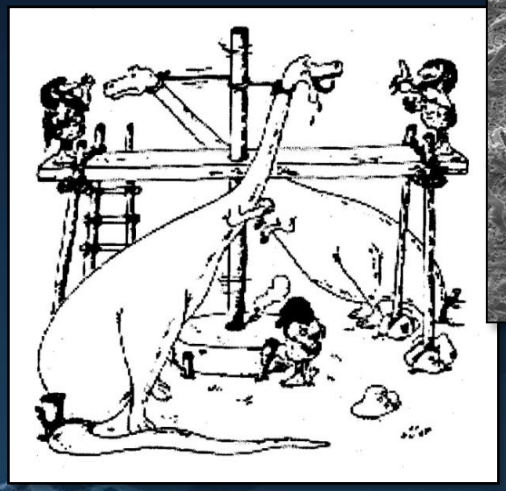
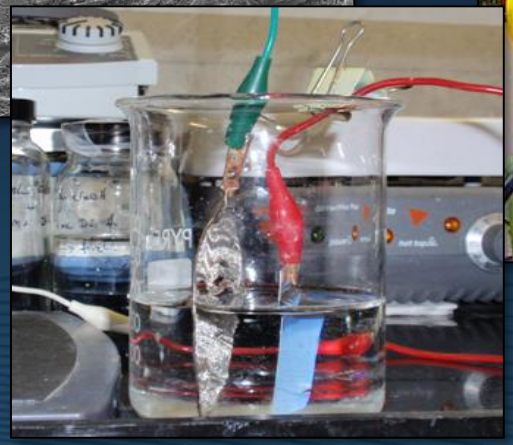
Multiscale Manufacturing of Fractals

Prelude to Humanitarian Engineering



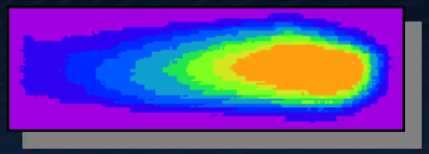


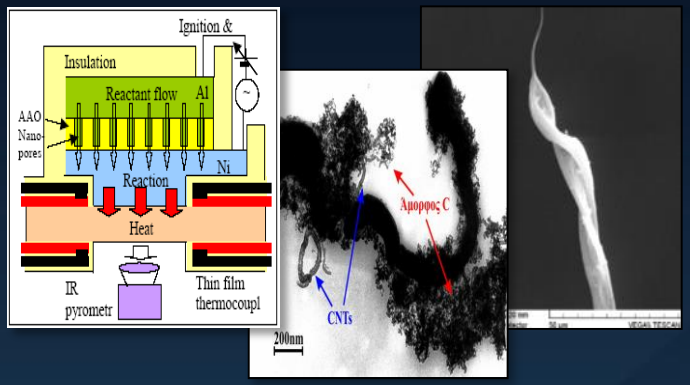
Dr. Haris Doumanidis, Marie Curie Professor

Presented at Purdue University – March 2013

Outline and Overview

* *Background and Philosophy in Manufacturing*





* *Current Multiscale Manufacturing Research*
  - Nanoheaters: Reactive sources in rapid thermal processing , microfluidic MEMS, microjoining/coating, self-sintering), breast cancer hyperthermias
  - Featherweights and ultrasonic nanocomposites for wind turbines, aviation, construction
  - Bioscaffolds for tissue engineering, drug delivery

* *Manufacturing Fractals:*
  solar fabrics, cooling, photodendra; vascular erythropoietic tissue, platforms, transportation; fractal art science

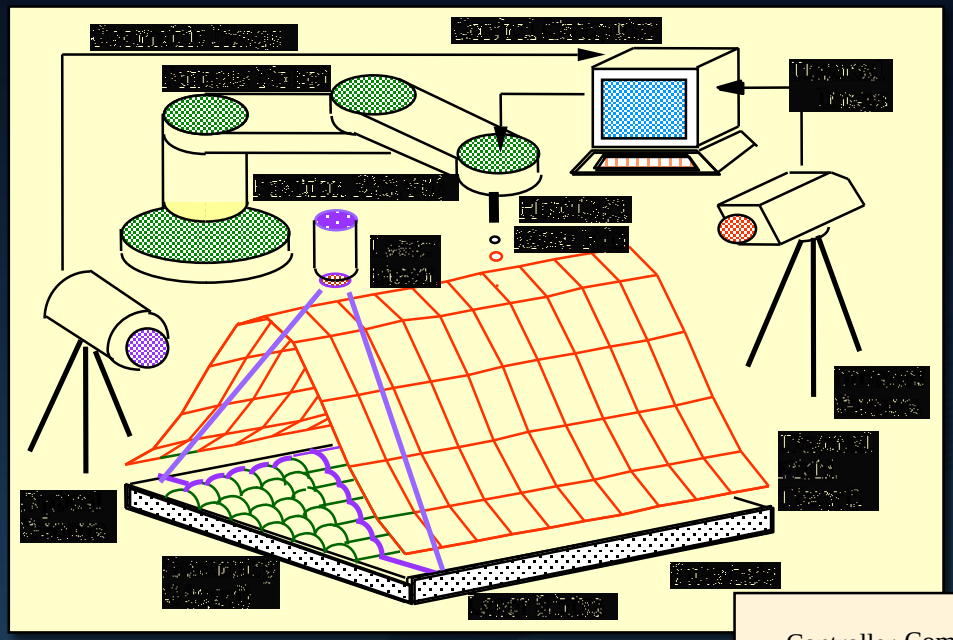
* *Teaching, Laboratories and Students*

* *Service at NSF Nanomanufacturing Program*

* *Humanitarian Engineering:*
  Vision and Planning

* *Epilogue and Credits*

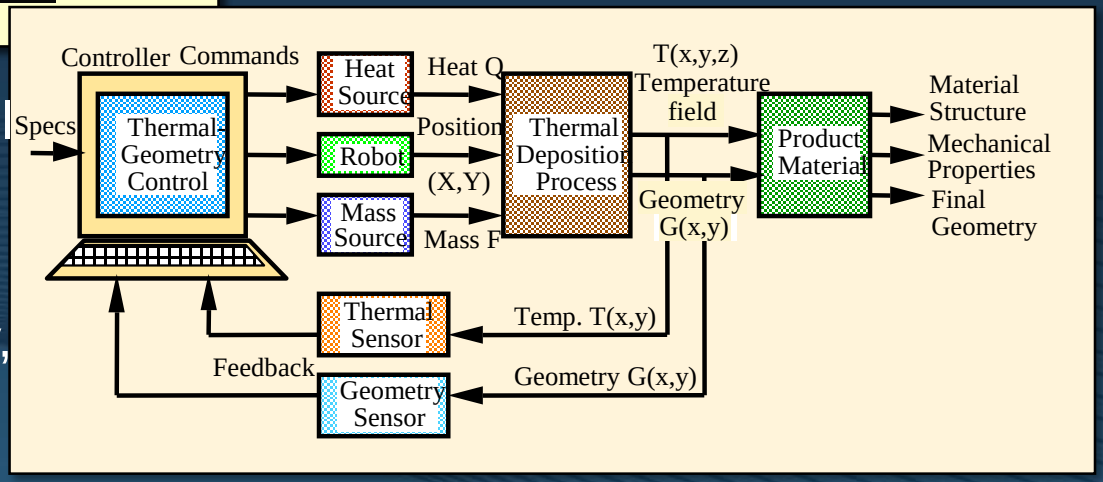
Manufacturing Transport - Process Modeling & Control



* Distributed-parameter, dynamic, coupled material-geometric fields
* Lumped-parameter, serial/scanned mass, energy, information transfer
* Thermal/diffusion & geometry field monitoring on external surface

PROCESS → STRUCTURE → → PROPERTIES → FUNCTIONS

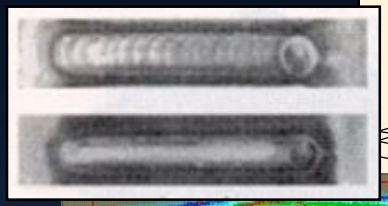
* Feedback/feedforward control
* Actuation of power, material feed and source trajectory
* Sensory feedback: pyrometry, profilometry, microscopy….

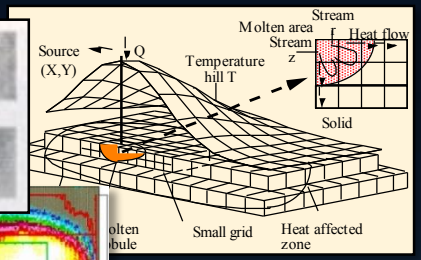


(e.g. Doumanidis C, Hardt D, Simultaneous In-Process Control of HAZ & CR Arc Welding, *Welding J* 69(5), 1990)

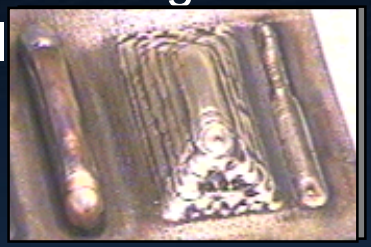
Previous Research in Macro- & Micro- Manufacturing

HONDA
The Power of Dreams
NSF
axcelis

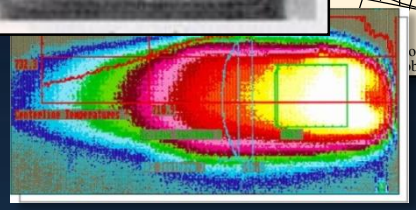




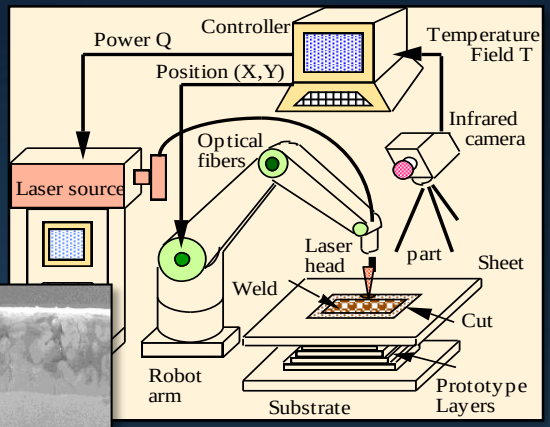
Scan Welding and Thermal Processing
-Adaptive DPS Robotic Control



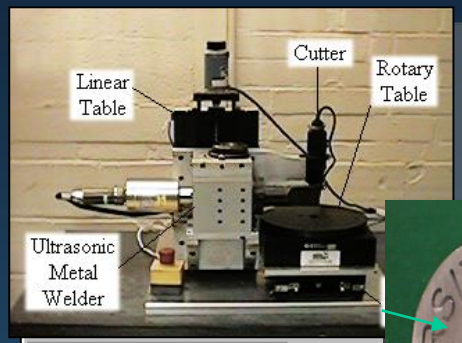
Scanned Rapid Manufacturing
- Material Deposition &Cutting

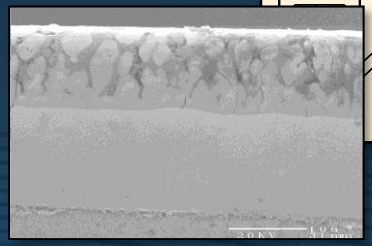


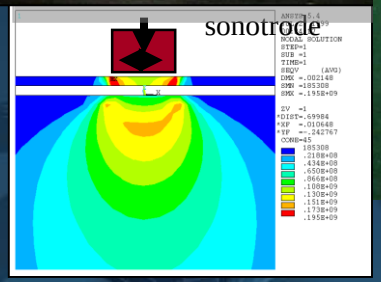
Metal Matrix Composite Coatings
By Welding of Layered Precursors

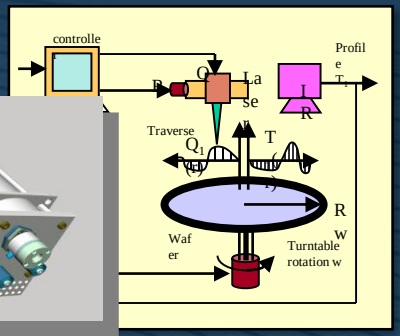


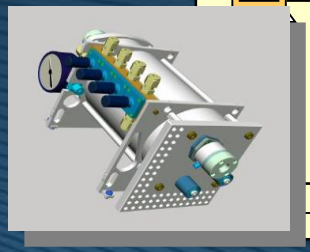
Ultrasonic Rapid Manufacturing of
Multi-Material Layered Devices











Active Deformable Surfaces, Tools

Rapid Thermal Processing, Scanned Annealing

(e.g. Fourligas N, Doumanidis C, Thermal Distr Control in Scanned Proc of Materials, *ACC 1998* (Best Paper Award))

Closed-Loop Control of Distributed-Parameter Processes

Linear spatial/temporal error operators

$$q(R;t) = K_a e(R) + \frac{K_G}{V}\int_{P\ t} e(P)\exp\left[-\frac{|P-R|^2}{s^2}\right]dV + K_L\nabla^2 e(R)$$

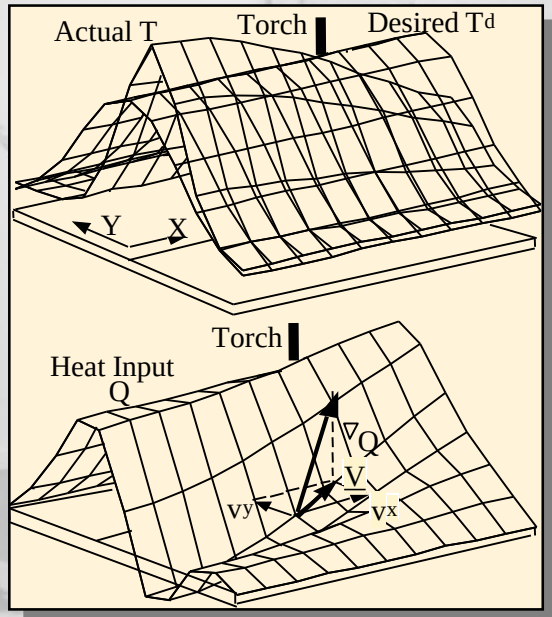
$$Q(R;t) = K_P q(t) + K_I\int_0 q(\tau)d\tau + K_D\frac{\partial q}{\partial t}(t)$$

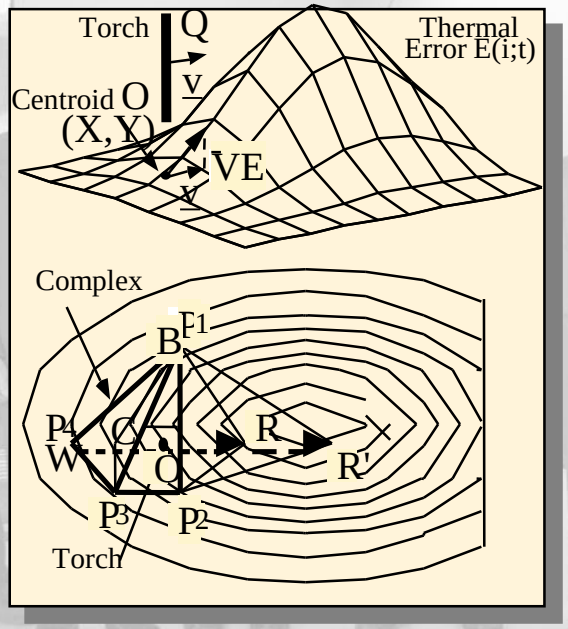
MIMO Linear Quadratic Regulators

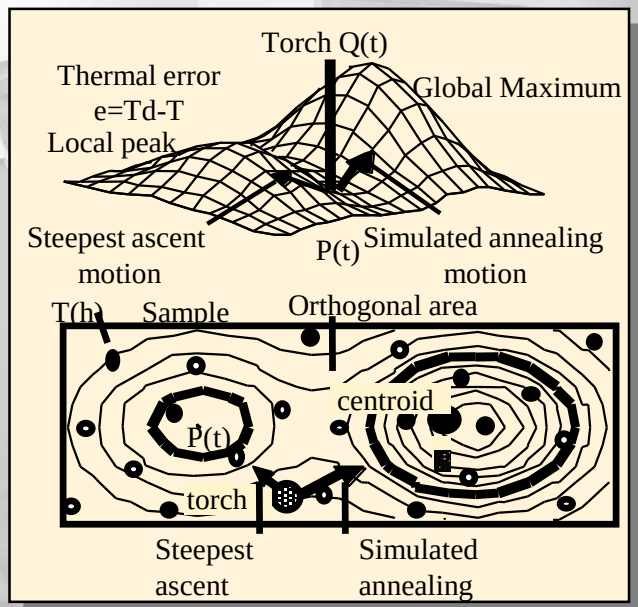
$$J(t) = \int_0^t \left[\underline{e}^T(\tau)\, S\, \underline{e}(\tau) + \underline{q}^T(\tau)\, R\, \underline{q}(\tau)\right] d\tau$$

$$-P(t) = A^T(t)\,P(t) + P(t)\,A(t) - P(t)\,B(t)\,R^{-1}\,B^T(t)\,P(t) + S$$

$$Q(t) = -R^{-1}B^T(t)P(t)e(t)$$







Steepest ascent gradient:

$\underline{V}$=k*grad(T)

Complex polytope:

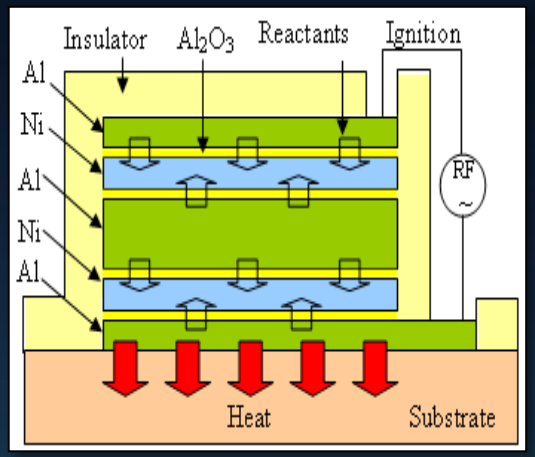
* Reflection * Expansion
*Contraction * Reduction

Simulated annealing:

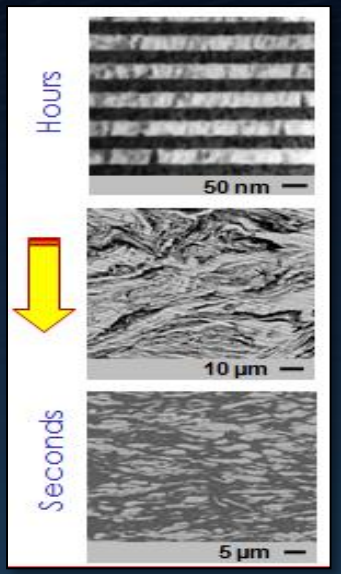
$$\mathcal{P}(P(h)') \sim \exp\left(-\frac{|P(h)'-P(t)|}{2u(t)}\right)$$

(e.g. Doumanidis C, Multiplexed and Distributed Control of Automated Welding, *IEEE Control Sys Mag* 14(4), 1994)

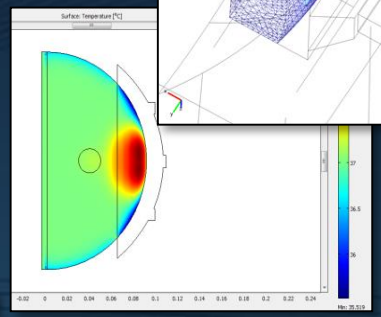
Nanoheaters: Miniature Ignitable Reactive Heat Sources



* Exothermic material system thin film multilayers or powder consolidates
* Controlled electrical or thermal ignition and heat conduction to substrate/bulk

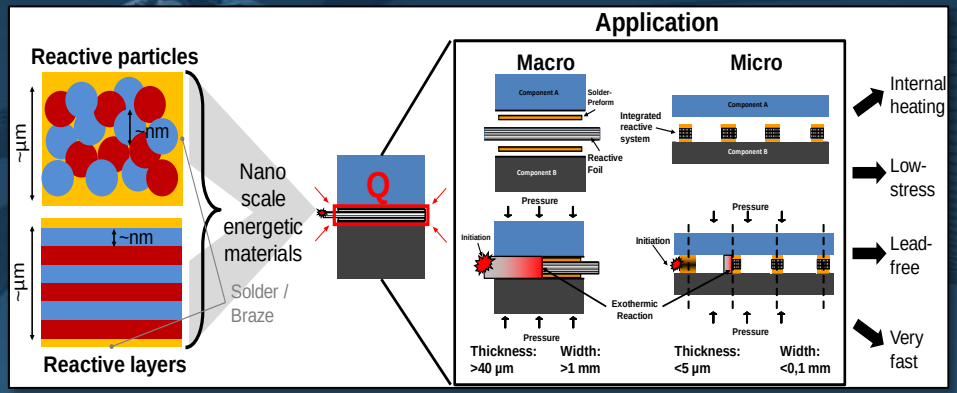


* Breast cancer hyper-thermias - MRI, laser, µwave (EPOS)

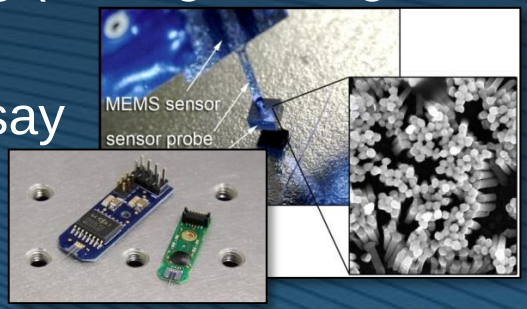


* In-situ local rapid thermal processing in semiconductor devices (Axcelis)
* Microcoating and microjoining (Bosch)

* Self-sintering powder (Siemens), pyro-technics (Fukuda)



* Rock fracturing (mining, drilling, CCS)
* Metastatic cell compliance assay µfluidic chips (Femtotools)



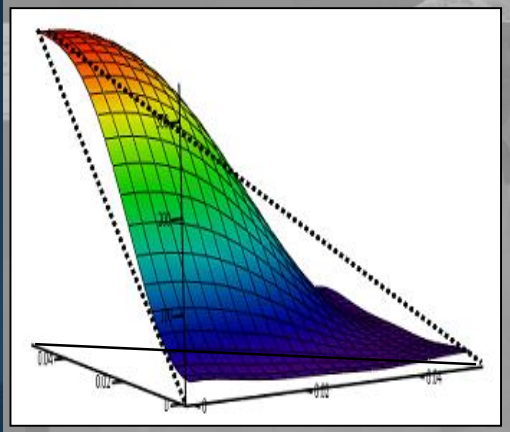
Distributed-Parameter Control and Observation of Conduction/Diffusion

Galerkin optimization of energy penalties with Green interpolation functions:

$$R_V(P;t)=\rho c\frac{\partial T_d}{\partial t}(P;t)-\nabla\left(K\nabla T_d(P;t)\right)+h\left(T_d(P;t)-T_\infty\right)\quad R_S(R';t)=K\frac{\partial T_d(R';t)}{\partial n}-Q_S(R';t)$$

* DSP controllability space and controller by linear deconvolution:

$$\int_t^\infty\left[\int_V G(P,R',\tau-t)*R_V(P;t)dV+\int_S G(R,R',\tau-t)*R_S(R';t)dS\right]d\tau=0$$

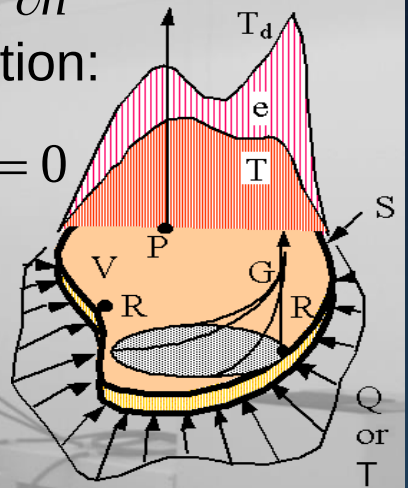


2D control of temperature distribution

$$G(x,y,x',y',\tau,t)=\frac{1}{\rho c}*$$

$$\frac{}{4\pi\alpha(\tau-t)}*$$

$$\sum_{n=-\infty}^{\infty}\left[\exp\left[-\frac{(2nL+x-x')^2+(2nL+y\mp y')^2}{4\alpha(\tau-t)}\right]+\exp\left[-\frac{(2nL+x+x')^2+(2nL+y\mp y')^2}{4\alpha(\tau-t)}\right]\right]$$



* DSP observability and observer by backward deconvolution:

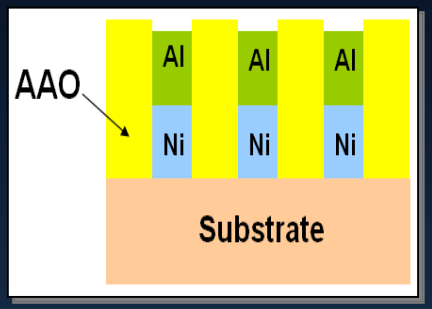
$$\int_0^t\int_S G(R,P',t-0)*h\left(T_S(R;t)-T_\infty\right)dSdt=$$

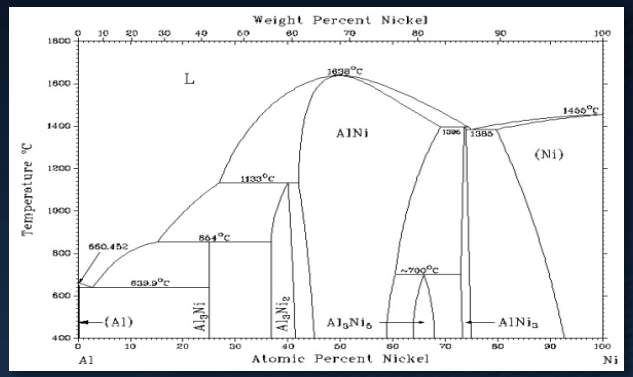
$$\int_0^t\int_S G(R,P',t-0)*K\int_V\frac{\partial G(R,P,t-0)}{\partial n}\rho cT(P;0)dVdSdt$$

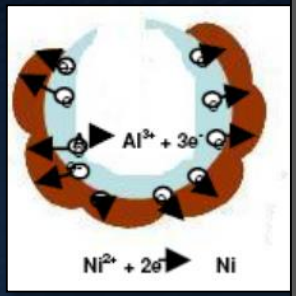
(e.g. Alaeddine M, Doumanidis C, Distributed-Parameter Thermal Controllability, *IJ Num Meth Eng* 59(7), 2004)

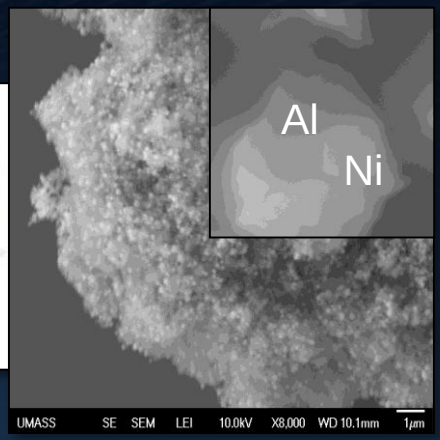
Nanoheater Dots (0D) and Nanowires (1D)

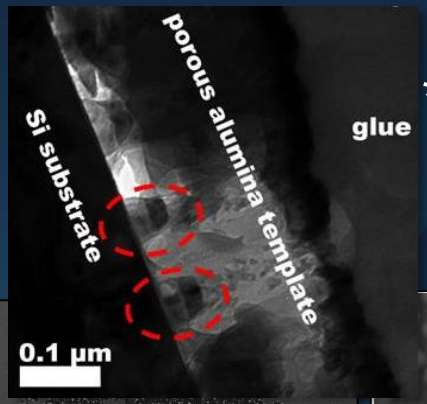
* Al-Ni bimetallic nanoheaters in AAO templates





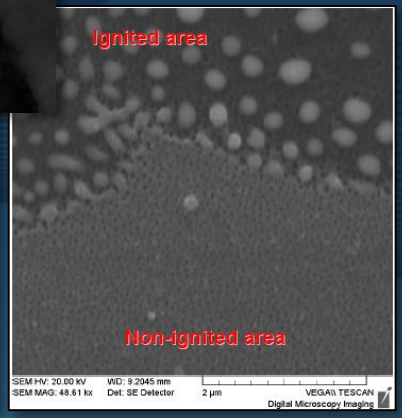


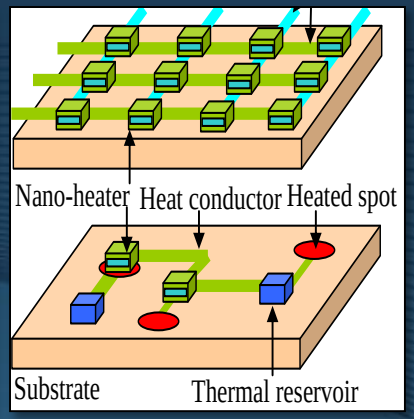




* Nanodot bilayers by e-beam evaporation in AAO templates

* Hollow core-shells by galvanic replacement of Ni on Al powder (*Z. Gu, UMLowell*)

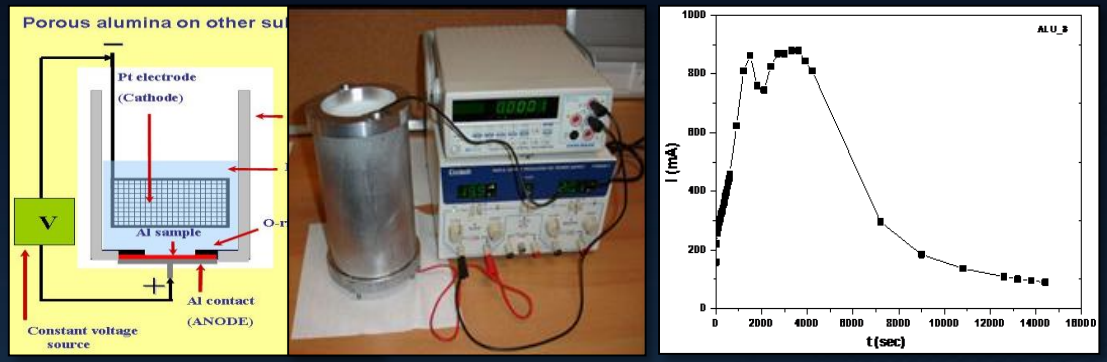




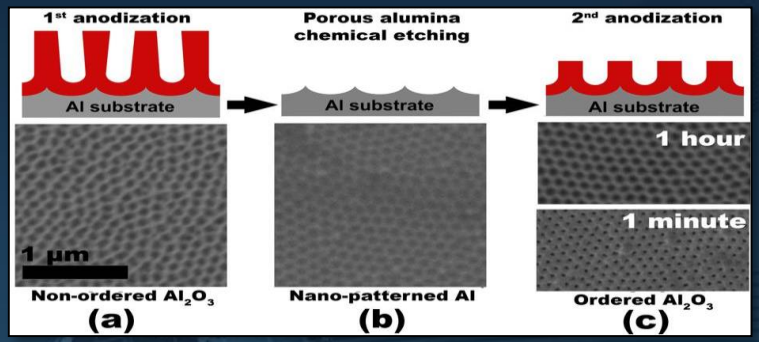
* Ni-Al nano-wires by Al shell evaporation on templated Ni wires

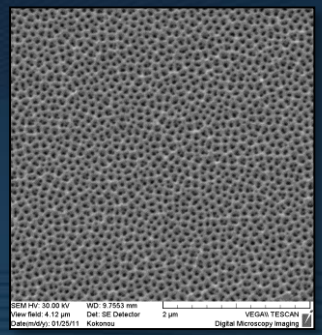
(e.g. Kokonou M, Rebholz C, Giannakopoulos K, Doumanidis C, "Fab nanorods in AAO", *Nanotechnology* 18, 2007)

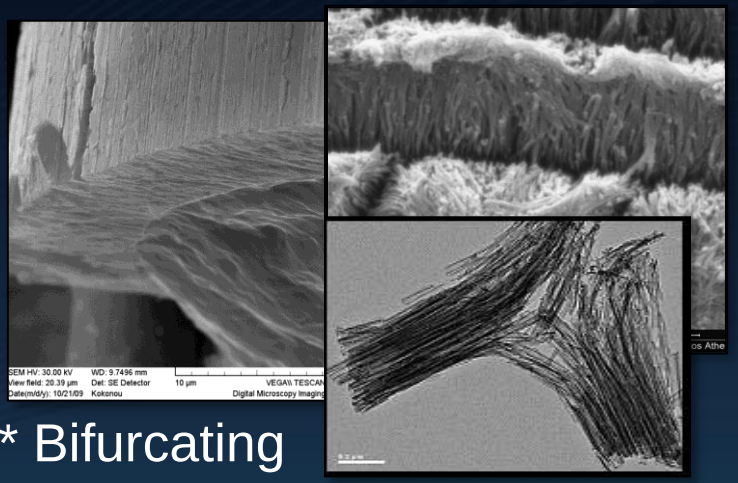
Nanoheater, Nanodot and Nanowire Templating by Anodized Al Oxide



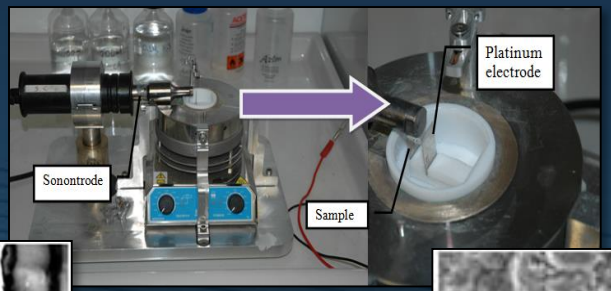
* Double anodization in electrochemical cell

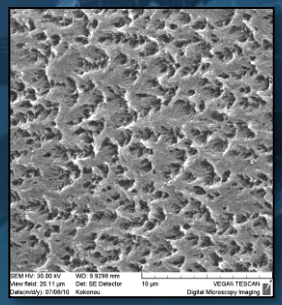




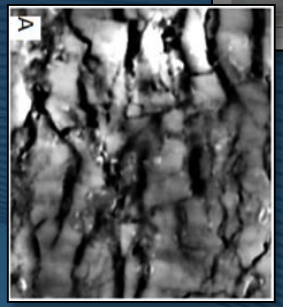


* Bifurcating AAO nanotubes on wire surface

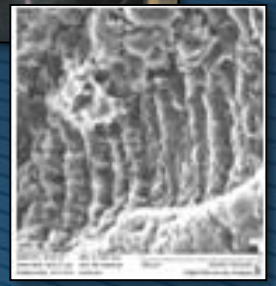




* Sol-gel CeO_2 nanowires
* Sputtered W, Cr nanodots
* Ni nanowires/nanoheaters
* PMMA branch membranes



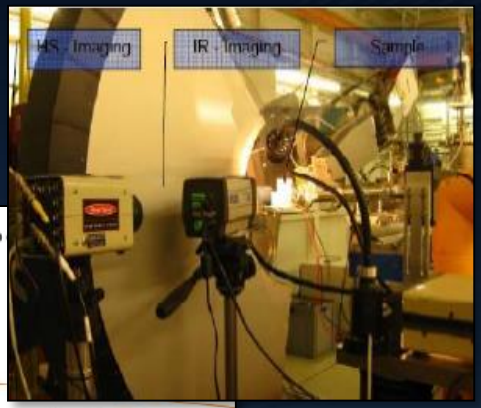
* Ultrasonic anodization of intestinal template

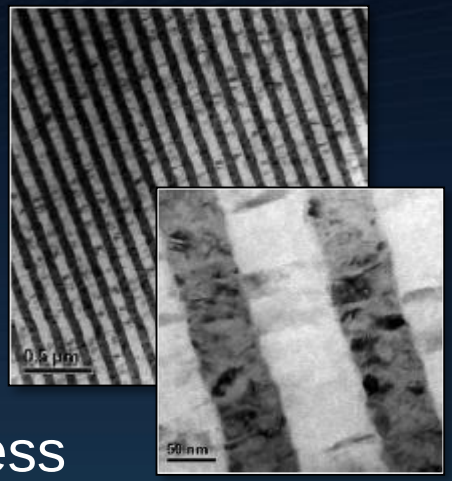


(e.g. Kokonou M, Giannakopoulos K, Doumanidis C, "Low Aspect Ratio AAO", *Microelectronics Eng 85*, 2008)

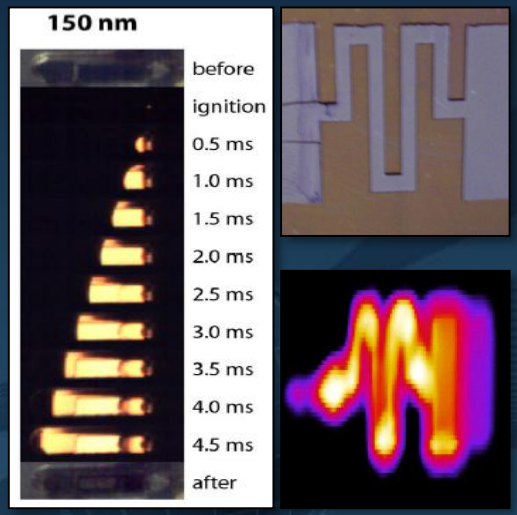
Nanoheater Multilayer Foils (2D)

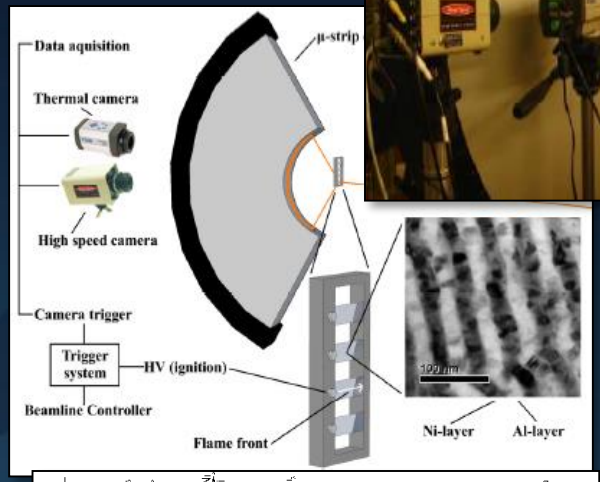
* Twin thin film sputtering PVD

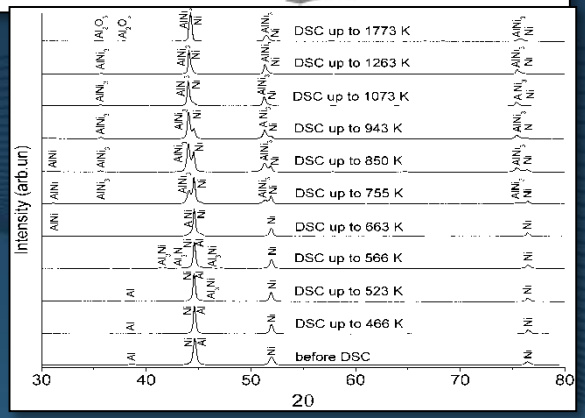


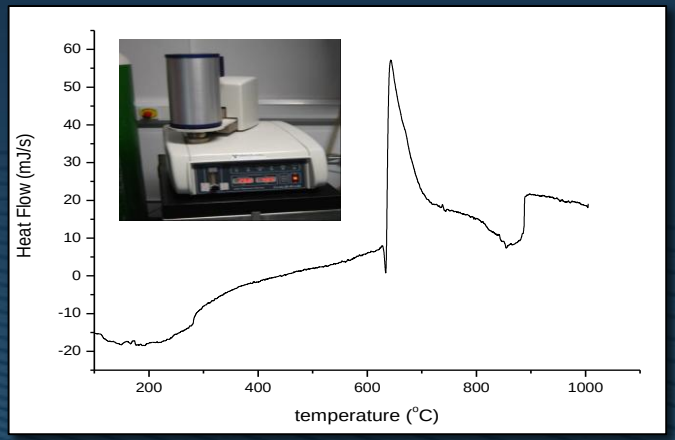


* In-process synchrotron XRD at PSI







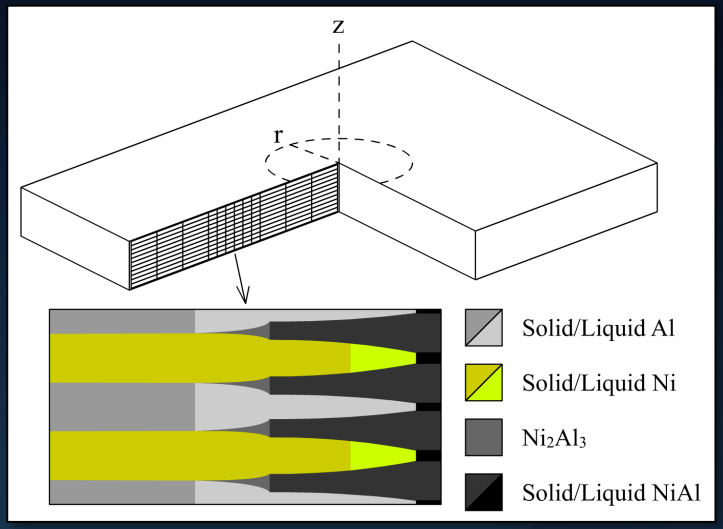


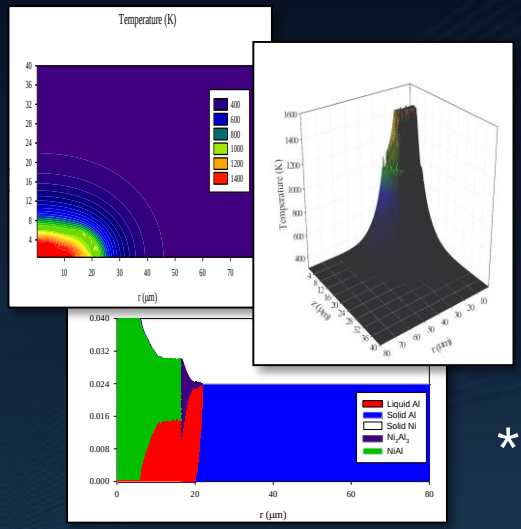
* Infrared pyrometry & high-speed video

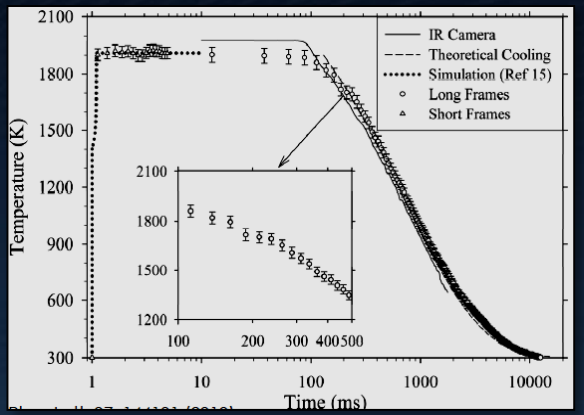
* DSC exotherm enthalpies

(e.g. Fadenberger K, Rebholz C, Doumanidis C, "In-situ Observation of Ni-Al…Sync Radiation", *APL* 9 (1), 2010)

Self-Propagating Exothermic Reaction Thermal Numerical Simulation





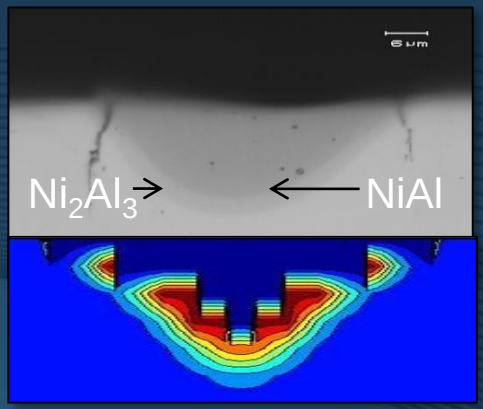


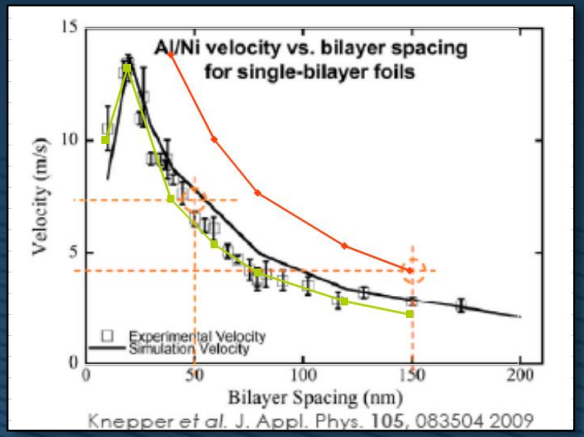
* Temperature validation by infrared pyrometry

$$H_{r,z}^{t+1} - H_{r,z}^{t} = \frac{\Delta t \cdot \Delta k_r}{\left(\rho(T_{r,z}^t)\cdot C_p(T_{r,z}^t)\right)^2}\frac{dk}{dT}\left[\left(\frac{T_{r+1,z}^t - T_{r-1,z}^t}{2\Delta r}\right)^2 + \left(\frac{T_{r,z+1}^t - T_{r,z-1}^t}{2\Delta z}\right)^2\right]$$
$$+ \frac{k(T_{r,z}^t)}{\left(\rho(T_{r,z}^t)\cdot C_p(T_{r,z}^t)\right)}\frac{\left(T_{r+1,z}^t - 2T_{r,z}^t + T_{r-1,z}^t\right) + \left(T_{r+1,z}^{t+1} - 2T_{r,z}^{t+1} + T_{r-1,z}^{t+1}\right)}{2\Delta r^2}$$
$$+ \frac{k(T_{r,z}^t)}{\left(\rho(T_{r,z}^t)\cdot C_p(T_{r,z}^t)\right)}\frac{\left(T_{r,z+1}^t - 2T_{r,z}^t + T_{r,z-1}^t\right) + \left(T_{r,z+1}^{t+1} - 2T_{r,z}^{t+1} + T_{r,z-1}^{t+1}\right)}{2\Delta z^2} + \alpha\Delta H_r$$

* Polar 2D, dynamic FDM of conduction/diffusion field, parabolic reaction kinetics

* 2-stage Ni_2Al_3-NiAl transformation





* SPER front & velocity

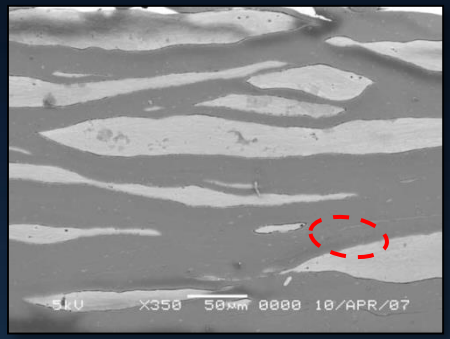
(e.g. Gunduz I.E, Rebholz C, Doumanidis C, Ando T, "Modeling of SPER in Ni-Al Multi-Foils", *JAP 105 (1), 2009*)

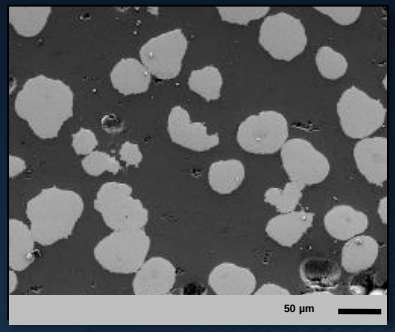
Nanoheater Pellets (3D) by Ultrasonic Powder Consolidation

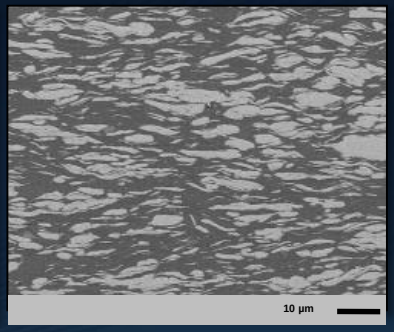
FUKUDA METAL FOIL & POWDER CO.,LTD.

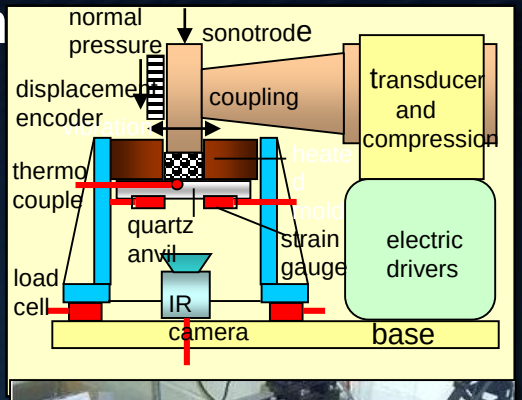
HONDA The Power of Dreams

* Preheated ultrasonic consolidation of Ni & Al micropowders & flakes

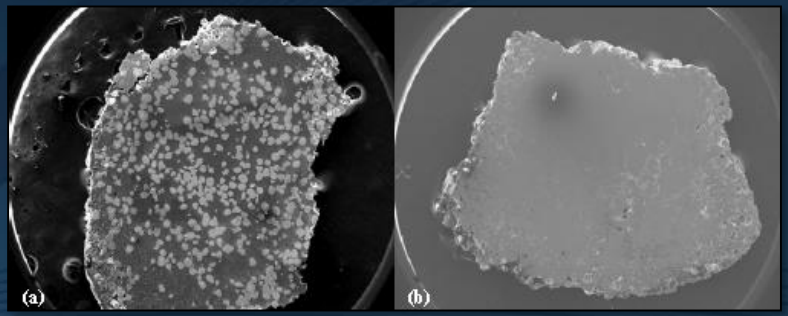


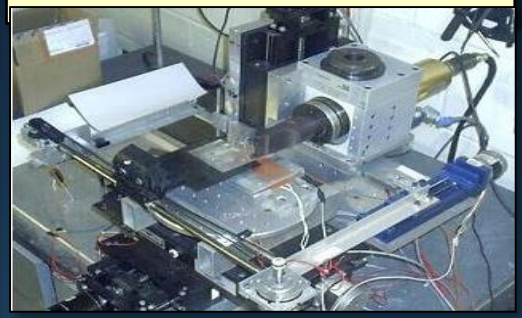




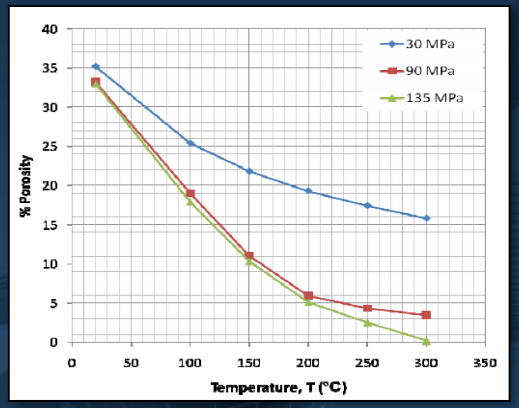


* Fold & Roll bonding of Ni & Al multifoils

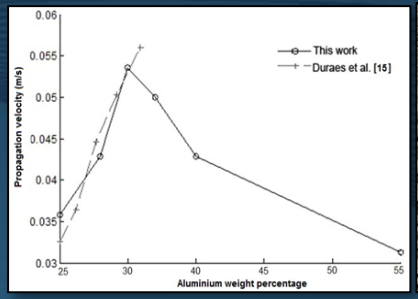


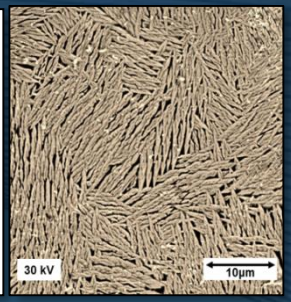


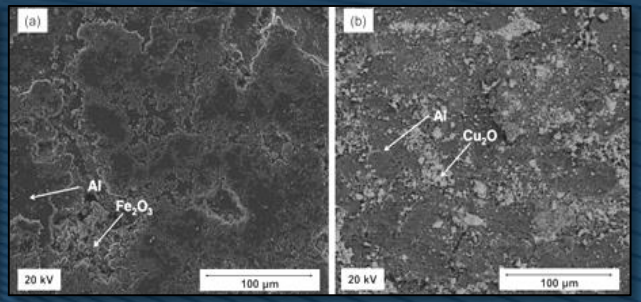
* Al/Fe_2O_3 and Al/Cu_2O thermite consolidates



* Pressure/temperature affects density & speed

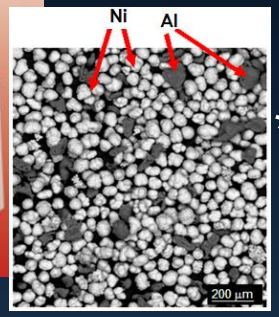




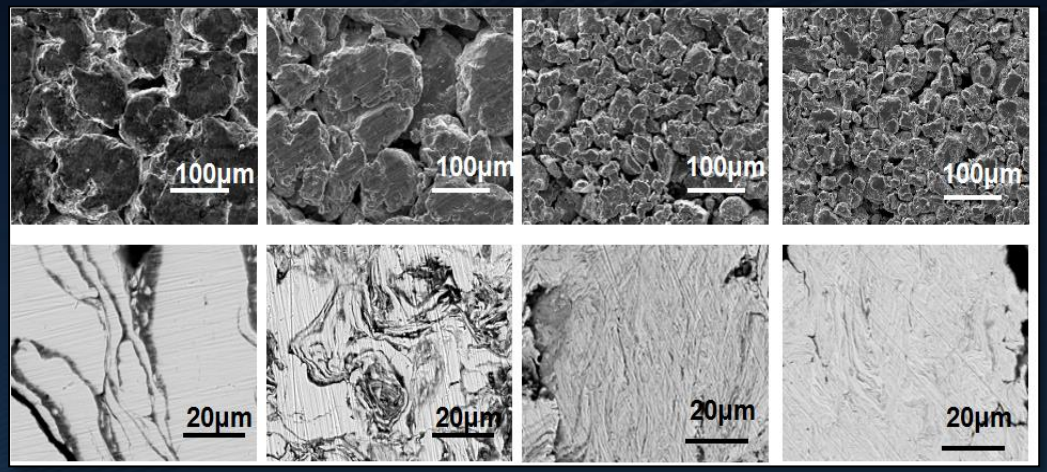


(e.g. Pillai S, Ando T, Doumanidis C et al "Ultrasonic Consolidation -Ignition of Thermite Composites", *IJACT 2011*)

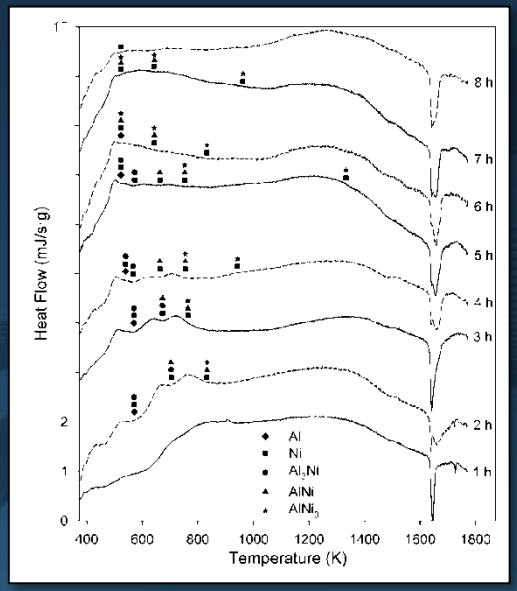
Nanoheater Compacts (3D) by Mechanical Alloying



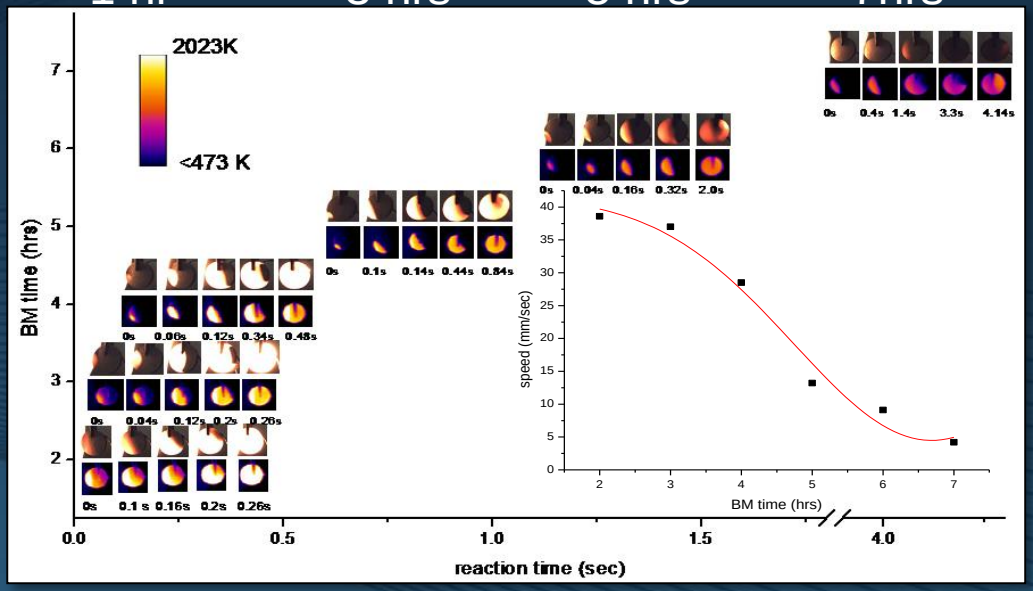
* Ball milling of Al & Ni powders
* Pressure compaction to pellets



* DSC – XRD identified phase transforms: Al_3Ni-AlNi-$AlNi_3$



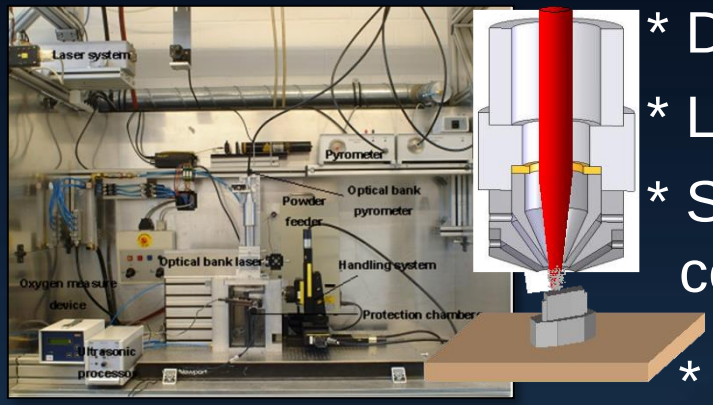
*Ignition: IR pyrometry & HS video for reaction time/speed



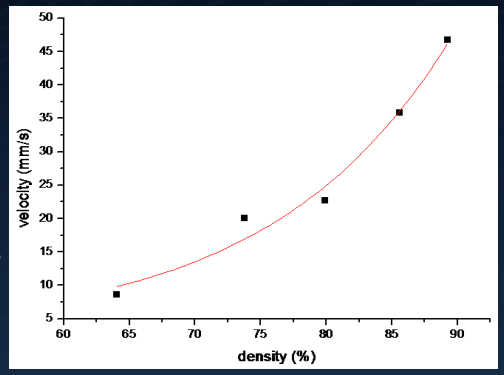
(e.g. Hadjiafxenti A, Doumanidis C et al, "Synthesis of Reactive Al-Ni Structures by BM", *Intermetallics* 18 (2010))

Selective Laser Consolidation of Self-Sintering BM Powders

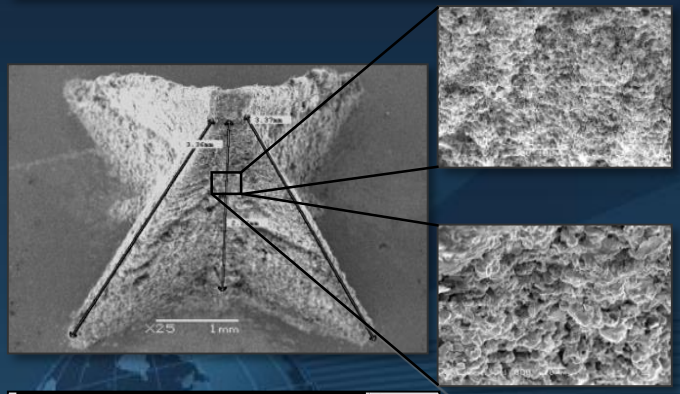
SIEMENS

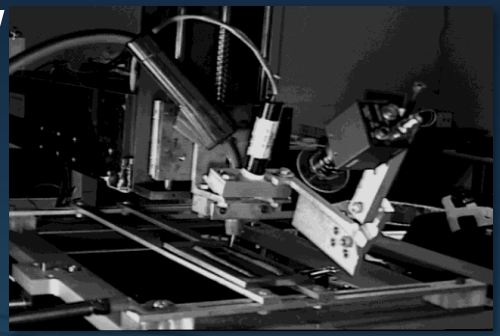


* Direct precision sintering
* Laser/aerodynamic focus
* Self-sintering metal and ceramic with BM powders

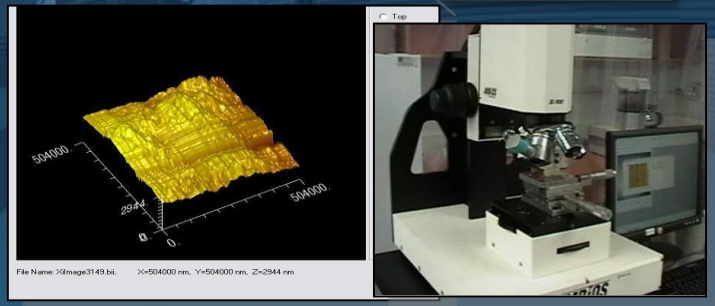


* Laser ignition - sintering density – SPER velocity/ size - enthalpic release

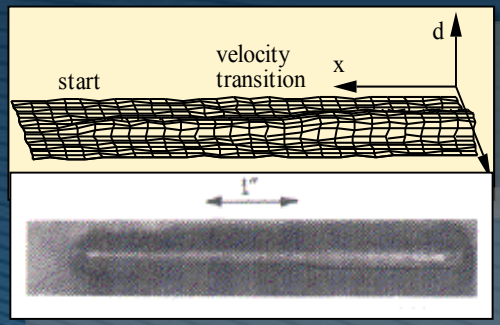




* Deposition geometry & material transformation modeling for RT control



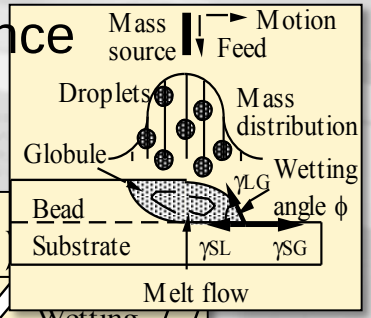
* Rapid prototyping feature analysis by off-line profilometry

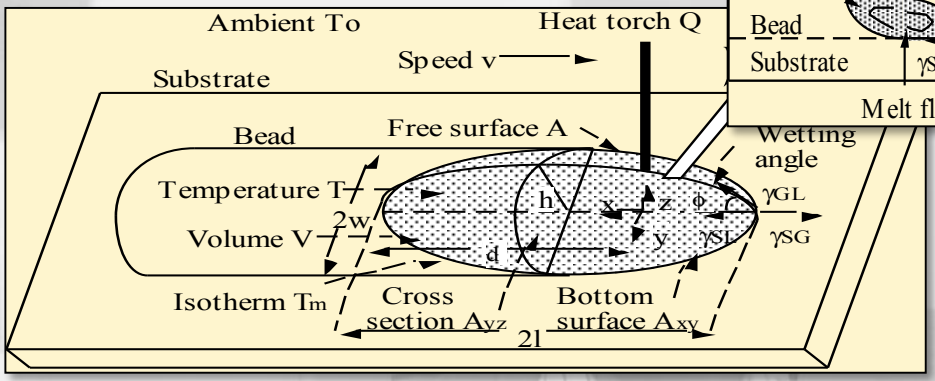


(e.g. Ioannou Y, Fyrillas M, Polychronopoulou K, Doumanidis C, Analytical Model Geometrical, *IJ NanoMan* 2009)

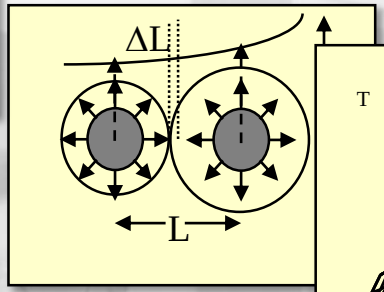
Modeling for Control of Deposition Geometry and Material Structure

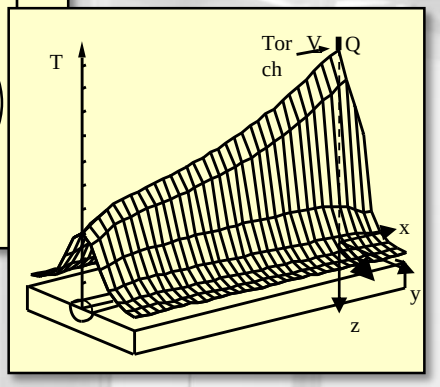
- Mass, momentum, energy balance
- Wetting and conduction field
- Source model and identification

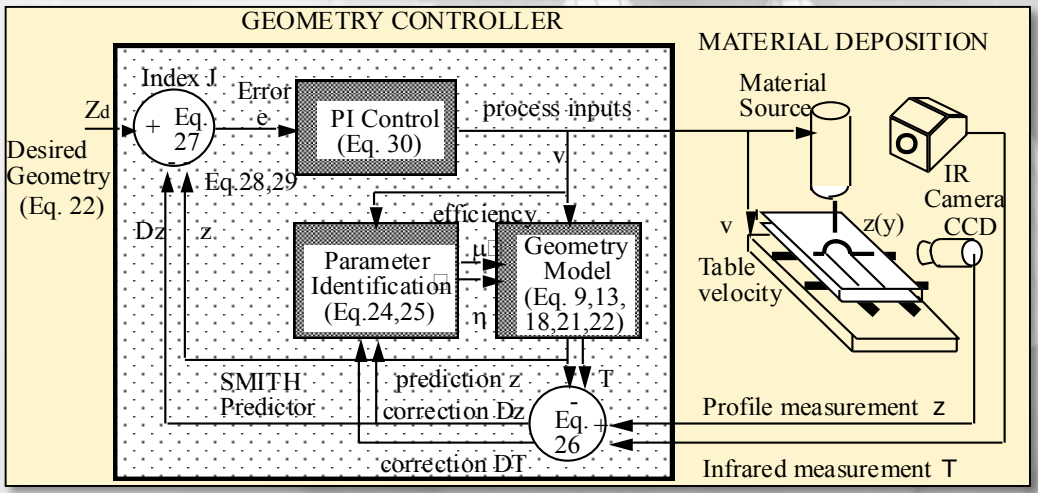




- Rosenthal temperature field
- Arrhenius transformation rate
- Confined grain growth







$$\upsilon = U \exp\left(\frac{-E}{RT}\right)$$

Point $$T - T_o = \frac{Q}{2\pi kr} \exp\left(\frac{Vx}{2\alpha}\right) \exp\left(\frac{-Vr}{2\alpha}\right)$$

Line $$T - T_o = \frac{Q}{2\pi kh} \exp\left(\frac{Vx}{2\alpha}\right) K_o\left(\frac{-Vr}{2\alpha}\right)$$

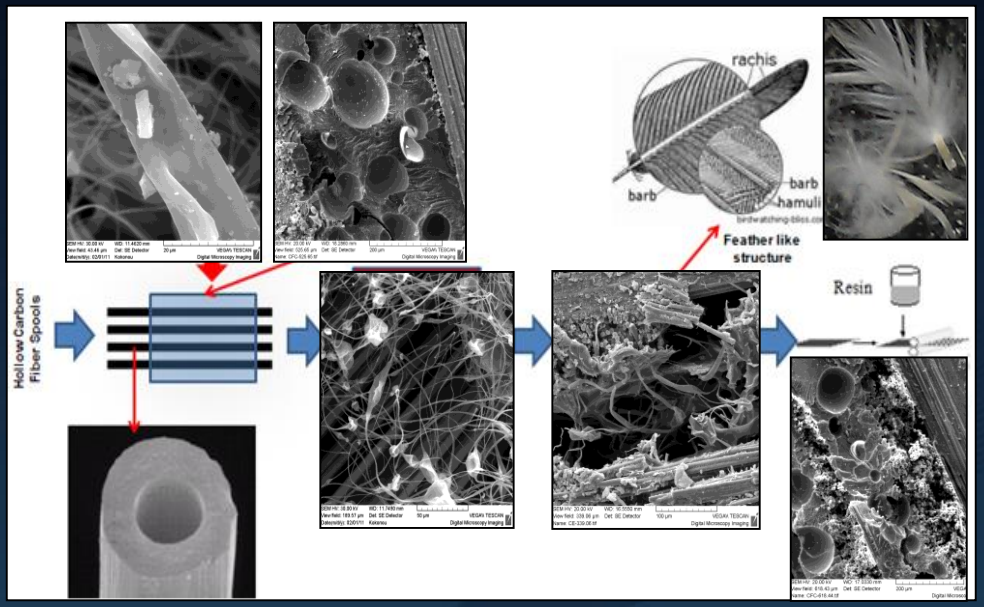
$$\frac{\Delta W}{W} = \left(\frac{\Delta L}{L}\right)^3 = -\frac{EL^2}{4RT^2}\left[\nabla^2 T - \frac{2}{T}(\nabla T)^2\right]$$

(e.g. Doumanidis C, Kwak YM, Multivariable Adaptive Control of Bead Profile Geom, *IJ Pres Ves Pip*. 79(4), 2002)

Featherweight Composites For Aviation and Wind Turbines

BOEING

'TORAY'
Innovation by Chemistry

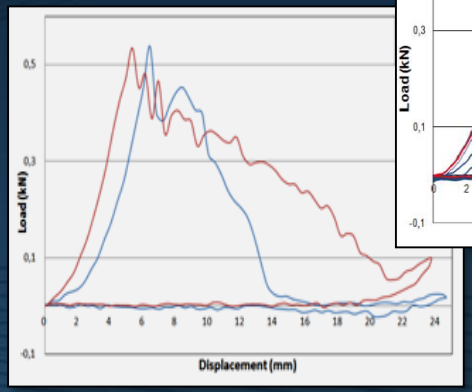


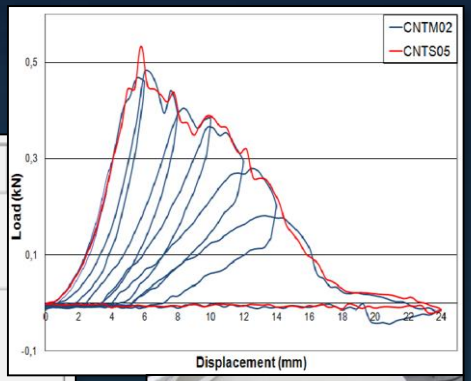
*Feather-like fractal-hollow core:
C microfibers-electrospun fibers-CNT

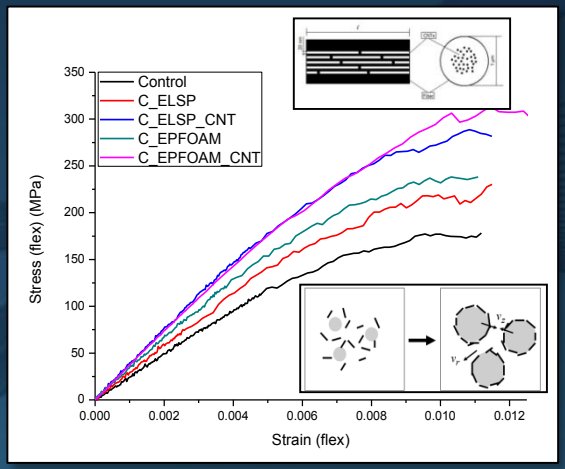
*Interlayer epoxy foam,tangential CNT

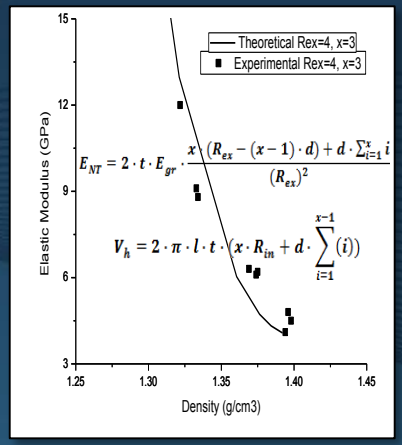
*Self-heating matrix epoxy resin/foam

* CFRP laminate composites





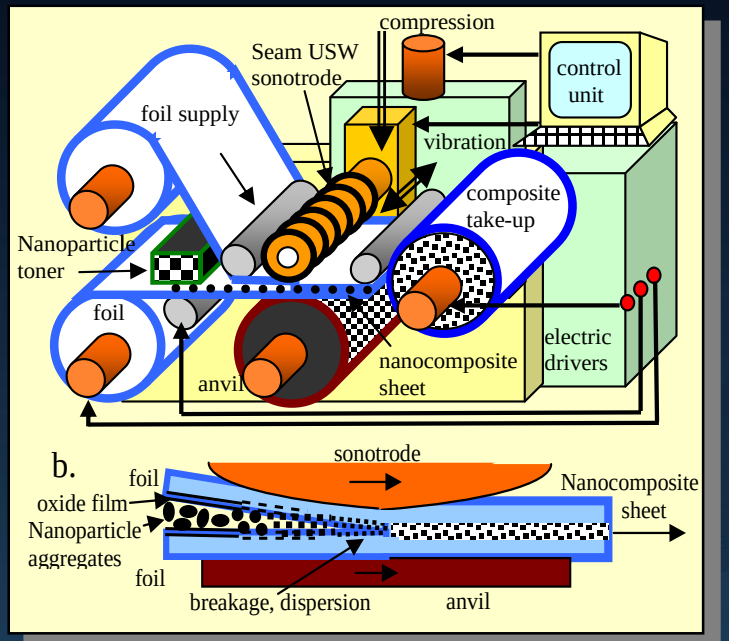




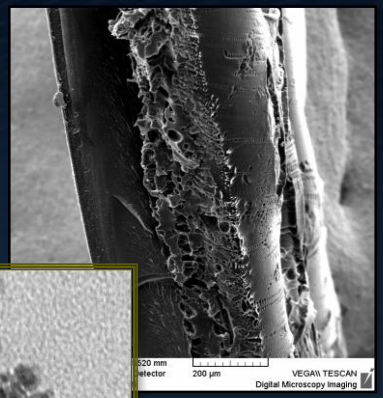
* Strength/weight ratio
* Interlayer adhesion
* Electrical conductivity
* Non-autoclave low-cost manufacture

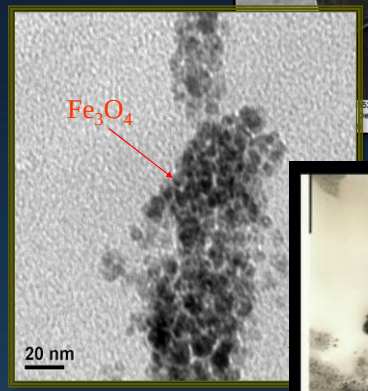
(e.g. Drakonakis V, Seferis J, Wardle B, Nam J, Papanikolaou G, Doumanidis C, *Acta Astronautica J*, 2010)

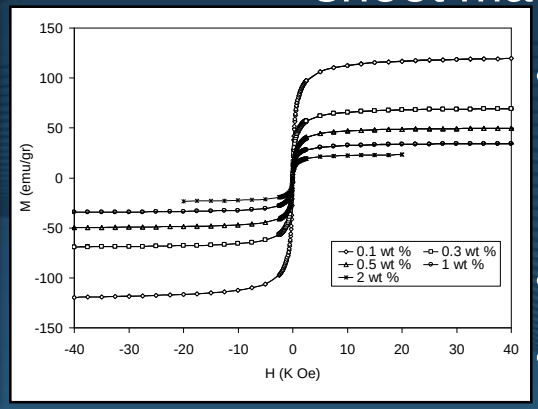
Nanocomposite Multilayer Foils by Ultrasonic Welding



* PVC, Al sheet matrix with magnetite, MWNT, CA fibers
* Spin coating deposition, continuous seam USW
* SEM/TEM analysis, mechanical DMA, magnetic PPMS
* Universal precursor nanocomposite sheet materials



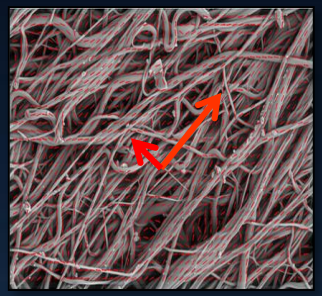


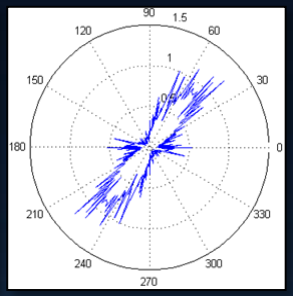


- Ultrasonic levitation, agglomeration, orientation, percolation of particles
- High ferromagnetic saturation
- Reinforcing and biodegradation

(e.g. Christophidou A, Viskadourakis Z, Doumanidis C, "Structural, Magnetic…by USW", *J Nano Research 10*, 2010)

Modeling of Strength and Permeability of Fiber Membranes

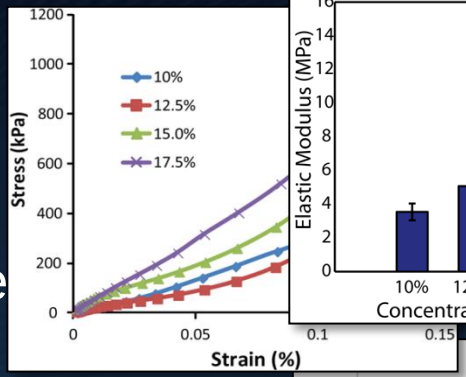


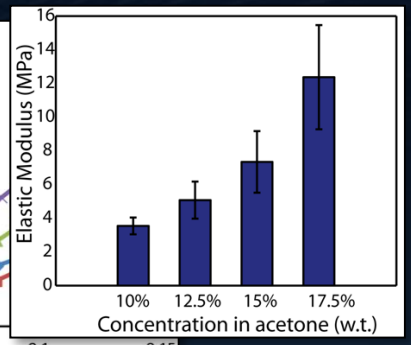


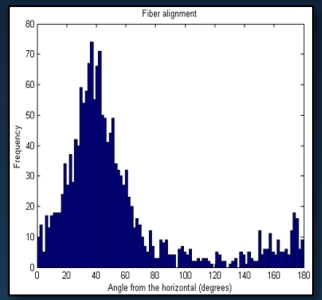
*Anisotropic fiber mesh

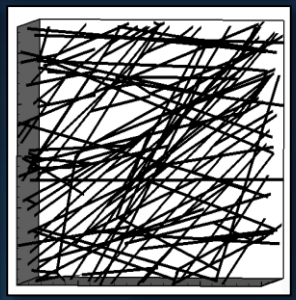
*Spatial Fourier trans-form/ Fiber alignment histogram

*In Silico microstructure



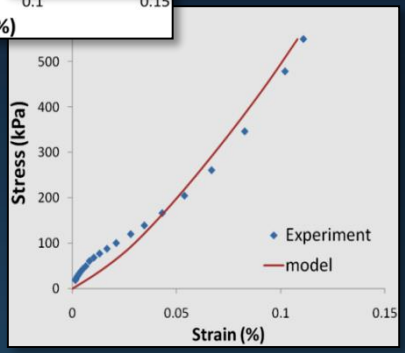




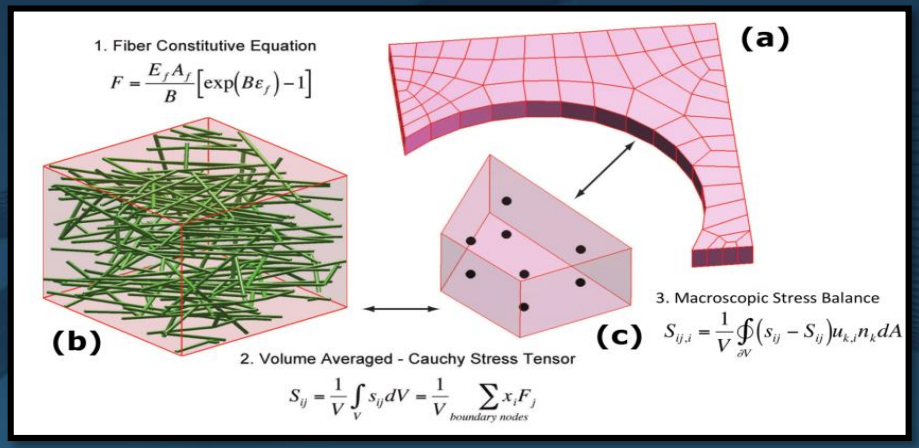


* Multiscale force balance by volume averaging theory

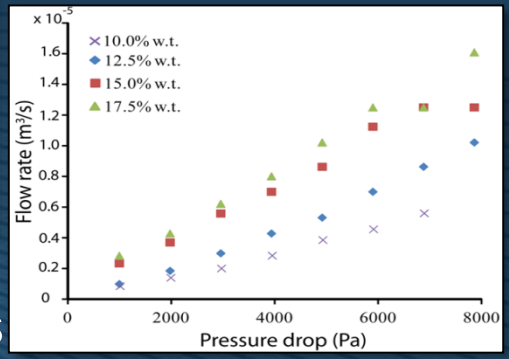
* DMA tensile tests of meshes



* Fiber properties



* Darcy hydraulic permeation tests



(e.g. Stylianopoulos T, Kokonou M, Doumanidis C, "Characterization of Mech & Transport..", *Proc 3rd IC4N*, 2011)

Bioscaffolds and Composites by Fiber Electrospinning

EPOS-IASIS

*Fiber electrospinning 3D rapid prototyping

* Cellulose acetate, PMMA, PEO/PLLA

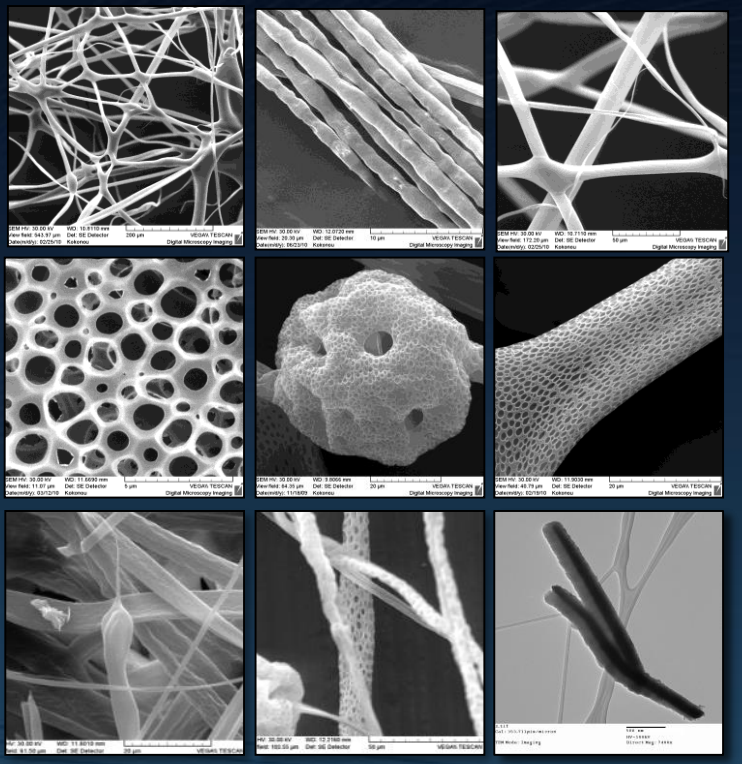
*Nonwoven, oriented, connected networks

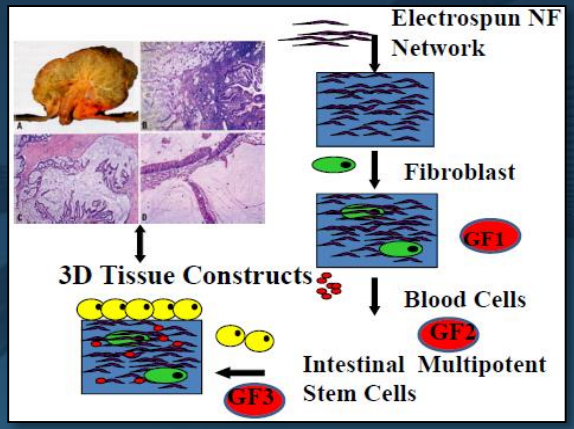
* Fibers, belts, beads,

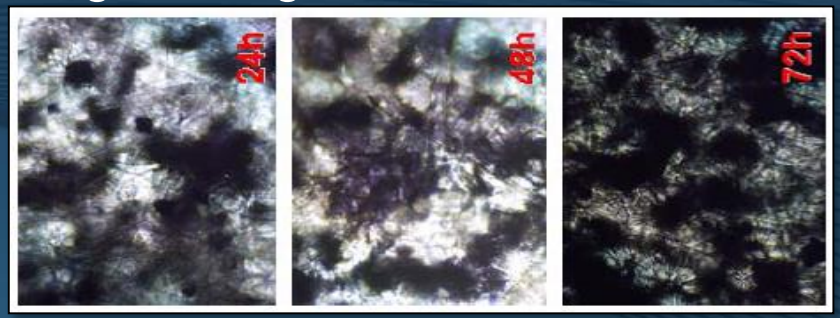
* Nanoporous foams

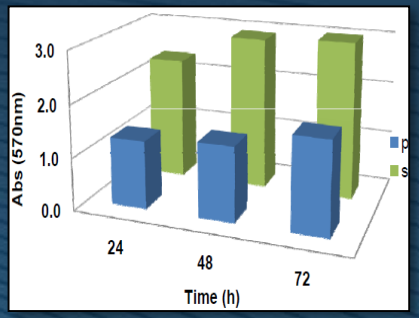
* Coaxial core-shells with Fe_3O_4 nheaters

* Intestinal tissue engineering





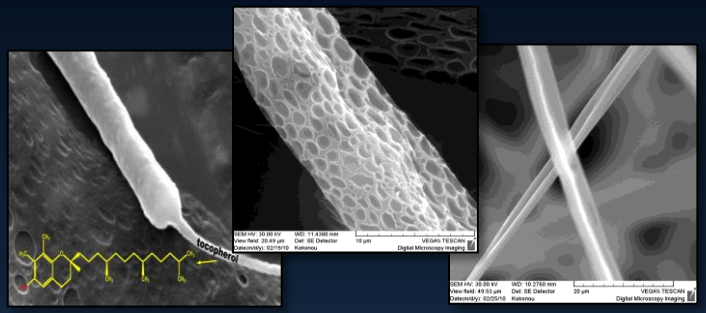




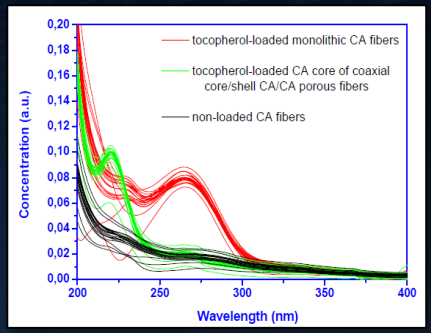
(e.g. Christoforou T, Doumanidis C, Biodegradable CA Nanofiber Fab by Electrosp, *Trans IMechE JNN* 2009)

Drug Delivery by Loaded Scaffolds Nanocombs and Nanocapsules

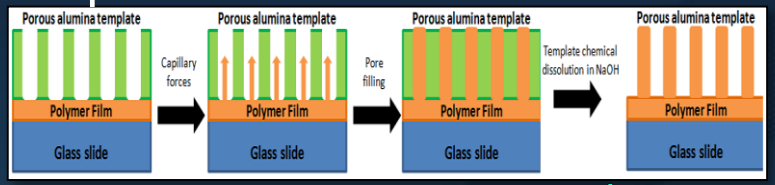
Regulon
Improving Human Life™

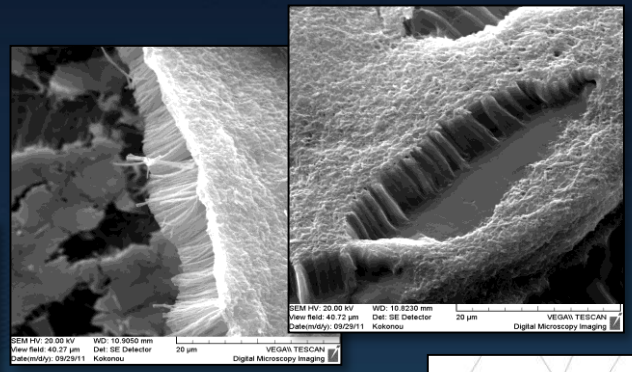


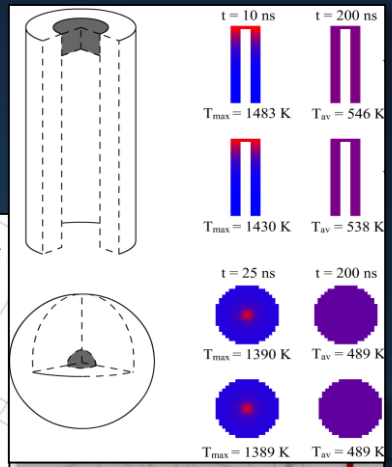
* Tocopherol Growth Factor and Ibuprofen in CA/porous
* Pharmacokinetics by UV/Vis

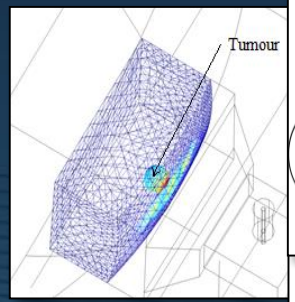


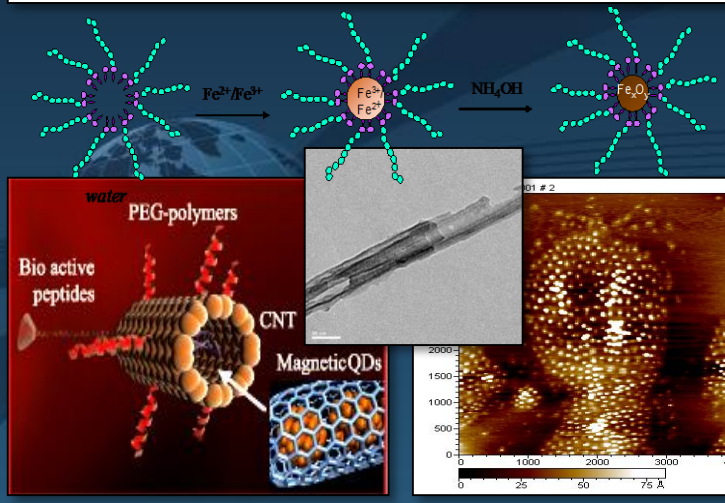
*AAO Templated Nanocombs: Naproxen in PEO/PLLA









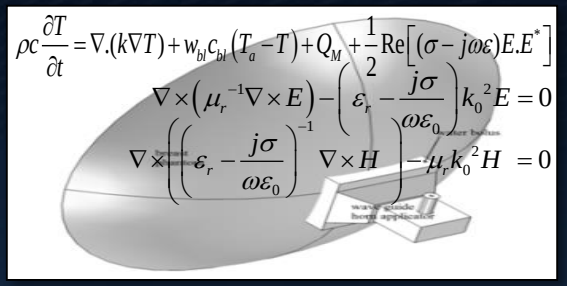


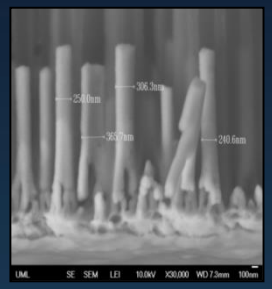
* PEGMA-b-AEMA micelles by RAFT w/doxorubicin
-MRI guidance
-Antibody docking
-hyperthermia response
* Nanoheater capsule and implant thermal simulation

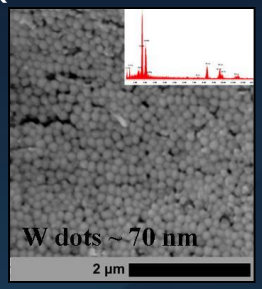
(e.g. Trifonos A, Kokonou M, Doumanidis C, Odysseos A, "Coaxial Nanofibers…Release", *Proc 3rd IC4N*, 2011)

Research Resources and Impacts

* *European Com* FP6/7, Marie Curie, Interreg [€ 2.61M]
* *Research Promotion Foundation* [€ 1.05M]
* *National Science Foundation* [$ 2.54M]
* Industry (*Honda, Boeing, Toray, Siemens* etc) [$ 2.32M]
* Universities etc (*Tufts, UCY, NAE, NIST, DoE*) [0.62M]

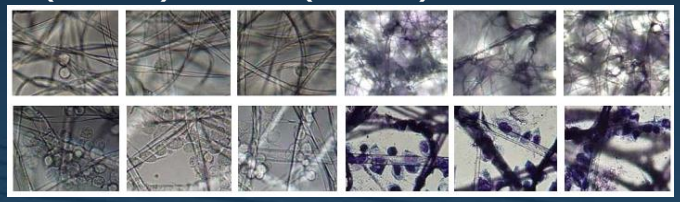


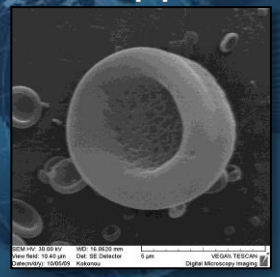




* EC *Marie Curie Excellence Team* (2006)-Nanoheaters
* EC *Marie Curie Chair* (2004)-Ultrasonic Laminates
* ASME *Blackall Manufacturing Award* (2002)
* White House *Presidential Faculty Fellow* (1996)
* NSF *Young Investigator* (1994), *RIA* (1992)

* US Patent # 5,552,575-Scan and Orbital Welding
* US Patent # 6,450,393-Ultrasonic Rapid Prototyping
* US Pat Appl UML06-17-Nanoheater Systems





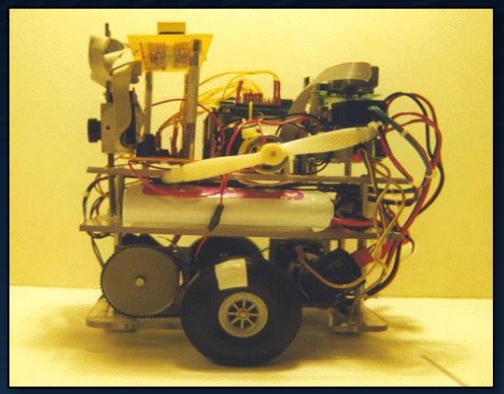
* AVS/ICMCTF Best Paper 2011- Ni-Al multilayers (w K. Fadenberger)
* *ISNM* Best Paper 2005-Nanosource DPS (w M. Alaeddine, T. Ando)
* *ASME JMSE* Best Paper 2002-Material deposition (w YM Kwak)
* *ACC* Best Paper 1998-Thermal scanning (w N. Fourligas)

* Plenary/keynote lectures *: ICN, AMPT, VW Fdn, JRC, ASME, IIW, MNE, MRS, CIRP*
* Cited by *J Szekely†, E Kannatey-Asibu, S G Tzafestas, RJ Goldstein, ERG Eckert†*

Introductory, Undergraduate and Advanced Manufacturing Courses

*Prototyping Home Robots
*Art by Rapid Prototyping
*Engineering Laboratory

- diverse audience: engineering orientation, communication skills, constructivist projects, design contest

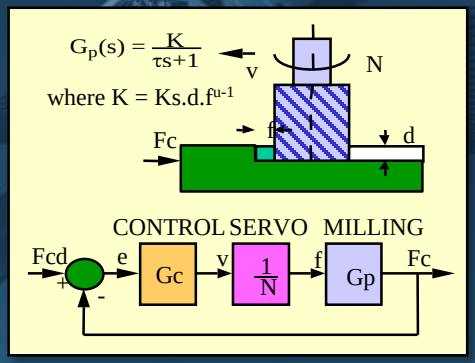


*Advanced Eng Controls
*Thermal Manuf. Processes

-Research training; sustainability, societal, ethical, entrepreneurship, intl market & industry exposure

*Dynamic Systems
*Design & Manufacture

-connect with science back-ground, hands-on labs, intro to manufacturing, teamwork



*Computer-Controlled Systems
*Manuf. Process Automation
*Introduction to Robotics

-manufacturing modeling & control tools, leadership & management skills, fore-taste of research, industrial internships

(e.g. Doumanidis C, Thermomechatronics, Chap V in *Mechatronics*, C. Leondes Ed, Gordon & Breach 2000)

Manufacturing, Controls & Robotics Laboratories at Tufts and UCY

* Thermal Manufacturing Laboratory
  -Robotic welding, rapid prototyping, pyrometry, profilometry
* Robotics and Controls Laboratory
  -Experimentation workstations, SCARA/mobile robots, 3D digitizers
* Tufts Prototyping Shop
  -3D printers, CNC mills and lathes

* Prometheus Manufacturing Laboratory
  -Machine-shop, rapid prototyping/scanning, robotics & laser lab
* Micro- & Nano-Systems Laboratory
  -SEM/AFM microscopy, spectroscopy, profilometry, lithography
* Introductory Engineering Laboratory
  -12 computer-controlled general experimentation

* Adv. Characterization Laboratory
  -Spec preparation, microscopy, mech. tests
* Systems Assembly Shop
  -Wood and metal construction and assembly
* Internal Combustion Engines Lab
  -ICE generators, exhaust analyzers
* Biomedical Engineering Laboratory
  -Fiber scaffold electrospinning and culturing

Graduate Advising, Thesis Supervision

(8 Phd+6 pending, 26 MS+2 pending)

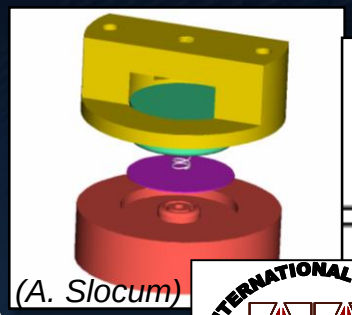
Artemis Agelaridou, PhD - *Factory Mutual*
Marios Alaeddine, PhD- *Harvard Children's Hospital*
John Angelis, MS – *ELVAL Greece*
Raj Chowdhury, MS - *Applied Materials/UEC*
Theopisti Christoforou, MS - *Hellenic Bank*
Vasilis Drakonakis – *Polymeric Composites Lab*
Ravindra Durvasula, PhD – *GE Materials*
Nikos Fourligas, PhD – *Harvard/McLean*
Yuan Gao, MS – *China Helicopter*
Glory Hardjadinata, MS – *Infovalue Comp*
Dirie Herzi, MS – *Dell Computer*
Georgia Ioannou, MS – *Univ of Surrey*
Norbert Johnson, MS - *Medtronic/BI*
Yong-Min Kwak, PhD - *GE Aircraft Engi.*
Robert Lind, MS - *Tufts University*

Joey Mansour, MS – *Boston University*
Brian Marquis, MS – *Volpe Natl Transportation Ctr*
Ioannis Martinos, MS – *MIT/Thenamaris Shipping*
George Papanikolaou, MS – *Papanikolaou Assoc*
Loucas Paraschis, *CISCO Systems Intl.*
Anastasia Paskaleva, MS – *MIT Mechanical Eng*
Kyriakos Roushia – *Univ of Cyprus/Hephaistos*
Eleni Skordeli, MS – *Fakas Consulting, CY*
Harry Sfetsos, MS – *Self-Employed Consulting*
Emily Shattuck, MS - *Philips Medical*
Marios Stylianou, MS – *Cyprus Automation Ltd*
Hiep Tran, PhD - *Varian Semicon/PRI Automation*
Alex Tsai, MS – *Univ. Puerto Rico Mayaguez*
Olga Vayena, PhD – *ELVAL Greece*
Shailendra Yadav, MS - *MIT Broad Inst/Neumitra*

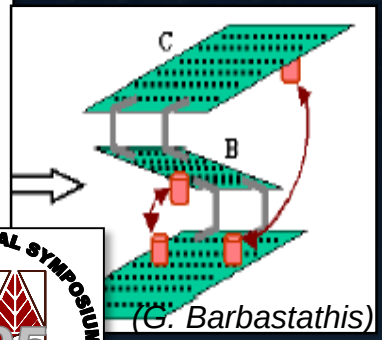
NSF Nanomanufacturing Program

(www.nsf.gov/div/index.jsp?div=CMMI)

* Focus on manufacturing *scale-up* issues for market-scale, sustainable production: *producibility, predictability, productivity*
* Emphasis on system *up-scaling* design, and multidisciplinary, multiscale integration *nano-structures → functional devices → system architectures → products & services*

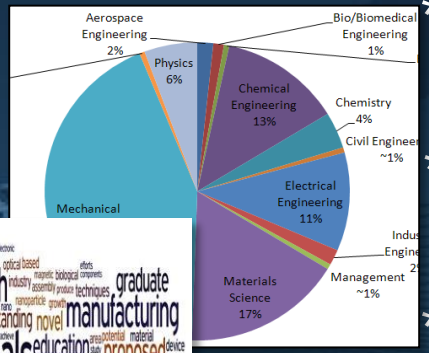


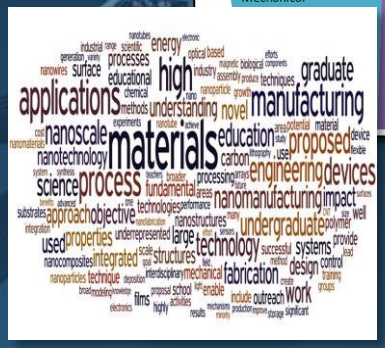
(A. Slocum)



(G. Barbastathis)

3RD INTERNATIONAL SYMPOSIUM 2005 UCY NANOMANUFACTURING

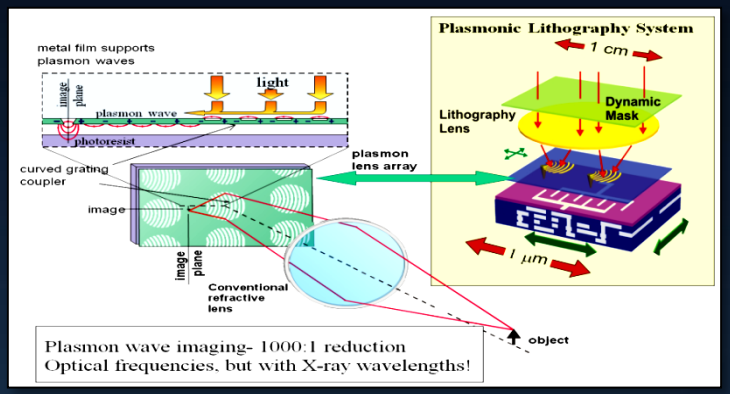




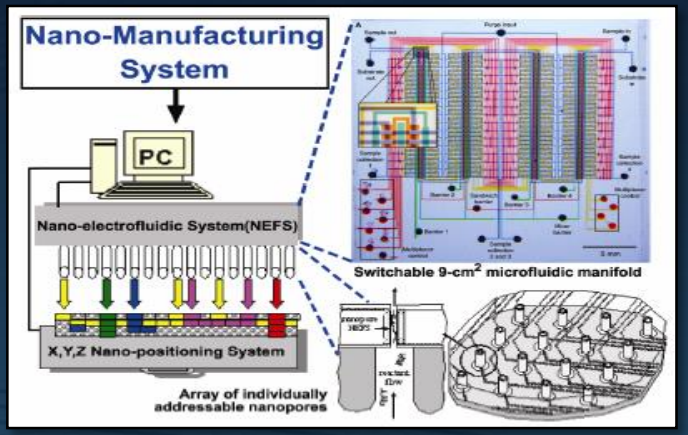
* Education and jobs for people, transformative concepts and ideas, technology platform tools
* Emphasis on environmental-health-safety and ethical-legal-societal & financial sustainability
* Flagship for Nanoscale Science & Engineering and NNI Signature Initiatives at NSF
* Current portfolio 135 awards/$150M investment Annual cycle of 350 proposals/40 awards/$30M

(e.g. Doumanidis C, The Nanomanufacturing Programme at NSF, *Nanotechnology* 13(3), 2002)

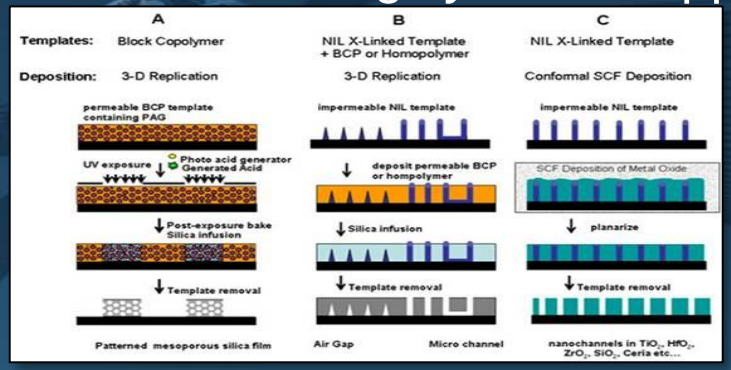
Nanoscale Science and Engineering Centers (NSEC) in Manufacturing



* Scalable and Integrated Nano Manufacturing *(SINAM, UCLA/UC Berkeley)*
  - -plasmonic imaging lithography
  - -ultra molding & imprint lithography
  - -field assisted parallel nanoassembly



* Center for Nano Chemical-Electrical-Mechanical Manufacturing *(NanoCEMMS, UIUC)*
  - -nanoscale molecular gate arrays
  - -nano-photodetector array sensing
  - -manufacturing system & applications

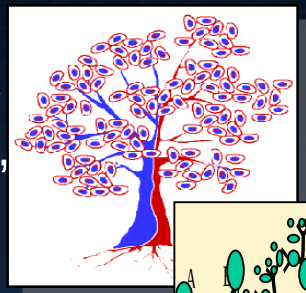


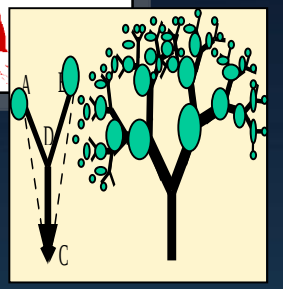
* Center for Hierarchical Manufacturing *(CHM, UMass Amherst)*
  - -nanoscale polymer materials & processes
  - -nanoelectronics, magnetics, photonics
  - -bio-directed assemblies and devices

(e.g. Kramer B, Chen SC, Doumanidis C, NSF Programs in Nanomanufacturing, *Proc 6th ISNM*, 2008)

Fractal Manufacturing in Nature and Technology

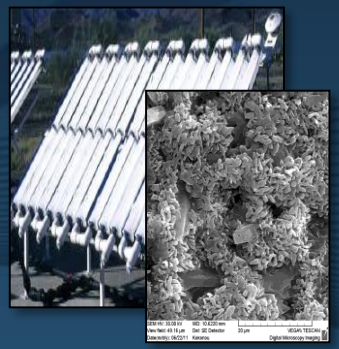
* Natural rivers, snowflakes, fire, dendrites, rocks, clouds, galaxies
* Plant structures, corals, sponges, animal tissue-alveolar, lymphatic, circulatory, nervous systems



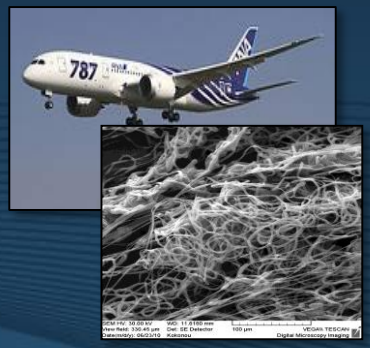


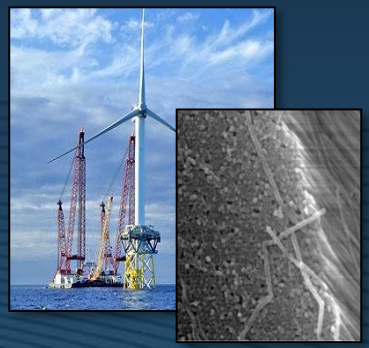
- Optimal mass/energy/information perfusion, transport and transduction

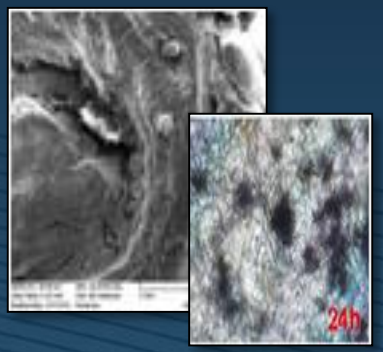
*Catalysis, water filtration, desalination advanced oxidation membranes



* Antennae, batteries, supercapacitors, network grids, transportation, offshore platforms (AEC)







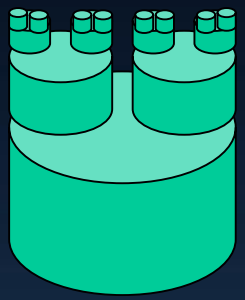
*Organic & hybrid photovoltaics (Konarka)

*Aerospace, wind turbine composites, cables (Boeing, Siemens, Fukuda)

*Vascularized tissue scaffolds (EPOS)

(e.g. Doumanidis C, Nanomanufact. Random Branching Material Arch, *J Microelectronic Eng* 86, 2009)

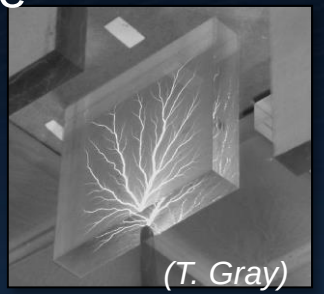
Intellectual Objectives and Research Hypotheses



* Fractal Research:Descriptive-Functional-Constructive

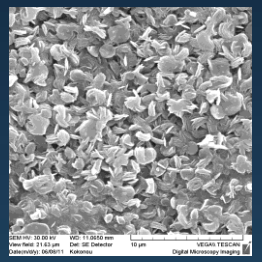
* *Technical Manufacture:* Euclidean, deterministic, layered 2½ D, static, simple, finite-scaled

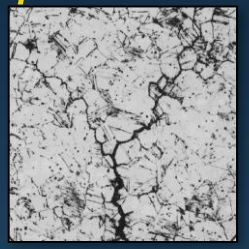
* *Natural Manufacture:* Fractal, random, genuine 3D, dynamic, complex, multi-scale

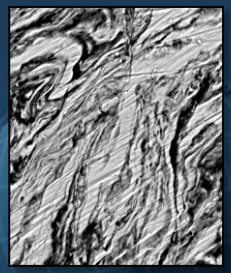


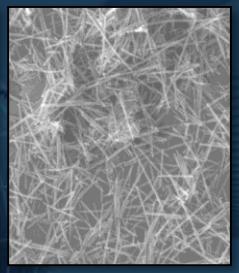
Introduce, understand, control and design nature-like manufacturing processes and systems for functional fractal structures and products

1. Simple process laws lead to scale-independent chaotic dynamics, generating self-similar structures
(loci of boundaries among transport pathways/perfusion domains of different dimensionalities)

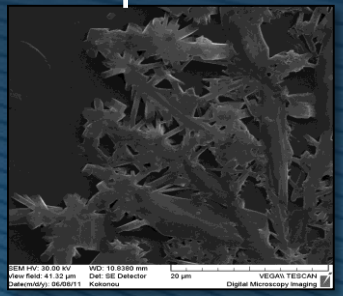








2. Fractal structures with optimal operational functionality are optimally manufactured by similar-law processes
(maximizing exergetic loss via generalized flow/effort in nonlinear impedance fields)

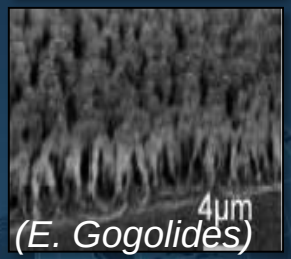


3. Optimality of fractal structures is connected, via their mathematically elegant and intelligible forms, to aesthetic appeal (extending Birkhoff's *aesthetic theory*)

Fractal Manufacturing Phenomena and Processes

* **Accumulation:** Diffusion-limited aggregation, self-assembly, precipitation condensation, solidification, electrodeposition, polymerization, colloidal clusters, agglomeration, bacterial aggregation
* **Erosion:** Dielectric breakdown, electrochemical corrosion, cavitation, fracture cracking, polverization, porosification, leaching, melting, evaporation…
* **Transformation:** Phase transition, crystallization-quasicrystals, dendrite growth, dislocations, oxidation, Hele-Shaw fingering, turbulence, mixing, Baker's folding, evolutionary chain reaction…

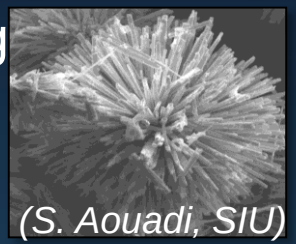

(K.Polychronopoulou)



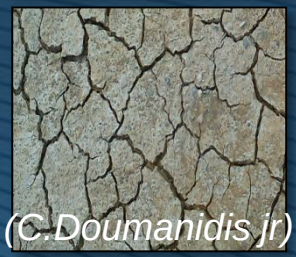
(E. Gogolides)


(T. Gray)

* Ultrasonic consolidation, ball milling, folding & rolling
* Ultrasonic texturing by anodization, AAO templating
* Carbon hierarchical networks, viscous fingering
* Electrospinning of fibrous networks and sponges
* *Atmospheric plasma-treated hydrophobic polymers*
* *Electroplating, Dendritic oxide growth*
* *Block copolymer micelles by RAFT polymerization*
* Melting-ablation by reacting nanoheater particles
* Cryo-fracturing by ultrasonic particle agitation
* Supercritical erosion via dry ice microflakes
* Discharge micro-structures (Lichtenberg μfigures)
* Patterning by natural organic nets, dried clays

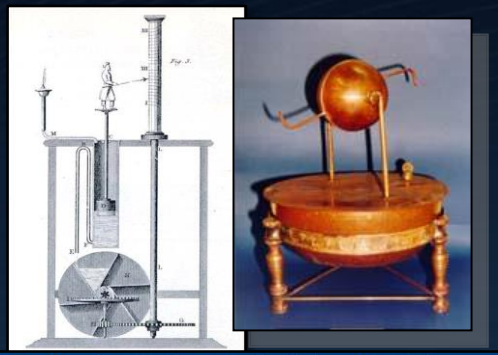

(S. Aouadi, SIU)


(M. Kokonou

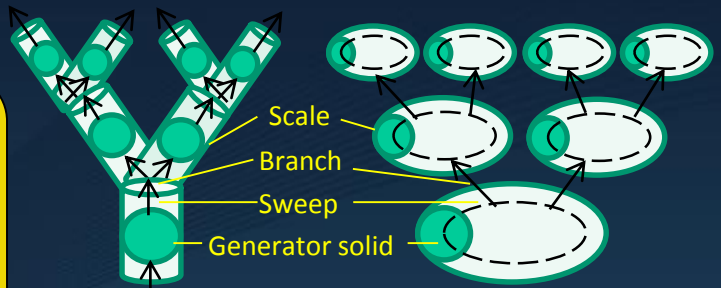

(C.Doumanidis jr)

Research Methodology: Multi-Scale Modeling for Control

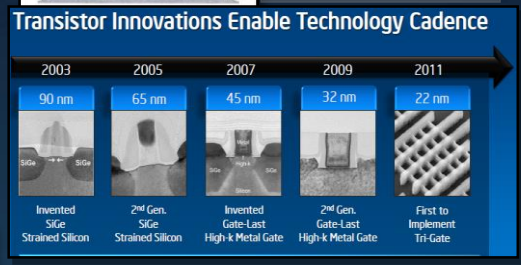
EXPERIMENTATION
Characterization via:
Microscopy, Profilometry, BET, Tomography, EISpectroscopy, Imaging, Box Counting etc



MODEL FOR CONTROL
Generative Sweep (Voronoi-Minkowski), Spatial Occupancy Octrees, Markov Processes, Cellular Automata, Affine Trans



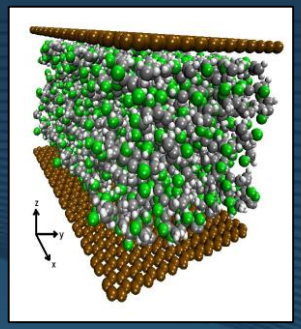
$$\max\left(\iiint_V \left[E(p)-\oint_L R(p)\,d\underline{I}(p)\right]dQ(p)\right) \quad with \quad R(p;t)=f\left(I(p;t),\int_0^t I(p;\tau)\,d\tau\right)$$

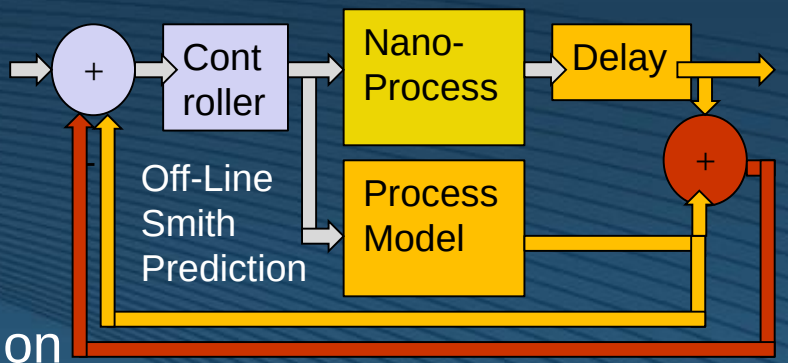


In-situ control
By archaeomimetics

CONTINUUM SIMULATION
Potential Fields, Nonlinear DPS Dynamics, Chaos, Level Set Theory

DISCRETE COMPUTATION
Atomistic MD/DFT
Monte Carlo
Probability Theory
Percolation

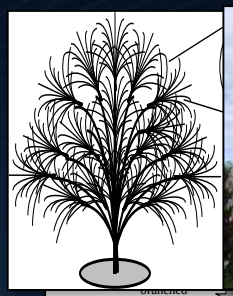




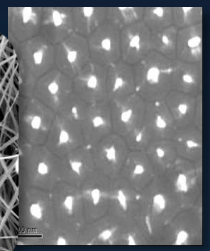
Timed spatial modulation: e.g. nanoheater ignition

Fractal Manufacturing Applications

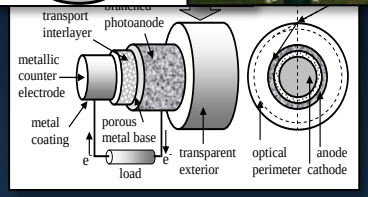
* Solar Fractals: Photodendra, solar fabric, solar cooling foil



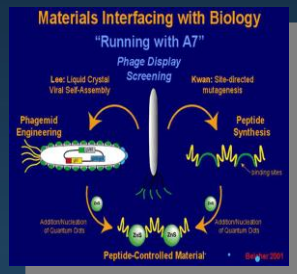
* Vascular Tissue, erythropoiesis, edible protein, medication-loaded bandages, biofuel



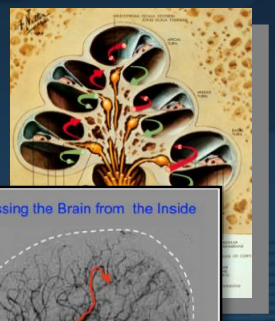
* Materials/membranes for water filtration, desalination, construction

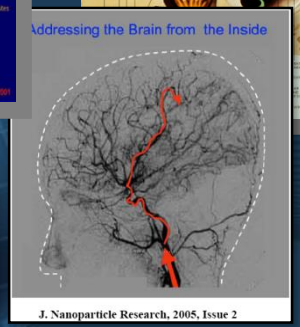


* Transportation and Platforms *(Extreme Engineering) :* macro self-assembly, in-situ robotics, communication optoelectronics

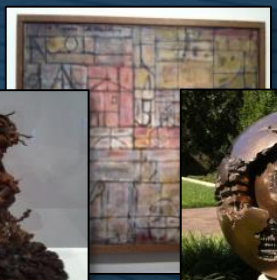


(A. Belcher, MIT)





* Brain-Machine Interfacing *(Biomanufacturing):* nano-robotic transceivers, imaging



+ Fractal Art Science: origami, architecture, linguistics, psycho-physics, neuroscience

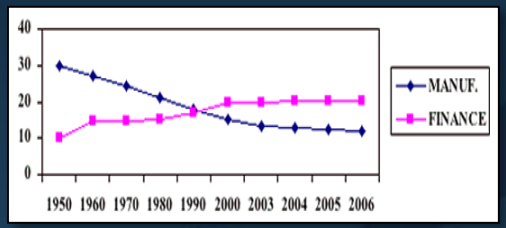
+ Sci & Tech Education

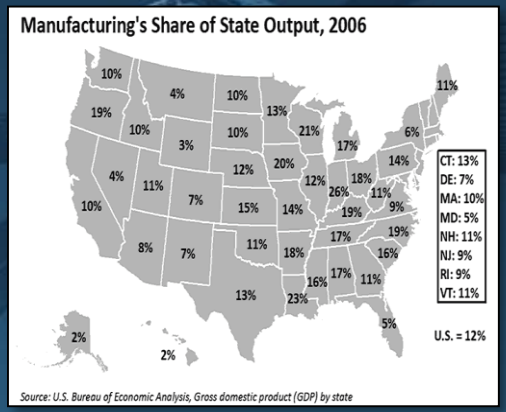
Humanitarian Manufacturing: A New Marshall Plan?

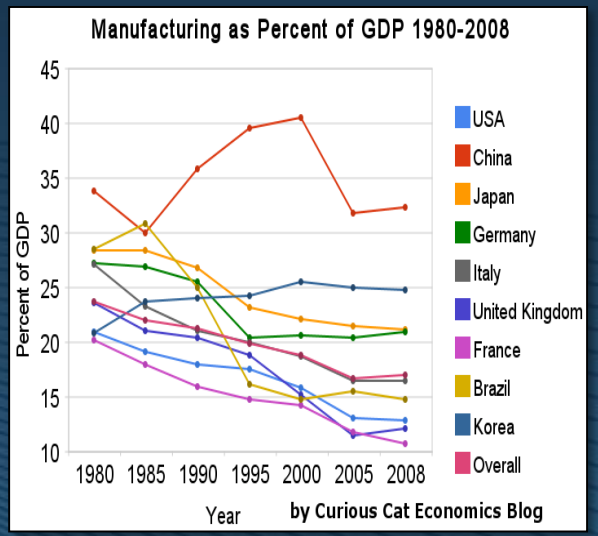
- Transportable or in-situ products, infrastructures, services
- Scalable, robust, low-cost, temporary/low-lifetime technologies
- Low-tech/historic with modern/ advanced manufacturing

* A Modern Humanitarian Initiative:

- Relieve global disaster-afflicted and underdeveloped areas
- Revitalize manufacturing, open target new global markets
- Ensure access to raw materials, labor resources
- Create international alliances, preempt expanding influences
- Balance military with philanthropic expenditures







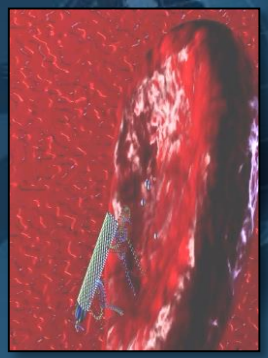
Research, Education and Service Initiatives

** Research and Funding:*

-*Functional Fractal Manufacturing for Humanitarian Engineering* Center
-Connect with industry (Honda, Boeing, Bosch) and VC investors (GloCal)
-International PIREs with Europe (Marie Curie), M.East (KFAS,QNRF,UAE)
-Liaise with government (NSF, NIST, DoE, NIH)

** Education and Advising:*

-Mentor and support junior faculty, postdocs, student investigators
-New courses- *Nanoworld as Engineering Playground, Nanomanufacturing,* grad courses: *Fractal Engineering, Nanomedicine/Nanotheranostics*
-New interdisciplinary Minors in *Nanotechnology* and in *Manufacturing*
-Student internships & placement in industry, enterpreneurship contest
-Professional training program for 21st Century Manufacturing skill set
-Establish and share *Nanomanufacturing Laboratory*



** Outreach and Service:*

-Public-private partnerships for technology transfer and innovation
-Work with *NSF* for serving the young researcher community (PWW)
-Work with *EWB, Gates Fdn, WHO* on humanitarian engineering projects
-Work with local school teachers for class-lab demo and hands-on aids
-Public education via seminar series, online tutorials and tours
-Work with Art & Science Museums for *Nanomanufacturing the Future*

Epilogue and Acknowledgments

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