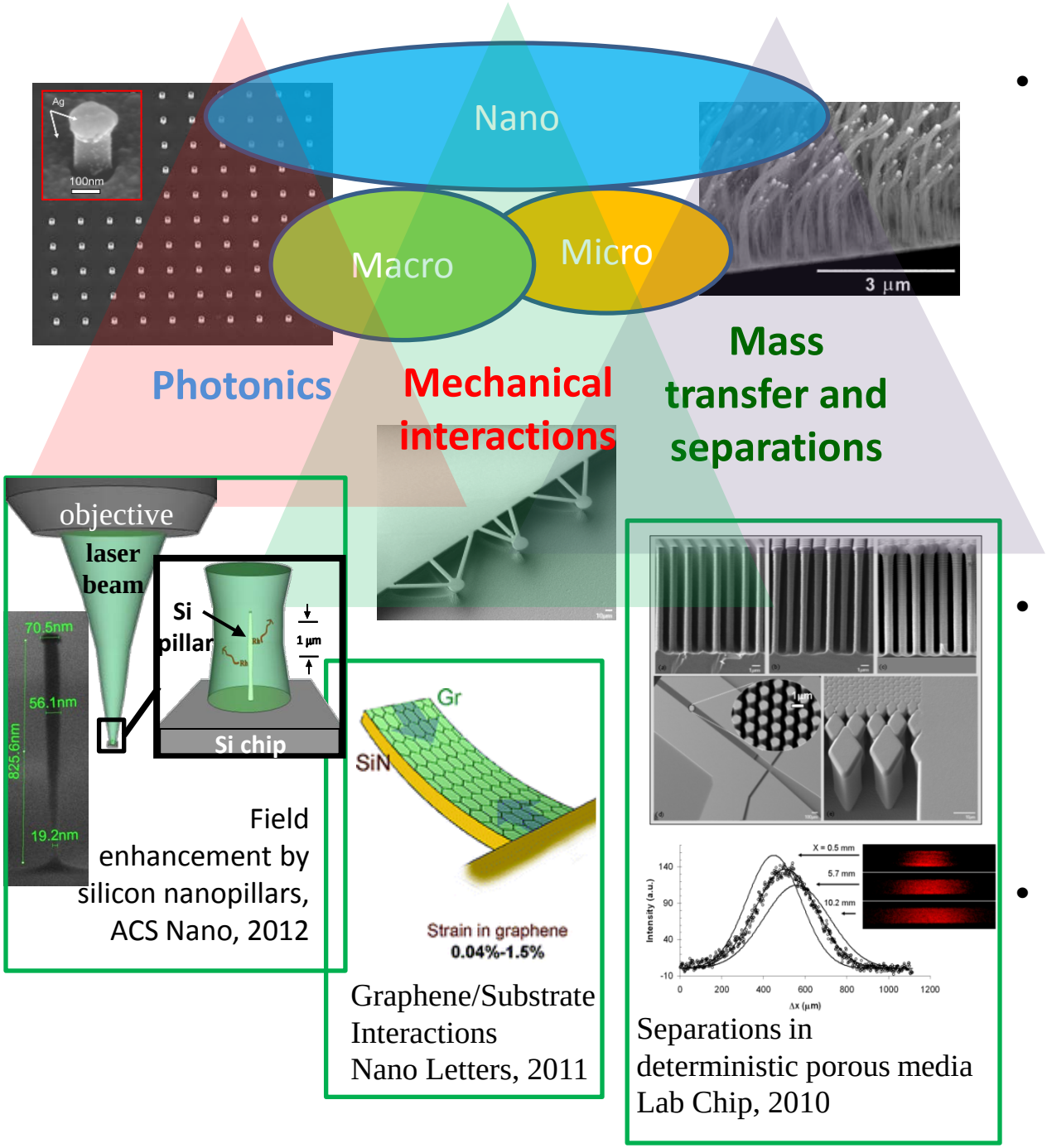
Signature Strength

Multiscale Structures Integrated on Chips (MuSIC)

One of the five Grand Challenges outlined in the BESAC "Grand Challenges" Report underscores the continued quest for ***remarkable properties of matter that emerge from complex correlations of the atomic or electronic constituents.*** In the Nanofabrication Research Laboratory (NRL), we are addressing this Grand Challenge as well as the underlying idea of ***orchestrating the behavior of billions of electrons and atoms to create new phenomena*** by designing and exploring a diverse family of **Mu**ltiscale **S**tructures **I**ntegrated on **C**hips (MuSIC) that enable multiple scenarios of energy transduction and separations mediated by optical and mechanical phenomena. By building on the continuously advancing NRL capabilities and the expertise of the NRL staff, we create MuSIC architectures that bridge macro and nano worlds and enable experimental access to phenomena that span strikingly distant spatial scales, from single digit nano to tens of millimeters. By pushing the boundaries of wafer scale technologies, developing innovative technological strategies, and integrating silicon based materials with newly emerging nanomaterials, we have demonstrated both science driven and user inspired MuSIC systems that combine unique photonic, plasmonic, nanomechanical and mass transfer properties. While demonstrated properties of MuSIC systems emerge at the level of interacting atoms and electrons, their spatial manifestation extends by more than 6 orders of magnitude making the chip level platform ideally suited for experimental explorations that enable a wide variety of optical, mechanical, electronic, and chemical experimentation. The MuSIC Signature Strength has already enabled discovery of new functionalities with important practical implications and will continue to focus on the progressively more complex systems with the ultimate goal of orchestrating the behavior of billions of electrons and atoms to create new phenomena.



- MuSIC architectures enable multiple scenarios of energy transduction and separations mediated by optical and mechanical phenomena that involve spatial scales spanning more than ***6 orders of magnitude,*** *i.e.* from single digit nano to tens of millimeters (10^{-9} to 10^{-2} m)
- Extensive expertise in lithographic, direct-write and bottom-up patterning of materials with controlled stress
- Integration of conventional silicon based materials and wafer scale processes with newly emerging nanophases and innovative technological strategies

MuSIC *Signature Strength* : recent publications

Wells *et al.* “Silicon Nanopillars for Field-Enhanced Surface Spectroscopy”, *ACS Nano*, 6, 2948-2959 (2012).

Noh *et al.* “Toward active-matrix lab-on-a-chip: programmable electrofluidic control enabled by arrayed oxide thin film transistors”, *Lab Chip* 12, 353-360 (2012).

Fowlkes *et al.* “Parallel assembly of particles and wires on substrates by dictating instability evolution in liquid metal films” *Nanoscale*, 4, 7376-7382 (2011)

Bhandari *et al.* “Nanotransfer Printing Using Plasma Etched Silicon Stamps and Mediated by in Situ Deposited Fluoropolymer”, *JACS* 133, 7722-7724 (2011).

Conley *et al.* “Graphene Bimetallic-like Cantilevers: Probing Graphene/Substrate Interactions”, *Nano Letters*, 11, 4748-4752 (2011).

Plank *et al.* “Fundamental Proximity Effects in Focused Electron Beam Induced Deposition”, *ACS Nano* 6, 286-294 (2011)

Wells, *et al.* “Efficient disc on pillar substrates for surface enhanced Raman spectroscopy”, *Chem. Comm.*, 47, 3814-3816 (2011).

Fowlkes *et al.*, “Self-assembly versus directed assembly of nanoparticles via pulsed laser induced dewetting of patterned metal films” *Nano Letters*, 11, 2478-2485 (2011).

Hatab *et al.*, “Free-standing optical gold bowtie nanoantenna with variable gap size for enhanced Raman spectroscopy” *Nano Letters* 10, 4952-4955 (2010).

Bolakis, *et al.* "Design and characterization of terahertz-absorbing nano-laminates of dielectric and metal thin films," *Optics Express* 18, 14488-14495 (2010).

Lavrik *et al* “Enclosed pillar arrays integrated on a fluidic platform for on-chip separations and analysis”, *Lab Chip*, 10, 1086 – 1094 (2010).

Williams *et al.* “High-resolution PFPE-based molding techniques for nanofabrication of high-pattern density, sub-20 nm features: a fundamental materials approach” *Nano Letters*, 10, 1421-1428 (2010).

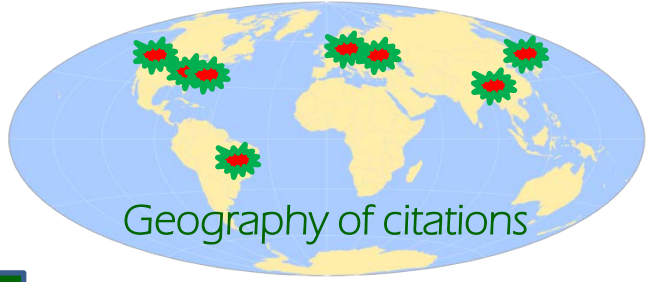
MuSIC *Signature Strength* : impact

"Cantilever transducers as a platform for chemical and biological sensors" *Review of scientific instruments* **2004**, **cited 721 times**

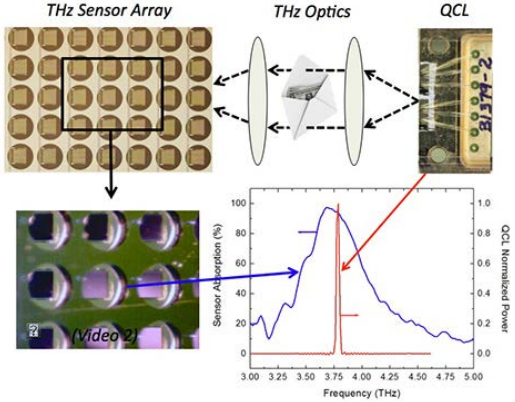
"Vertically aligned carbon nanofibers and related structures: controlled synthesis and directed assembly", *Journal of Applied Physics* **97**, 041301. **cited 475 times**

"Femtogram mass detection using photothermally actuated nanomechanical resonators" *Applied Physics Letters* **2003**, **cited 237 times**

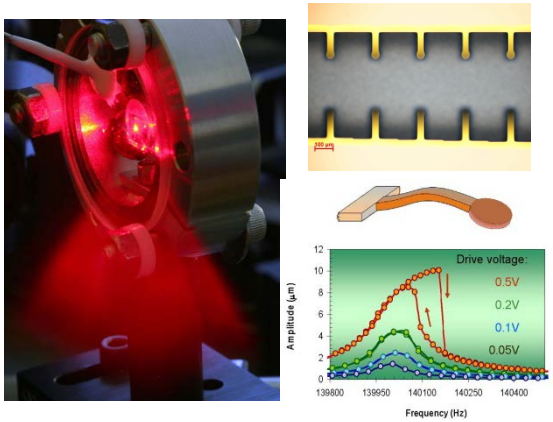
Number of R&D 100 Awards: 3
Number of publications and patents: > 100
Total number of citations: > 3000



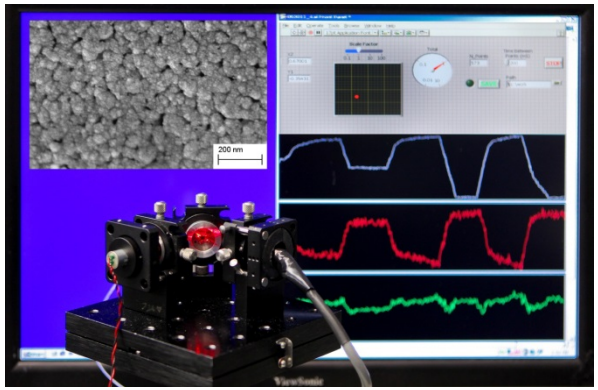
Advanced Terahertz Imaging at Naval Postgraduate School



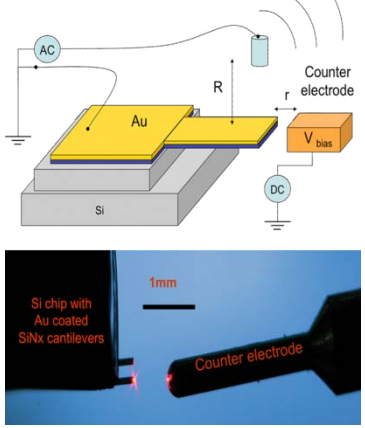
R&D 100 2010 "Ultrasensitive Nanomechanical Transducers Based on Nonlinear Resonance"



R&D 100 2011 "Nano-Optomechanical Hydrogen Safety Sensor Based on Nanostructured Palladium Layers"



R&D 100 2012 "Broadband Micromechanical Antenna



Nickolay V. Lavrik

Staff Scientist,
Nanofabrication
Research Laboratory

Nanoscale and multiscale systems with optical, mechanical and chemical sensing functionalities

> 80 peer reviewed publications; h-index 27

Google Scholar profile:
Nick Lavrik

R&D 100 Award 2012
R&D 100 Award 2011
R&D 100 Award 2010
R&D 100 Award 2003

Dayrl P. Briggs
Lead Cleanroom Engineer, Nanofabrication Research Laboratory

Manage daily operations, maintenance, engineering, and user activities for the CNMS Cleanroom.

Thin Film Growth, Deposition and Etch Processing. LPCVD, PECVD, ALD, RTP, RIE.

2012 R&D 100 Award

26 years Semiconductor Equipment and Process Engineering.

Philip D. Rack
Group Member,
Nanofabrication
Research Laboratory

Professor
Materials Science
and Engineering
UT

Controlled synthesis and directed assembly of nanomaterials, Advanced materials and device integration

>110 peer reviewed publications; 2 U.S. Patents; h-index 23

Google Scholar profile:
Philip D. Rack

High profile publications

Nano Letters, ACS Nano (4 papers)

Small, Angew. Chem. Int. Ed., Nanoscale, Lab on Chip (6 papers)

Scott T. Retterer
Research Staff,
Nanofabrication
Research Laboratory

Multi-scale fluidic environments for interfacing with biological systems; Nanostructure fabrication and assembly

>50 peer reviewed publications; h-index 16

Google Scholar profile:
Scott Retterer

High Profile Papers

Nano Letters, ACS Nano (7 papers)

Advanced Functional Materials, Lab on Chip (8 papers)

Ivan I.Kravchenko
R&D Staff,
Nanofabrication
Research Laboratory

Electronic and Ionic
Functionality on the
Nanoscale

Design and
manufacture of
nanometer scale
electronic, optical,
and plasmonic
devices.

~100 peer reviewed
publications;
h-index 13
Google Scholar
profile:
Ivan Kravchenko

High profile publications

Science, Nano Letters,
ACS Nano (3 papers)

Dale K. Hensley
Controlled Synthesis Engineer,
Nanofabrication Research Laboratory

Nanofabrication, Microscopy, Carbon NanoFibers and Pedal Like Carbon

>70 peer reviewed publications; h-index 20
Google Scholar profile:
Dale K Hensley

30 years of User Facility experience

Jason D. Fowlkes
Staff Scientist,
Nanofabrication
Research Laboratory

Theme;
Collective
Phenomena in
Nanophases

Beam-induced chemistry and assembly, Self and directed assembly of thin film materials, Nanobio-related reaction/diffusion systems

>80 peer reviewed publications; h-index 22

Google Scholar profile:
Jason Fowlkes

High Profile Publications

ACS Nano and
Nano Letters (5 papers)

Small, Nanoscale, Lab on Chip (4 papers)

Bernadeta Srijanto
Research Associate
Nanofabrication
Research Laboratory

Support operations for the CNMS Cleanroom

Develop and characterize fabrication processes: lithography and ething

Nano/microfluidics and multiscale platform MEMS

Kevin C. Lester
Cleanroom Engineer,
Nanofabrication
Research Laboratory

All aspects of
Equipment
Installation and
Maintenance for the
CNMS Cleanroom

Expertise in Chemical
and Physical Vapor
Deposition and Etch
Processing

17 years
Semiconductor and
Solar Panel
Manufacturing

Pat Collier
Research staff,
Nanofabrication
Research Laboratory

Microfluidics
Nanofabrication
Single-molecule
Dynamics
Collective
Phenomena

54 peer reviewed publications; 6 patents; h-index 28

Google Scholar profile:
Pat Collier

High profile publications

Science (4 papers)

Nano Letters, ACS Nano, Phys. Rev. Letts. (6 papers)

Michael L. Simpson
Distinguished R&D Staff and Group Leader, Nanofabrication Research Laboratory

Theme Co-Leader
Collective Phenomena in Nanophases

Controlled synthesis and directed assembly of nanomaterials, stochastic processes in complex systems, biomimetic nanoscience

>150 peer reviewed publications; 33 U.S. Patents; h-index 44

Google Scholar profile:
Mike Simpson

Fellow of the AAAS

Fellow of the IEEE

College of Fellows of the AIMBE