The Center for Paper Business and Industry Studies

Institute of Paper Science and Technology

TechnoBusiness Forum -- 2005

Open Innovation

-- Enterprise Transformation --

Nanotechnology Cross-Industry Focus

Diran Apelian – Worcester Polytechnique Institute

& Director the Metals and Materials Sloan Center

Worcester Polytechnic Institute

METAL PROCESSING INSTITUTE

www.wpi.edu /+mpi

Metal Processing Institute

- Advanced Casting Research Center
- Center for Heat Treating Excellence
- M. Boorky Powder Metallurgy Center
- Sloan Industry Studies

(PMRC)

Metal Processing Institute

An industry-university alliance with **110 corporate partners** ***dedicated to advance the frontiers of net shape manufacturing through knowledge creation and dissemination, and through education.***

Materials Science and Engineering -- HISTORICAL PERSPECTIVE

- *Evolved from mining departments; Mineral engineering heritage – 1860's / Utah, Rockies, etc.*
- *1860's…. steel production: 20,000 tons/year*
- *Bessemer (1864), Open-Hearth process (1880)*
- *1880's iron ore deposits – Missouri, Lake Superior*
- *By late 1890's, steel production: 22 million tons*
- *Railroad mania… Bridges, infrastructure, etc.*
- *Construction with steel framework in 1890*

HISTORICAL PERSPECTIVE - continued

- Birth of structure-processing-property-performance
- Electric generators – 1860's
- Carbon filament electric light bulb – 1879
- Graham Bell invention of the telephone (1876)
- Availability of electrical energy: Al production (1888)
- 1900-1930…. New processes, exploding civilian markets, autos 15 million model Ts were produced between 1908-1927 vacuum cleaners, electric iron, washing machine
- Aircraft production … 1935 Douglas DC3
- 1929 production: steel 62 million tons/year & Al 114,000 tons/year (3K in 1900)

HISTORICAL PERSPECTIVE - continued

MARKET NEEDS – STRENGTH, RELIABILTY, PERFORMANCE

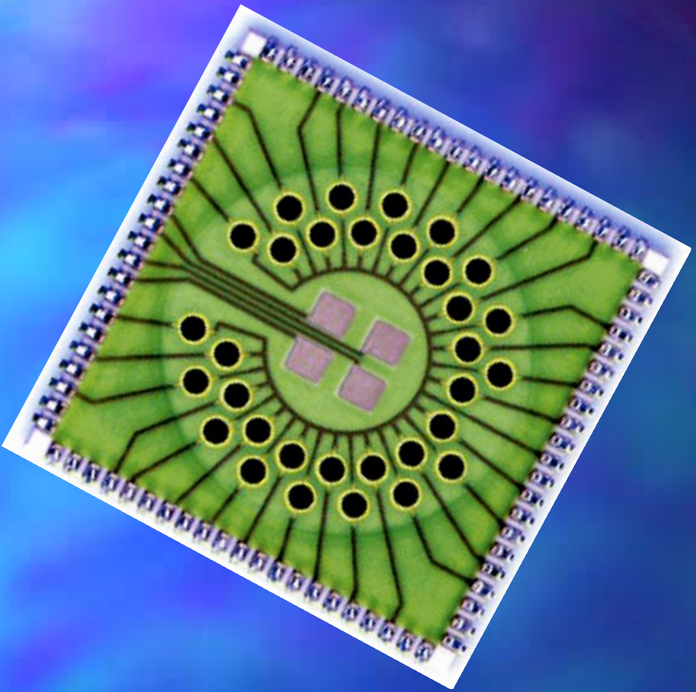
- Superalloys (1947); WWII - Ti, U, Be, Pl
- First dislocations observed 1950
- Teflon 1950
- Polycarbonate 1953
- High Density Polyethylene 1955
- Transistor 1948

- *Integrated circuit 1958*
- *1959 DARPA… Interdisciplinary Research centers in Materials… a seminal initiative!*
- *1970's IC more than 10,000 components per chip*
- *Kevlar – mid 70's*
- *Composite materials*

SHIFT FROM STRUCTURAL MATERIALS TO

FUNCTIONAL MATERIALS

SENSORS



	1996 Units	Markets	2002 Units	Market
Anti Collision Sensors	0.01m	$0.5 million	2m	$20 million
Pressure Sensors	115m	$600 million	300m	$1.3 billion
Chemical Sensors	100m	$300 million	400m	$8 billion
Magnetoresistive Sensors	15m	$20 million	60m	$60 million

Source: Nexus: MST Market study, 1996 – 2002

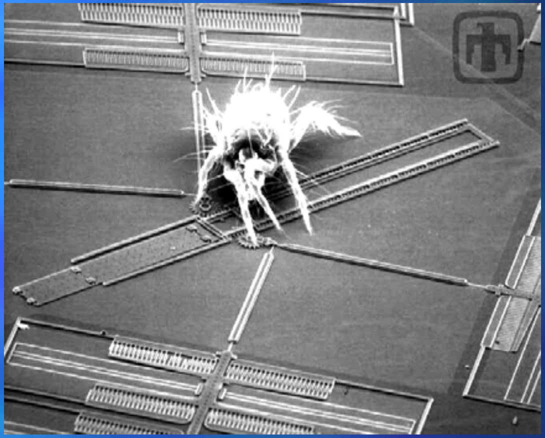
MEMS

Microelectromechanical systems: applications

What are MEMS ?

MicroElectroMechanical Systems (MEMS) is a revolutionary enabling technology that merges the functions of

sensing
actuation and
controls with
computation and
communication
collocated on a chip

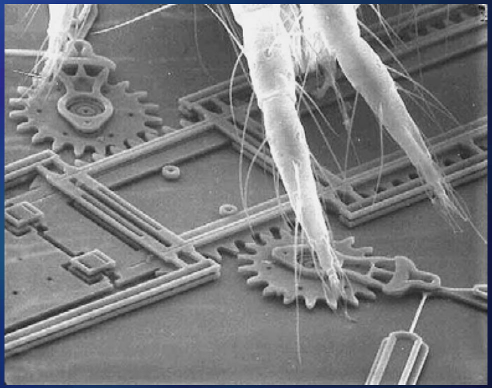


In some cases …

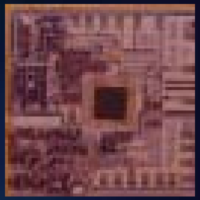
duplicates MOTHER NATURE

to affect the way people and machines interact with the physical world, and does so

in very small sizes
using very low power
for operations in multi environments



APPLICATIONS OF MEMS

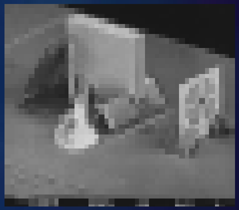


Inertial navigation units on a chip for package guidance and personal navigation

Electromechanical signal processing for ultra- small, ultra low- power wireless communication

Distributed unattended sensors for asset tracking, environmental monitoring, security surveillance

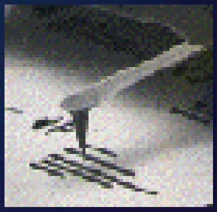
Integrated fluidic systems for miniature analytical instruments, propellant, and combustion control



Embedded sensors and actuators for condition- based maintenance

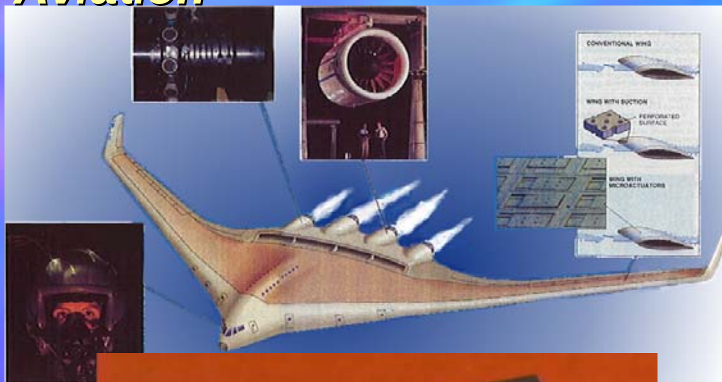
Mass data storage devices for high density, low power

Integrated micro- optomechanical components for displays and fiber- optic switches

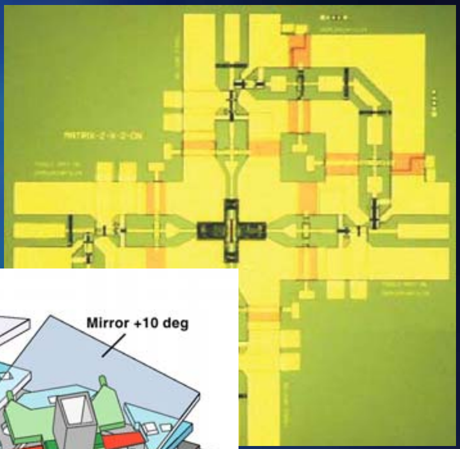


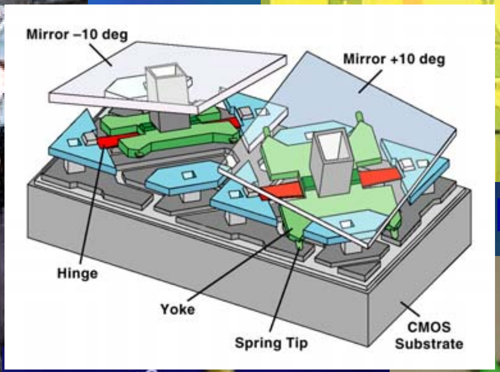
Active, conformable surfaces for distributed aerodynamic control of aircraft and adaptive optics

Aviation



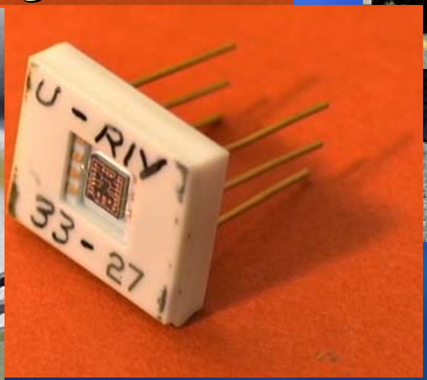
Microelectronics: RF MEMS

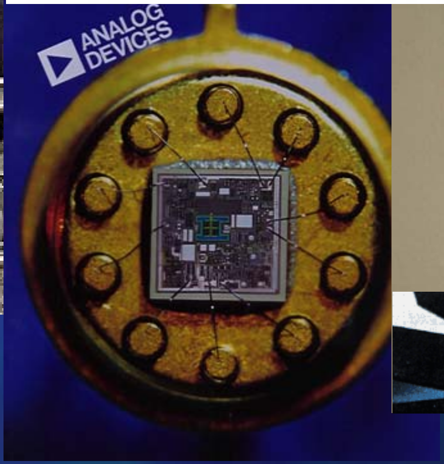




Photonics

Navigation/GPS





Segway: sensors

Tele-com

Controls

Automotive

Info-tech

Cantilever Tool

Use AFM-like cantilevers to detect target molecules in gases and liquids

Detect contaminants in water and air

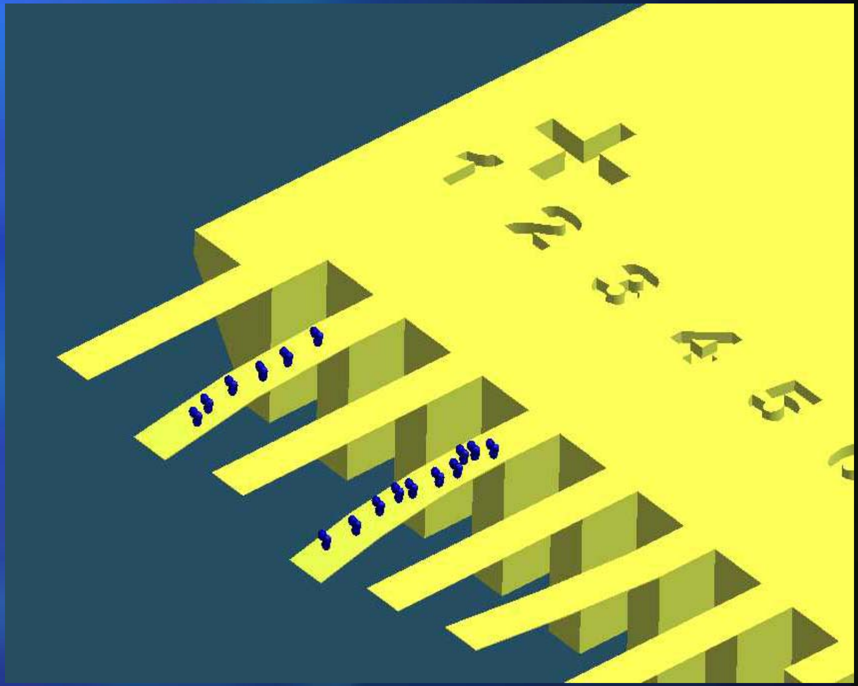
Detect presence of specific biomolecules for research and medicine

Detect biochemical metabolites

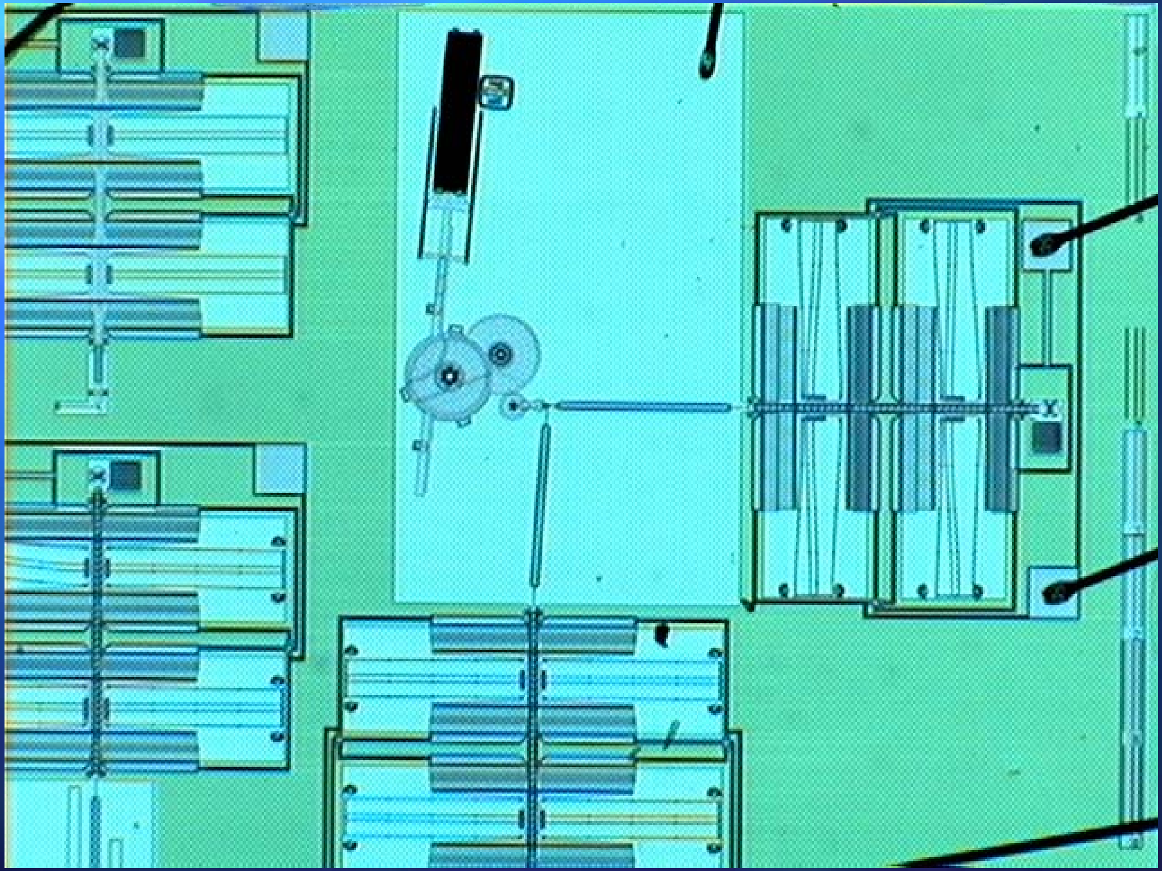
Detect explosives and toxic gases

As an artificial nose, study aromas and flavors

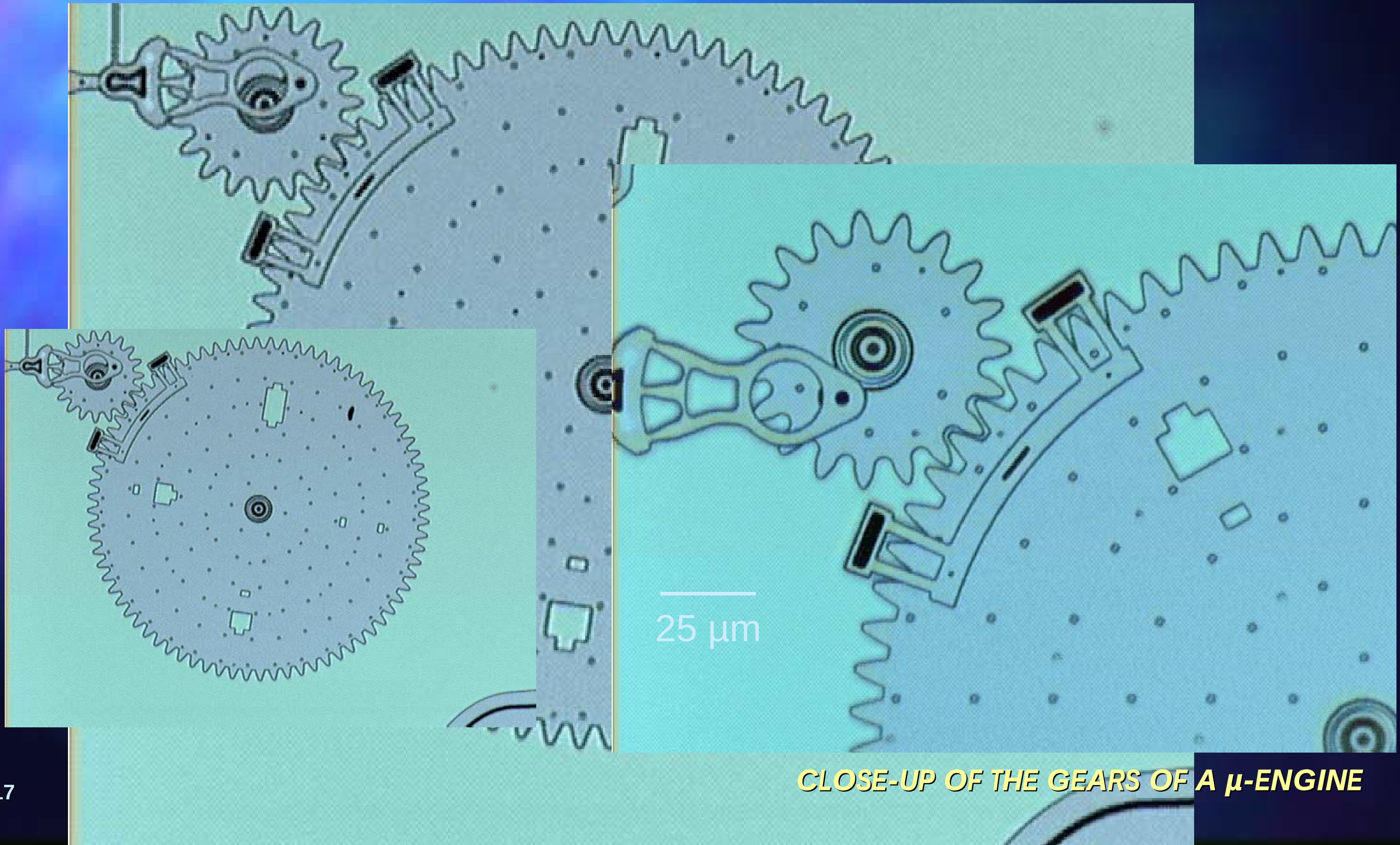
Measure surface stress during thin film deposition



SANDIA 1,000,000 rpm microengine

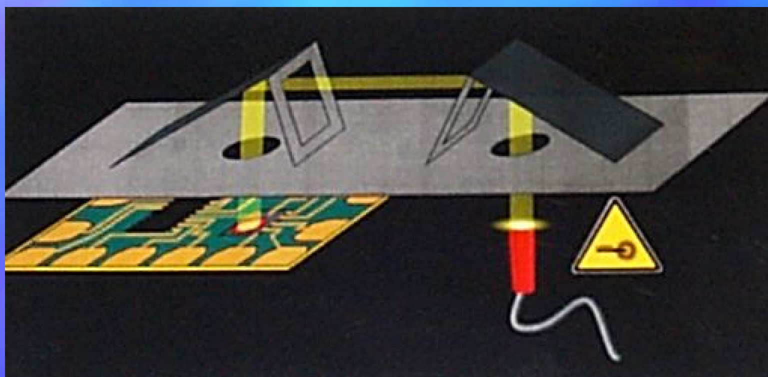


SANDIA 1,000,000 rpm microengine

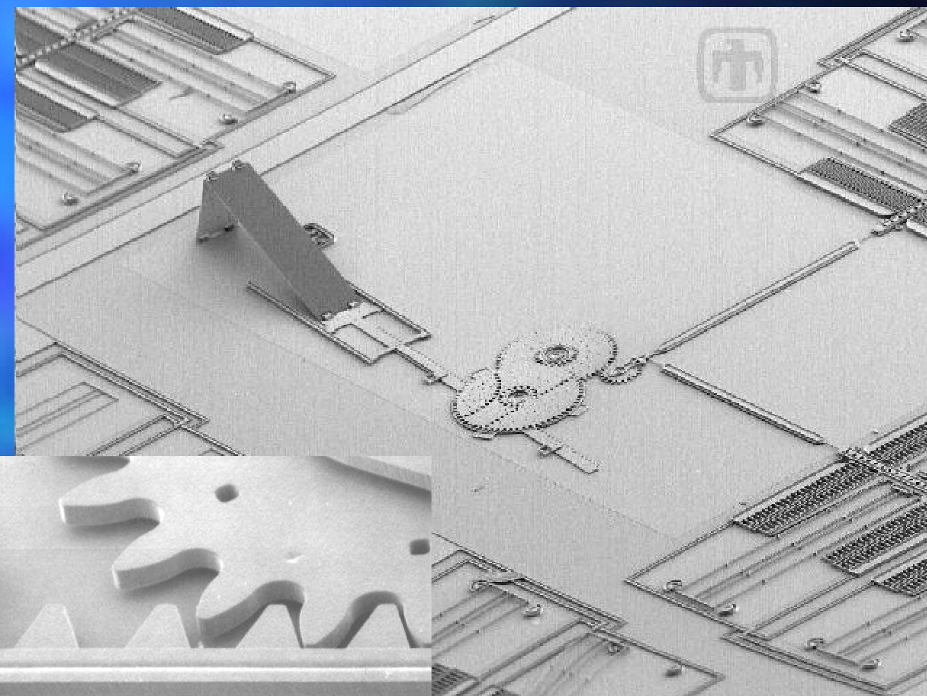


CLOSE-UP OF THE GEARS OF A µ-ENGINE

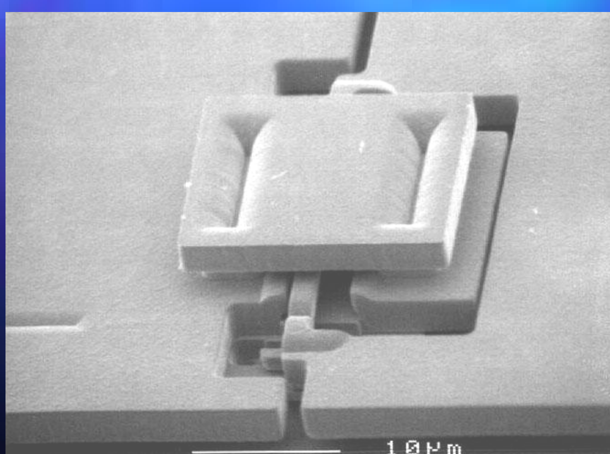
MEMS optical interconnection
Typical application of a microengine

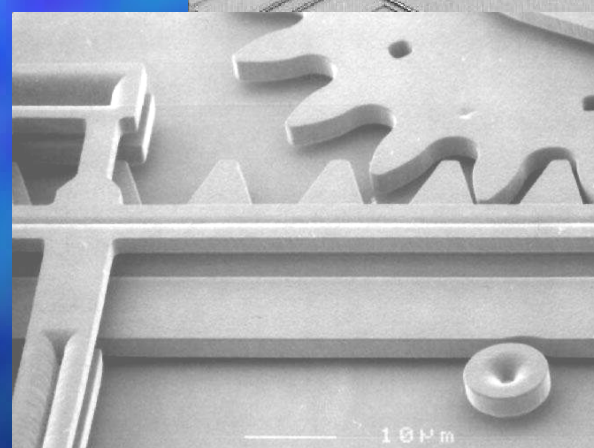


INTERCONNECTION CONCEPT



μ-ENGINE ACTUATED
μ-MIRROR DEVICE

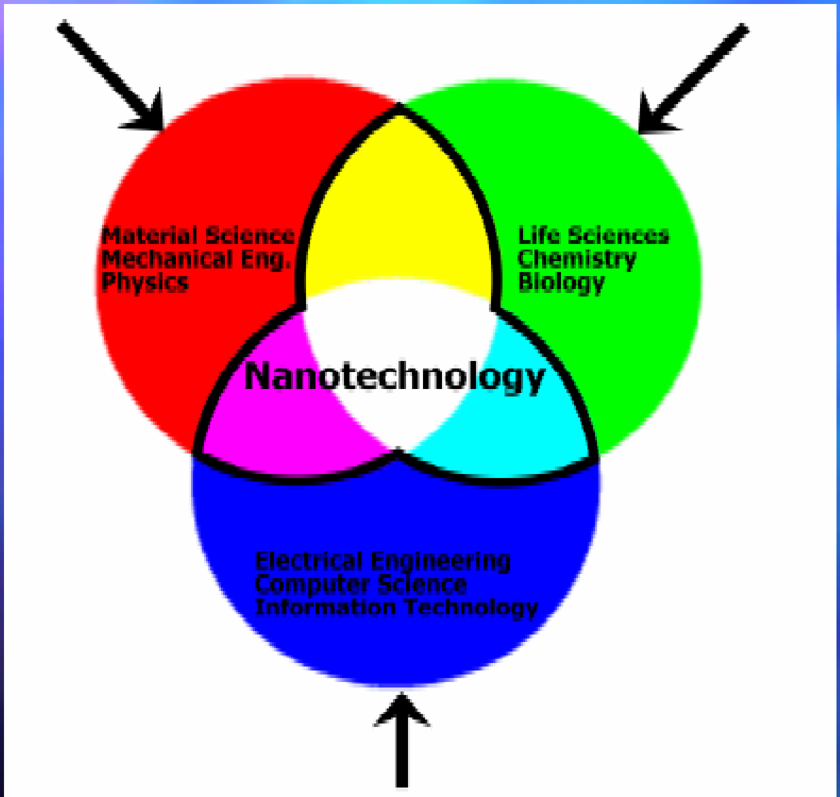




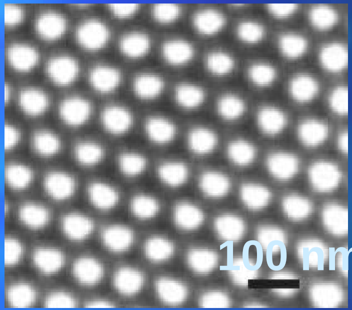
DEVICE DETAILS

S C A L E

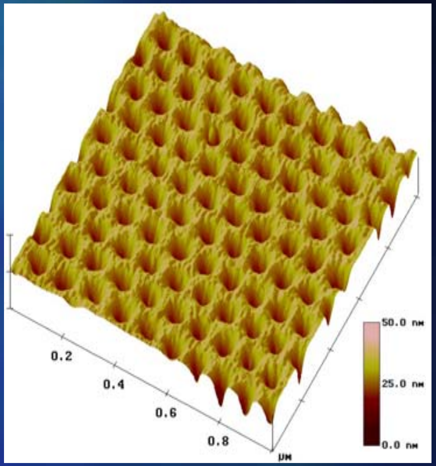
- *MEMS*
  greater than 100 nm
- *NEMS Nano-electromechanical systems*
  Less than 100 nm
- *Nanostructured components and materials*
  Less than 60 nm



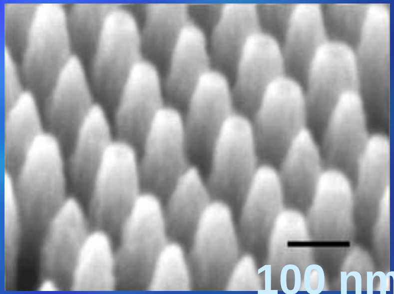
Source: Steve Jurvetson, Draper Fisher Jurvetson



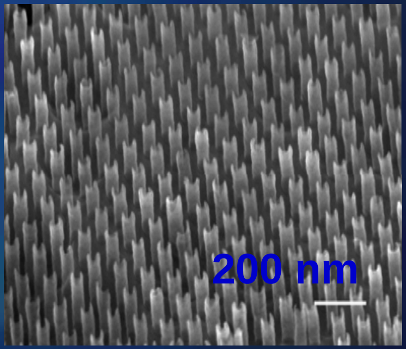
Ni nanodot array



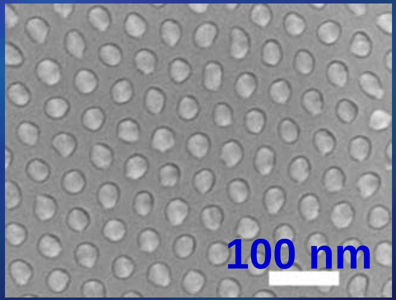
GaN nanopore array



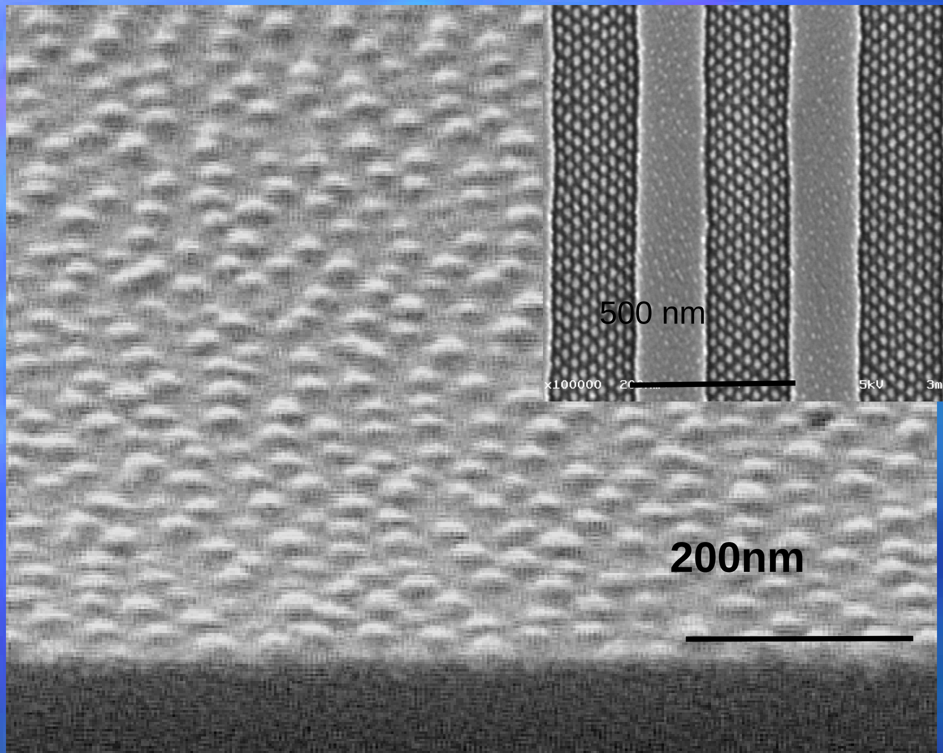
GaAs nanopillar array

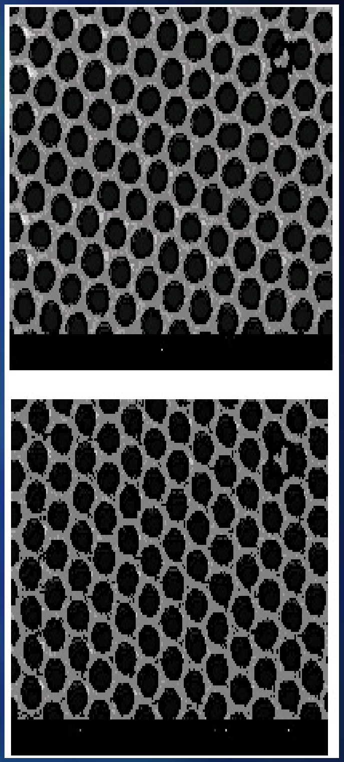


Carbon nanotube array



InAs nanodot array



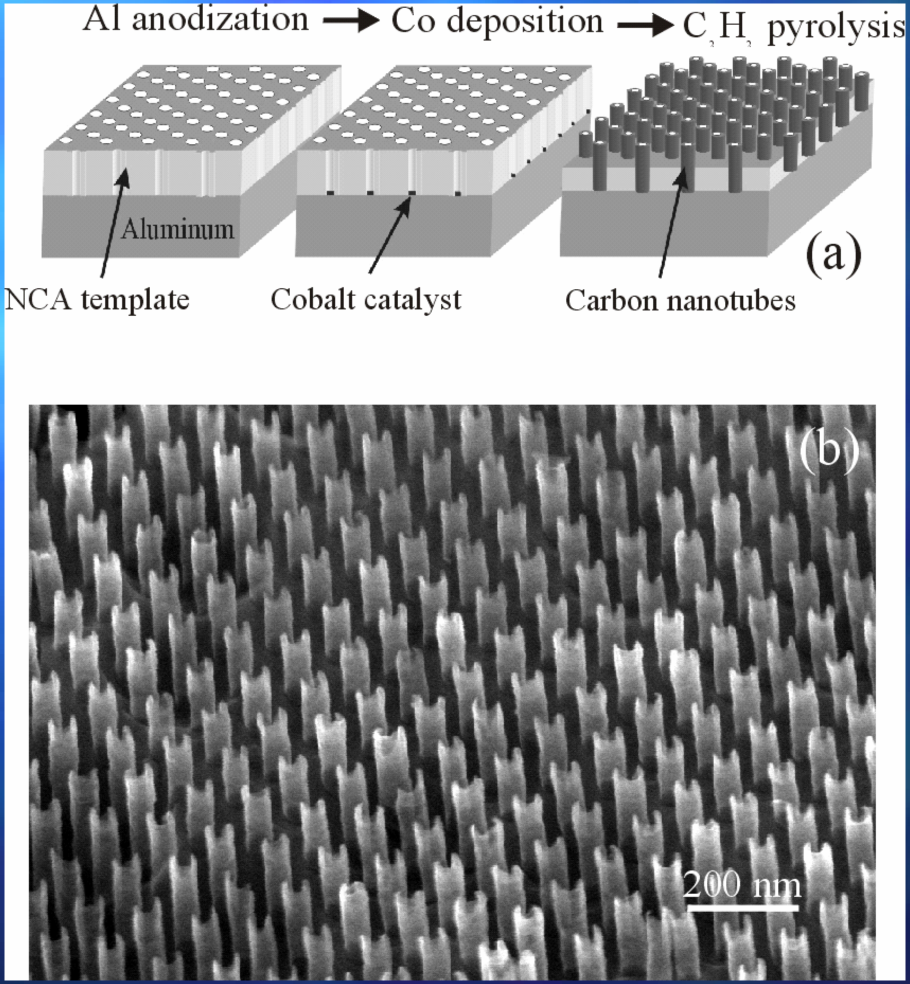


An array of 30 nm diameter Co dots with period of 50 nm; inset shows a block copolymer film self-assembled on a substrate with periodic grooves, providing the pattern with long-range order

Top and bottom views of a nanopore array (45 nm pore size) produced by anodization

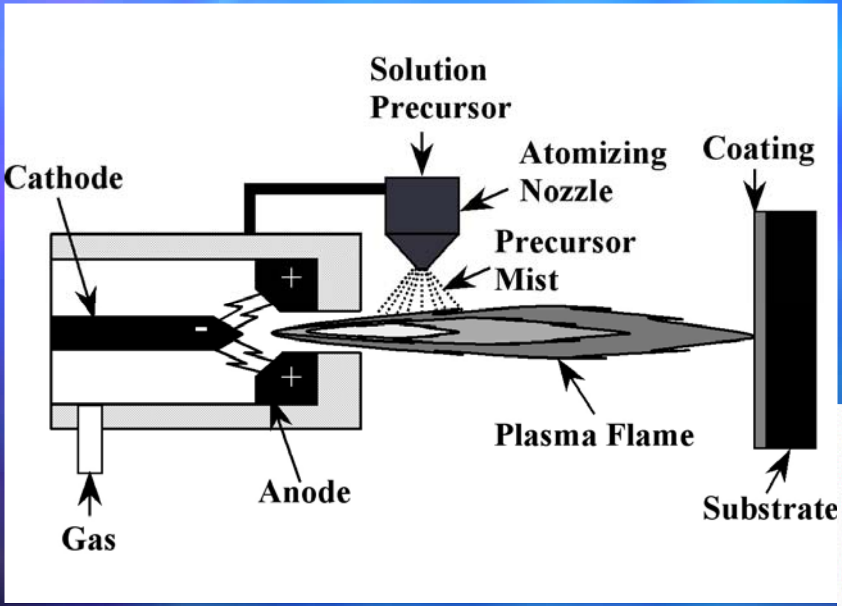
Courtesy: Prof. C. Ross -MIT

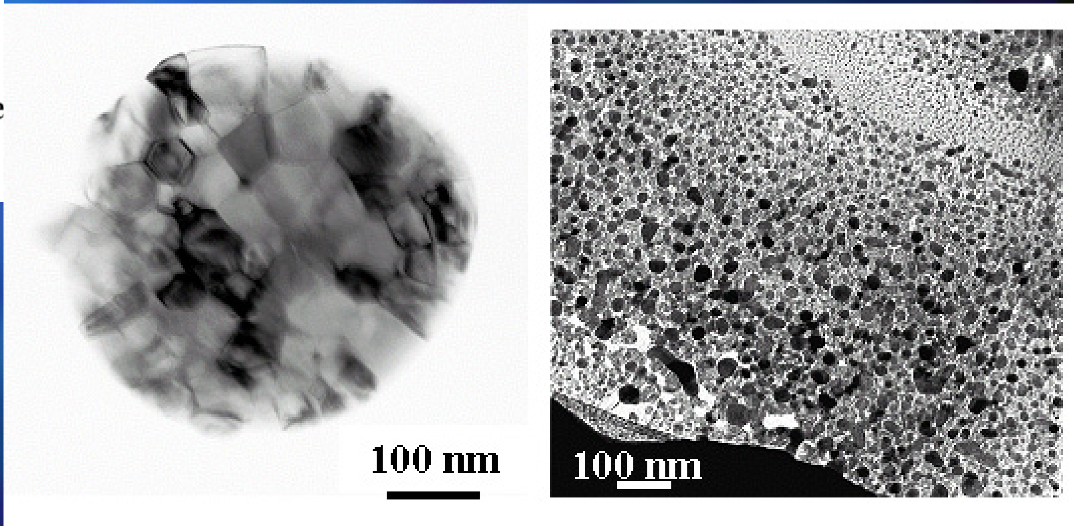
Anodization process and a periodic array of high aspect ratio aligned carbon nanotubes



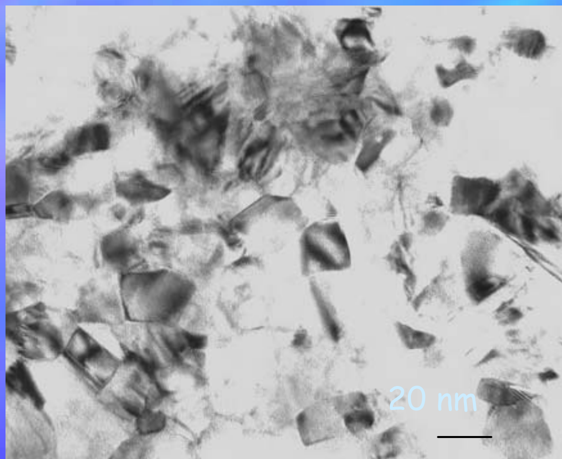
Courtesy: Prof. J. Xu – Brown University

Solution-Precursor Plasma Spray (SPPS) Process

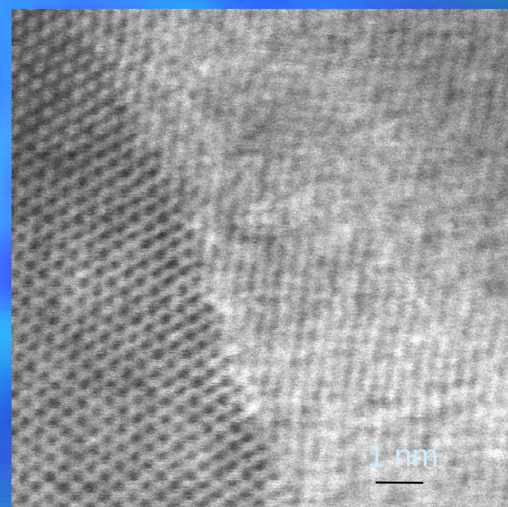




Courtesy: Prof. N. Padture - OSU

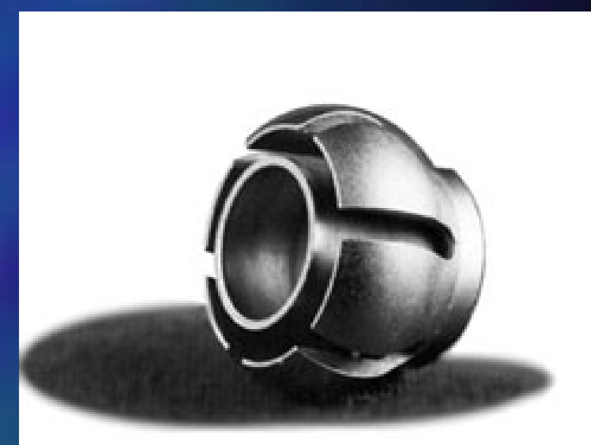


Fine uniform grains (~20-30 nm) in electrodeposited Ni



Crystallinity extending to the boundary and absence of any second phase at the boundary

A complex non-metallic component that has been successfully coated with a nanocrystalline metal by electrodeposition



Courtesy: Prof. S. Kumar – Brown U. & Integran website; www.integran.com

Application	Improvements using new attached molecules
Colloids	New structural, optical and thermodynamic properties.
Pigments	Better thermal stability without loss of absorption characteristics.
Dispersions	Tailoring of nanoparticle size, and molecular structures.
Emulsions	Engineering of viscosity and particle size.
Anti corrosion Coatings	Better surface mechanical properties, and stability in air.
Ferrofluids	Creation of 'fluid magnets', which can be externally manipulated and be made to exhibit different rheological properties and structure.
Magnetic particles	Below a critical size, magnetic particles are superparamagnetic and the collective magnetic response is fluid. A weak external magnetic field can produce a large response .
Passivated magnetic particles	Magnetic particles can be covered with insulators or molecular overlayers, and the surface made resistant to oxidation or insulated to electrical conduction. These particles can be made bio-compatible and used in medical applications.

Ceramic processing technology	'Customised' ceramics for one-off applications; particularly using stabilised zirconia
Nano-emulsion	Nanoparticle size and composition selected to produce required viscosity and absorption characteristics
Lubricants	Tailored viscosity and thermal expansion properties.
Drug delivery systems	Nanoparticles can determine the chemical reactivity rate, the location and the timing of drug delivery.
Bio-receptors for energy transfer	Nanocomposites can be designed to exhibit well defined singlet or triplet excitonic absorption spectra. These localised bundles of light energy can be transferred over long distances to a 'receptor' and used for example for photochemistry or charge generation (e.g. the photoelectric cell).
Cosmetics and UV protection gels	The addition of nanoparticles can influence the flow characteristics and mechanical properties of cosmetics, as well as the absorption of harmful radiation.
Sol-gel technology	In the design of different types of materials

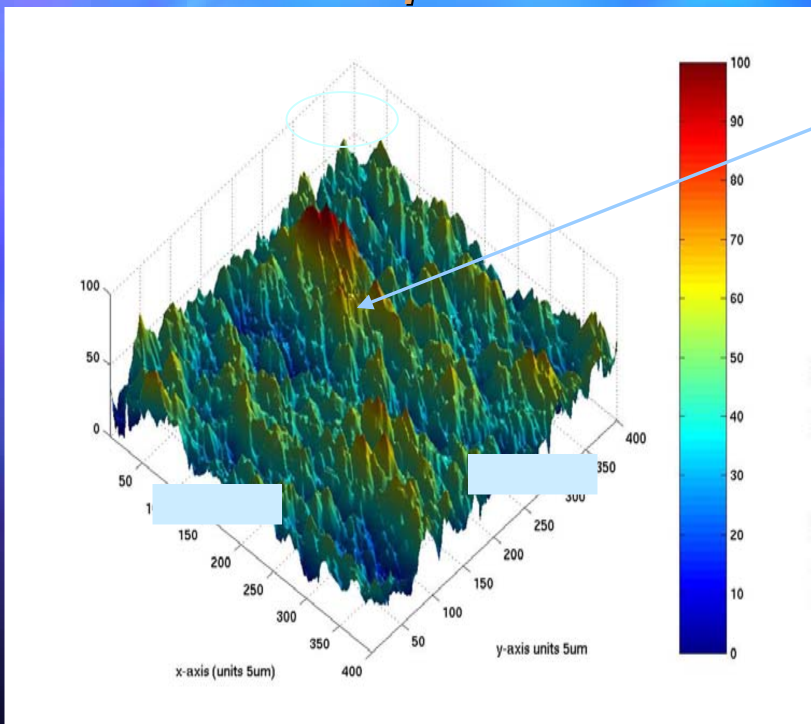
The Role of Paper Micro-Nano Structures on Commercial Paper Printability

- **PI: Nikolas Provatas**
  - *Associate Professor in Materials Science and Engineering, McMaster University 2002-*
- **Education**
  - *Ph.D. – McGill University, Condensed Matter Physics - 1994*
- **Work Experience**
  - *Research Fellow – University of Helsinki – random fibre networks and paper structure modelling –1994-1996.*
  - *Research Associate – University of Illinois at Urbana-Champaign – solidification microstructure modelling -1996-1999.*
  - *Research Scientist –Pulp and Paper Research Institute of Canada –1999-2002*

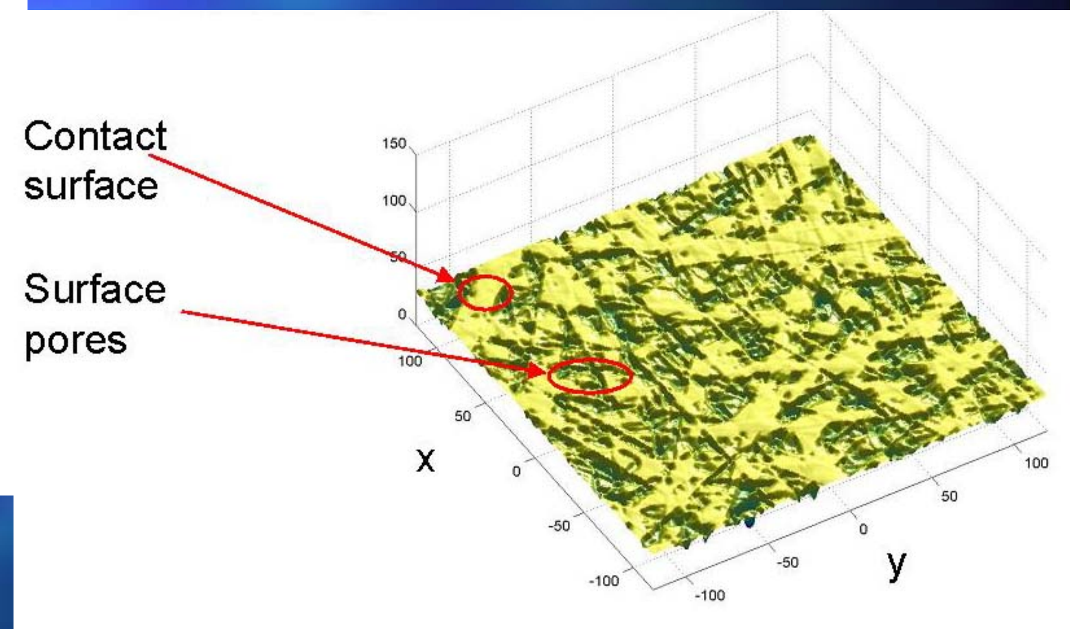
Virtual Paper Microstructures and Impact Printing

Uncalendered Paper Surface

Paper surface Asperities: nano-micro scale variation



Calendered Paper Surface

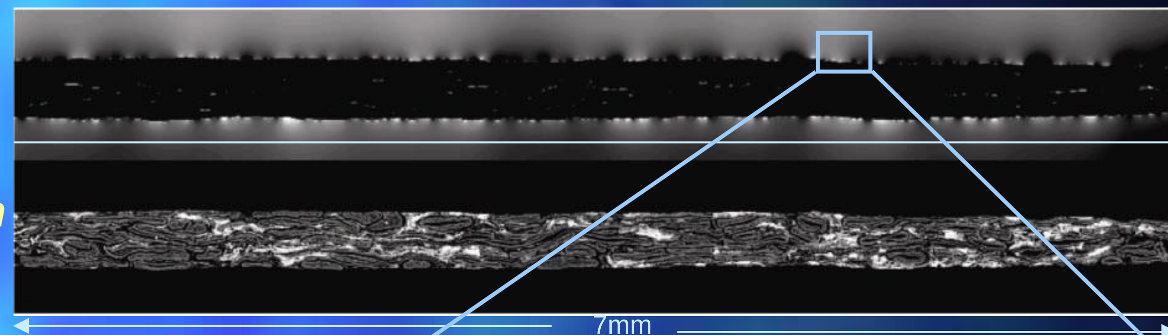


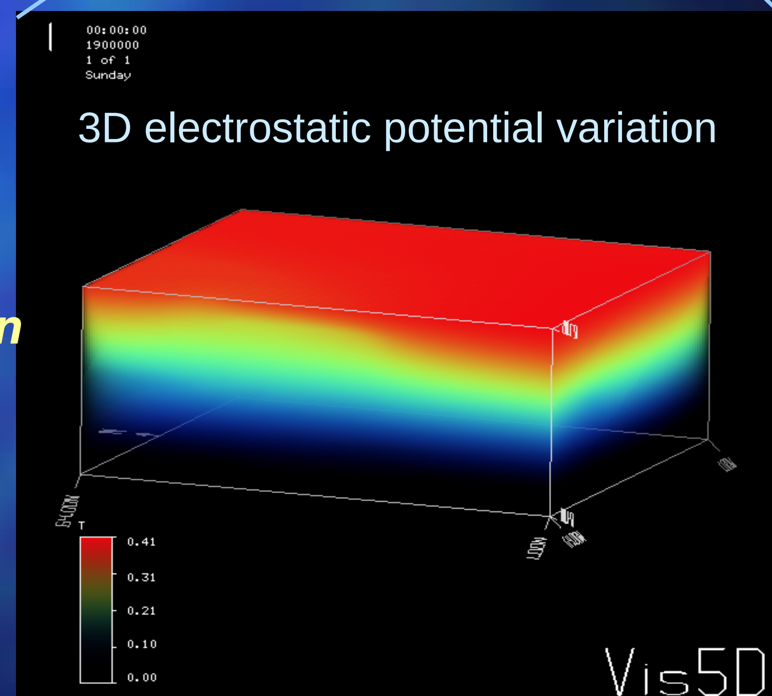
Surface roughness →source of print density (mottle) in commercial paper

Virtual Paper Microstructures and Xerographic Printing

Electrostatic field variation

Digitized paper cross-section (by SEM)





New 3D parallel, Multi-Grid code computes local (nanometer-micrometer) variations of electrostatic transfer forces on xerographic toner from virtual or experimental paper maps

Paper thickness & mass variations →source of electrostatic transfer forces

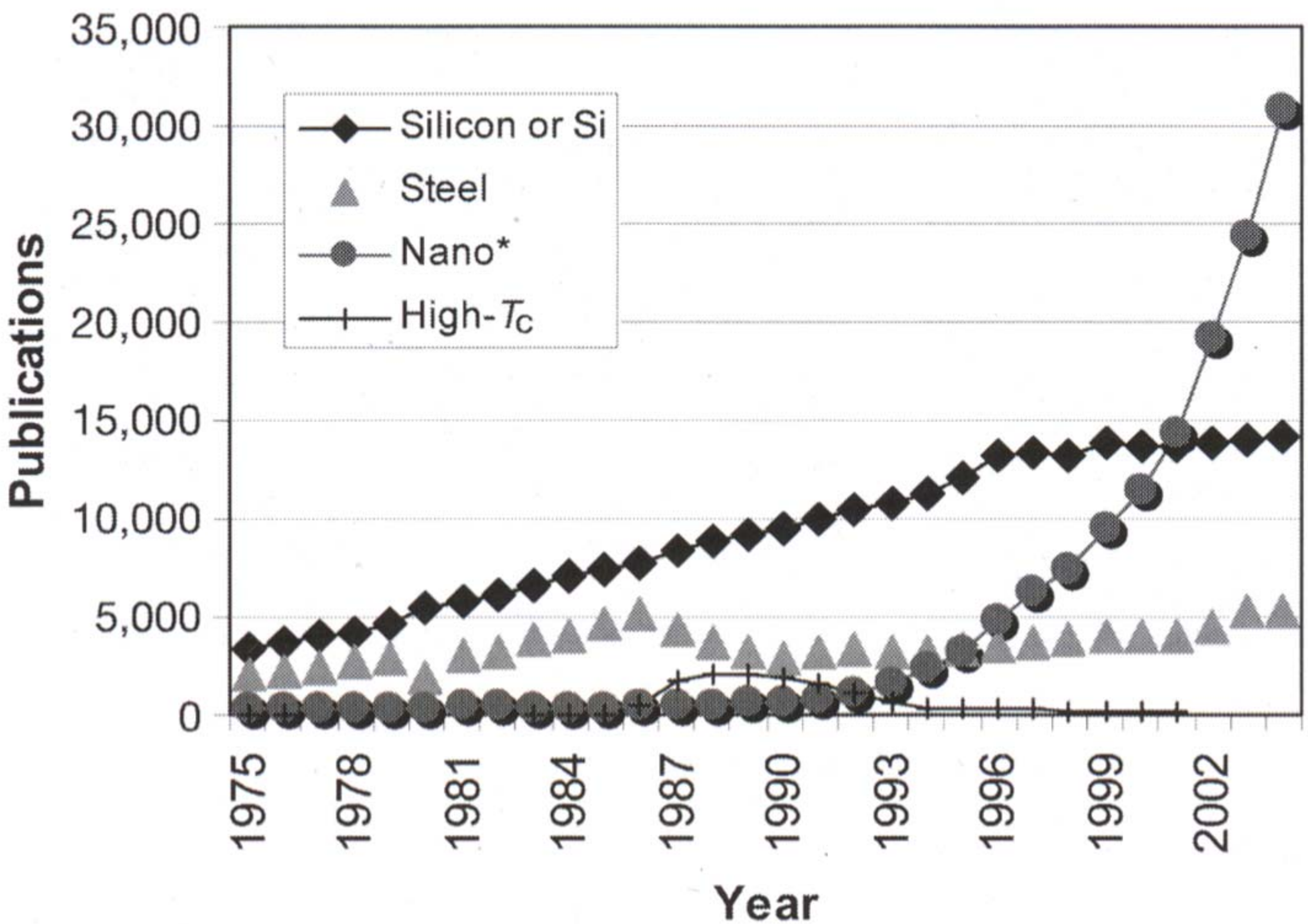


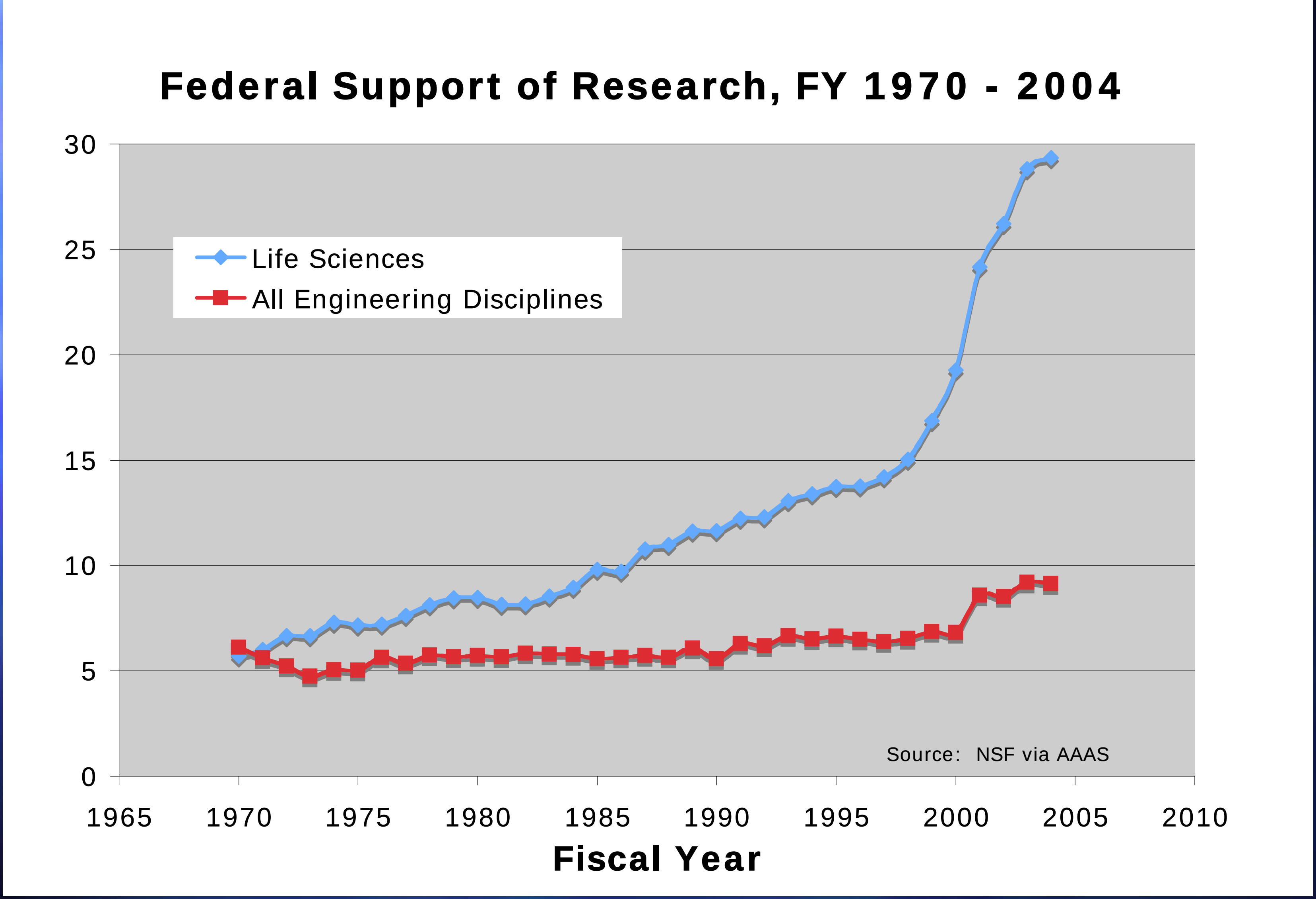
Figure 1. Publications over time by material topic.

Source: MRS

Table I: Correlation of Publications to Economic Activity.

Topic	2004 Papers	2004 Revenue ($ Billions)	2004 Ratio (paper/$1B revenue)	Growth	2010 Revenue ($ Billions)	2010 Ratio (paper/$1B revenue)
Silicon	14,185	160	88.7	10%	290	49
III-V	1300	13	100.0	17%	33	39
Steel	5354	205	26.1	3%	245	22
Nitrides	1200	2.5	480.0	47%	25	48
Nano	30,828	?	?	?	?	?

Source: MRS


Federal Support of Research, FY 1970 - 2004
30
25
20
15
10
5
0
Life Sciences
All Engineering Disciplines
Source: NSF via AAAS
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Fiscal Year