Microsystems, Scaling, and Integration

Amit Lal, Program Manager

YFA brief, Nov 16, 2006

MTO/DARPA

MTO MEMS Successes

2000s

1990s

1980s

Bio-Agent Warning System - 2004

SUVOS

MEMS

Precision Attack Missile - ~2006

VCSELs

F-18 E/F - ~2005

MCM Design

HOOK-112 - 1994

AWACS - 1998

Digital Micromirror Device

B-52 - 1991

Infrared Imaging

MAFET

FAB-T - 2004

Head Mounted Displays

Land Warrior - 2003

Uncooled Integrated Sensors

Driver's Vision Enhancer - 2002

IRFPA (Cooled)

Improved Bradley Acquisition Subsystem - 2000

MIMIC

Theater Missile Defense - 1995

Digital GaAs

OH-58D - 1992

4 Core MEMS/NEMS PMs

ME-PhD, MBA

Dr. John Evans

Space,
RF,
Power,

EE-PhD, MBA

Dr. Dennis Polla

Sensors,
Cooling,
Power, RF
MEMS
S&T

EE-PhD

Dr. Amit Lal

Navigation,
RF, Bio
interfaces,
Timing, MEMS
circuits

Physics-PhD

Dr. Thomas Kenny

Thermal
management,
RF, probe
based
processing

3D-MERFS(JE), ASP(GE), HERMIT (AL), HI-MEMS (AL), M/NEMS S&T (DP), MCC (DP), MEPS (JE), MGA (DP), MIATA (TK), MPG , MX (AL), NGIMG (AL)

More MEMS affiliations

Dr. Ray Balcerak

IR-Sensors

Dr. Michael W. Haney

Optics

Dr. Devanand K. Shenoy

Sensors

About myself…

Amit Lal:

- Joined DARPA/MTO in October 2005
- Degrees: BSEE-1990: Caltech, Ph.D.-1996: UC Berkeley
- Professional Background:
  - Associate Professor, School of Electrical and Computer Engineering, Cornell University
  - Other Appointments:
    - Dept. of Bioengineering
    - Dept. of Biological Engineering
- Interests: MEMS, ultrasonics, radioactivity, bio-MEMS, ultra-low power circuit design

Progression of MEMS

MicroElectroMechanical Systems

Si as a mechanical material (Petersen)

Pressure Sensor (Honeywell)

Si Pressure Sensor (Motorola)

SFB Pressure Sensor (NovaSensor)

IC

Anodic Bonding

HNA EDP KOH

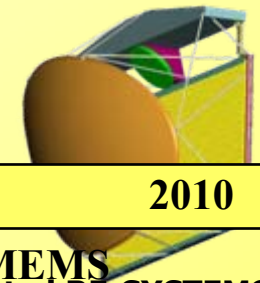
SFB TMAH

DRIE !!

XeF_2/BrF_3

1950 1960 1970 1980 1990 2000 2010

Chips-Scale Atomic Clock



Metal sacrificial process (US Patent)

RGT (Nathanson et al)

PolySi beams (Howe, Muller)

LIGA

PolySi Micromotor (Tai, Muller)

Metal Light Valve (RCA)

PolySi Comb Drive (Tang, Howe)

IR imager (Honeywell)

ADXL Accelerometer

DMD (TI)

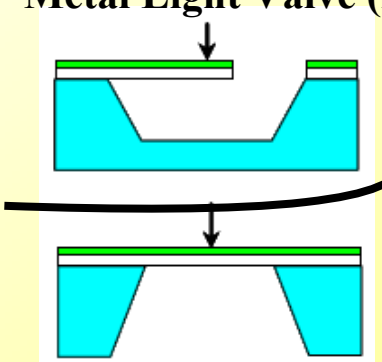
Si Gyro (Draper)

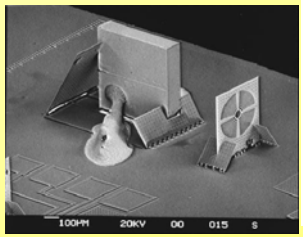
RF MEMS

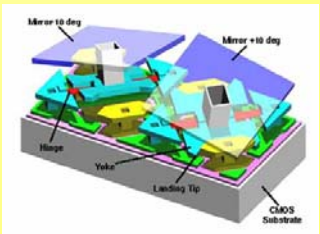
Bio MEMS

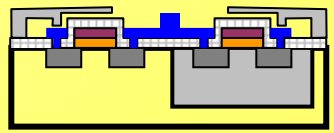
Integrated RF-SYSTEMS RADAR

Hybrid-Insect MEMS









NEMS-CMOS: Meshing of transistors and relays

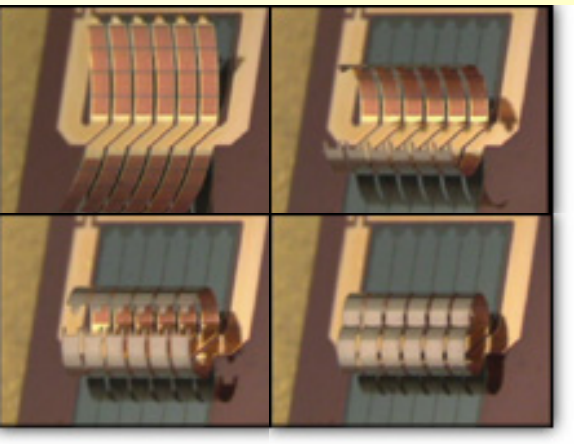
Problem 1: MEMS for everyone?

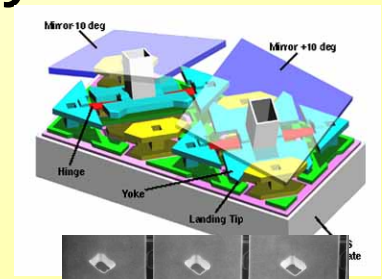
- Technology to make microscale mechanical parts integrated with electronics
- Another machining technology, like mill and lathe
- Mill and lathe were really exciting when they first came out - now we take them for granted
- DARPA MEMS Exchange is a program for users!
- **How can we make MX more effective?**

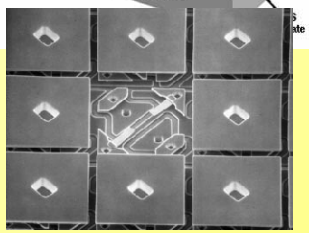
http://www.memsnet.org
http://www.mems-exchange.org

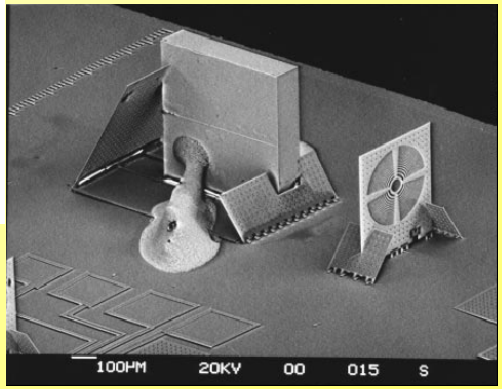
Problem 2: How to take care of so many possible things one can do?

- Micromachining enables a new way of thinking about mechanical structures
- Parallel (huge) arrays of machines are possible
- Machines comparable to size of biological objects are possible
- Environmental control for high performance
- Multi-physical systems









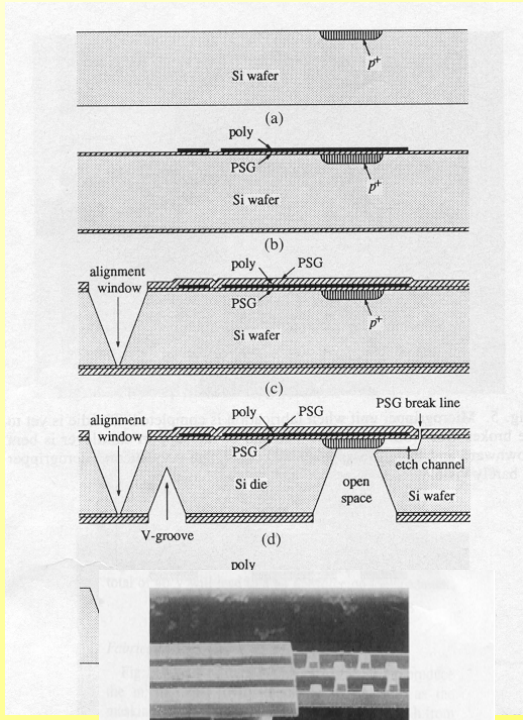


Fig. 6. SEM micrograph showing three conducting lines crossing the end of the support cantilever to the gripper arms. The remaining PSG insulating layer between the conducting lines and the support cantilever is marked.

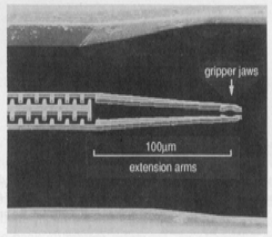
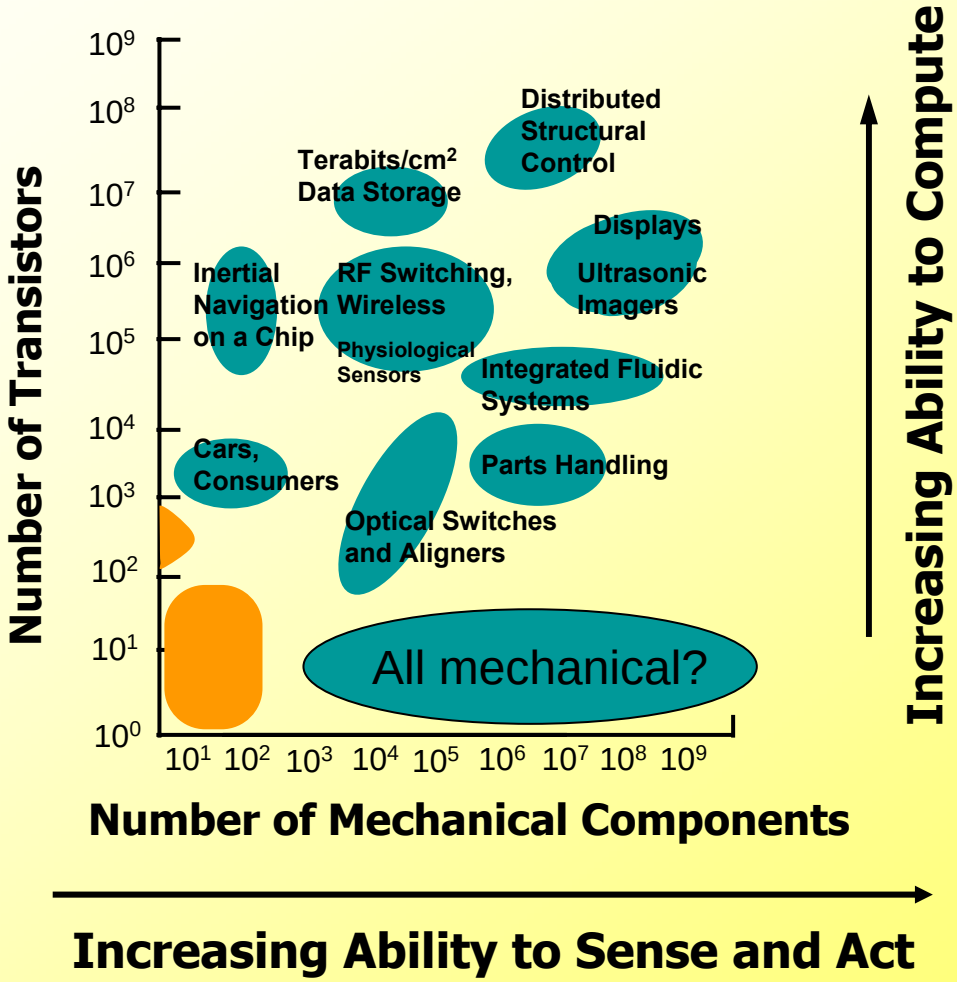


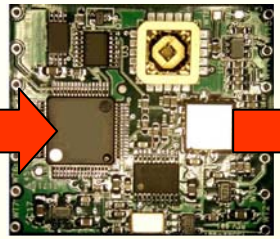
Fig. 7. SEM micrograph showing the flexible comb-drive structures, extension arms, and the gripper jaws.

Integration Space

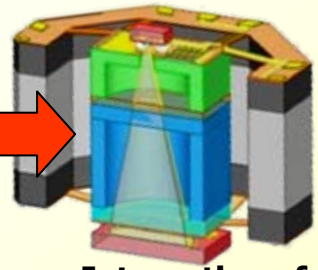


MEMS Fuel for Microsystems

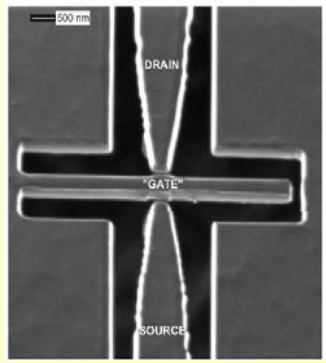
Temex RMO
Vol: 230 cm^3
Power: 10 W
Acc: 1×10^{-11}

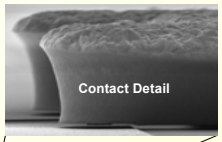


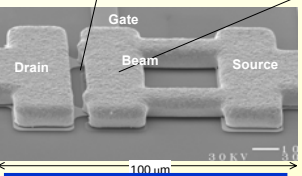
Symmetricom CSAC
Vol: 7.8 cm^3
Power: 95 mW
Stab: 5×10^{-11}/100s



Integration of Alkali-metal vapor on chip for atomic sensors

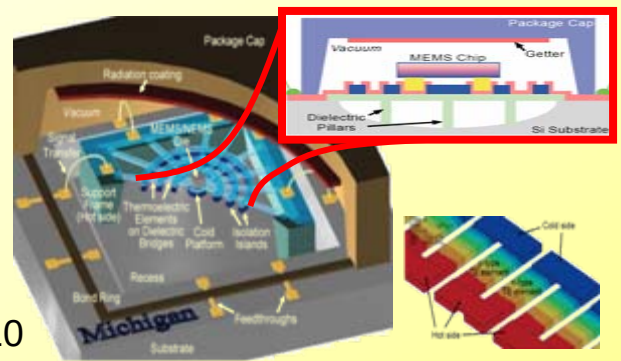


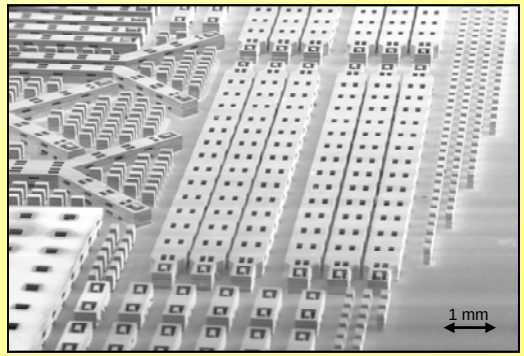


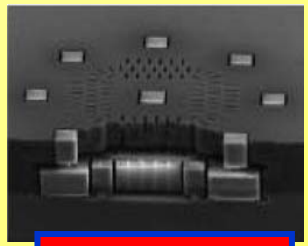


1. RADANT

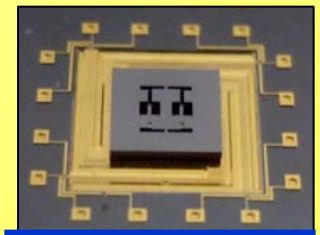
- **Miniaturization/Integration – SWAP**
- **Scaling for higher performance**
- **Integration of coupled science on chip**
- **Biological interfaces**
- **Gateways to nanoscale effects**
- **Environmental control over sensors and actuators**







Embedded MEMS

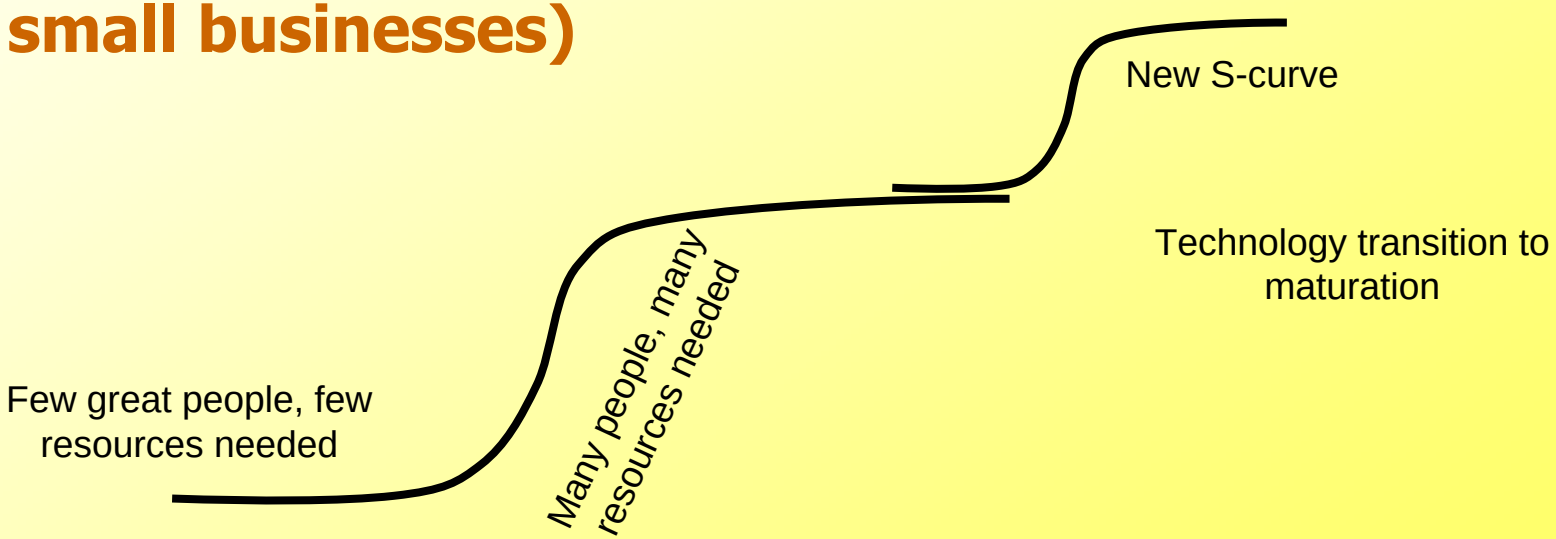


Universal MEMS package

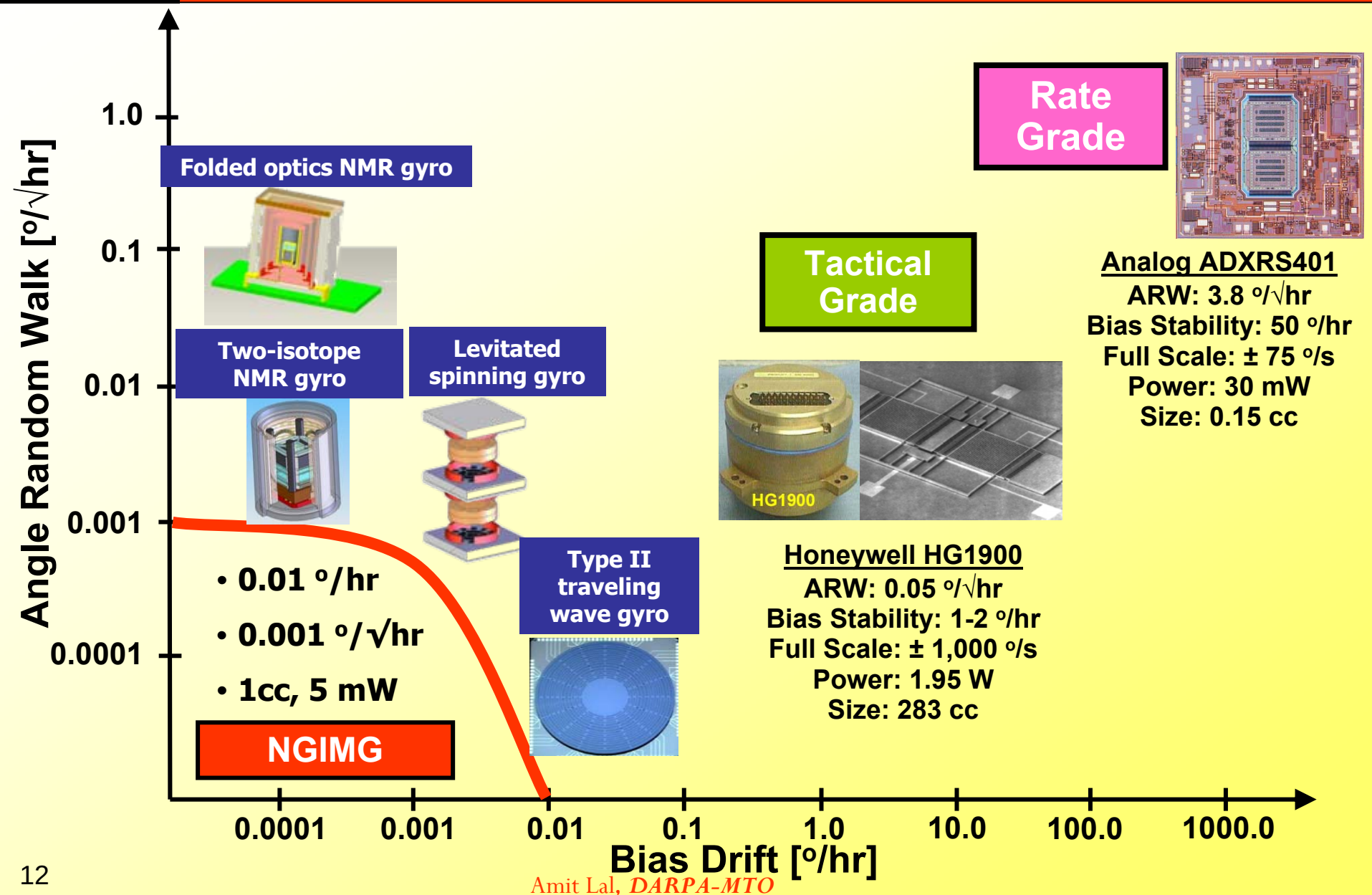
Amit Lal, *DARPA-MTO*

What excites me? New S-curves in MEMS

- **Project objectives – How challenging is the objective?** **What's new?**
- **Technical approach – What's the diamond-in-the-rough? Is it d?** **What's new?**
- **Benefits to DOD – Will it be just a novelty? Where could it be used?** **What's new?**
- **Benefits to national infrastructure (academia, defense companies, small businesses)** **What's new?**



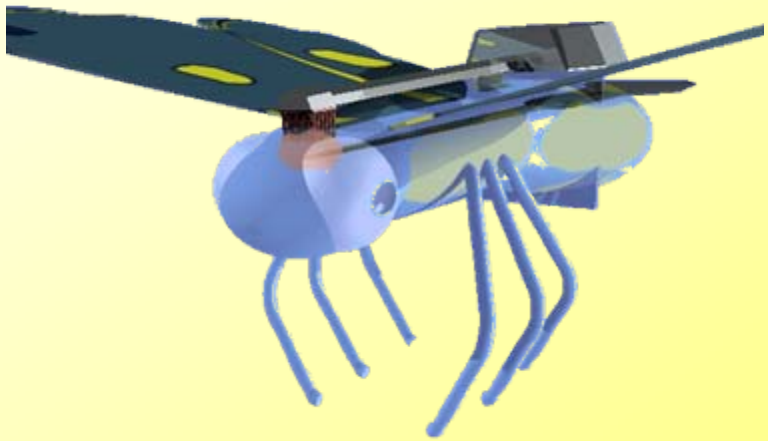
NGIMG: Multiphysics on Chip



Hybrid-Insect MEMS

VISION

Create technology to reliably integrate microsystems payloads on insects to enable insect cyborgs



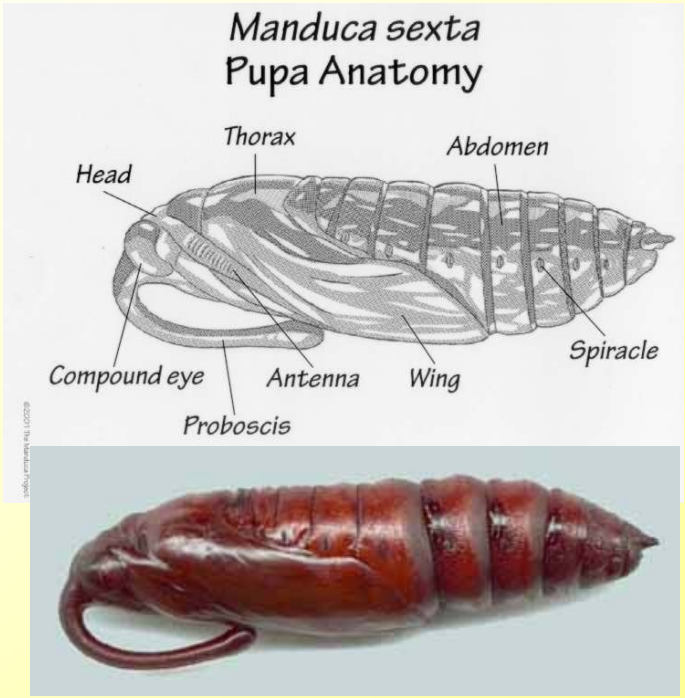
OBJECTIVES

- Develop technology to enable highly coupled electro mechanical interfaces to insect anatomy
- Demonstrate MEMS platforms for electronic locomotion control, power harvesting from insect, and eliminate extraneous biological functions

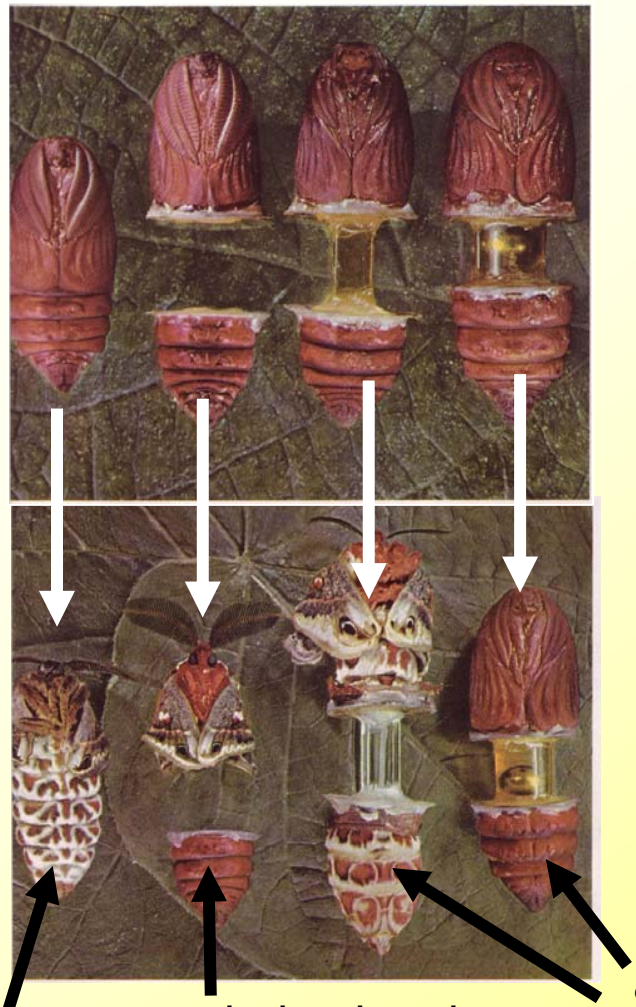
Background: Insect Metamorphosis

Storage of energy over weeks to use later for flight

1st instar | 2nd instar | 3rd instar | 4th instar | 5th instar

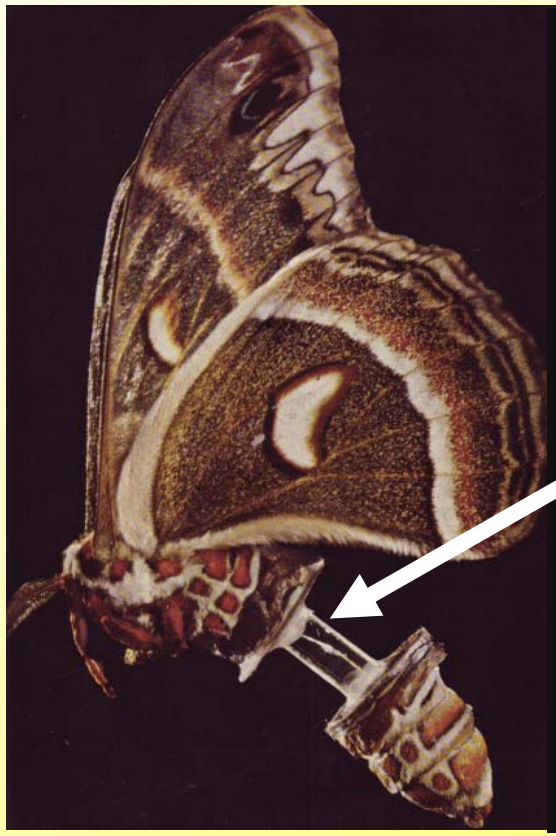


Key Experiments in 1940s



Normal growth

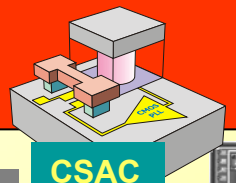
Pupa halved and front develops into moth

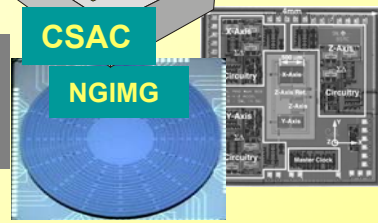


DARPA Program : Use object insertion ability into pupas to *reliably* insert microsystems (instead of glass tube) for insect control

Sectioned Pupa with pipe inserted for hormone transport – grows into moth shown above. Insertion of chemical blocking ball bearing results in no growth

MEMS Platform





Ultrasonic transducers

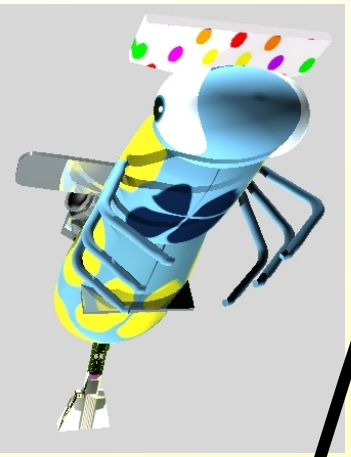
Platform for sensors, actuators, and comm

Piezoelectric flaps for power

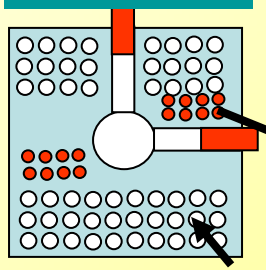
Pheromone ejectors

Light sources

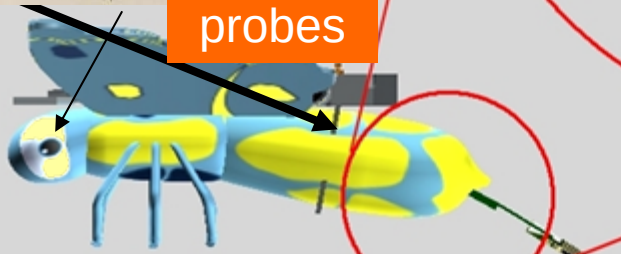
Thermoelectric power, flexible platform



Microfluidic port



Neural/ Muscle probes



Tissue-anchors

Cross and across inserts in pupae

- **Moth body weight ~1-5 grams**
- **Payload ~ 0.5-5 grams**

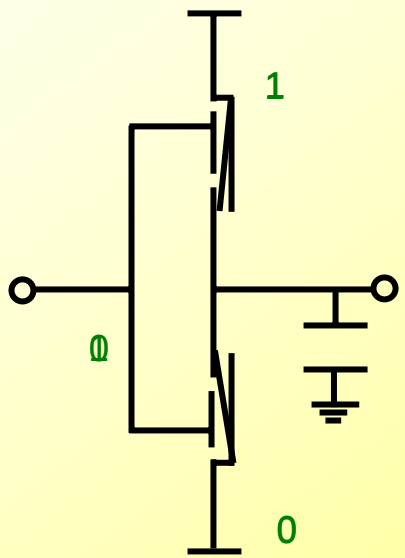
Hybrid NEMtronics

Objectives

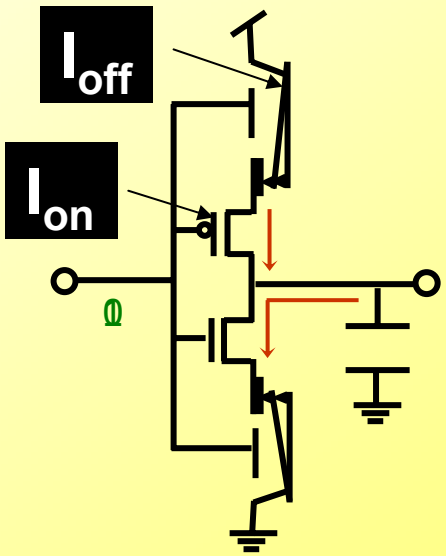
- Eliminate leakage power in electronics to enable longer battery life and lower power required for computing.
- Enable high temperature computing for Carnot efficient computers and eliminate need for cooling

Approaches

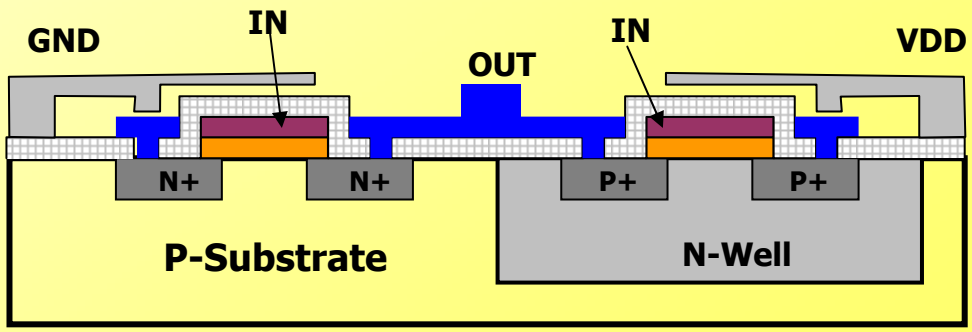
- Use NEMS switches with and without transistors to reduce leakage – I_{on}:Transistor, I_{off}: NEMS
- NEMS can work at high temperature, enabling high efficiency power scavenging.



All Mechanical Computing

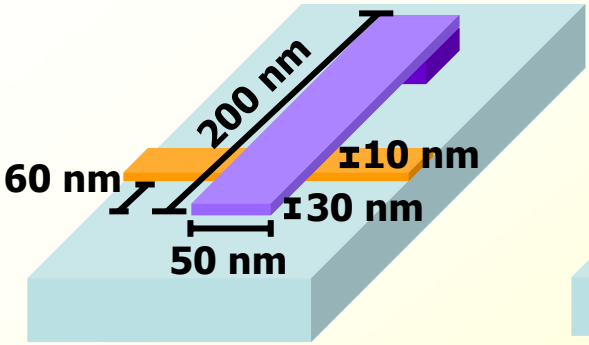


Hybrid NEMS/CMOS component integration

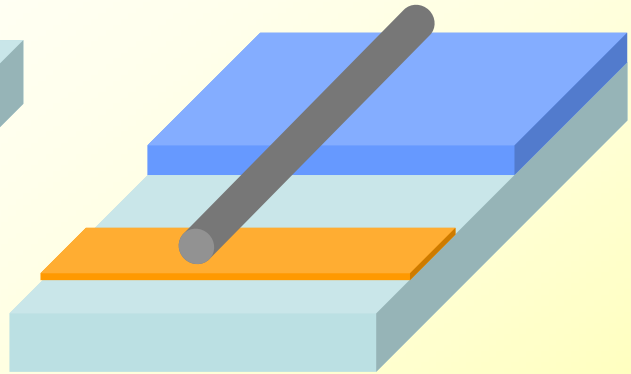


Hybrid NEMS/CMOS Device integration

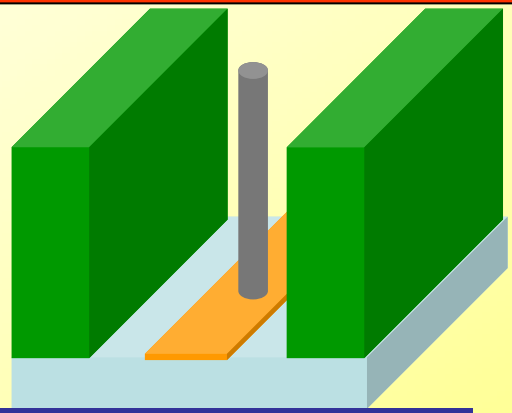
NEMS Design Space



Cantilever



Horizontal fiber cantilever



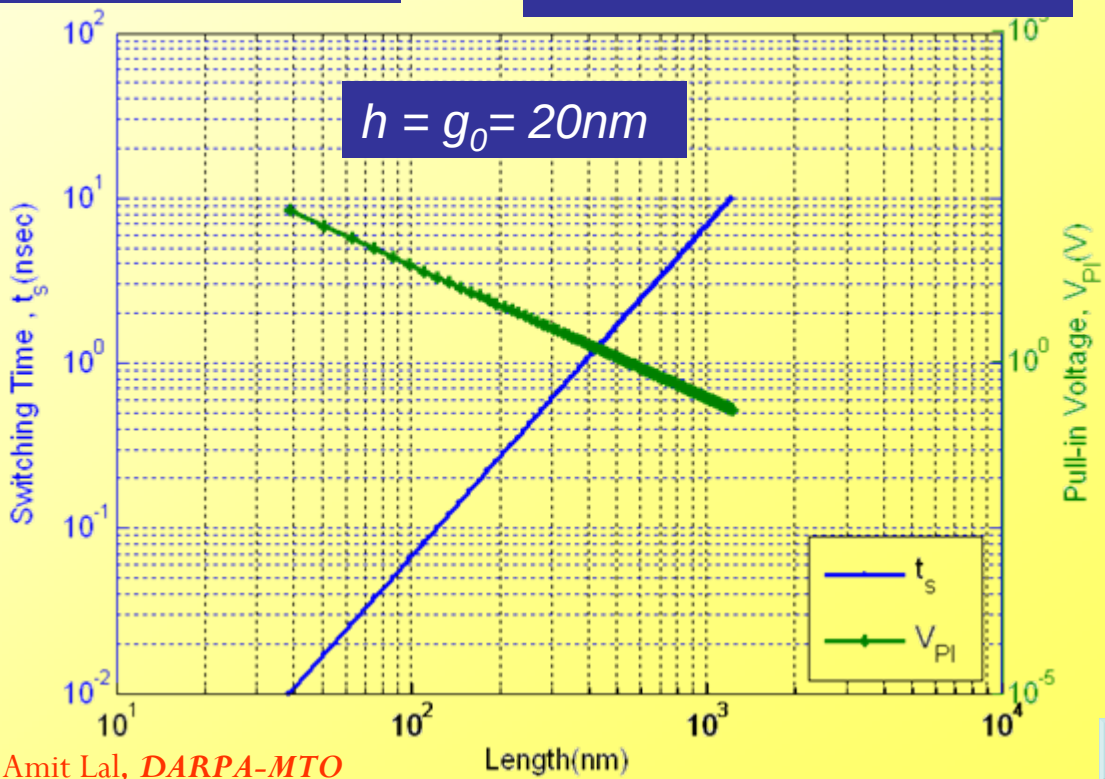
Vertical fiber cantilever

$$k = \frac{Ewh^3}{4L^3}, m = \rho wLh, c_{Beam} = \sqrt{\frac{E}{\rho}}$$

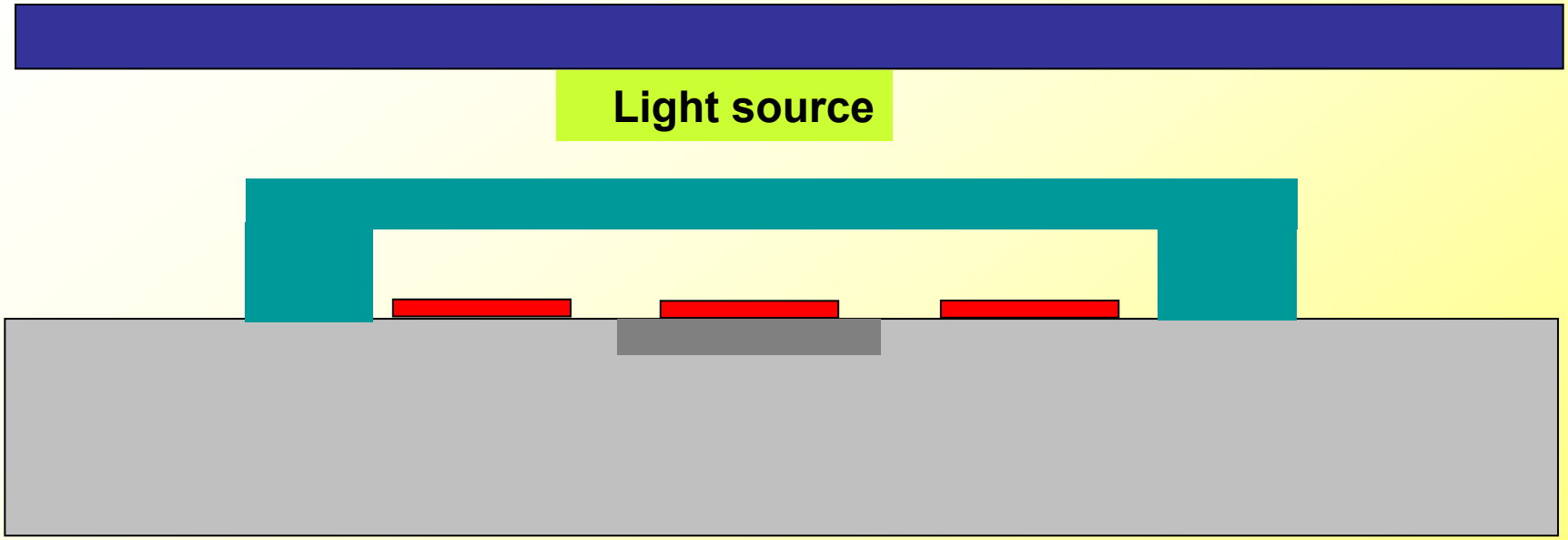
$$\omega_o = \sqrt{\frac{k}{m}} = \frac{h}{2L^2} c_{Beam}$$

$$V_{PI} = \sqrt{\frac{8kg_o^3}{27\varepsilon_o A}}$$

$$t_s = \frac{9V_{PI}^2}{4\omega_o Q V_S^2}, \text{for} V_{PI} \geq V_S$$

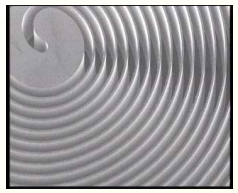


Self-Calibrating MEMS



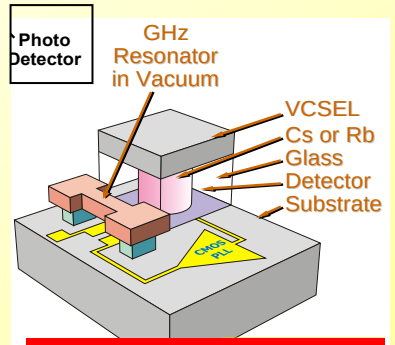
- **Measure many resonant frequencies – characterize dimensions and Young's modulus**
- **Measure electrode thin film thickness and gap optically (on chip ellipsometer)**
- **Stabilize gap, know spring constant**

AOC and Selected MTO MEMS

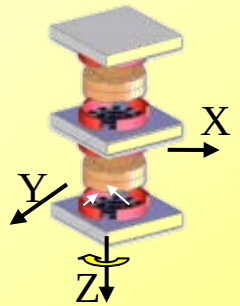


MGA

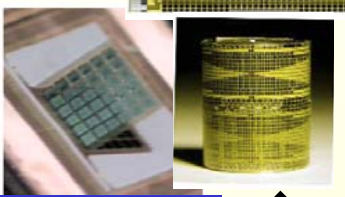
Atomic Sensors



CSAC



NGIMG



Micro Flaps

Sensors
magnetic, elevation, electric field, gases

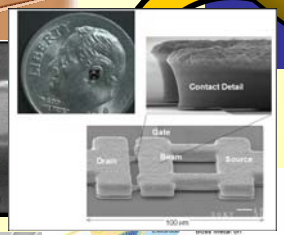
Chip-scale INS/GPS

Flight Control

Comm, Radar

Engine

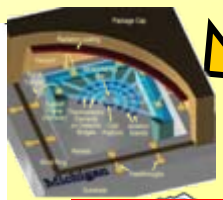
3D MERFS



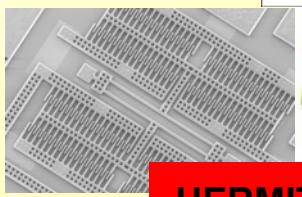
ASP

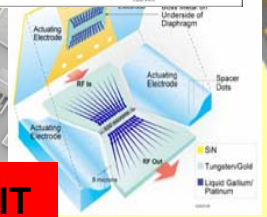
µfluidic fuel injector

µcombustion



MCC

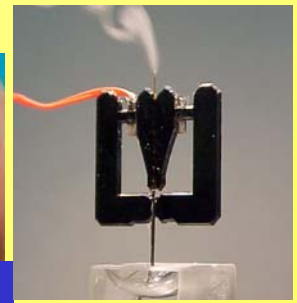




HERMIT

MIT µturbine

µWankel



Summary

- **MEMS offers pathways to miniaturized and chip-scale sensor and actuator systems and MULTIPHYSICS**
- **Upcoming MEMS will result in cost/performance benefits by integrating functionality**
- **The future for MEM Systems is bright!**

QUESTIONS?