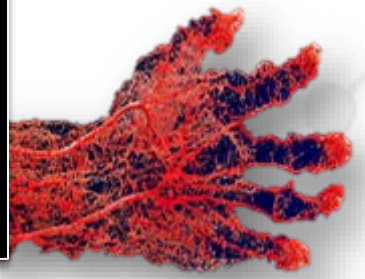
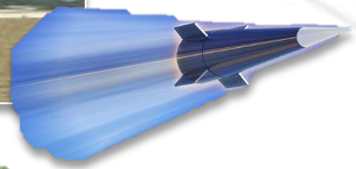
Nanoscience and technology development at the Office of Naval Research

Antti J. Makinen, Ph.D.
Naval Materials Division

ACCELERATING TO THE NAVY & MARINE CORPS AFTER NEXT

The Naval Research Enterprise

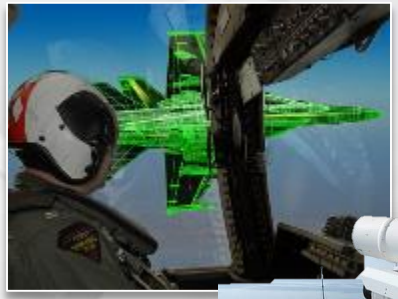



ONR HQ

U.S. NAVAL RESEARCH LABORATORY
NRL

ONR Global

4,000+ People
23 Locations
$2.5B / year
>1,000 Partners



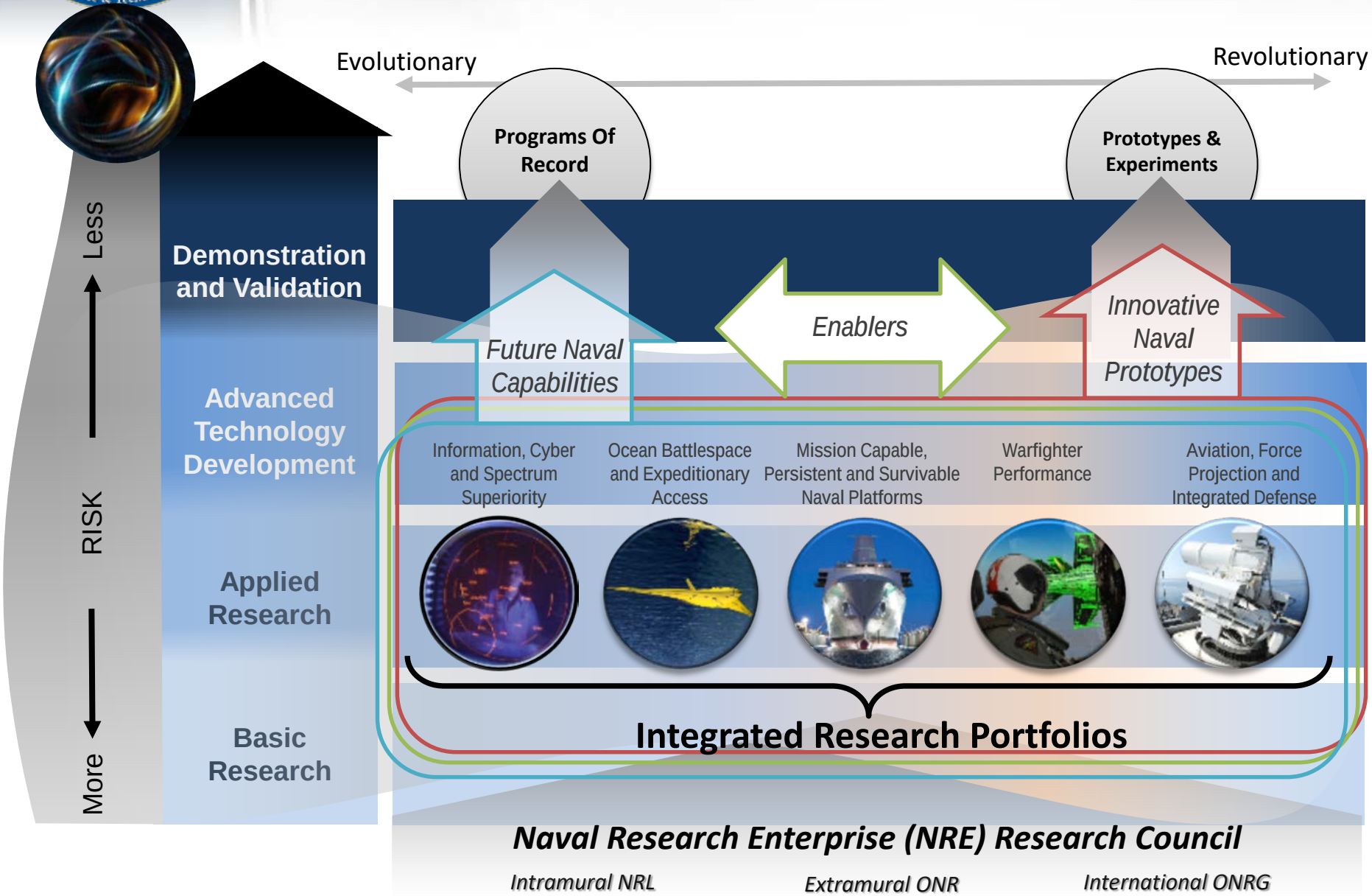



Basis of ONR Mission

— “to plan, foster, and encourage *scientific research* in recognition of its paramount importance to future Naval power and national security.” — Public Law 588 of 1946

— “…manage the Navy’s basic, applied, and advanced research to *foster transition* from science and technology to higher levels of research, development, test, and evaluation.”.” — Defense Authorization Act, 2001

The Naval Research Portfolio

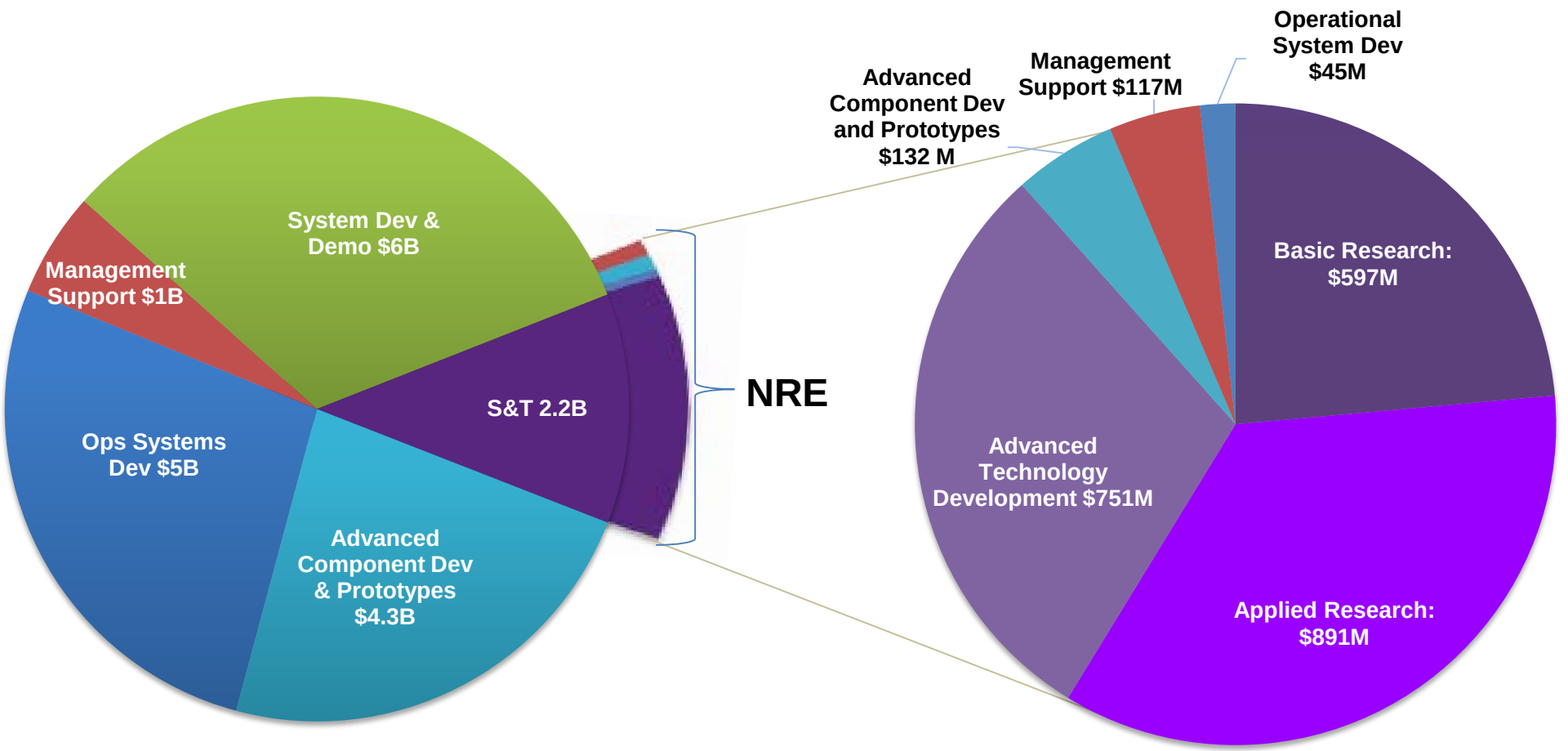


The Portfolio Investment

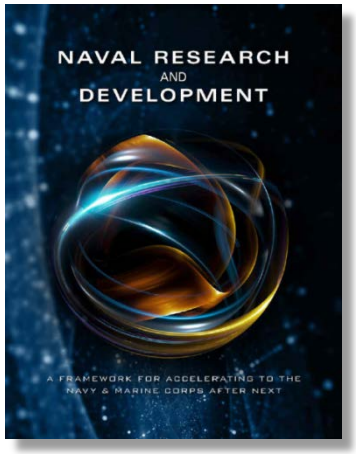
Relative to FY19 Navy Budget ($194.1B)

FY 19 DoN R&D $18.65B

Naval Research Enterprise
$2.5B of FY19 R&D Budget

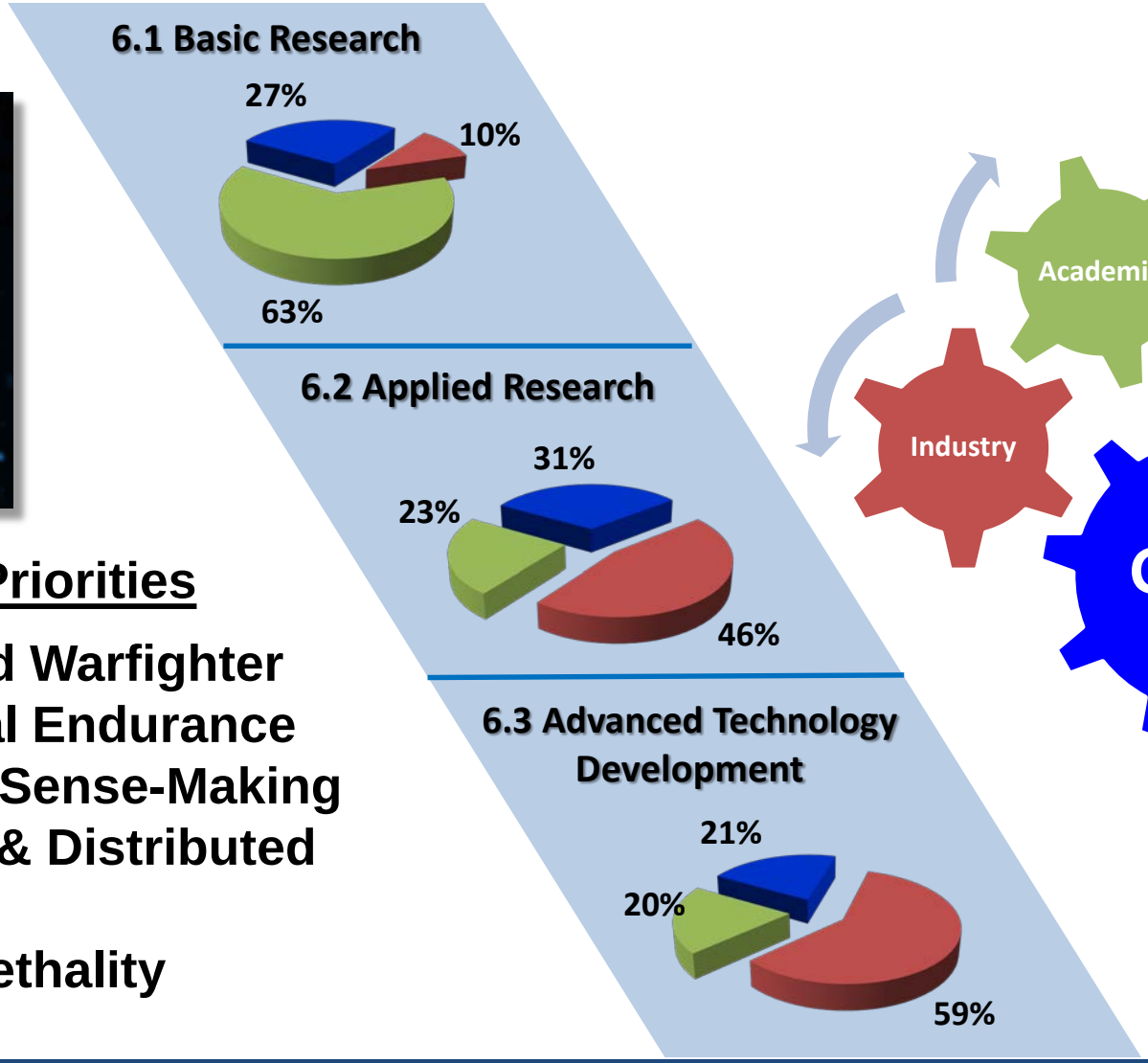


It Begins With Research



Framework Priorities

- Augmented Warfighter
- Operational Endurance
- Sensing & Sense-Making
- Integrated & Distributed Forces
- Scalable Lethality



Accelerating Knowledge to Technology to Capability

NNI and NRE Mission

(1) Diverse Scientific and Technical Domains:
- multidisciplinary
- long-term investments (> 10 years)

(2) Collaborative Community
- intra- and extramural (OSD MURIs)
- DoD and non-DoD agencies

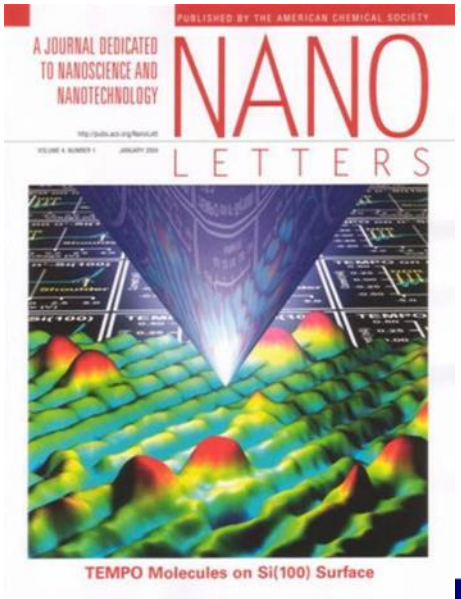
(3) Infrastructure Development
- intramural: NRL Nanoscience Institute (NSI)
- extramural: DURIP

Nanoscale Computing Devices and Systems

Chagaan Baatar, Ph.D.
Electronics, Sensors, and Networks Division

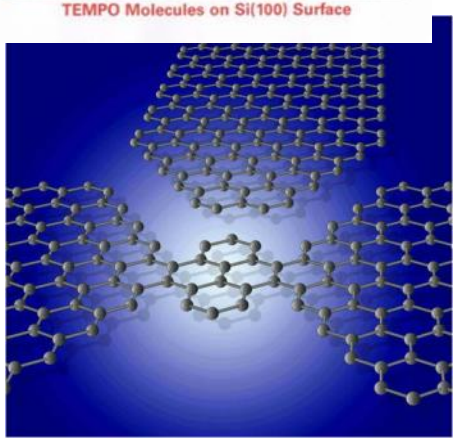
Vision:

Foster and encourage high risk innovative research in nanoscience that will enable new electron devices to their ultimate limits of high speed, light weight, low power consumption, and that interactively combine sensing, processing, computation and communications functions.



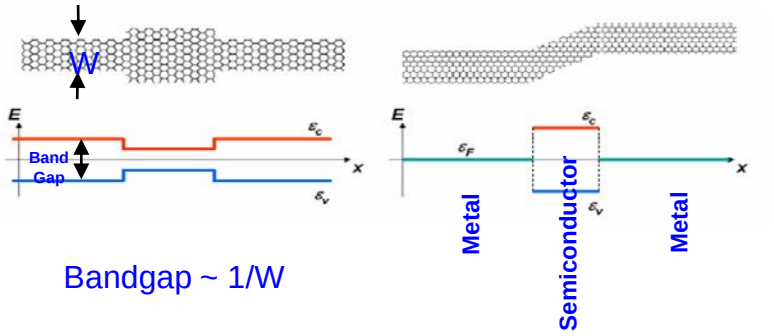
Research Challenges:

- Fundamental building block of information handling *beyond transistor*
- Novel computing architectures *beyond von Neumann*
- Reliable and cost-effective manufacturing techniques *beyond top-down lithography*

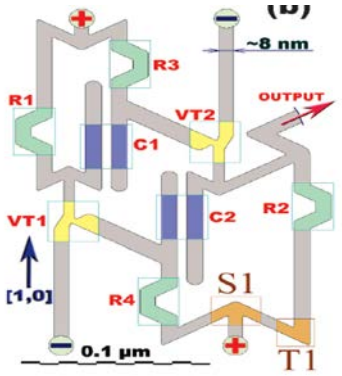


Program Example: Graphene

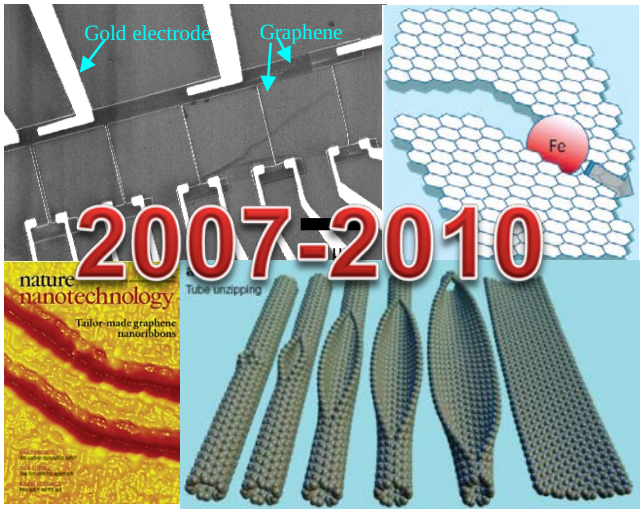
Electronics in Single Layer of Carbon Atoms

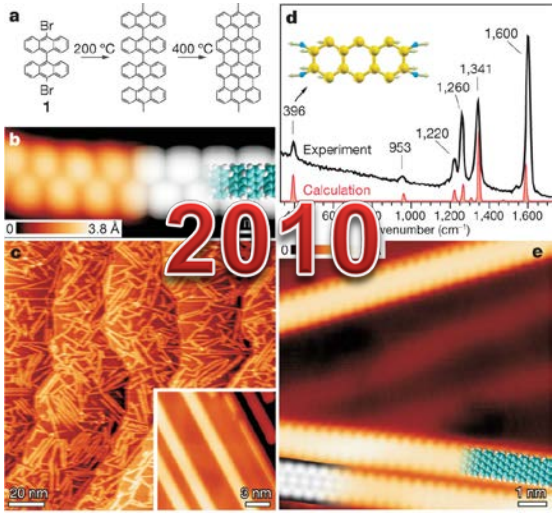


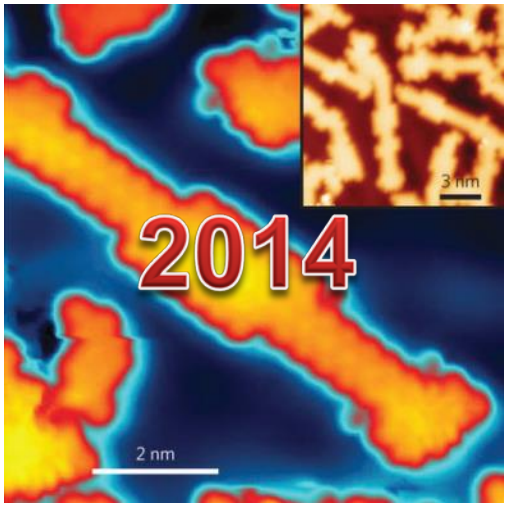
2007



Challenge: sub-10nm patterning capability with atomically sharp edges along specific crystal orientation!

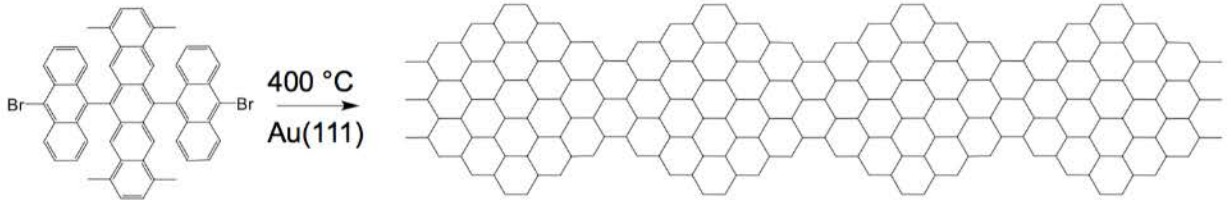






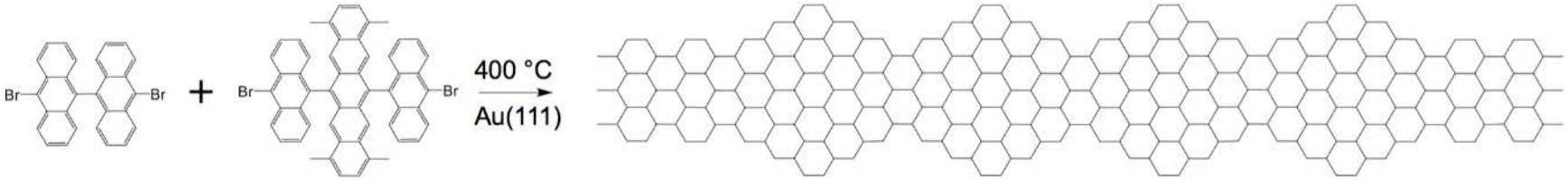
GNR Heterostructures

Topological end states in zz-segmented 7-AGNRs



Molecular precursor from Klaus Müllen's group (MPI Mainz)

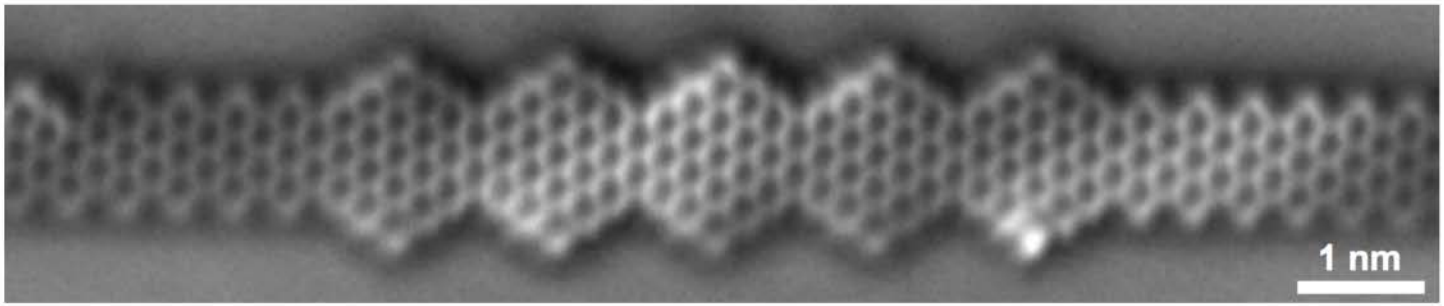
Topological Insulator



arxiv.org/pdf/1805.06635

Nano Lett.2018 18, 11, 7247

nc-AFM image



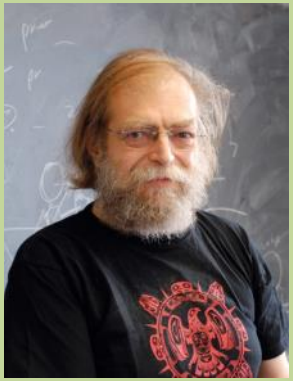
Program Outcome

Nobel Prize (Physics)

Andre Geim (2010)

Kostya Novoselov (2010)

Kavli Prize (Nanoscience)



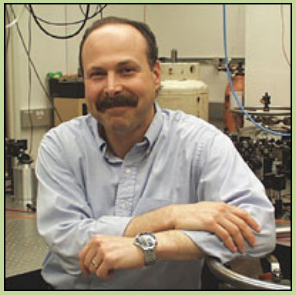
Ned Seeman (2010)

Millie Dresselhaus (2012)

National Medal of Science

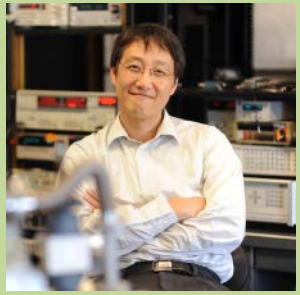
Jackie Barton (2010)

APS Buckley Prize



David Awschalom (2005)

Jagadeesh Moodera (2009)



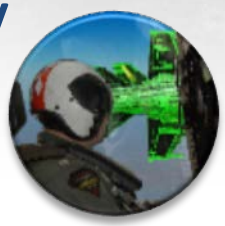
Philip Kim (2014)

McArthur Fellow

Mark Hersam (2014)

Biomaterials and Bionanotechnology

Laura Kienker, Ph.D.
Warfighter Protection and Applications Division

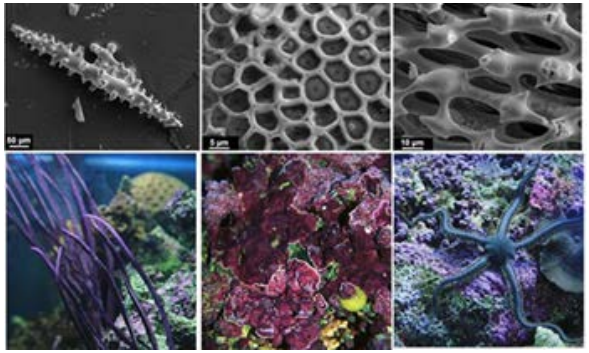


Vision:

Generate new materials from naturally occurring biological materials using biological components or processes.

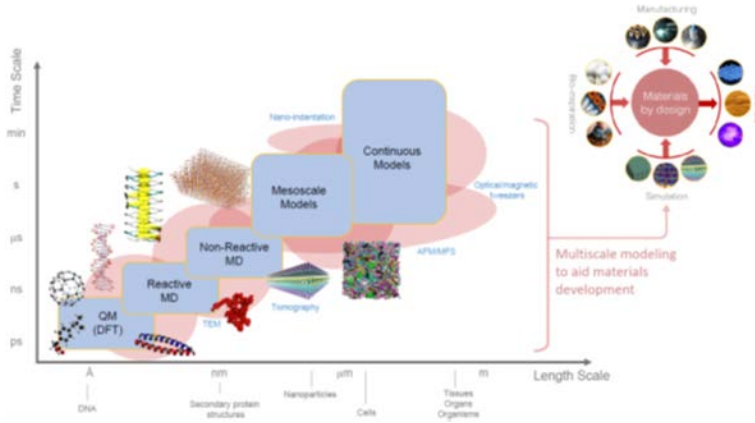
Design and synthesize de novo biologically-based materials.

Fabricate bio-inspired and biomimetic materials and devices.



Research Challenges:

- Fabrication techniques for hierarchical, biologically-based materials with defined properties.
- DNA nanotechnology and application for functional device platforms.
- Synthesis and patterning of materials by microorganisms.
- Design and fabrication of bio-inspired and biomimetic materials and devices using nature's design principles



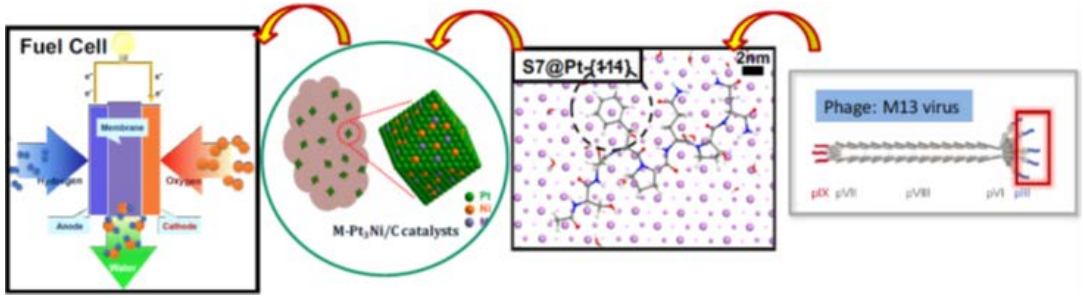
Energy Harvesting/Conversion Materials

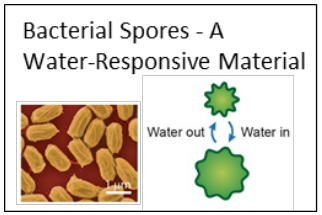
Objectives

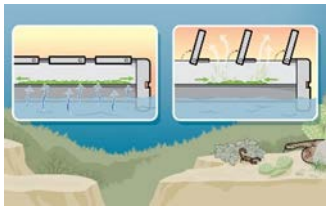
- Develop full fuel cell devices.
- Demonstrate evaporation-driven active materials exhibiting high work and power density.
- Explore naturally-derived biopolymer fundamentals (silk) for generation of functional materials for energy harvesting/storage and batteries.

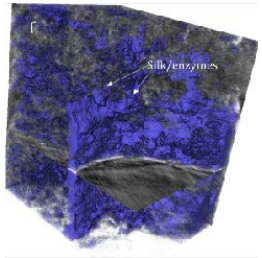
Technical Approach

- Proton Exchange Membrane Fuel Cells Based on Designer Catalysts.
- Use bacterial spores assemblies in macroscopic actuators.
- Elucidate the mechanism behind spores' response.







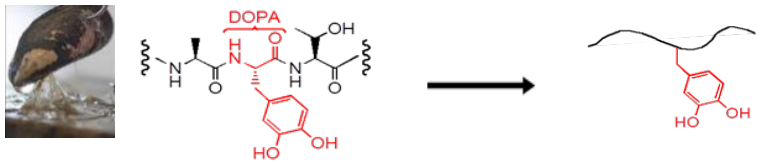


Nanoscale 3D Visualization of Enzymes within Lattice of Carbon Nanotube/Silk/Enzyme Composites

Underwater Curing Adhesives

Objectives

- Develop biomimetic and bio-inspired underwater curing adhesives based on glue-producing aquatic organisms

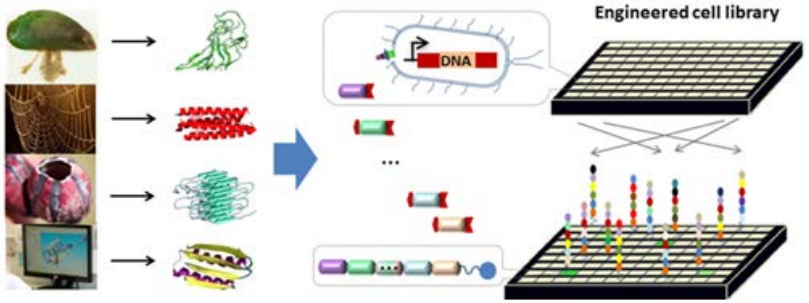


- Complex adhesive protein
- DOPA cross-linkable sidechains
- Simple polymer backbone
- Pendant catechol groups

Polymer Mimics of Mussel Adhesive Proteins for Wet Adhesion

Technical Approach

- Engineer hybrid protein-based adhesive materials.
- Engineer designer amyloid materials from barnacles.
- Develop higher performing protein-based biomimetic wet adhesives that are charged, debondable and tough.



Bio-directed Synthetic Approach for the Covalent Assembly of High Molecular Weight Protein Polymers with Precisely Defined Subunit Order and Ratio

Nano-engineered Materials

Antti Makinen, Ph.D.
Naval Materials Division

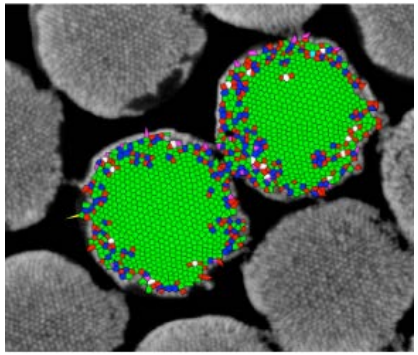
Vision:

Understand the scientific phenomena that defines the unique properties of structural and multifunctional nanomaterials.

Identify material systems and processes enabling the assembly of these materials at mesoscale and beyond, while preserving and potentially enhancing the material properties initially defined at the nanoscale.

Research Challenges:

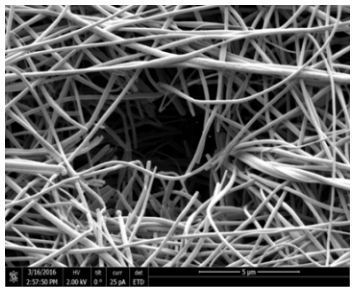
- Functional and robust optical coatings
- Inorganic-organic hybrid nanomaterials
- Mesoscale behavior of nanoassemblies
- Metrology of nanomaterial assemblies
- Hierarchical 3D surfaces

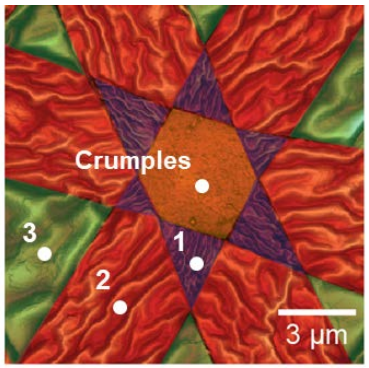


Non-equilibrium Assembly of Nanomaterials

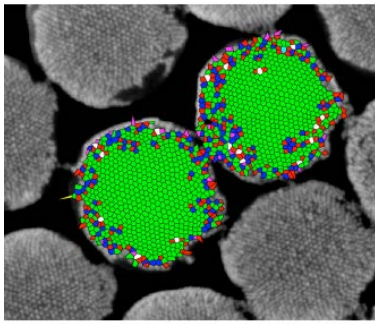
Objectives

- Mesoscale mechanics of nanostructures
- Scaled-up assembly
- Multifunctional materials
- Metrology





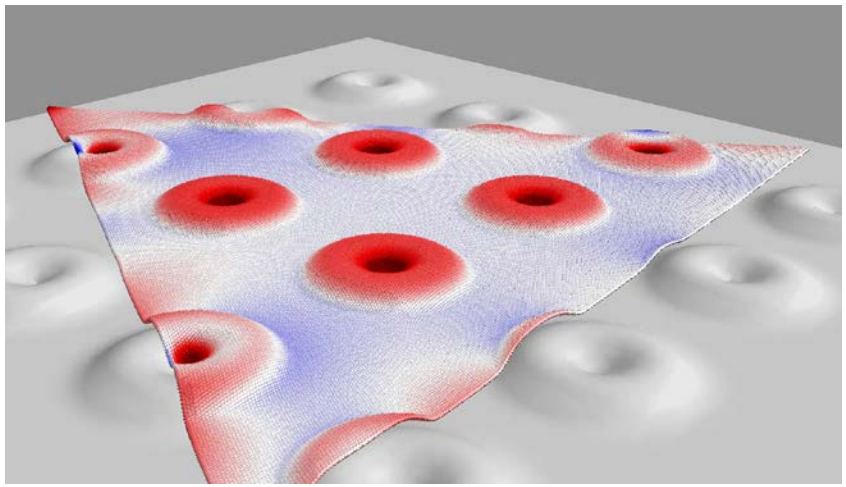
Nano Lett. 2016, 7121



Soft Matter 2018, 14, 9107

Technical Approach

- 3D graphene and graphenic glass
- Hierarchical 3D surfaces
- Nanoparticle sheets
- Nanofibers and –yarns
- Field-assisted sintering of ceramics.

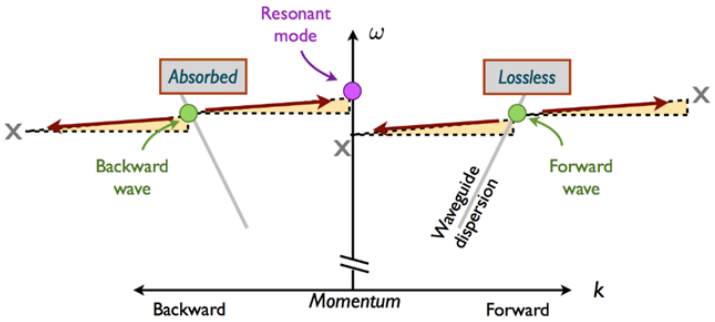


Sci. Adv. 2019, **5:** eaav4028

Future Photonic Materials

Objectives

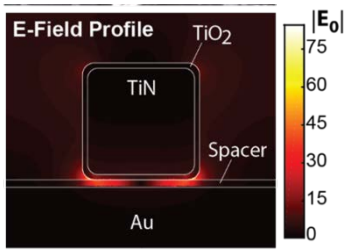
- Functional and robust optical coatings.
- New photonic material architectures.

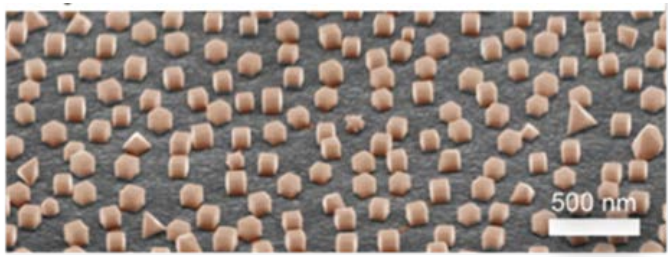


arXiv:1905.02778

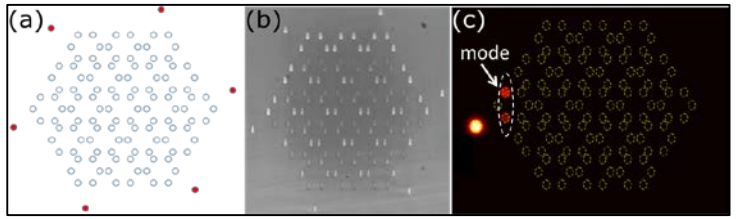
Technical Approach

- Explore topological phenomena in microwave, photonic, and mechanical metamaterials.
- Exploit "topological protection" in design to realize robust photonic devices.
- Develop techniques for achieving nonreciprocal wave propagation in metamaterial systems.





DOI: 10.1021/acsphotonics.9b00851



Nature Photonics 2018, **12**, 408

DOD OXR Agency Coordination

ONR Announcement # N00014-19-S-F005
ARO Announcement # W911NF-19-S-0008
AFOSR Announcement # FOA-AFRL-AFOSR-2019-0002

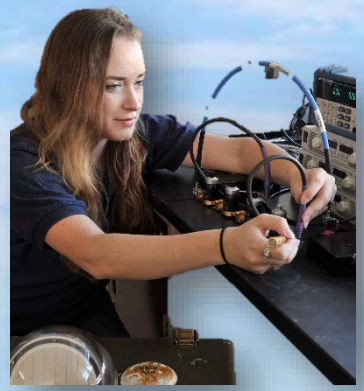
Fiscal Year (FY) 2020 Department of Defense
Multidisciplinary Research Program of the University Research Initiative

Topic 5: Photonic High-Order Topological Insulators (PHOTIs) [*ONR*]

Topic 12: Axion Electrodynamics beyond Maxwell's Equations [*ARO*]

Topic 25: Weyl Fermion Optoelectronics [*AFOSR*]

Naval Research Laboratory



U.S. NAVAL RESEARCH LABORATORY

- *The Navy's Corporate Laboratory*
- *World Class Research Team*
- *Basic and Applied Research and Advanced Technology Development for Anticipated Navy and Marine Corps Needs*

NRL Institute for Nanoscience

Mission:

- Provide state-of-the-art nanofabrication and characterization facilities to NRL scientists
- Manage a research program in basic, interdisciplinary nanoscience

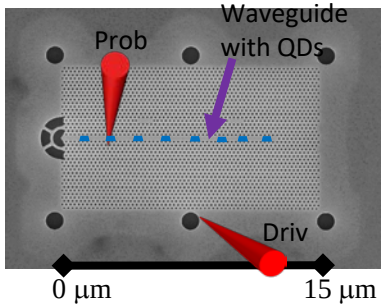
Research Program:

- Support multi-disciplinary basic nanoscience
- Goal: To enable transformational technologies for the Navy of the future
  - Traditional nanotechnology has produced incremental improvements in technology
  - Transformational technologies will most likely require complex nanosystems
- Research divided into three scientific subareas
  - Materials: Controlled growth/assembly of nanocomponents
  - Interactions: Understand and control the interactions between nanocomponents and their environment
  - Nanosystems: Assemble and understand behavior of functional complex nanosystems
    - Quantum systems
    - Neuromorphic systems
    - Bio/inorganic systems: Communicating and interacting with living systems

Quantum sensing with Spin-Mechanical Systems

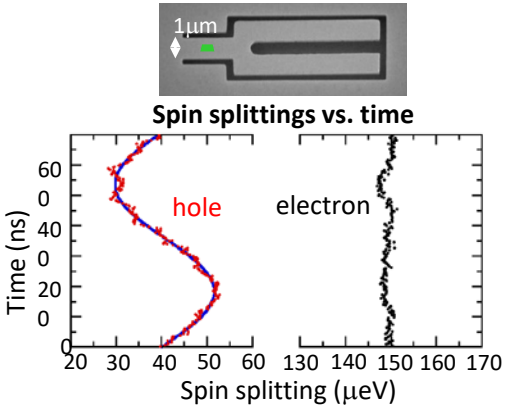
Objective: Develop a solid-state quantum sensor for accelerometry, vector magnetometry, etc.

Mapped QD coupling to photonic crystal membrane



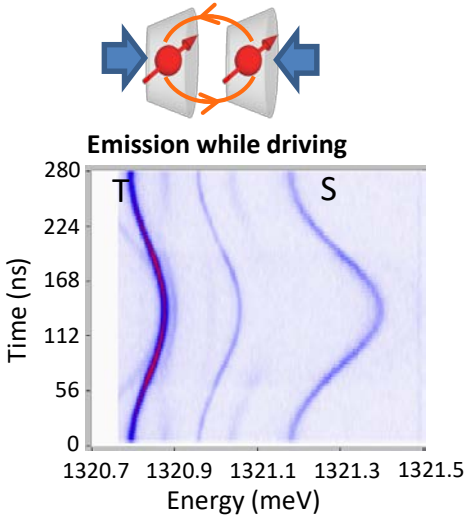
S. G. Carter *et al.*, Appl. Phys. Lett. 111, 183101 (2017).

Spin mechanical coupling for single QDs



S. G. Carter *et al.*, Phys. Rev. Lett. 121, 246801 (2018).

Spin mechanical coupling for entangled spin states

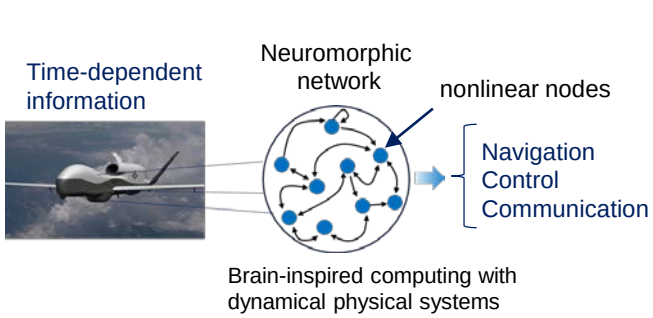


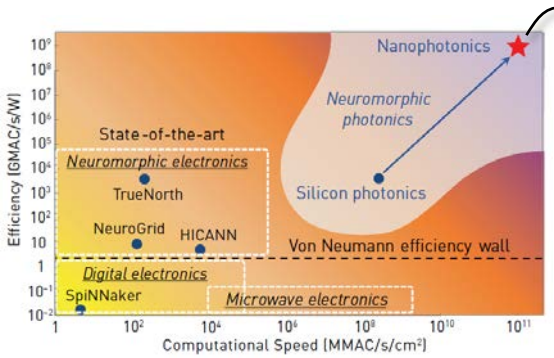
- First spin-mechanical coupling of QDs in mechanical resonators
- Demonstrated new spin-mech coupling approach: AC Stark shift
- Demonstrated DC to 10s of GHz coupling to QDs
- Goal: detect motion at the single phonon limit

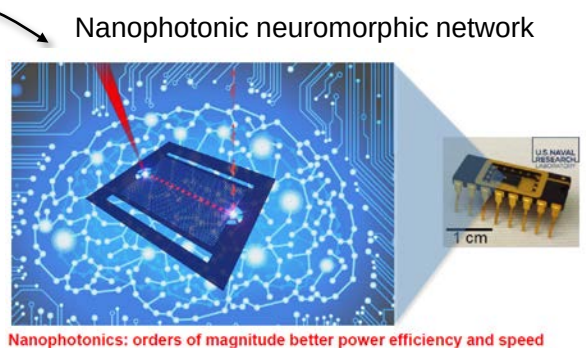
Nanophotonic Neuromorphic Networks

Establish the foundation for neuromorphic information processing using photonically coupled quantum-dot lasers

Navy need: Low-SWaP, real-time information processing



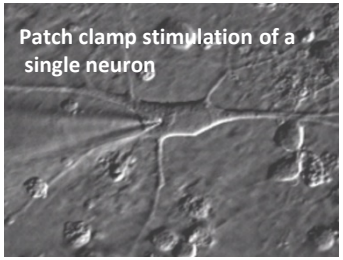


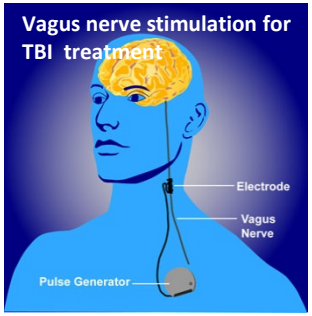


Nanophotonics: orders of magnitude better power efficiency and speed.

Nanoscale systems for Wireless Control of Living Cells

Roadblock/Challenge

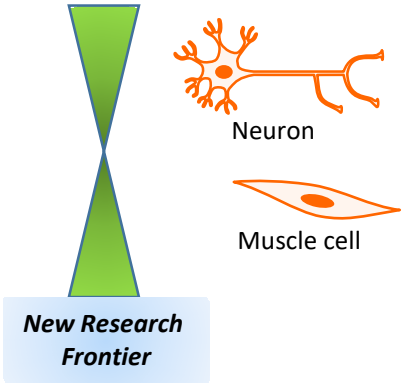




- Chief goal of the President's "BRAIN" Initiative is to develop new modalities for brain imaging ***and*** stimulation
- Critical for understanding normal brain function *and* treating dysfunction (critical DoD areas of need: TBI, PTSD, concussion, depression)
- Current methodologies for stimulation of *neurons and muscle cells* utilize drugs or electrodes
- We will develop the nanomaterials and techniques that will enable ***wireless stimulation*** of cells

Research Opportunity

Basic science problem with a materials solution



New Research Frontier

- The nano and neuro communities agree this is a scientific problem best addressed with stimuli-responsive nanoprobes that target the plasma membrane
- Our expertise uniquely positions us to have an *early* and *significant* impact on ***nanoparticle-mediated cellular stimulation:*** a new research frontier

Summary

www.onr.navy.mil

www.nrl.navy.mil

Questions?