Impact:

- 105 teachers involved since 2004 in 7-week program
- 7,000+ students impacted
- Nearly all SDP high schools represented
- Suburban schools from PA, NJ, DE and NY

NANO / BIO INTERFACE CENTER

High School research: Project SEED

- SEED engages high school students from Philadelphia to participate in an eight-week chemistry research program.
- Provide students with a real-world experience in science research, college exposure, and an opportunity to develop professional and work-related skills.
- Students develop skills in science writing, use of spreadsheets to analyze data, and presentation skills.

Significant impact on students typically Underrepresented in STEM:

- 82% African Americans
- 12% Latina
- 71% Women

Successfully motivates students to enter college

- Penn (2)
- LaSalle University
- Penn State (2)
- Cheyney University
- Tuskegee University
- Bloomsburg University
- Allegheny College

NANO / BIO INTERFACE CENTER

Research Experience for Undergraduates in Nanobiotechnology

- 10-week interdisciplinary research
- All participants from outside Penn undergraduate community
- Focus on cultural and gender diversity

- 59 undergrads from 46 universities
- 46% under-represented minorities
- 49% women

Campus partners included:

- Greenfield Intercultural Center
- La Casa Latina

Impact:

- 20 in graduate school (2 with NSF Graduate Research Fellowships)
- 12 in the workforce
- 1 teaching high school physics (SDP)

Publications:

- Penn Science
- Inquiry (George Washington Univ)
- ACS Nano Letters
- Osteoarthritis & Cartilage

NANO / BIO INTERFACE CENTER

NSF

International Research Exchange

MINATEC®

- Research exchange involving Penn graduate and undergraduate students funded by IRES - 13 students
- Grenoble INP Master-level students in mutual exchange – 15 students

NANO / BIO INTERFACE CENTER

NSF

Global Networking

Presidents Gutmann and Yeon-Cheon Oh sign a MOU
May 2011

Prof. Yung Woo Park

Provost's Distinguished Visiting Scholar

Two Penn faculty members visited Seoul in

Geometric and Electronic Structure in One Dimensional Nanosystems

Young Kuk

Department of Physics and Astronomy, Seoul National University

August 10, 2009

NANO / BIO INTERFACE CENTER

NBIC Outreach Program

Summary of Outcomes/Impacts

- 105 science and math teachers participating in RET influence ~7000 students
- 53 teachers in 3 cohorts in ITEST-nano
- 800+ high school students visited during NanoDay @ Penn programs
- 63 high school and 7 grad students received awards in research competitions
- 10 classroom kits have been developed and began use in 2008
- 6 grad students developed 6 new modules for ITEST program
- 18 teachers/principals took nanoscience professional development courses
- 59 REU students (46 % under-represented groups)
- 200+ high school students attended SASST (summer academy in nanoscience)

Diversity Strategy and Progress

Emphasis on diversity in NBIC programs
- diversity in NBIC participants
- focus on Philadelphia for high school programs
- SEED program

Support deans in faculty recruiting

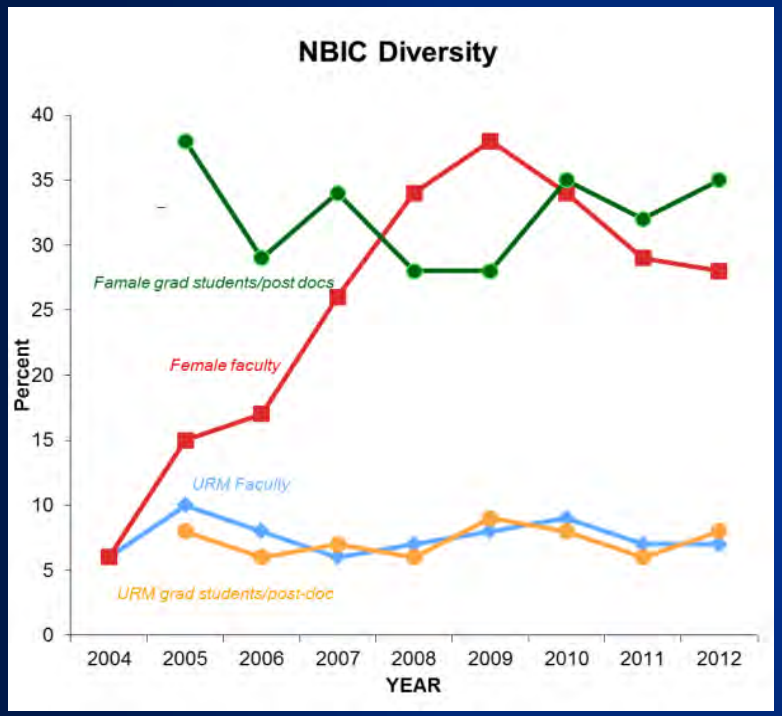
Recruitment of graduate students in all disciplines with quantitative analysis of impact

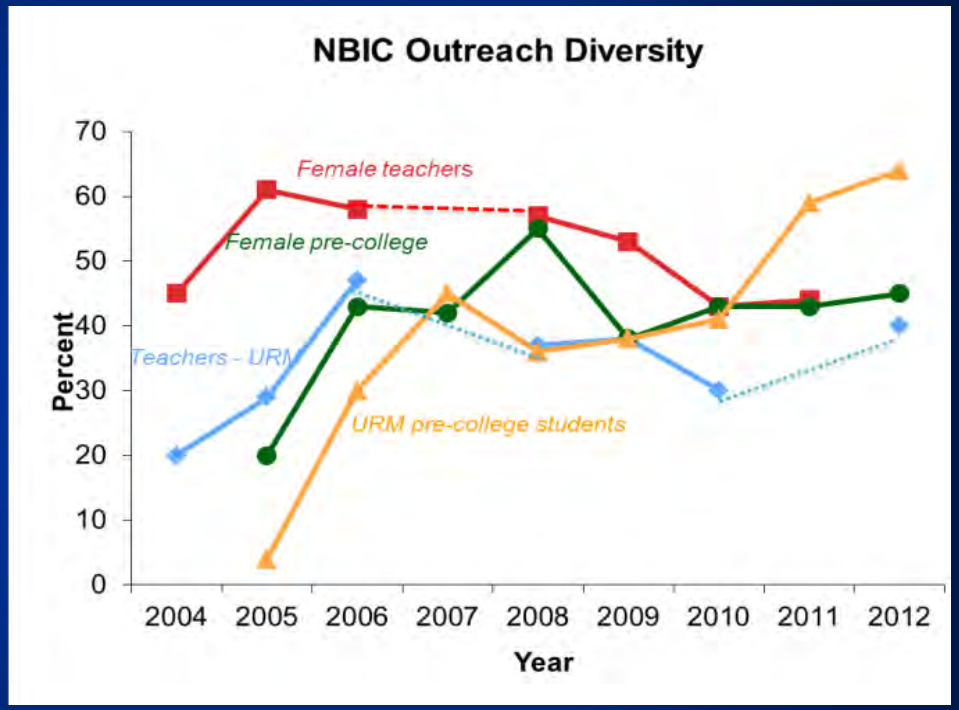
Emphasis on diversity in REU

Partnership with Alabama State University

Co-organizer of the NSF/DoE workshop on Gender Equity in Materials Science and Engineering

Leadership by Example: Diversity in NBIC Programs

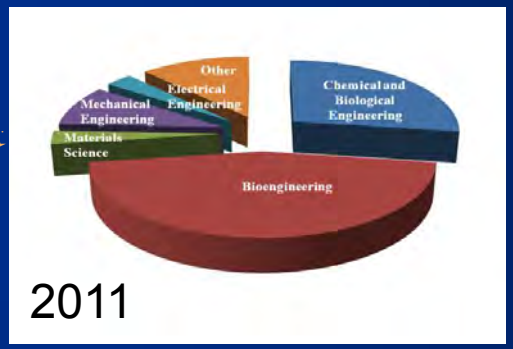




NANO / BIO INTERFACE CENTER

UNDEGRADUATE MINOR In NANOTECHNOLOGY

- 125 students participating
- 34 students currently enrolled
- 29% women



NANOTECHNOLOGY MASTERS DEGREE

36 students in the program to date

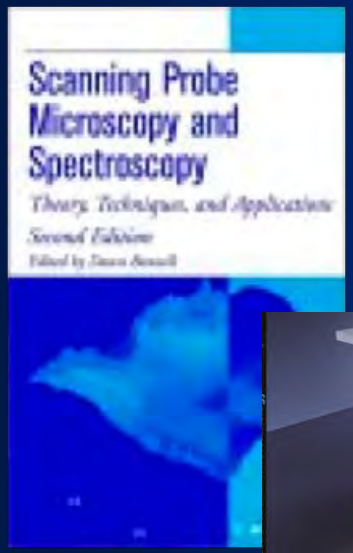
18 currently enrolled : 11% female, 6% UR groups

Alums: 20% female, 10% UR groups

NANO / BIO INTERFACE CENTER

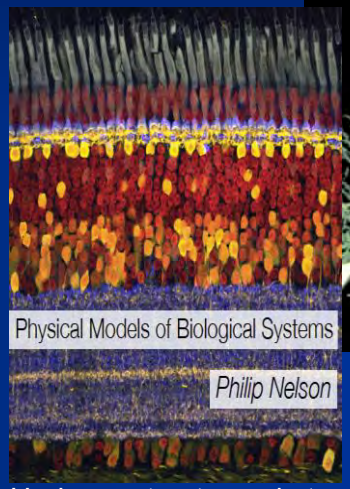
NSF

Broader Impacts on curriculum

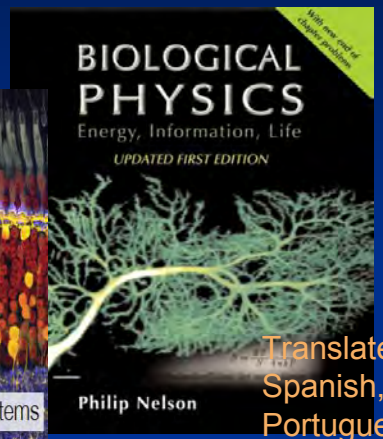


Bonnell 2000

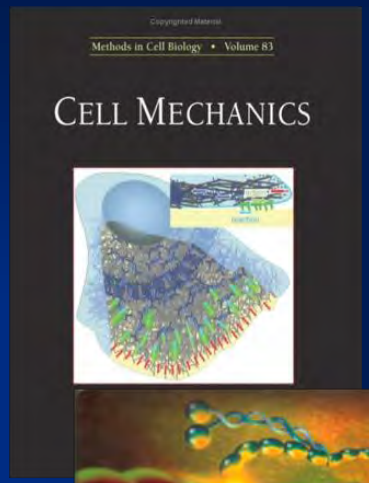
2013



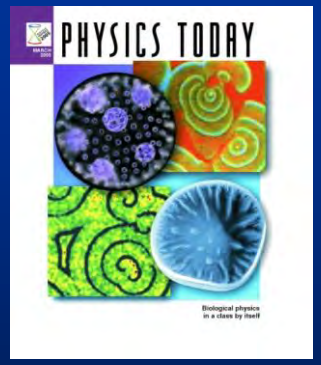
Under contract; used at Harvard, U Chicago, Florida , UCLA, Washington, & Penn



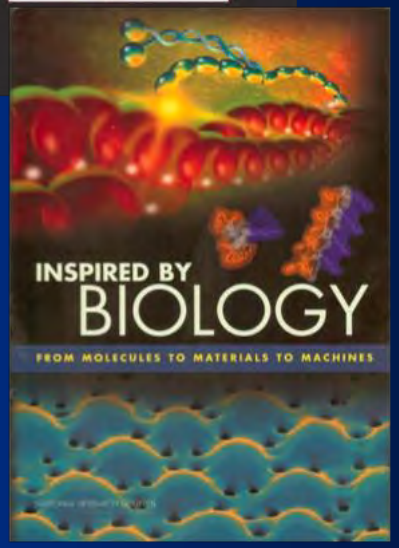
Translated in Spanish, Portuguese, and Chinese



Discher



P Nelson, RE Goldstein, and TR Powers, Cover article, ***Physics Today***, March 2005



Goldman

NANO / BIO INTERFACE CENTER

NSF

Status of the Field in 2002/2003

The intersection of biology and nanotechnology focused on:

the interactions of microfabricated structures and cells

nanoparticle functionalization for medical diagnostics and therapeutics

Status of the Field in 2013

The NBIC has developed a field in which proteins can be designed with engineered function and linked to nanostructures (quantum dots, wires, graphene transistors) to produce latices and devices for sensing and energy harvesting.

Advanced understanding of protein function in complex biological environments.

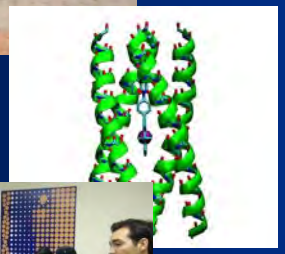
This has been facilitated by the invention of probes of local properties (3-D motion in TIRF, simultaneous force and fluorescence of single ribosome, dielectric polarization mapping).

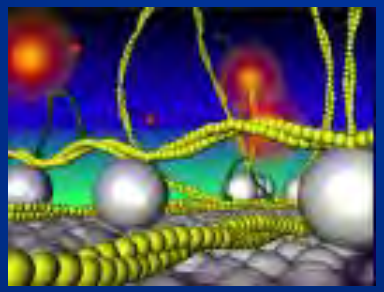
Established a facility that makes these advances available to the research community.

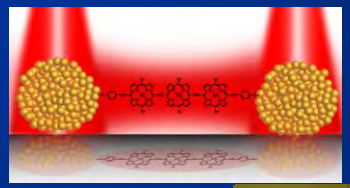
NANO / BIO INTERFACE CENTER

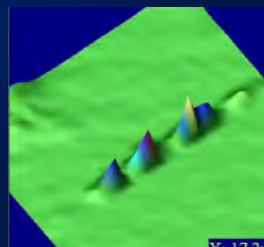
Nano/Bio Interface Center

The Nano/Bio Interface Center research establishes the foundation for understanding the interface of physical and biological systems.









NANO / BIO
INTERFACE
CENTER

Nanoprobe Network

Think small, look deeper

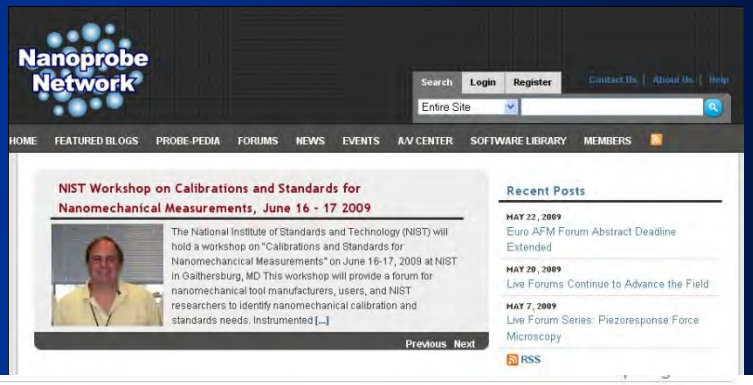
A seed group of investigators from England, Korea, Germany, and 8 institutions in the US met in 2006 at a workshop at Penn to outline the mission and initial project goals

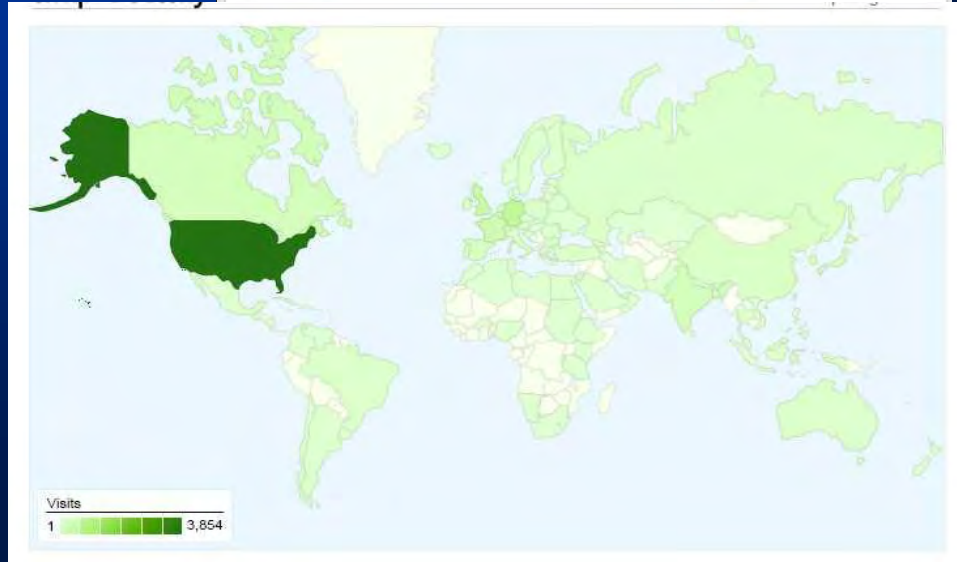
Over 800 subscribers in 72 countries, a truly global reach.

Facilitating outcomes of an EU/US joint commission workshop (Ispara, Italy June 2008) on nanobiotechnology.

Facilitated DoE strategic planning workshop on SPM in 2008

Hosting Live Forum Events





NANO / BIO INTERFACE CENTER