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Meta-Materials

Idea:

Preserve the superior properties of low dimensional material architectures in novel, engineered, nano-composite "meta-materials"

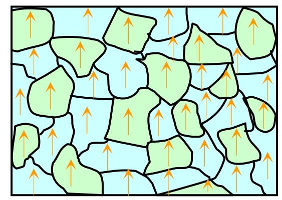
Technical Challenges:

- Engineering unit cell "building blocks" that exploit the superior properties of "small-scale" physics
- Assembling these building blocks into 3-D, bulk materials while still preserving their superior performance

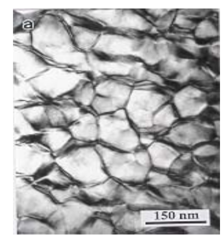
Impact:

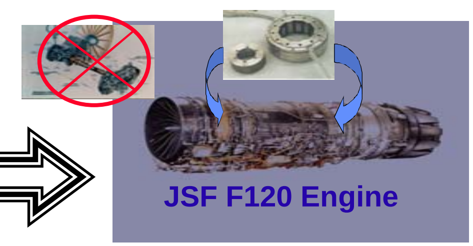
- High performance magnetic meta-materials for power electronics, electronic propulsion and power generation
- Novel microwave meta-materials for communication, radar, and wireless

Superior properties=New design freedom



Example: Novel magnetic meta-materials will enable new aircraft engine designs for "More-Electric" DoD air vehicles





Highlights:

- Program start in FY01
- Major contractors include Boeing, Rockwell, Univ. of Michigan, Georgia Tech, Univ. of Delaware, Johns Hopkins, RTI, and U. Texas Arlington
- Service Agency partners include ONR, AFOSR, AFRL and NRL

Meta-materials: Changing the design paradigm

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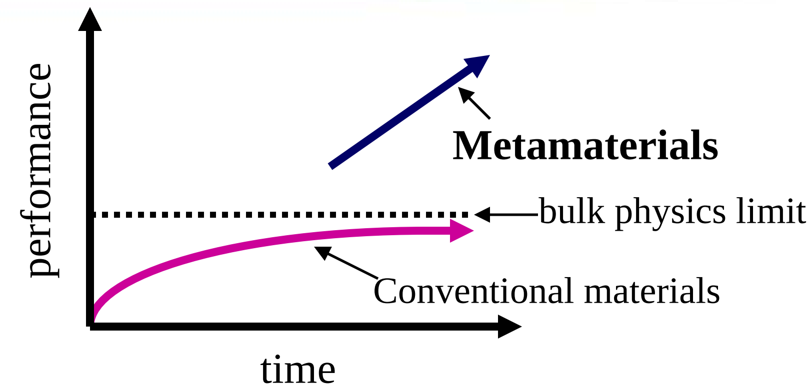
Problem

The ultimate performance of conventional bulk materials is limited by physics.

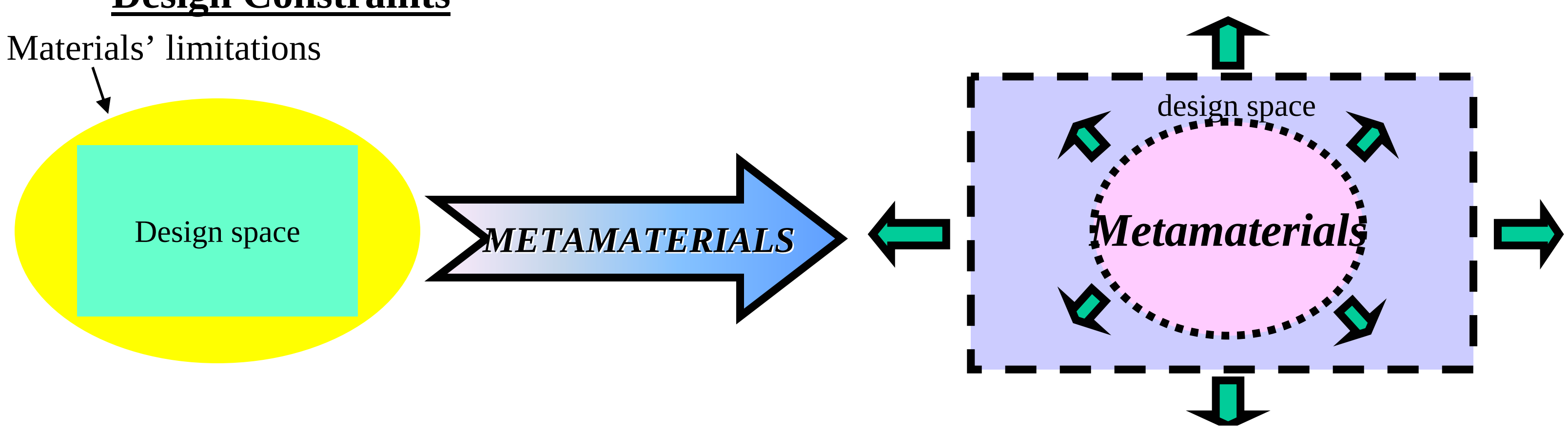


Solution

Metamaterials: New physics = enhanced performance

Design Constraints

Design Freedom

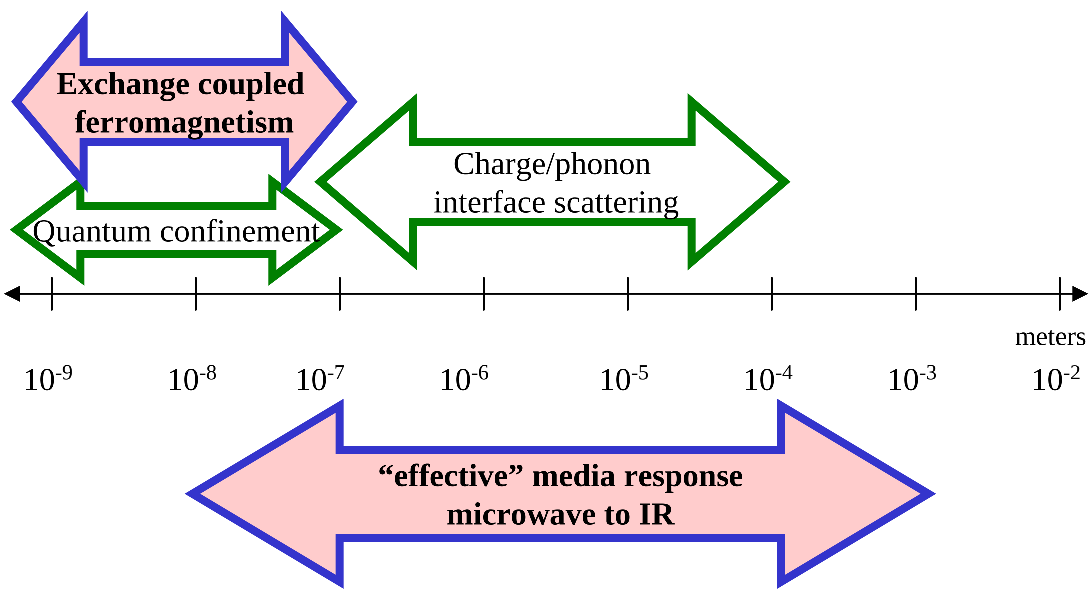


Why Meta-materials?

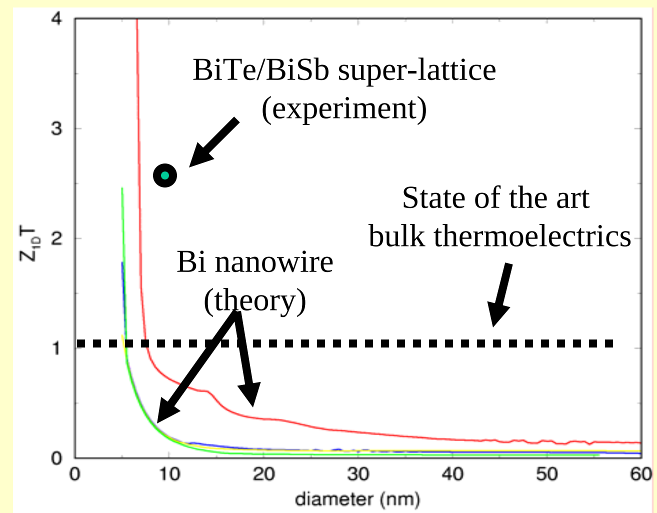
… ***because the physics at "small" scales is different, interesting, and in many cases, better from a performance perspective***

METAMATERIALS OBJECTIVE

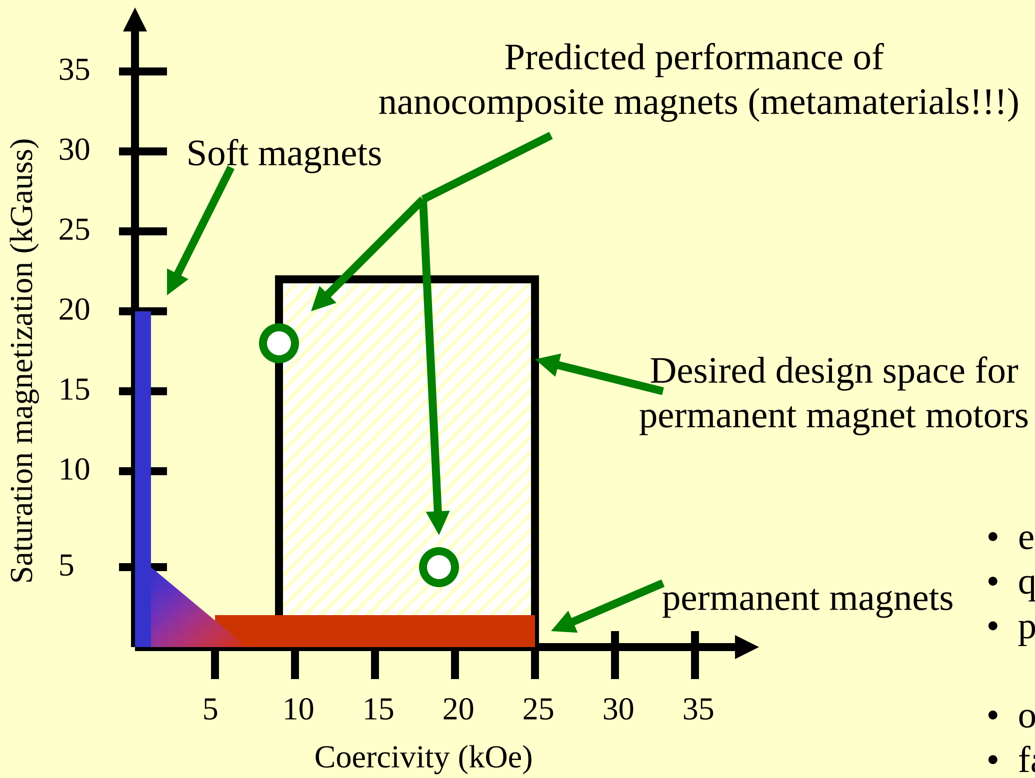
Preserve the superior properties of low dimensional systems in new bulk materials constructed from unit cell building blocks that are engineered to exploit "small" scale physics

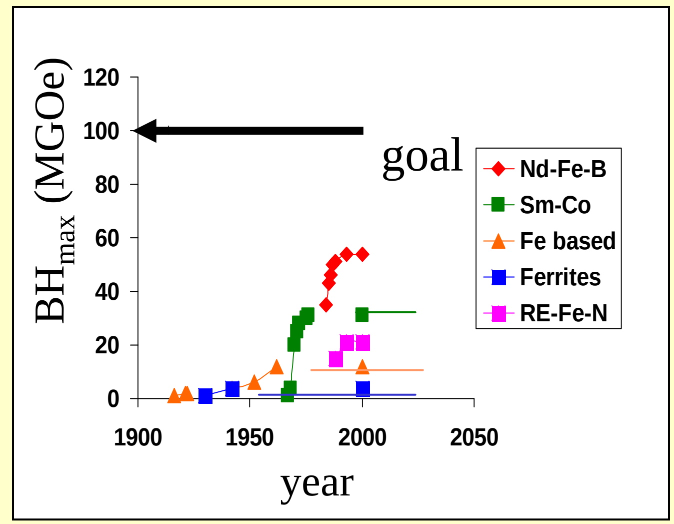


***Example*: Thermoelectric figure of merit ($ZT = S^2T/\rho\kappa$)**



Magnetic nanocomposites (meta-materials) will enable electric drive/propulsion

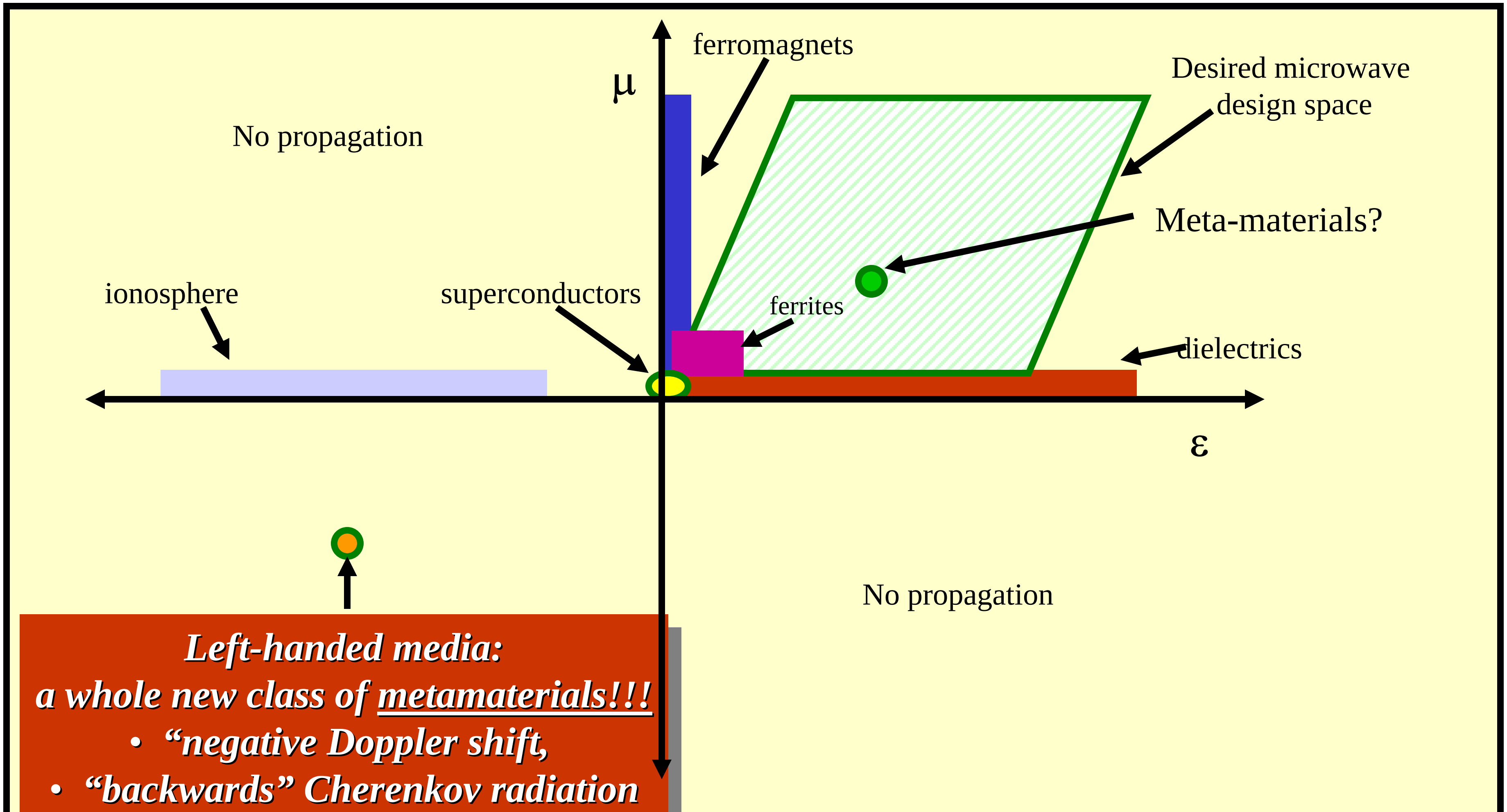




Low cost ($5-$10/lb), high performance, permanent magnets will enable:

- electric drive (tanks, automobiles)
- quieter, more efficient motors (UUV propulsion)
- permanent magnet biased bearings (lubeless motors/generators)
- open MRI
- faster spindle motors for hard drives (hard drive capacity increases 60 %/ year)

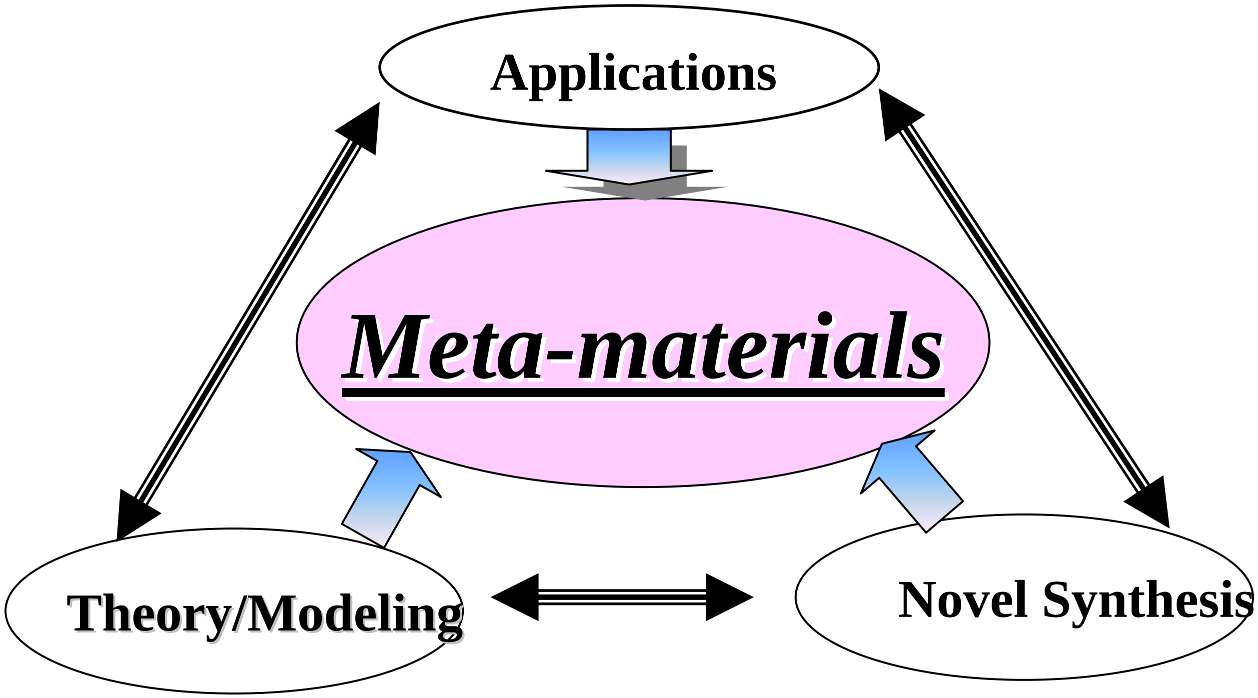
Meta-materials: Filling the void in the microwave design space



Left-handed media:
a whole new class of <u>metamaterials!!!</u>

- ***"negative Doppler shift,***
- ***"backwards" Cherenkov radiation***
- ***novel optical properties***

The Meta-materials Program



Metamaterials will deliver:

- low frequency (< 1 MHz) meta-materials with superior magnetic properties for power electronics, electric propulsion, and power generation
- high frequency (> 1 MHz) meta-materials with superior microwave and/or optical properties for communication and wireless power transfer applications.

Meta-Materials Selected Efforts

Meta-Material	***Application***
• composite dielectrics/magnetodielectrics	antennas (electrically large, physically small, embedded, etc.)
• superparaelectrics/nanostructured ferroelectrics	microwave/radar components (circulators, filters, etc.)
• low loss, high permeability ferrite composites	inductors, capacitors for power electronics
• exchange biased permanent magnet composites	electric drive/propulsion
• high temperature, soft magnet composites	high temperature motor components (rotor, stator, etc.)
• left-handed composites	antennas, communications, frequency selective surfaces
• super radiant emitting structures	thermal management

Novel Approaches to the synthesis, processing and applications of nanocomposite magnets

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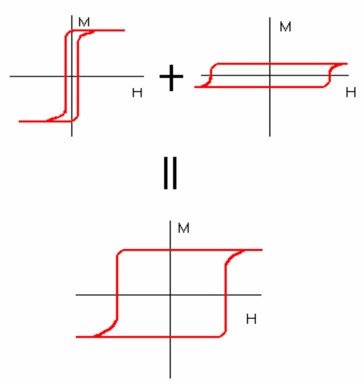
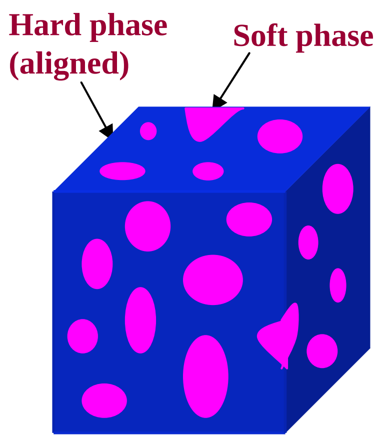
Exchange-coupled nanocomposite magnets

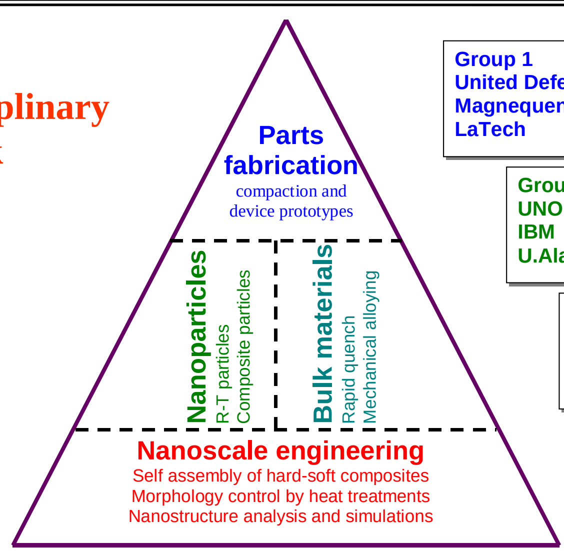




Experimental approaches:

- New synthesis methods for nanoparticles
- Novel compaction techniques
- Multi-step heat treatment and morphology control
- Phase diagrams of composition and tunable properties
- Patterned soft phase in hard-phase matrix or vice versa

Multidisciplinary team work



Group 1
United Defense
Magnequench
LaTech

Group 2
UNO
IBM
U.Alabama

Group 3
Magnequench
LaTech
U.Alabama

Group 4
Argonne
GaTech
LaTech
U.Alabama

Objectives:

- Better understanding of the exchange coupling
- Tunable and high energy isotropic magnets
- Processing methods for fabricating anisotropic magnets
- Compaction techniques for nanostructured materials
- Prototype of devices with improved hard magnets
- Enhanced tie between the academy and the industry
- Students and postdocs education and training

IBM University of New Orleans United Defense Georgia Institute of Technology AMC

Electromagnetic Meta-Materials (EMMs)
for Aerospace Applications

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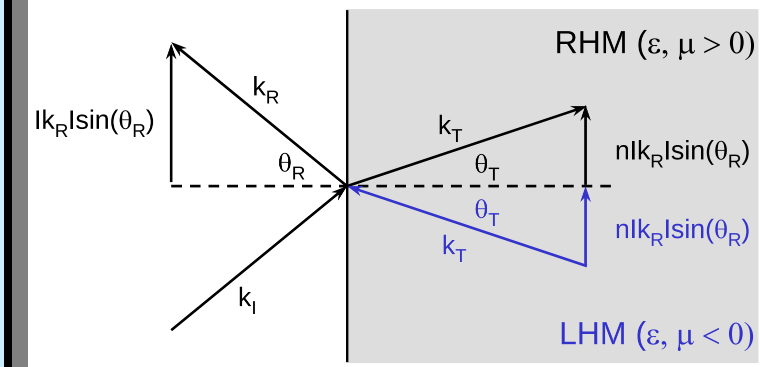
BOEING

Program Objective: **Develop, fabricate, and evaluate 3-D, tunable (ε,μ) EMMs for high payoff military and commercial applications**

Technical Approach:

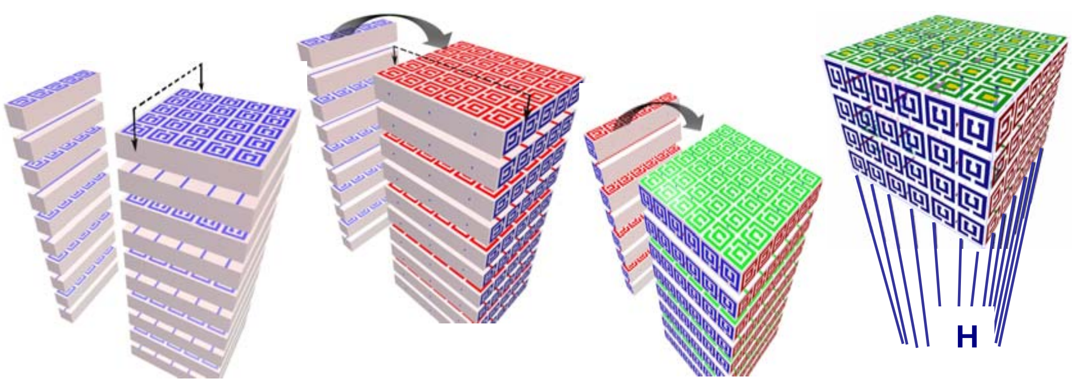
- **determine maximum bandwidth of EMMs**
- **employ novel material synthesis approaches to achieve 3-D structures and tunability**
- **establish figure of merit for various 3-D structures**

Left-Handed Behavior in EMMs



Target Applications

- ***Tunable RF absorbers***
- ***Aircraft and missile radome coating materials***
- ***Wide-angle impedance matching for phased array antennas***
- ***Generation of nearly divergence-free RF beams***



UCSD, UCLA, IOWA ST., TUD, LSU

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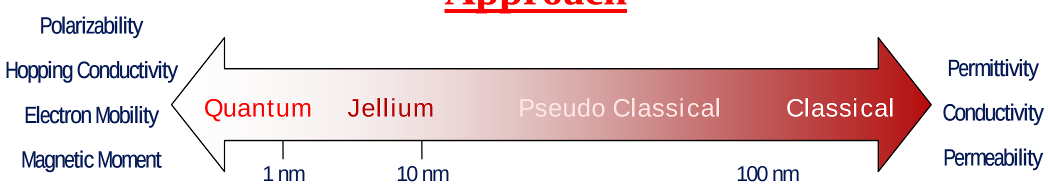
Science and Application of Meta Materials (SAMM)

Objectives:

- Develop design tools to span scale between quantum mechanics and macroscopic behavior
- Improve understanding of nano-scale effects on bulk material properties
- Apply SAMM process to develop DoD materials (microwave, IR, and optical) and antennas

Approach

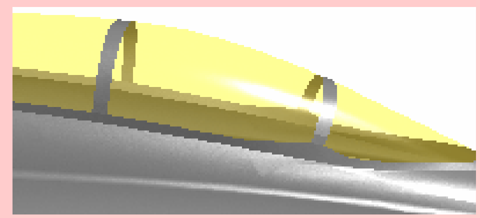


Nano-Scale Physics Theory & Model ↔ Effective Media and Full-Wave EM Models ↔ Synthesize & Characterize Samples ↔ Apply to DoD Requirements

GIT, GTRI, NASA, SRI ↔ Advisory Board: DoD Technology Integrators

Georgia Tech Research Institute

Target Applications



IR and Optical Coatings

Compact, Rugged Antennas

Meta-Material Structures for Super-Radiant Emitters and Sensors

Rama Venkatasubramanian, Research Triangle Institute, North Carolina

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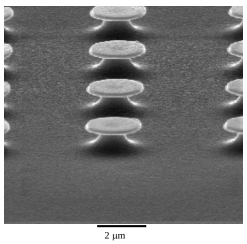
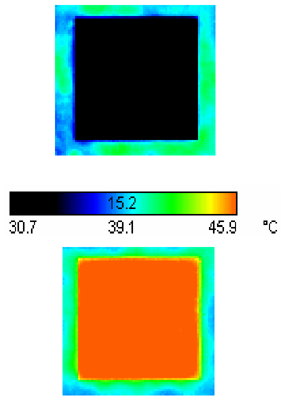
Program Year Started: 2001 **Program Manager: G. Pomrenke (AFOSR)**

Metamaterials With Enhanced IR Emission Characteristics





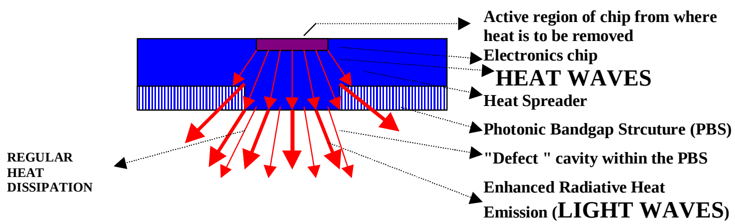
Program Objectives

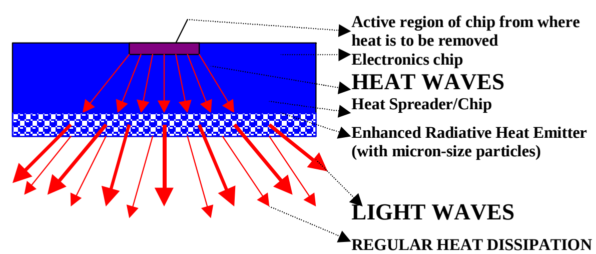
- **Explore and demonstrate new physics of meta-materials for enhanced IR emission / absorption**
- **Develop characterization techniques to measure the properties of the meta-materials**
- **Develop improved implementation methodologies for the fabrication meta-materials**
- **Evaluate prototype meta-materials and their devices in thermal management and IR-sensing applications**

DOD Relevance

Revolutionary advances in thermal management in a variety of military systems and Improved IR sensing applications

Approach

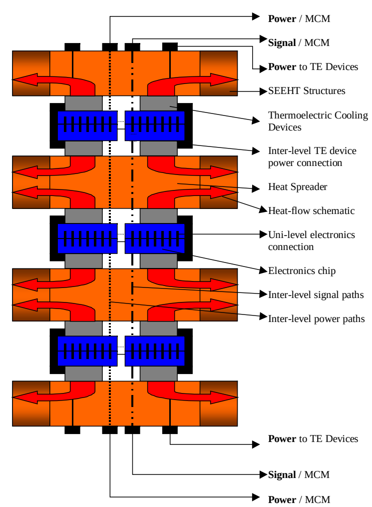




RTI

Prototyping and Technology Impact

Multi-chip module



Improved IR Sensors

MINIATURIZED ANTENNAS WITH ELECTROMAGNETIC METAMATERIALS

J. Halloran, University of Michigan

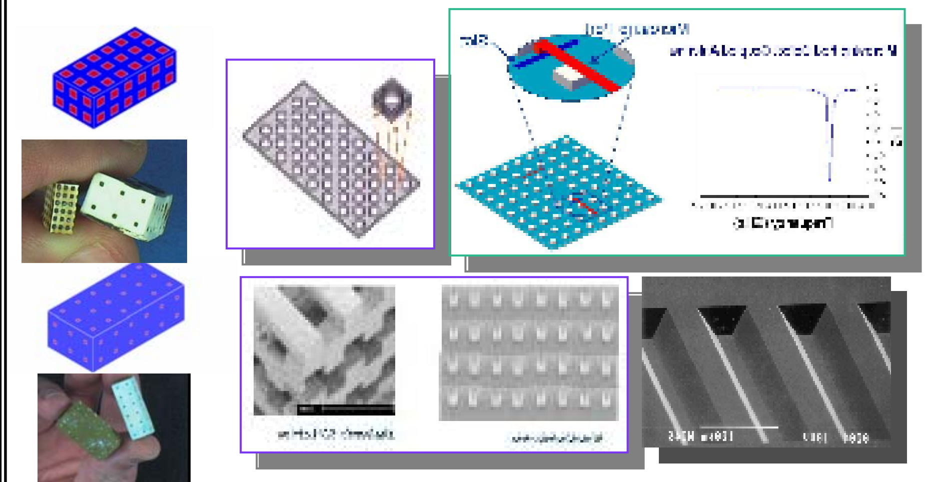
Multidisciplinary Approach

The University of Michigan and Harris Corporation will miniaturize antennas using magnetodielectric metamaterials created by topology design and automated fabrication methods

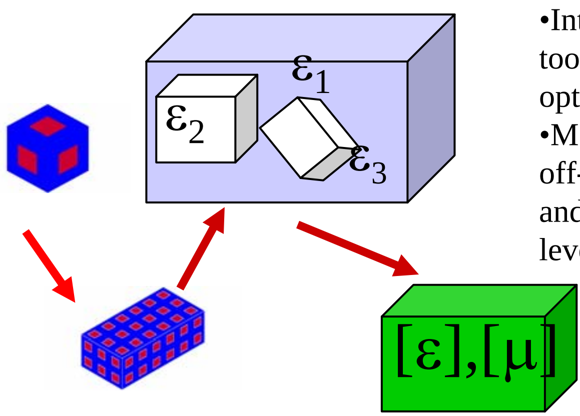
Fabrication:J. Halloran, Materials Science and Engineering
Electromagnetics: L. Katehi, K. Sarabandi, J. Volakis, Electrical Engineering
Optimal Design: Noboru Kikuchi, Mechanical Engineering
Integration, Design, Commercial Implementation: Harris Corporation

University (U. of Michigan) → **Industry** (Harris Corp) → **Military** (DARPA, etc.)

Solid Freeform Fabrication of Metamaterials



Electromagnetic Metamaterials Design Method

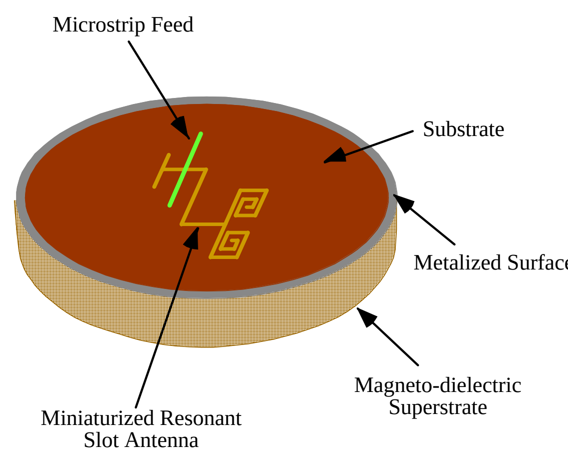


- Integrate full wave EM tools with topology optimization
- Metamaterials from off-the-shelf dielectrics and ferrites at several levels of granularity

Design with Periodic Microstructure allowing Spatially varying composition and properties

Objectives

- Metamaterials with unprecedented properties
- Optimal Design of Electromagnetic Metamaterials
- High efficiency miniaturized antennas and Microwave devices
- Lab and commercial scale fabrication



DoD Relevance

Revolutionary advance in antenna miniaturization, reduced cost and complexity