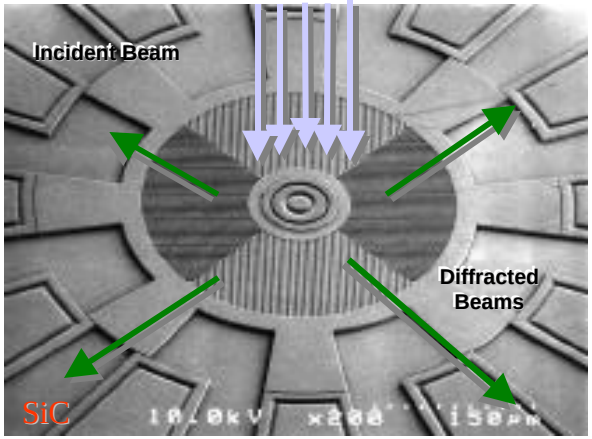
Micro-optoelectromechanical Systems (MOEMS)



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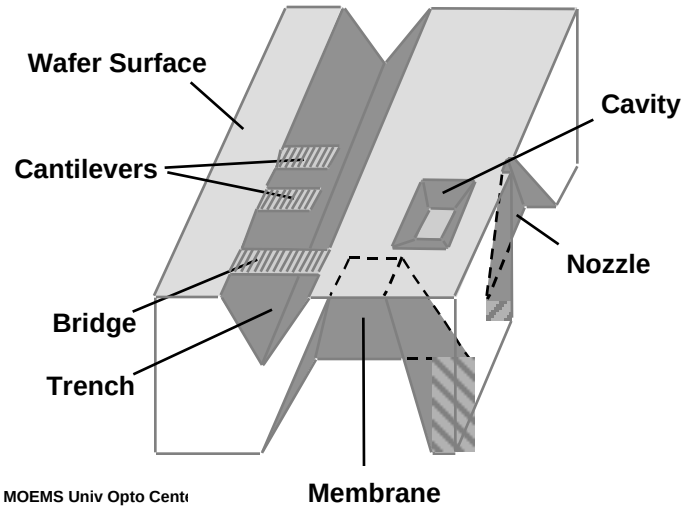
Outline

- The MEMS process
- MOEMS
  - Features and characteristics
  - Examples of micromachined optical elements
  - Examples of optical microsystems
- General MOEMS/MEMS Activity
- Summary

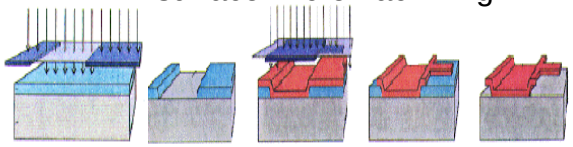
Common Micromachining Processes

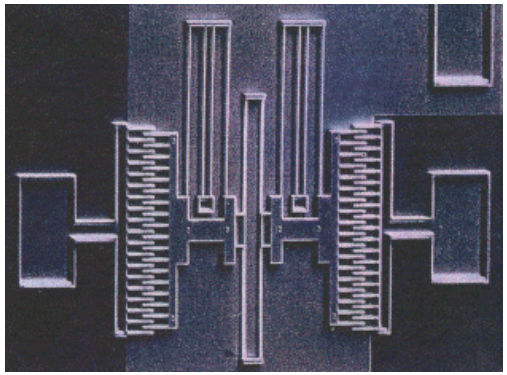
- Bulk micromachining removes “bulk” substrate material (i.e. large holes, pits, and sawing etc.)
- Surface micromachining removes material from “above” the substrate
  - involves deposition and removal processes
- Micromachining processes are either
  - subtractive: etching, laser machining, mechanical milling, etc.
  - additive: deposition of dielectrics, metals, glasses, etc.

bulk micromachining

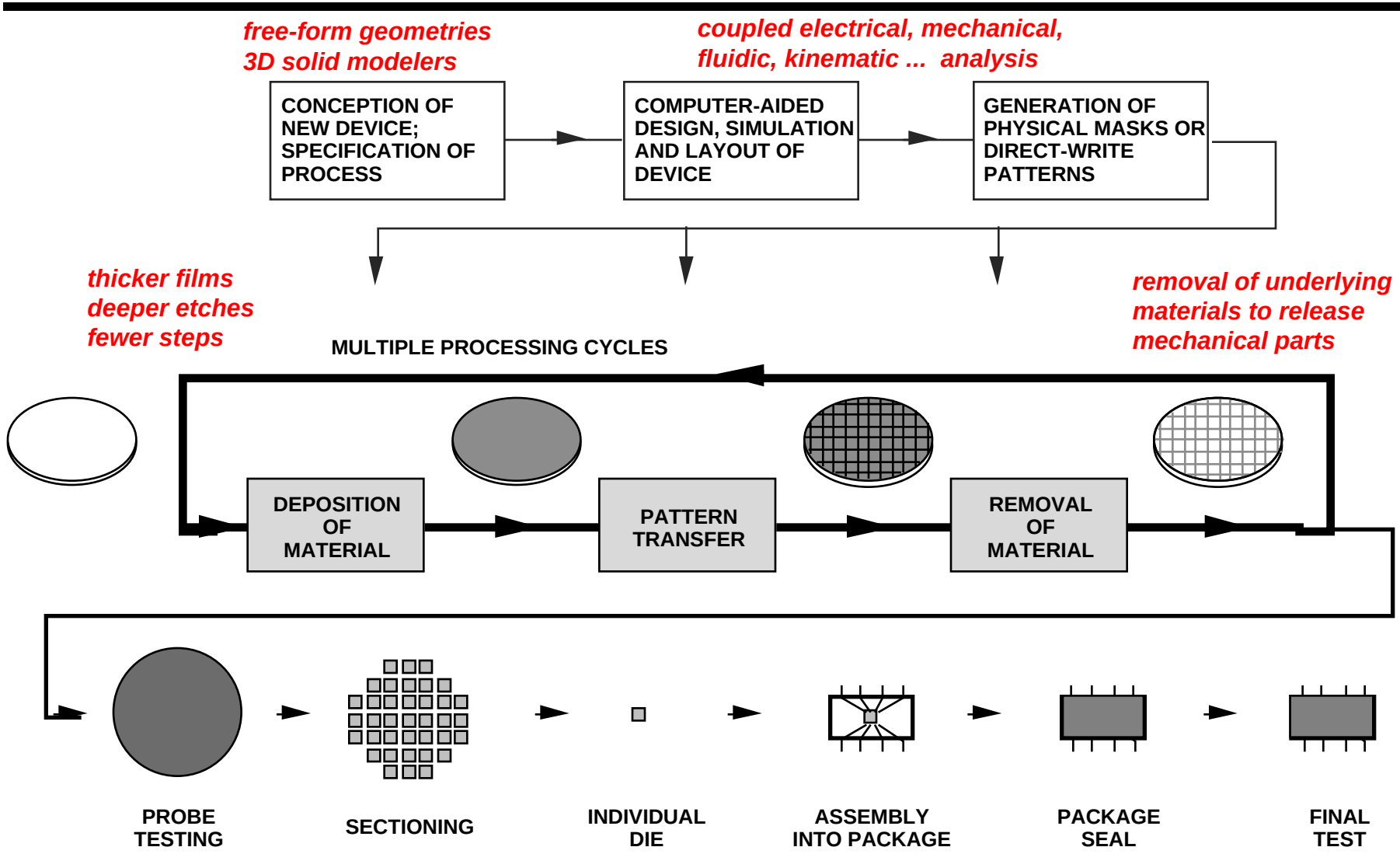


surface micromachining





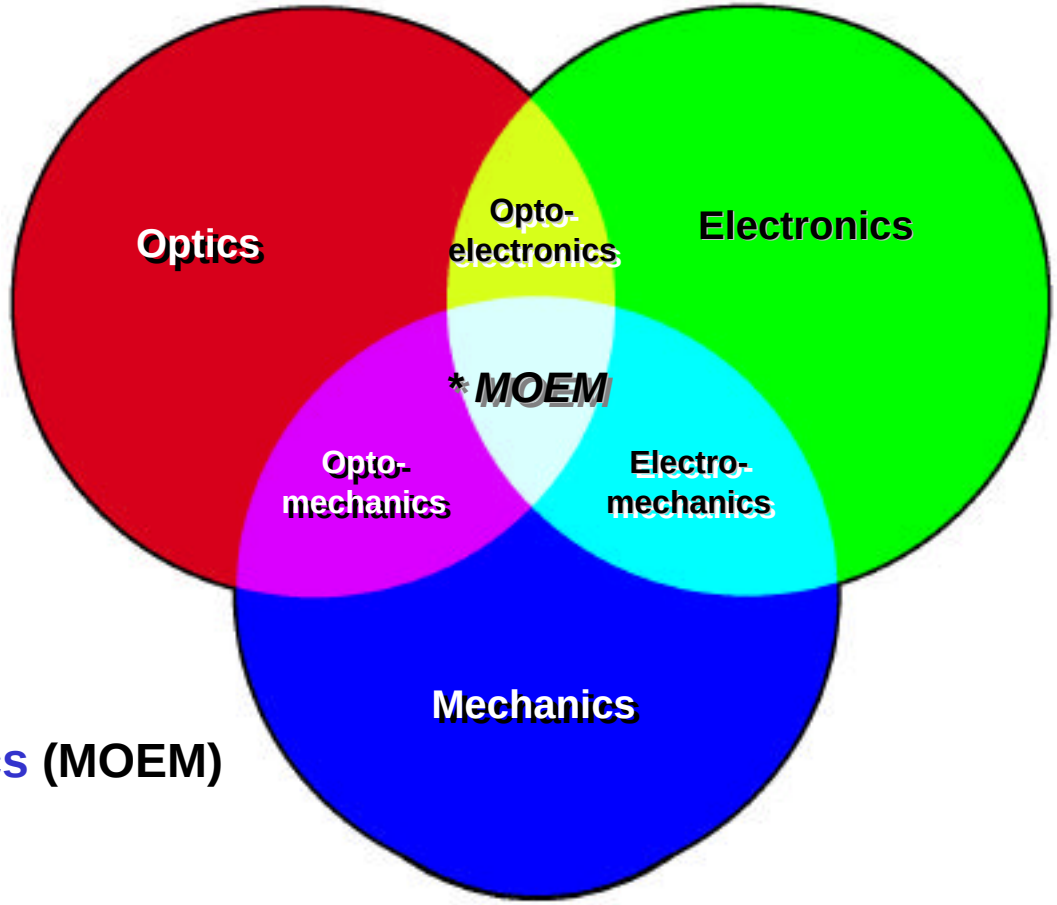
Micromachining Builds on Microelectronics Manufacturing Technology



MicroOptoElectroMechanical Systems (MOEMS)

MOEMS derive their functionality from the miniaturization of:

- **Optics**
- **Electronics**
- **Mechanics**



*** MicroOptoElectroMechanics (MOEM)**

The use of microelectronics batch-processing techniques makes possible the design and construction of microsystems.

What Does Micromachining Offer Optics

- Size reduction of optical elements
- Motion of optical elements
- Co-location of electronics for motion control

Micro-optical Elements

Element	Function
· Lens	¾ focusing
· Post/Stand	¾ mechanical support
· Mirror	¾ reflection
· Grating	¾ deflection/diffraction/spectral resolution
· Beam Splitter	¾ beam combiner/divider
· Waveguide	¾ beam guidance
· Modulator (Chopper)	¾ modulation/attenuation

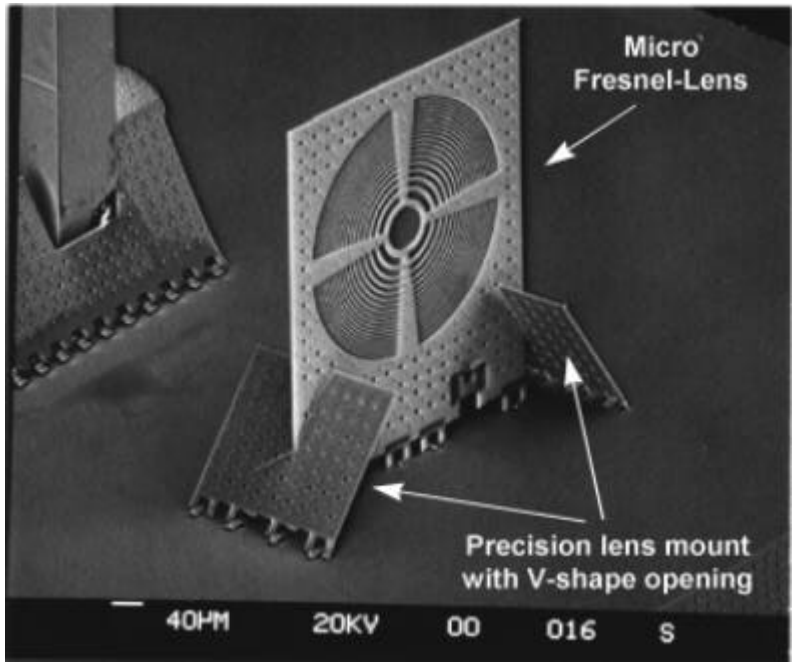
Features of Optical Micromachines

- Micro-Mechanics provide:
  - micro-actuation
  - micro-mechanical linear and rotary motion.
- Micro-Optics can be:
  - diffractive, refractive, or reflective micro-optical elements (fixed or movable)
    - e.g., lenses, gratings, mirrors
  - elements that exploit free-space optical properties of light
  - self-aligned micro-optical elements.
- Micro-Electronics provide
  - drive voltages and currents for linear and rotary motion
  - local signal pre-processing capability

Characteristics of Micromachines

Size:	(small) microns to mm scale
Speed:	100's of nanoseconds to 1 second
Actuation energy:	$CV^2/2$ (electrostatic)
Complexity:	can be fairly complex
Scalability:	1 to 10^6 components
Integrability:	with electronics and optics
Optical paths:	free-space or guided
Cost:	cost of chip + assembly/package

A Fresnel Micro-Lens



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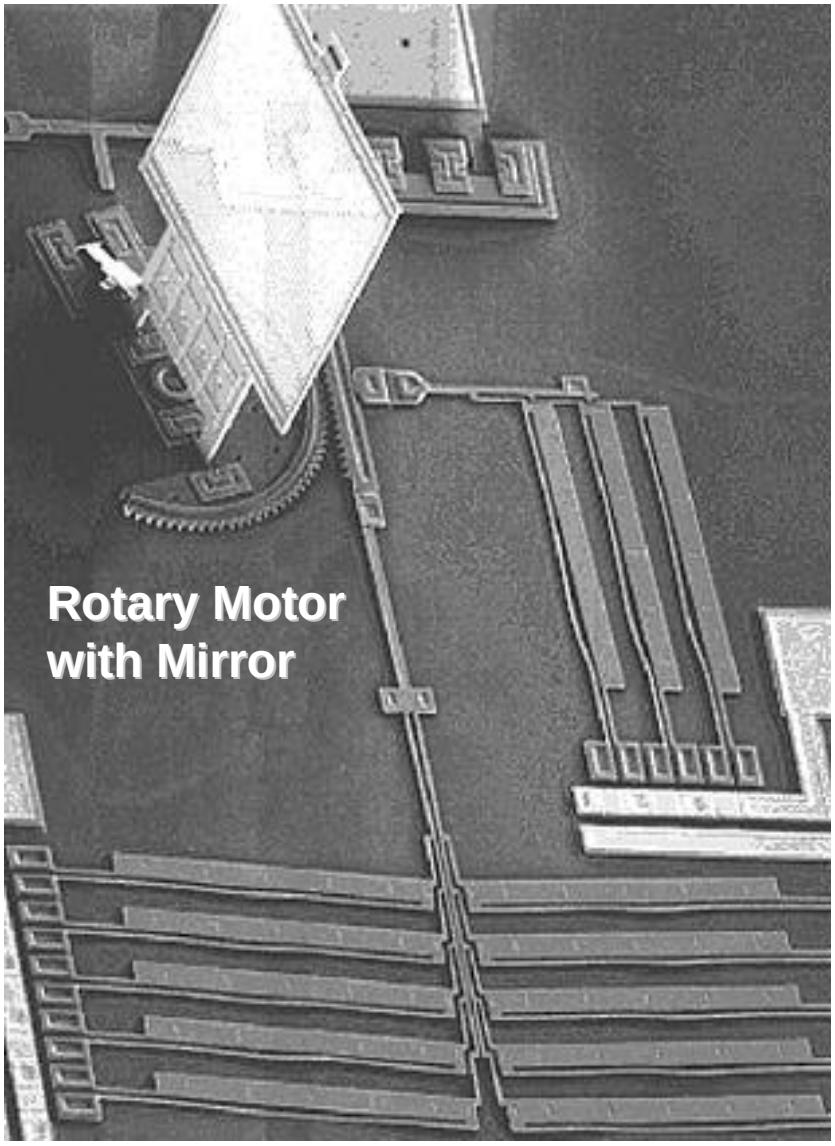
Movable Micro-mirror



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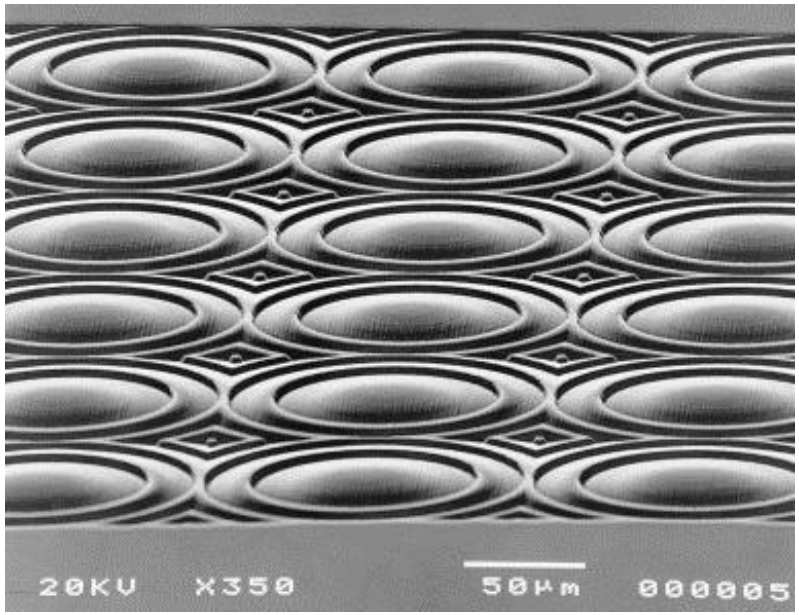
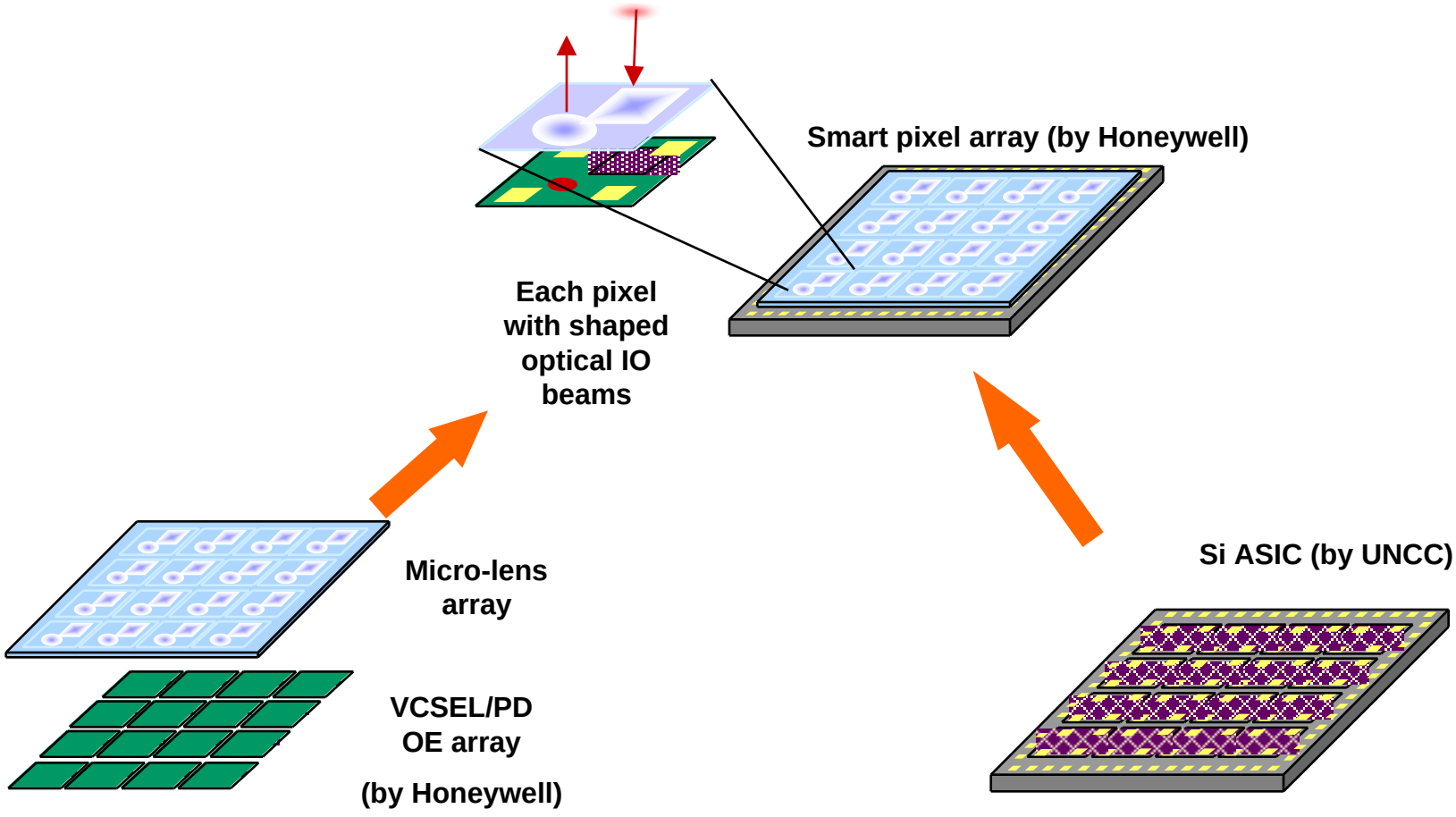
Batch-micromachined Optical Elements

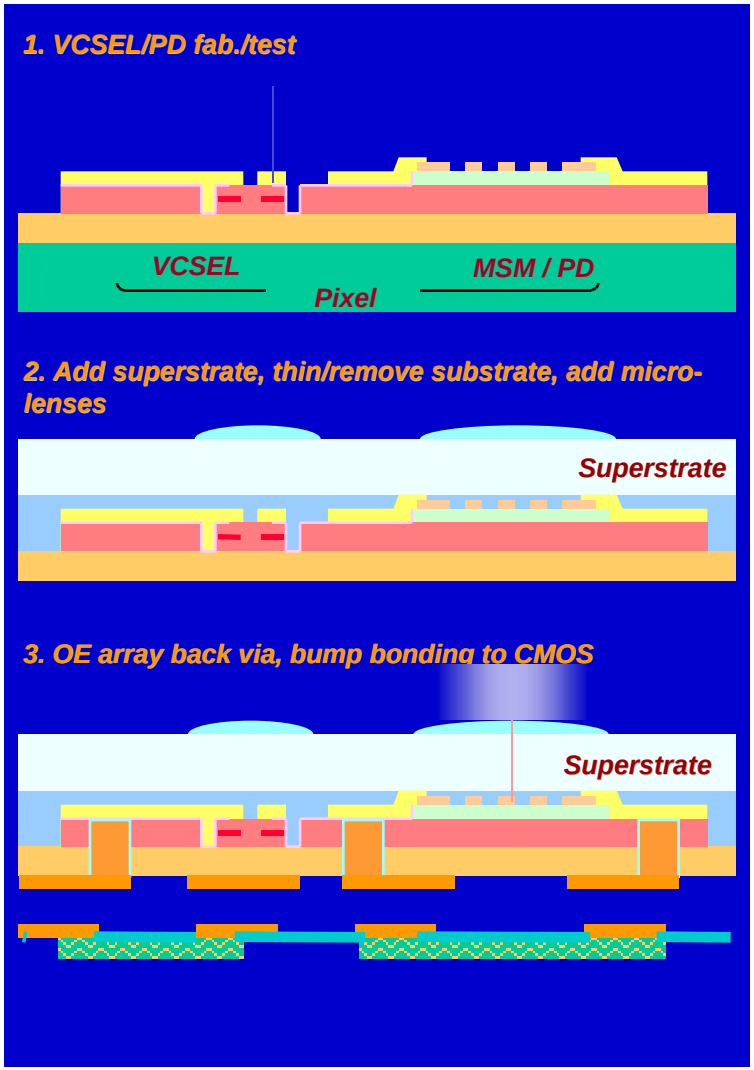


- A microlens array compatible with planar electro-optical device arrays

Example of Heterogeneous Integration



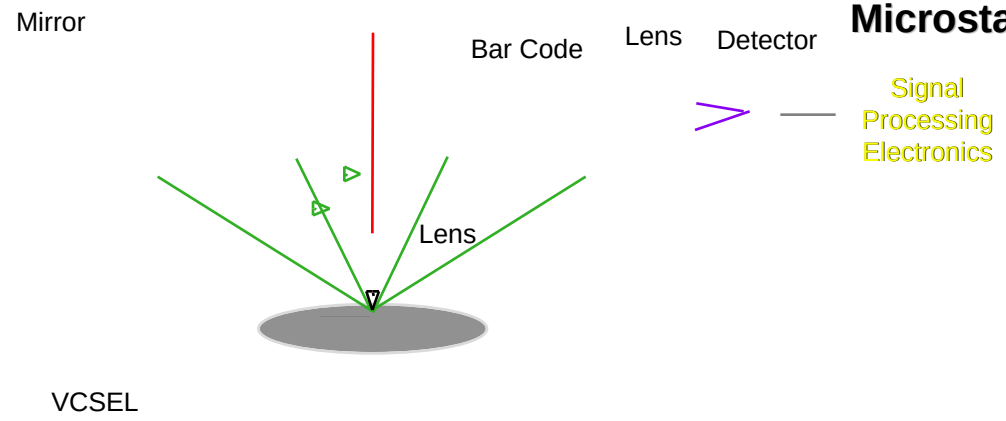
Details on Heterogeneous Integration



Focus of Current MOEMS Work

- New types of displays
  - based on physical motion of reflecting surfaces (light modulation)
- Communication systems
  - fiber-optic switches, crossconnects, add/drop filters, etc.
  - based on physical motion of mirror to direct right to where it is needed

Microstatormotor with a diffraction grating

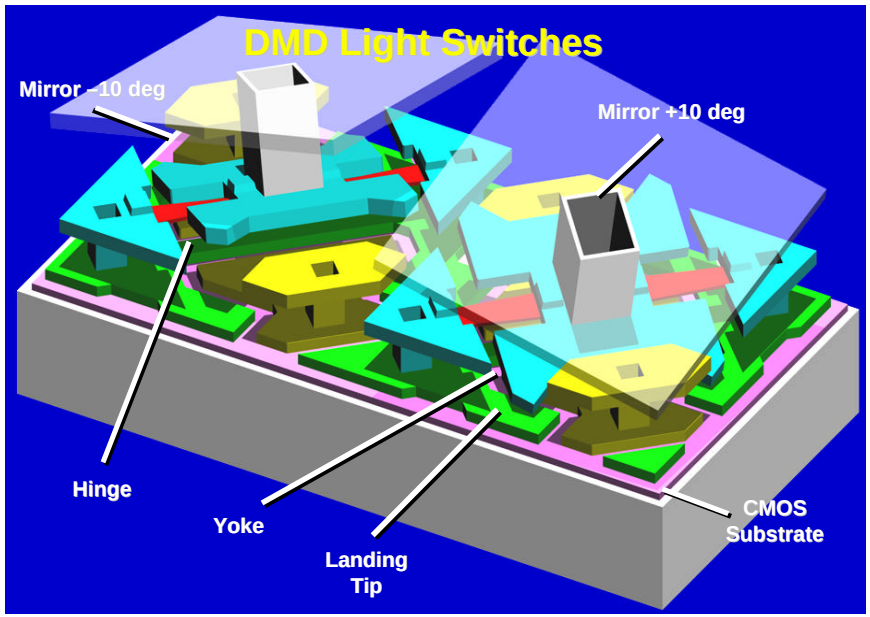


Features:

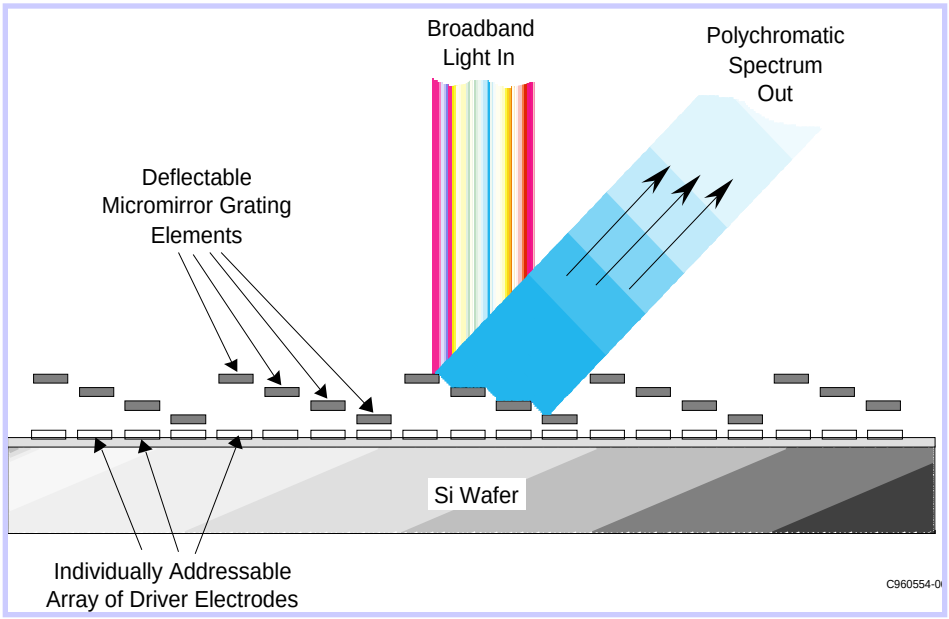
- **20V operating voltage**
- **up to 5000 rpm scan speeds**
- **0.5 mm deflected light spot**
- **high-quality spot / beam profiles**
- **High reliability**
- **Minimal assembly**

MicroOptoElectroMechanical Systems (MOEMS)

- Manipulation of light for signal sensing and processing
  - The mechanics provide motion controlled by electronics
- Examples of controlled mechanical motion of optical beams:

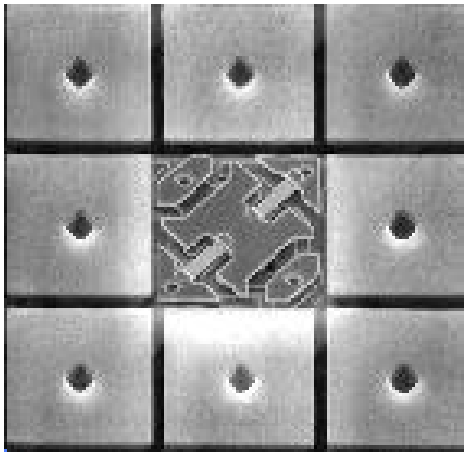


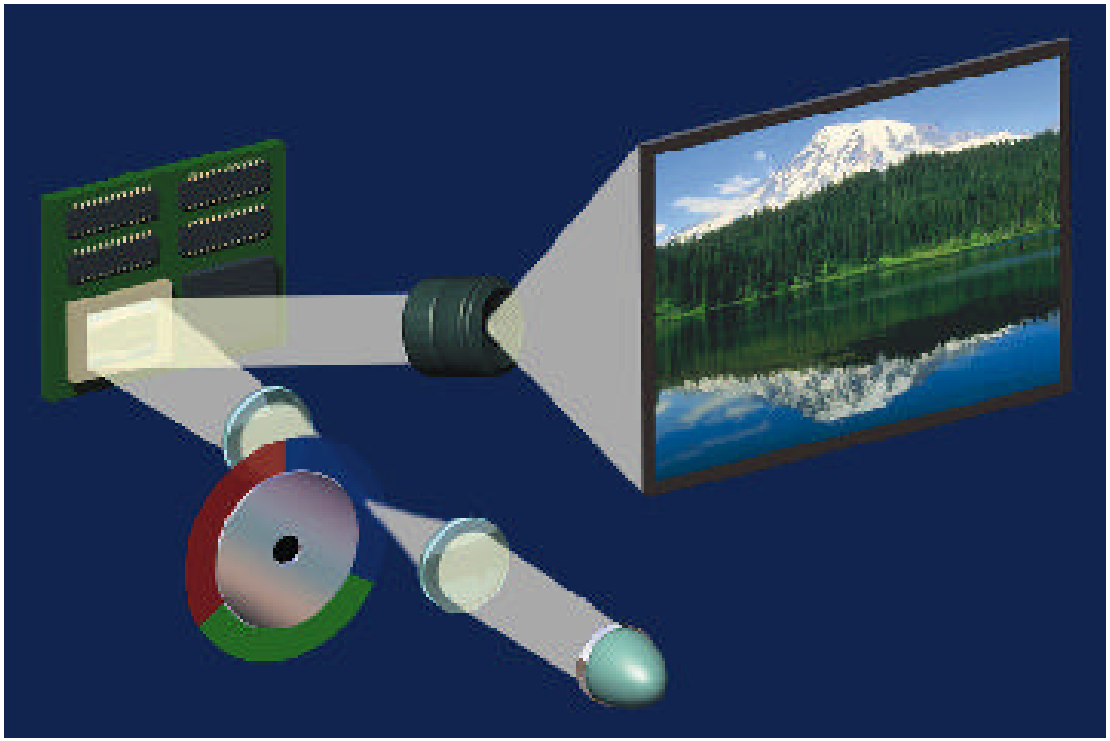
Beam Deflection



Spectral Separation

The Digital Micromirror Display

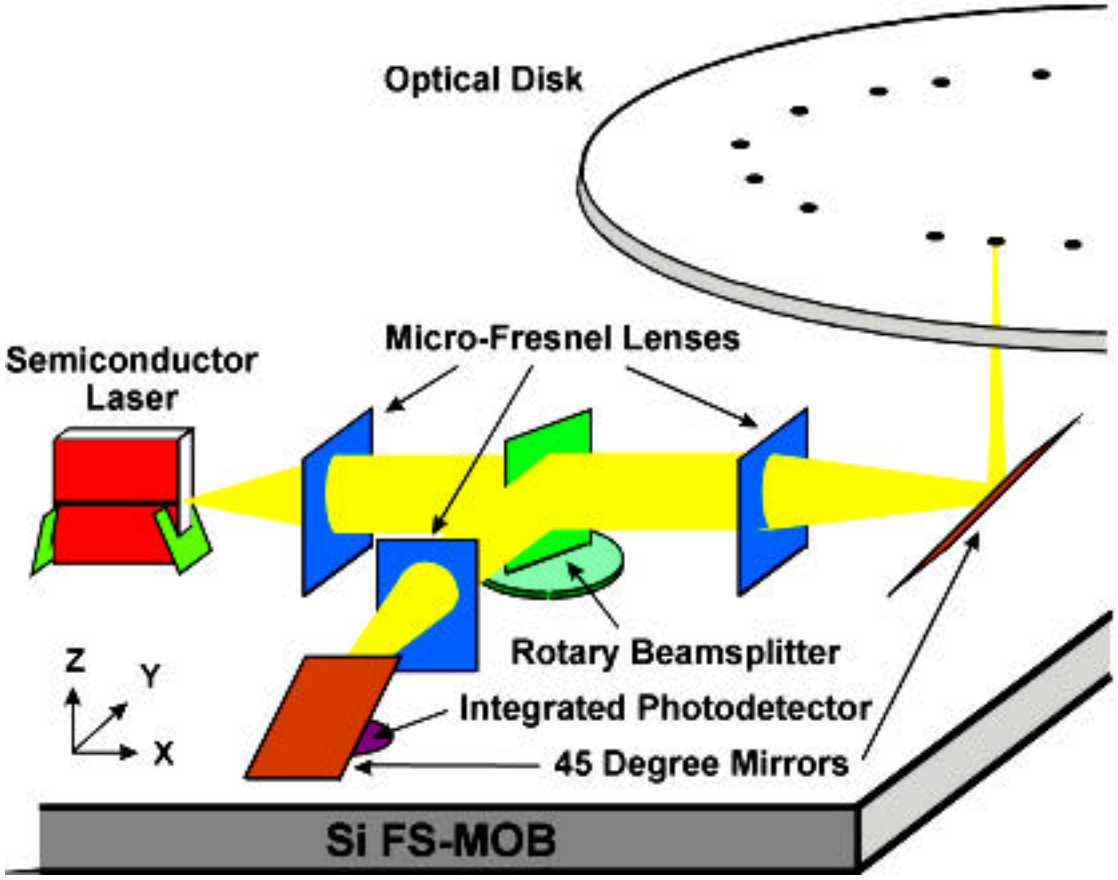




- 2000x1000 pixel resolution (2 million micromirrors)
- 16 µm x 16 µm mirrors
- digital gray scale using pulse width modulation

Texas Instruments, Inc.

Micro-optical Disk Pickup Head

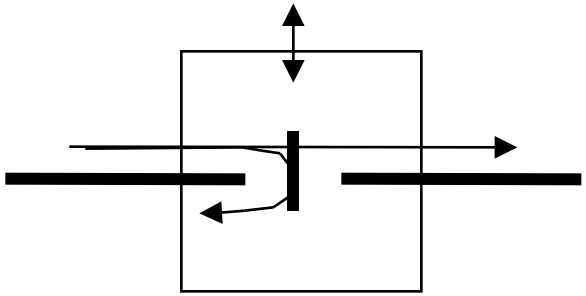


UCLA

MOEMS in Communications

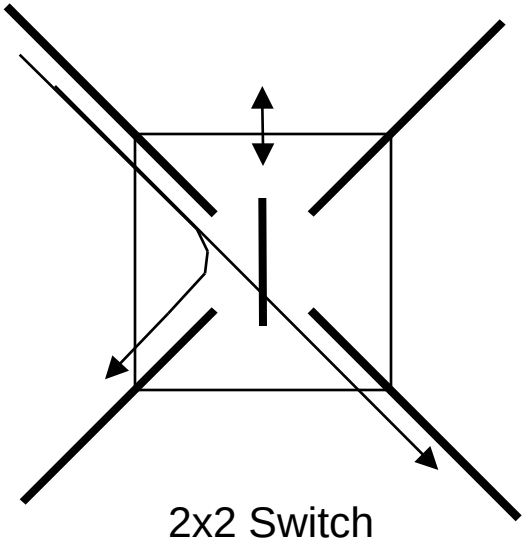
- Devices required for communication systems
  - modulators
  - switches
  - micromirrors
- Enabled systems
  - WDM add/drop filter
  - active equalizers
  - optical crossconnects

Optical Switch Configurations

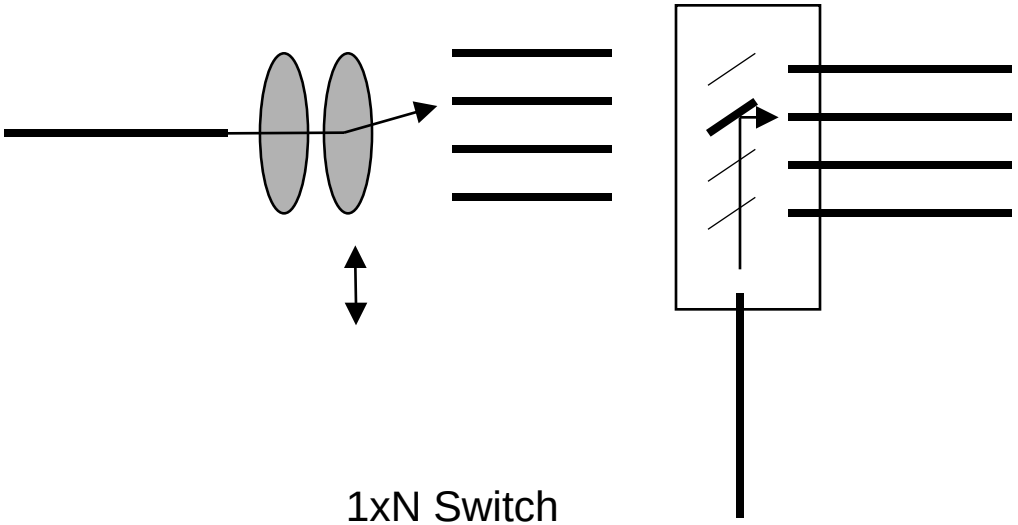


ON-Off Switch

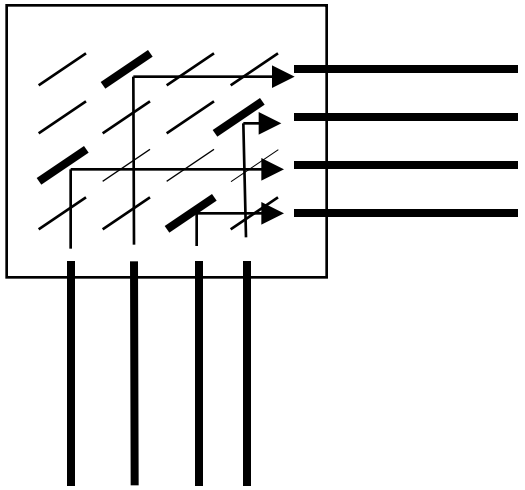
(optical gate)



2x2 Switch

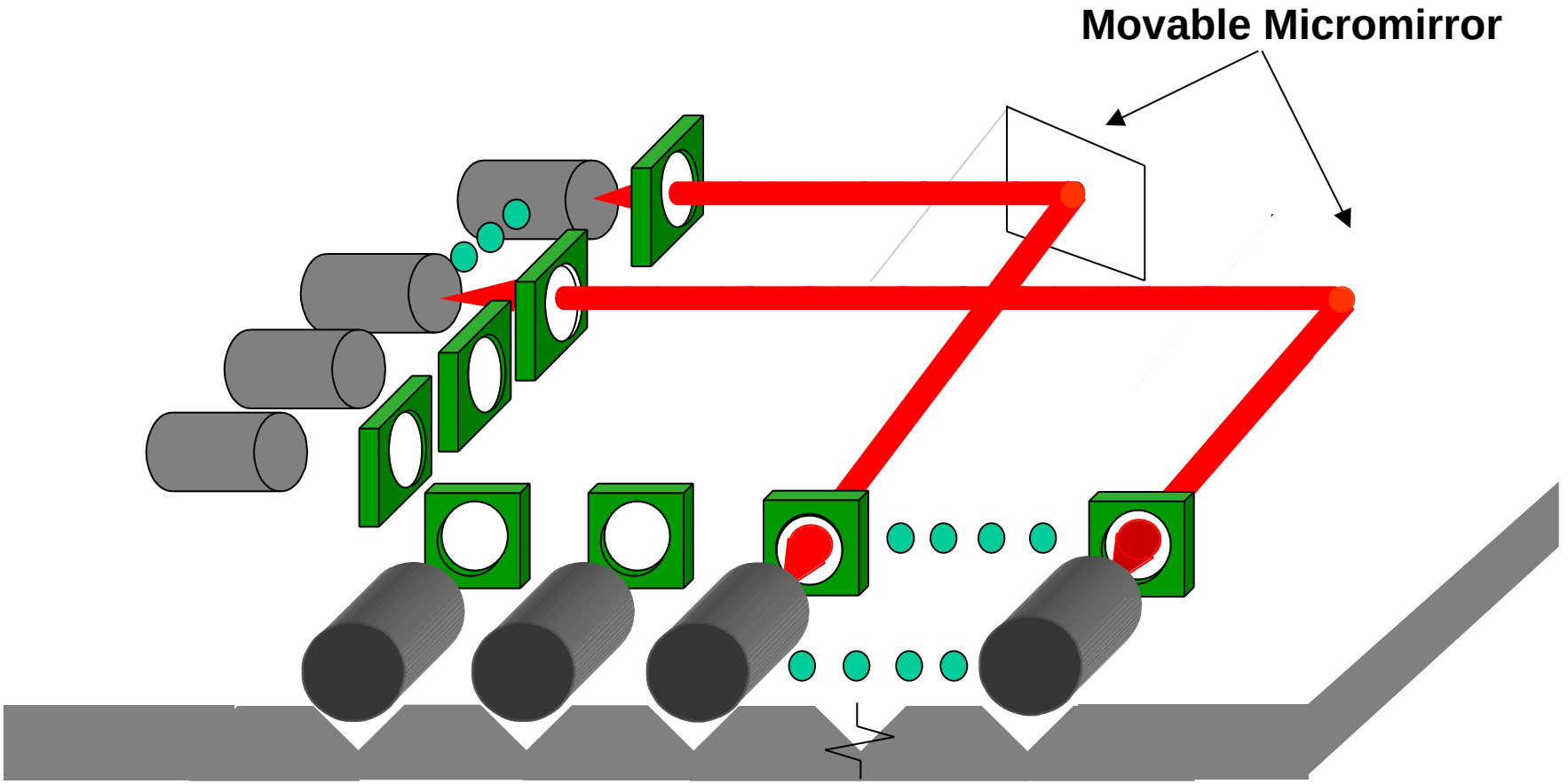


1xN Switch



NxN Switch

Optical Cross-Connect Switch



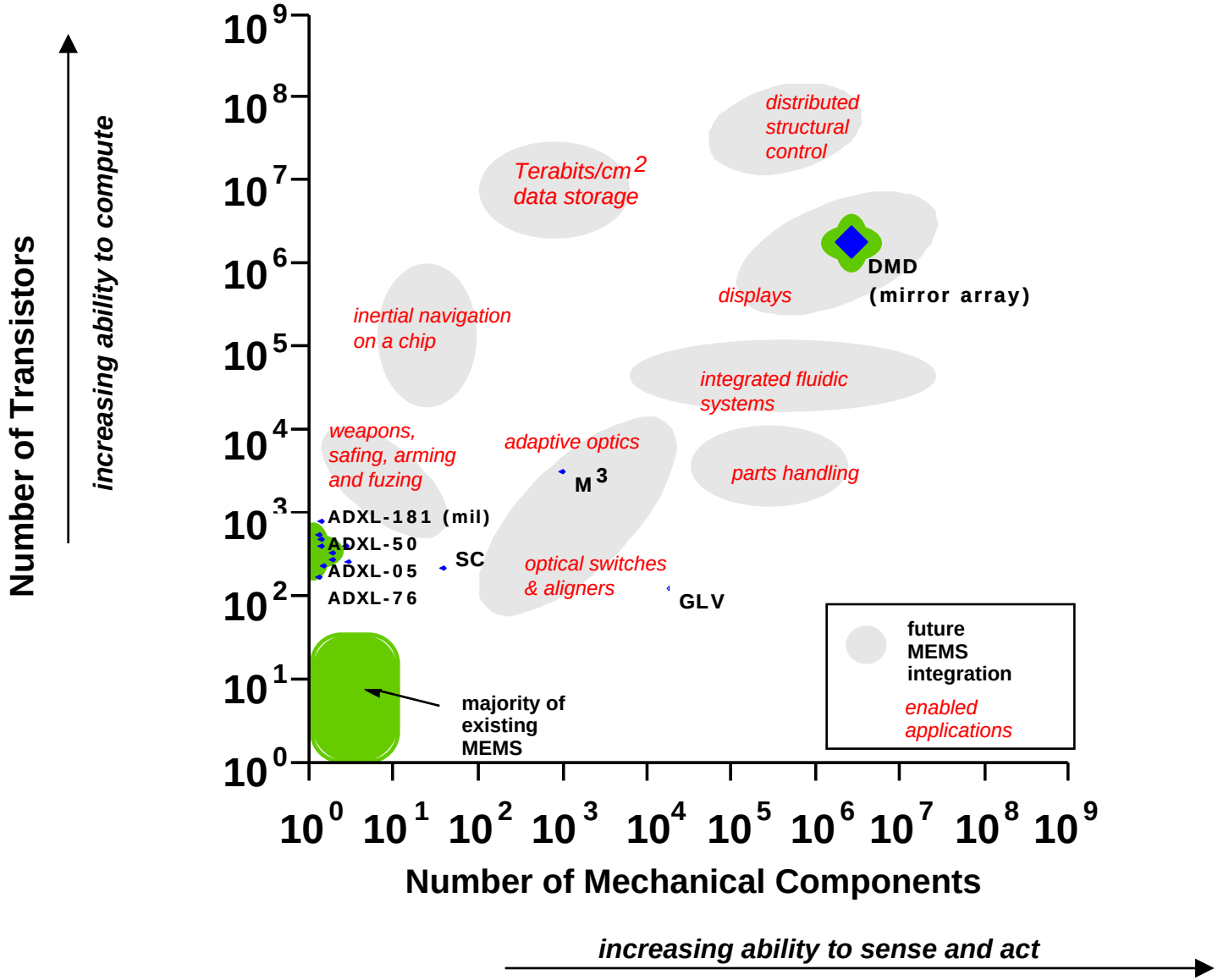
Challenges in Optical MEMS

- MEMS are inherently 2-dimensional
- Classical physical optics is inherently 3-dimensional (although modern photonics can be 2-dimensional)
- Complicated and elaborate assembly process required
- Packaging is a problem

Significant MOEMS Activity

- UCLA, UCB, Optical Micro Machines, Silicon Light Machines
- TI, CWRU, CU, Sandia
- BU, General Electric, NCSU, Lucent, AT&T Labs, MCNC, AFIT
- University of Tokyo,Ritsumeikan University (Micromachining Multi-chip service), NTT, NEC, OMRON
- Switzerland, Belgium (IMEC), Germany, France

The Merging of Electronics and Micromachines



Summary

- Modern optics has been largely concerned with the
  - Generation
  - Modulation
  - Transmission, and
  - Detection of light
- Recent developments have focused on miniaturization of physical optical elements by micromachining
- Next significant developments will likely be the merging of
  - smart pixel arrays
  - optical micromachines
  - engineered nanostructure-based active optical devices
- For the exploitation of functionalities derived by the manipulation of spectral, polarization, and spatial attributes of light