Evolution of Metamaterials

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J.B.S. Haldane

The Creator, if he exists, has ...
… an inordinate fondness for beetles.
Engineers have had an inordinate fondness for composite materials...
... right from the Bronze Age.

Bronze = Copper + Tin
Evolution of *Materials Research*

- Material Properties (< ca.1970)
Evolution of *Materials Research*

- Design for Functionality (ca. 1980)
Evolution of *Materials Research*

- Design for System Performance (ca. 2000)
Multifunctionality

Thanks: Chuck Bakis
Multifunctionality

Performance Requirements on the Fuselage

1. Light weight (for fuel efficiency)
2. High stiffness (resistance to deformation)
3. High strength (resistance to rupture)
4. High acoustic damping (quieter cabin)
5. Low thermal conductivity (less condensation; more humid cabin)
Multifunctionality

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Future: Conducting fibers for
(i) reinforcement
(ii) antennas
(iii) environmental sensing
(iv) structural health monitoring
(iv) morphing
Evolution of *Materials Research*

- Material Properties (< ca. 1970)
- Design for Functionality (ca. 1980)
- Design for System Performance (ca. 2000)
Metamaterials
Rodger Walser

Walser’s Definition (2001/2)

• macroscopic composites having a manmade, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation
Walser’s Definition (2001/2)

manmade
Walser’s Definition (2001/2)

three-dimensional
Walser’s Definition (2001/2)

- Macroscopic composites having a manmade, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation.
Walser’s Definition (2001/2)

designed to produce an optimized combination of two or more responses to specific excitation
Walser’s Definition (2001/2)

available in nature

not
Walser’s Definition (2001/2)

- macroscopic composites having a manmade, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation.

D.G. Stavenga, Invertebrate superposition eye-structures that behave like metamaterial with negative refractive index, *JEOS-RP* 1, 06010 (2006).
Walser’s Definition (2001/2)

- macroscopic composites having a manmade, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation
‘Metamaterial’

— composite which exhibits properties:

* not observed in constituents

or

* enhanced relative to properties of constituents
Composite Materials with Viscoelastic Stiffness Greater Than Diamond

T. Jaglinski, D. Kochmann, D. Stone, R. S. Lakes

We show that composite materials can exhibit a viscoelastic modulus (Young's modulus) that is far greater than that of either constituent. The modulus, but not the strength, of the composite was observed to be substantially greater than that of diamond. These composites contain barium-titanate inclusions, which undergo a volume-change phase transformation if they are not constrained. In the composite, the inclusions are partially constrained by the surrounding metal matrix. The constraint stabilizes the negative bulk modulus (inverse compressibility) of the inclusions. This negative modulus arises from stored elastic energy in the inclusions, in contrast to periodic composite metamaterials that exhibit negative refraction by inertial resonant effects. Conventional composites with positive-stiffness constituents have aggregate properties bounded by a weighted average of constituent properties; their modulus cannot exceed that of the stiffest constituent.
Examples:
Particulate Composite Materials
with ellipsoidal inclusions
Homogenizable Metamaterials

- Enhancement of group velocity
- Enhancement of nonlinearity
- Voigt wave propagation
- Bianisotropy
- Negative phase velocity

http://www.esm.psu.edu/~axl4/lakhtakia/documents/Mackay_06_6MRI.pdf
What Next?
Nanotechnology, of course!
 Experience the power of nanoparticle technology.

**nanoNO**

**World's Fastest Nitric Oxide Injection System**

Unleash rapid increases in muscle size! Hardest hitting nitric oxide formula legally available.

Vein-gorging pumps with just 1 dose.

Diffusion ignites in 9 seconds.

By Team MuscleTech**
The Case for Nanotechnological Metamaterials
The Case
for
Nanotechnological
Metamaterials:
CELLULARITY
Nanotechnological Metamaterials

Morphology

Performance

Cellularity

Multifunctionality
Multi-component system = Assembly of different components
Nanotechnological Metamaterials

Multi-component system = Assembly of different components

Component:
Simple action

Assembly of components:
Complex action
Nanotechnological Metamaterials

Supercell
Nanotechnological Metamaterials

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Supercell

Energy harvesting cell

Energy storage cell

Energy distributor cell

Chemisensor cell

Force-sensor cell

Shape-changer cell

Light-source cell

RFcomm cell

IRcomm cell
Nanotechnological Metamaterials

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Supercell

Cellular Phenotypes

Communication cells

Energy cells

Sensor cells

Actuator cells

Light cells
Nanotechnological Metamaterials

Periodic Arrangement of Supercells
Nanotechnological Metamaterials

Superlattice of Supercells
Nanotechnological Metamaterials

Fractal Arrangement of Supercells
Nanotechnological Metamaterials

Functionally Graded Arrangement of Supercells
Nanotechnological Metamaterials

Supercellular Architecture
Nanotechnological Metamaterials

Biomimesis
Nanotechnological Metamaterials

Biomimesis
Nanotechnological Metamaterials

Fabrication

1. Self-assembly
2. Positional assembly
3. Lithography
4. Etching
5. Ink-jet printing
6. ....
7. ....
8. Hybrid techniques
Nanotechnological Metamaterials

A. Lakhtakia

Copyright: Disney World
1. Nanophysics ≠ Bulk physics
   • Danger in scaling!

2. Interaction between cells
   • Incidental
     • Serendipitous
     • Deleterious

3. Defects
Nanotechnological Metamaterials

in a car
Nanotechnological Metamaterials

in a car

Exterior Skin

- Mechanical stiffness
- Shock-absorbing crumple zones
- Maintenance of internal atmosphere

- Harvesting of energy
  * sun
  * overhead lights
  * wireless sources

- Collision-avoidance sensors

- Self-healing paintwork
Nanotechnological Metamaterials
in a car

Front Windscreen
- Mechanical stiffness
- Shatter-safety
- Visibility
- Defrosting
- Sunshine reduction
- Instrument displays
- Magnification zones
Nanotechnological Metamaterials in a car

Dashboard

- Moldings for receptacles
- Airbags
- Antennas for communications
  - GPS
  - Telephones
  - Appliances at home/work
- Biosensors for Driver’s Condition
Nanotechnological Metamaterials everywhere
Intelligent Infrastructure for Living
Nanotechnological Metamaterials everywhere
Nanotechnological Metamaterials everywhere
Nanotechnological Metamaterials everywhere

The Downside
Nanotechnological Metamaterials everywhere

The Downside

1. Social Footprint
   * Public health and safety
   * Worker health and safety
   * Privacy

2. Ecological Footprint
   * Waste management
   * Air, soil, water contamination
Nanotechnological Metamaterials everywhere

Management of the Downside

Researchers’ Responsibilities

1. Scenario Planning
2. Impact Studies
3. Public Education
"That's all Folks!"