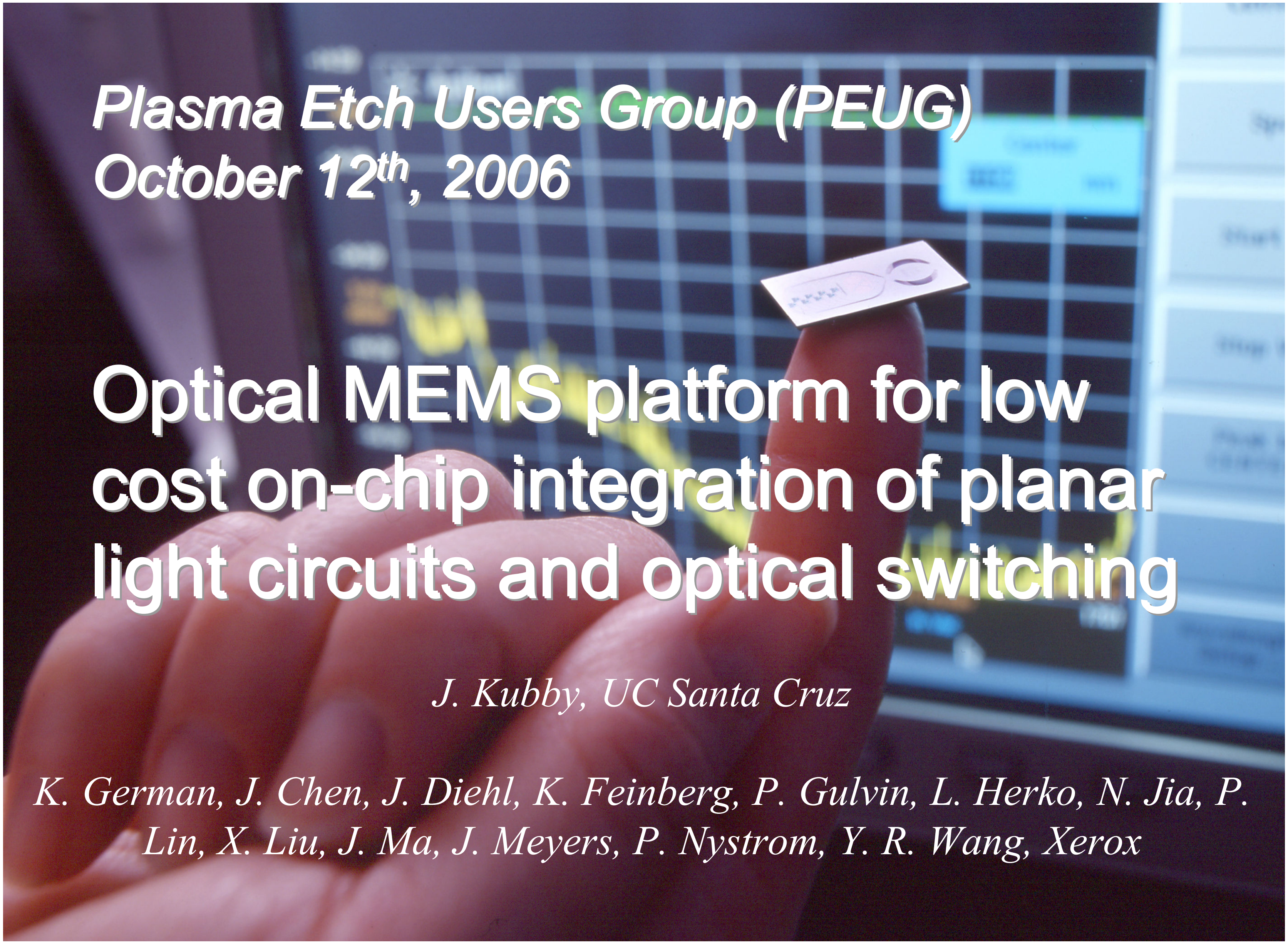

Plasma Etch Users Group (PEUG)
October 12th, 2006
Optical MEMS platform for low cost on-chip integration of planar light circuits and optical switching
J. Kubby, UC Santa Cruz
K. German, J. Chen, J. Diehl, K. Feinberg, P. Gulvin, L. Herko, N. Jia, P. Lin, X. Liu, J. Ma, J. Meyers, P. Nystrom, Y. R. Wang, Xerox

PLC and MEMS Waveguide Switch Integration

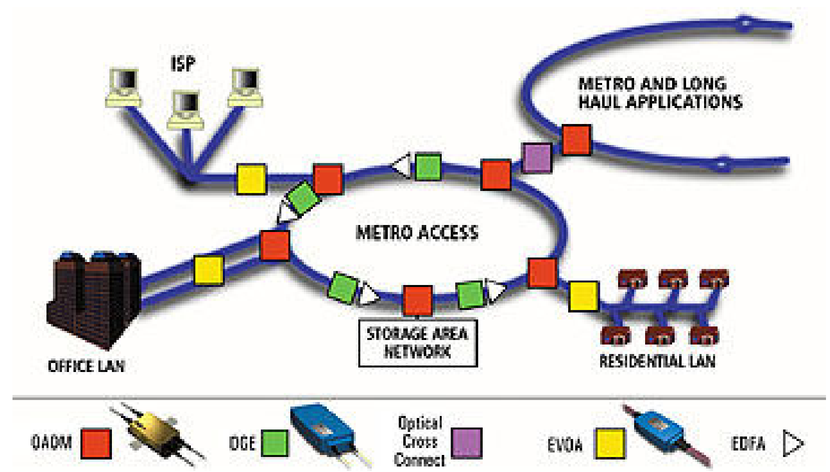
- Outline -

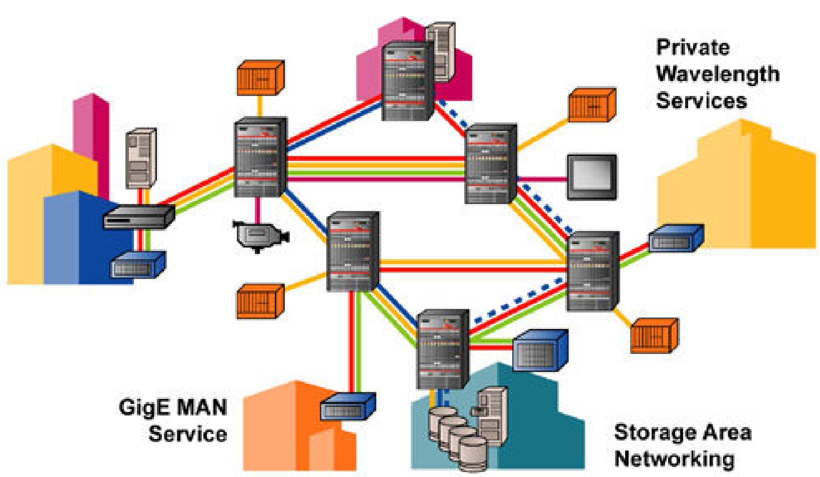
- Why Integrate: New technology for a new market
- Elements of compact affordable integration
  - Silicon on Insulator (SOI) PLC Optics
  - Latching MEMS waveguide switches
  - PLC and MEMS System Integration
  - Component reconfiguration
- Example Prototypes: ROADM and λ–Router
- Next Steps and Extensions
  - Infotonics Technology Center
  - Hybrid integration and active elements
- Summary
- Acknowledgements

Metro Networks

Optical Devices

- Affordable enabling components for wavelength services (~10x cost reduction)
- Optical Add/Drop Multiplexer at each on ramp and off ramp
- Additional network functions (VOA, DGE,….)

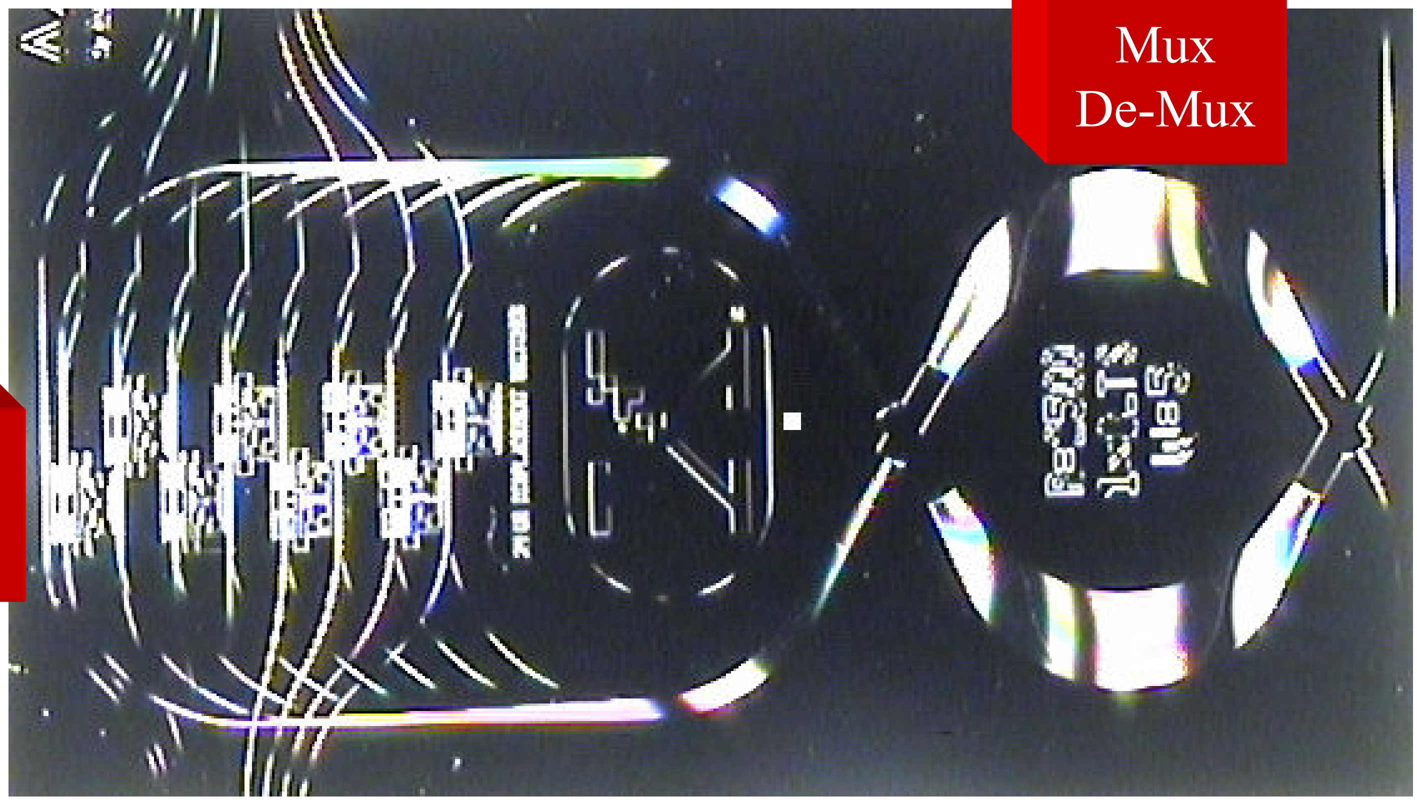




Wavelength Services

- Provide bandwidth on demand at the wavelength granularity
- Democratize bandwidth through affordable provisioning
- Enables new services (SAN, PWS, GigE) using existing WDM infrastructure

Elements of compact affordable integration



Mux
De-Mux

Latching
Optical
Switches

SOI for integrated MEMS and PLCs

SOI Optical Design Space

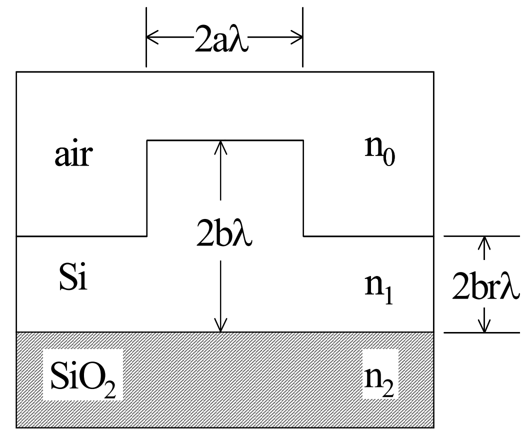
Intrinsic Trade-offs

- Insertion Loss/Length
- Cross Talk (single mode)
- Polarization Dependent Loss
- Minimum Bending Radius
- Coupling Loss
- Chip Size

Extrinsic Factors

- Process uniformity
- Waveguide Roughness

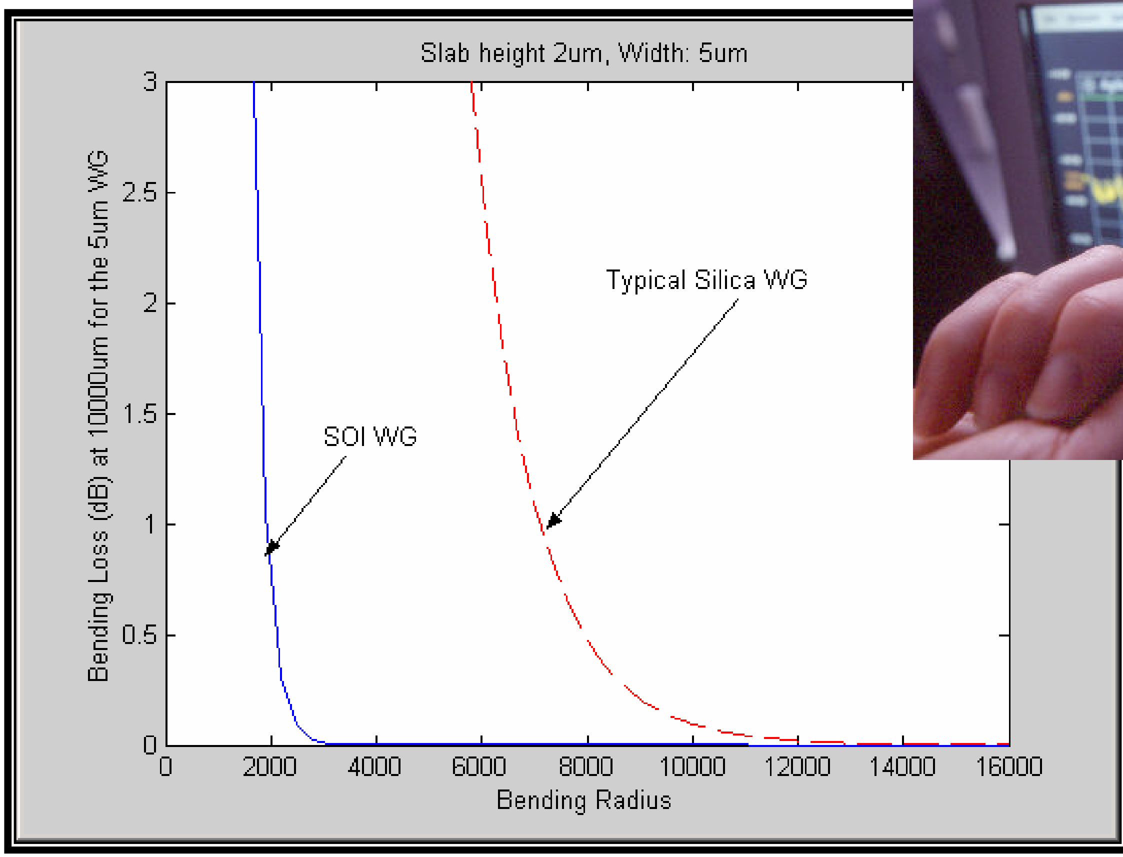
Rib Waveguide parameters

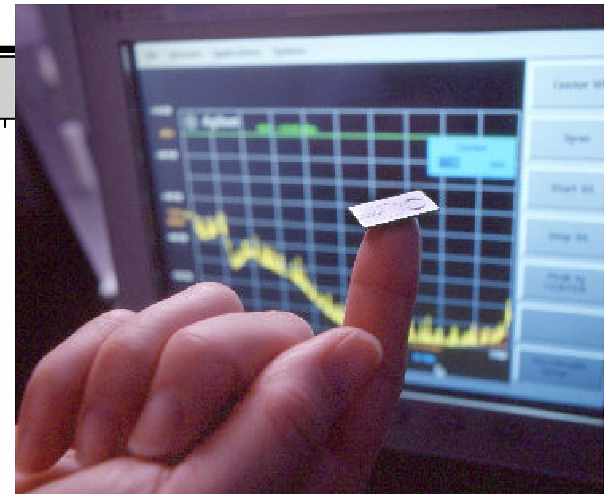


Single Mode Condition

$$a/b \leq 0.3 + r/\sqrt{(1-r^2)}$$

Compact Planar Light Circuits



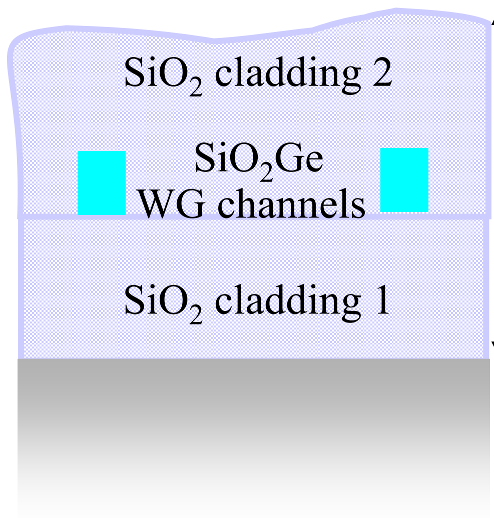


Silicon waveguides can have bending radii 3 to 4 times smaller than silica waveguides

Silicon: n = 3.42, absorption ~ 0.1 dB/cm   Silica : n ~ 1.45

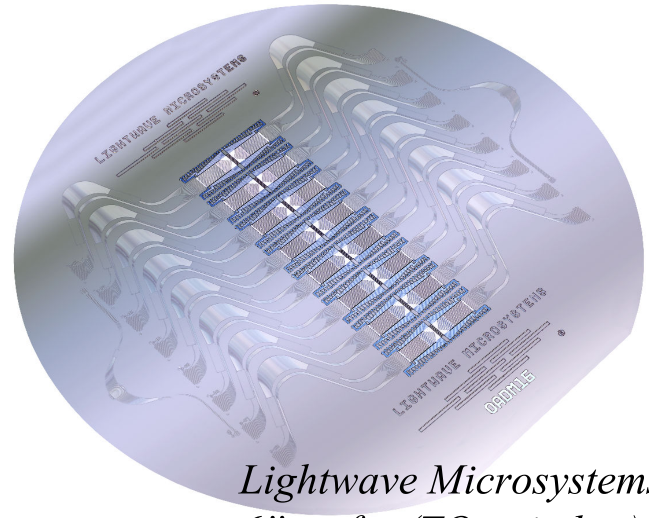
Waveguide fabrication comparison

Silica on Silicon



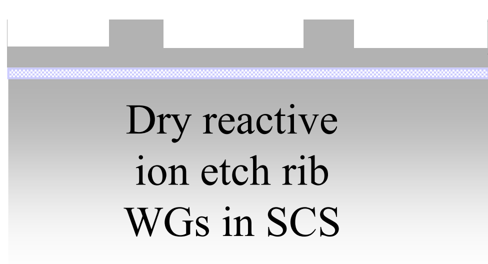
Total max thickness ~ 45 µm

Si wafer



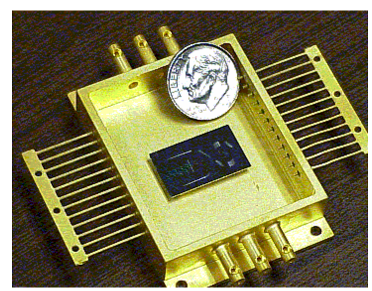
Lightwave Microsystems 6” wafer (TO switches)

Silicon on Insulator



5µm SCS

SOI wafer

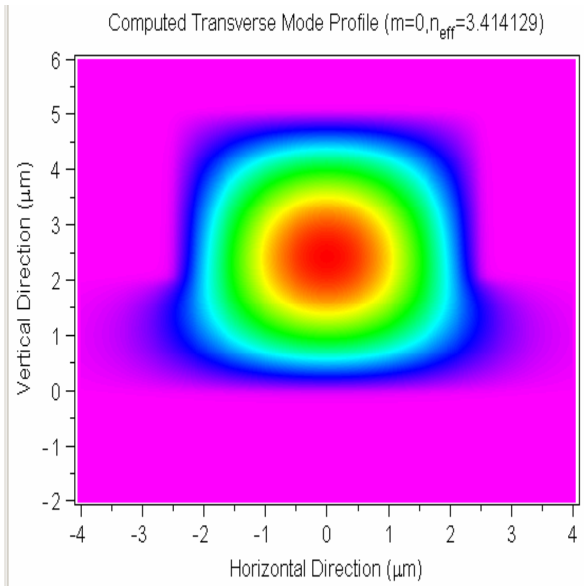


Example SOI ROADM 1.7 cm x 1.0 cm chip (MEMS switches)

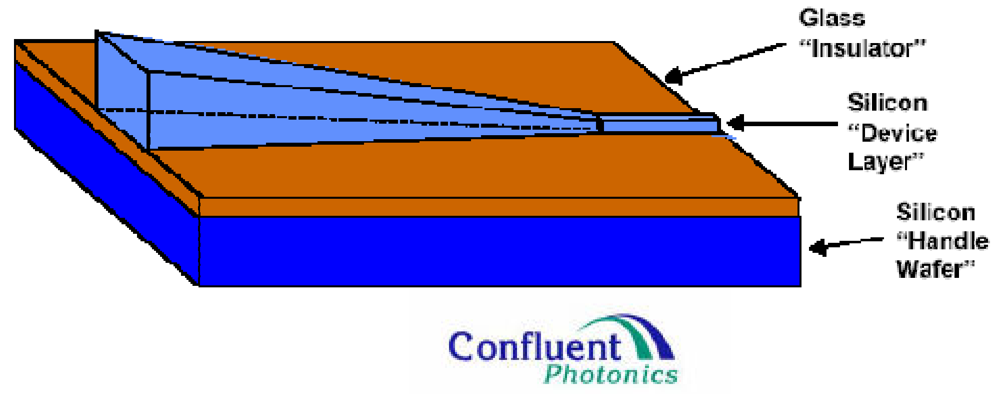
More devices and higher yield per wafer

Coupling fibers to SOI waveguides

Mode matching and adiabatic transformation help minimize losses associated with coupling



Computed SOI WG mode

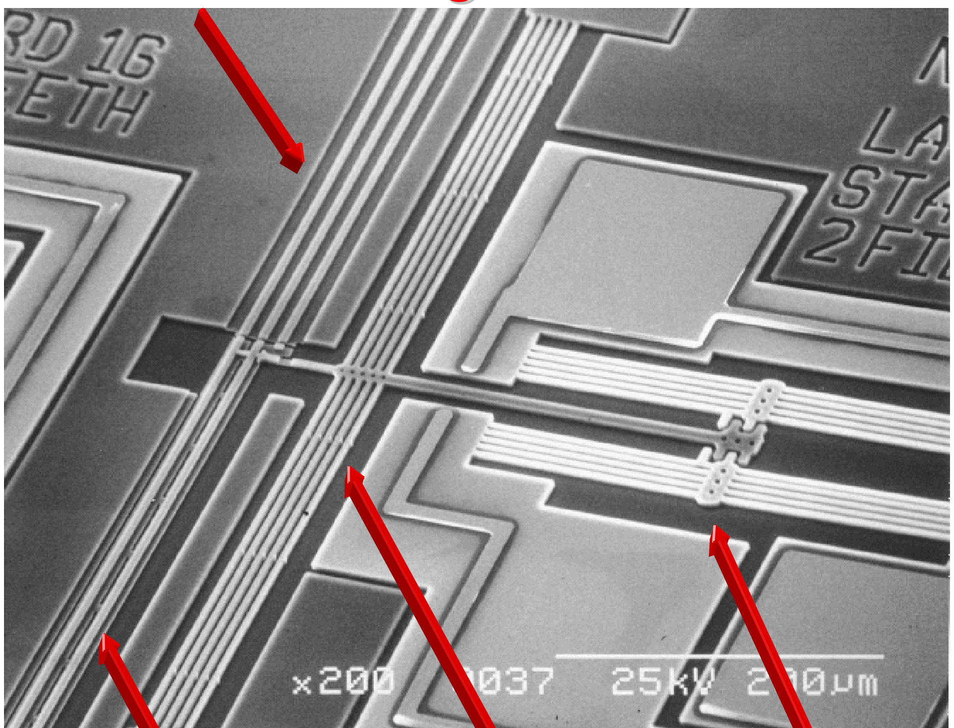


SOI vertically tapered mode adaptor

Measurements on prototypes project 0.7 dB coupling loss/facet when AR coatings are applied

Latching MEMS Waveguide Switch

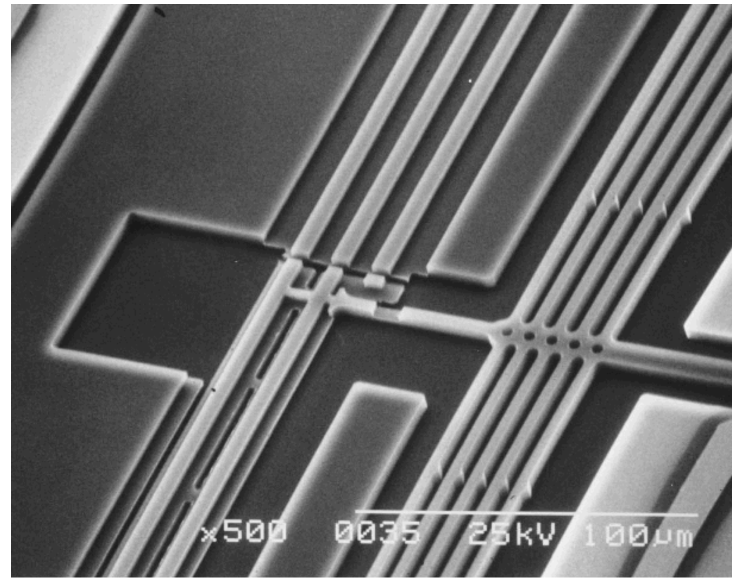
Anchored Waveguides

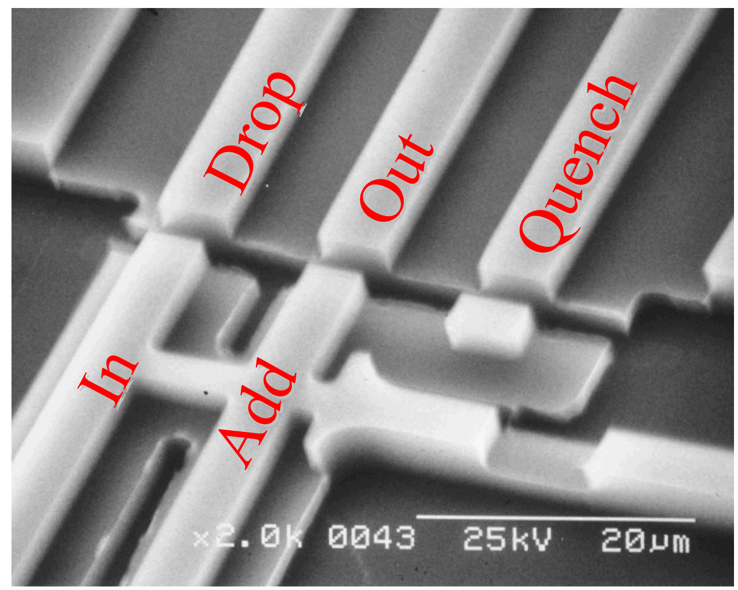


Released
Waveguides
(cantilever)

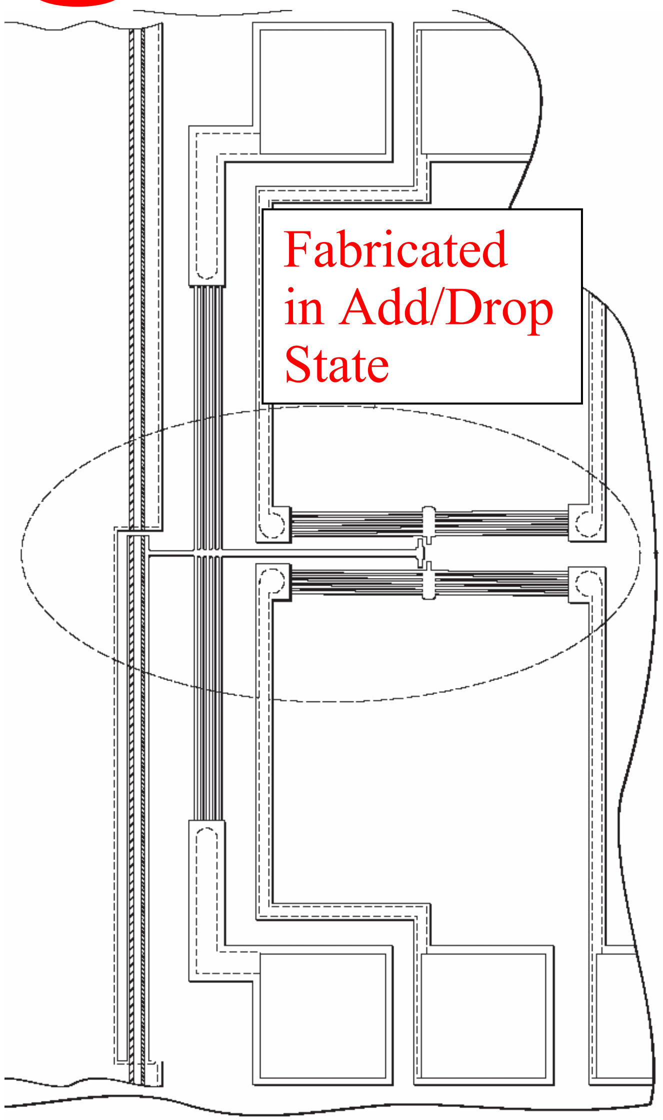
Drive

Latch

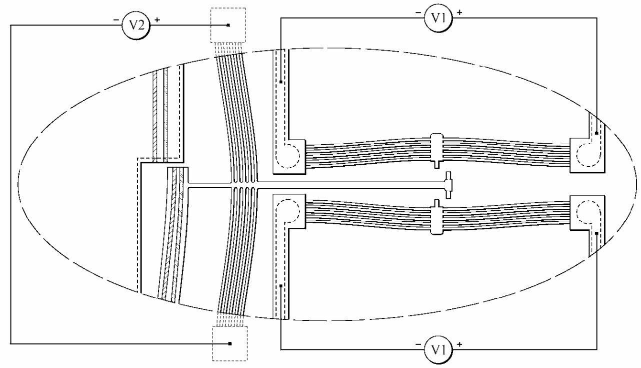




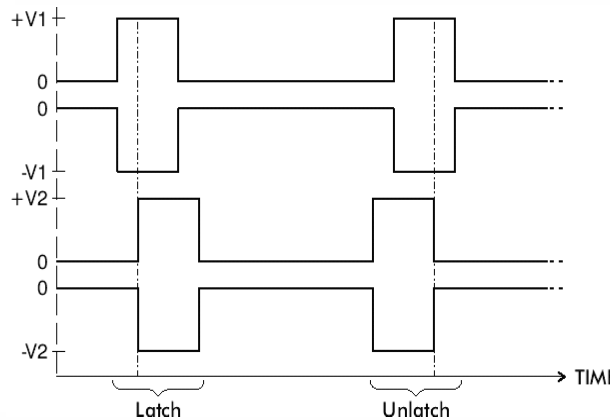
Switch Operation



Fabricated in Add/Drop State

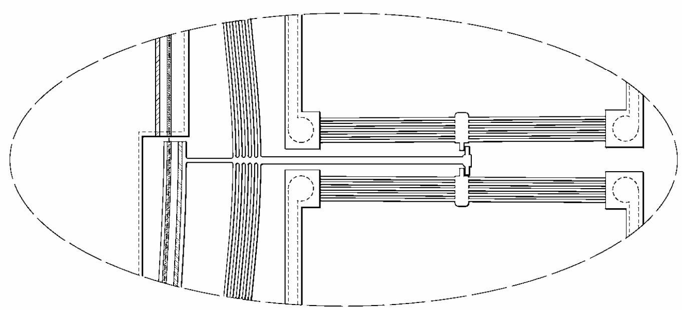


Apply latching sequence



Pulses symmetric wrt voltage common:

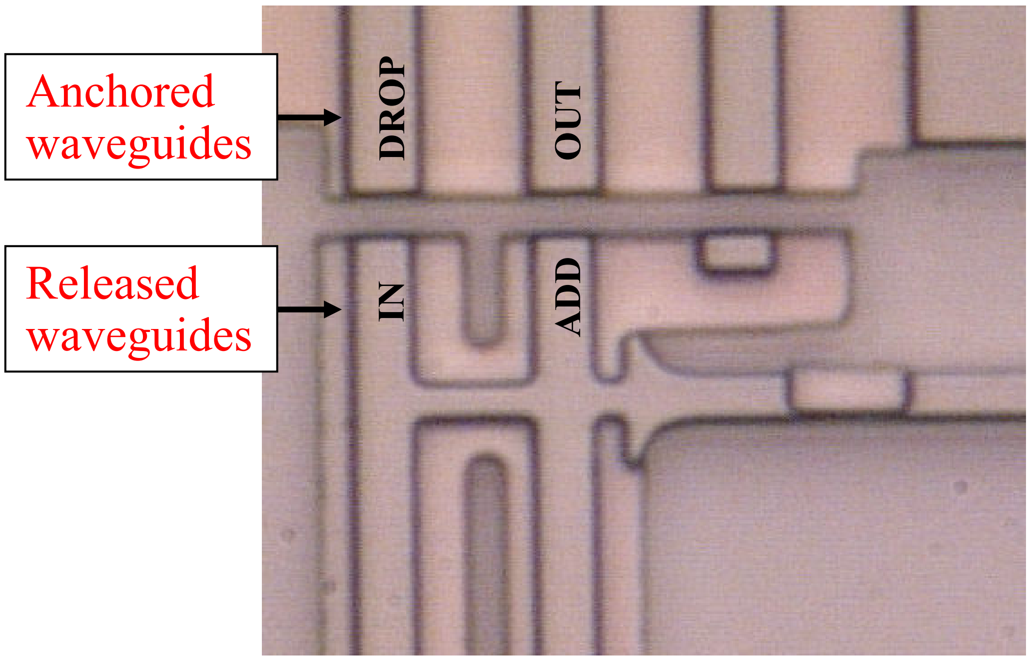
- minimizes pulldown and potential difference at latch contact points



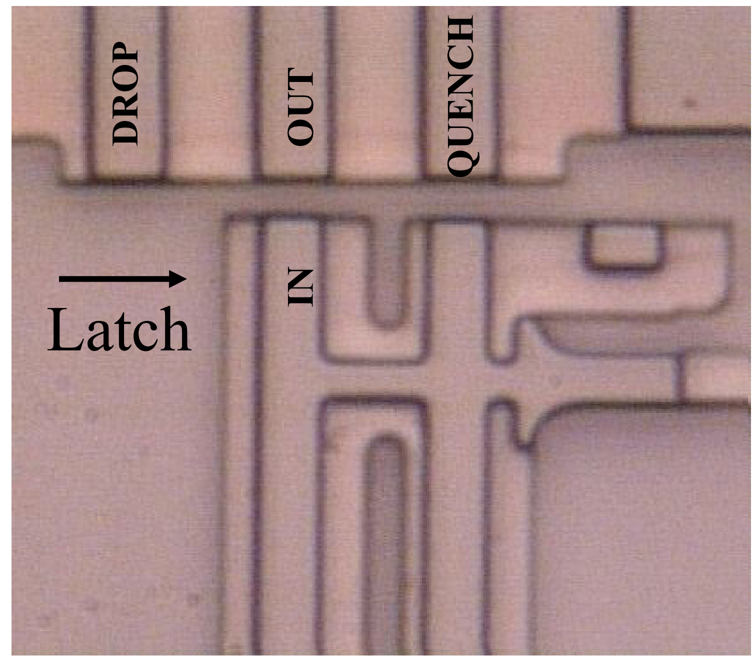
Latch in Through State

Latching MEMS Waveguide Switch States

Add/Drop State

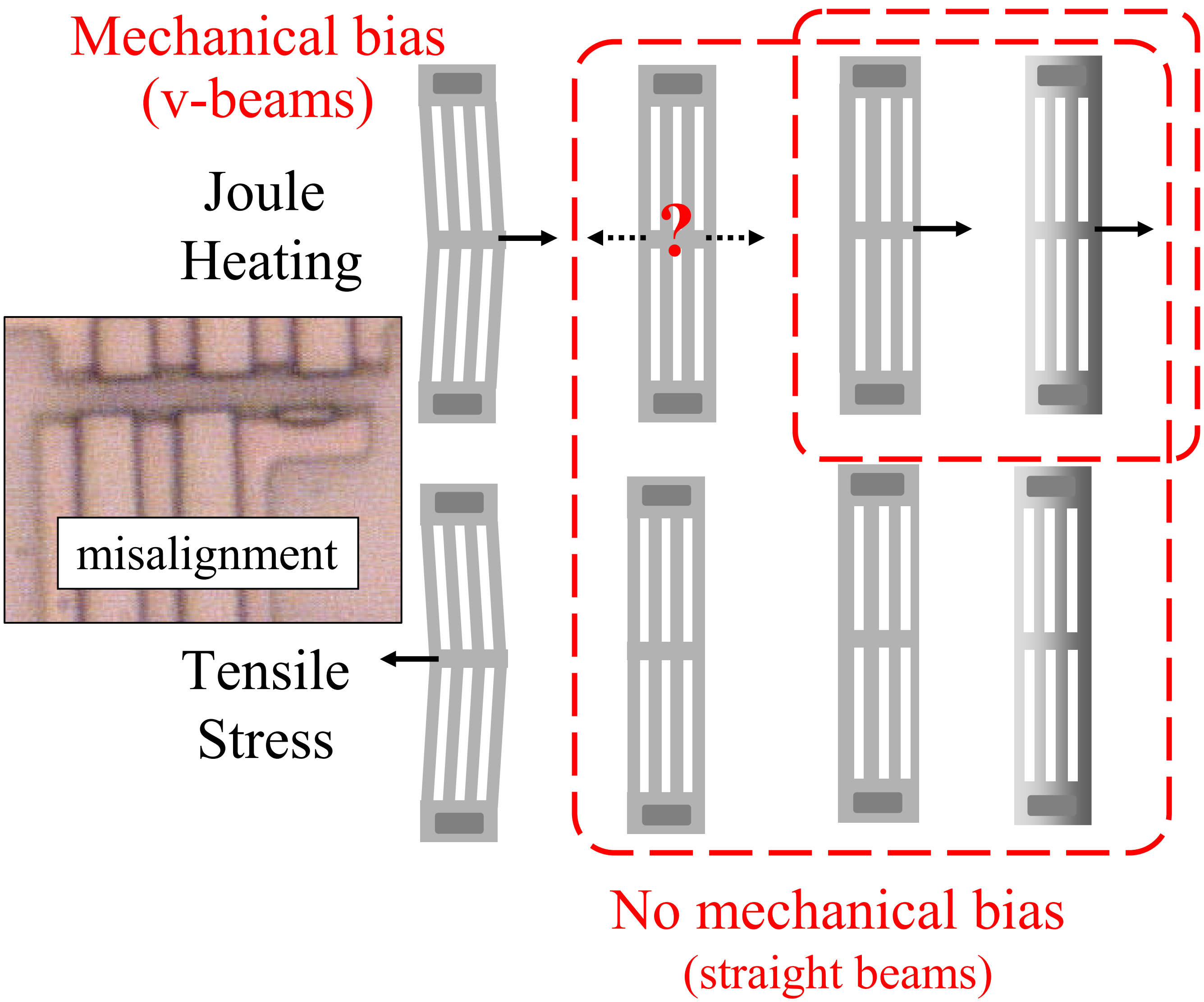


Thru State



- Power is required to change state
- No power is required to hold either state (failsafe)

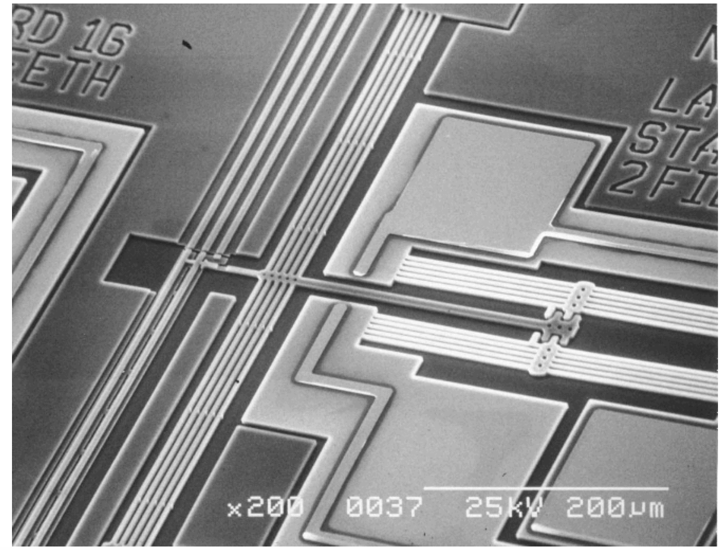
Heatuator designs for robust alignment



- Variations in beam width and doping produce thermal gradients
- Thermal gradients induce predictable displacement direction
- Straight beams enable stability under tensile stress

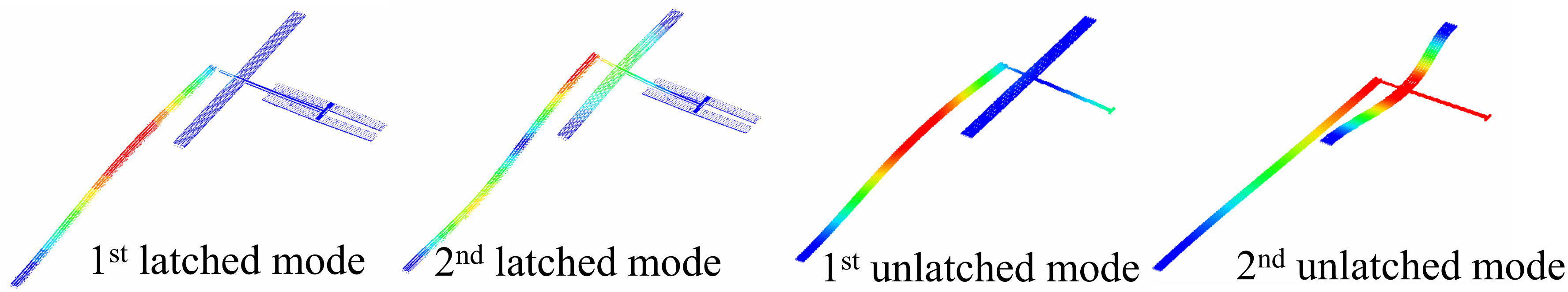
System Advantages of Heatuator Drive and Latch

- Low voltage (< 10 V)
- Small footprint (length < 1 mm)
- Good mechanical suspension
  (Lowest natural frequency ~ 30 kHz)



FEM ANALYSIS

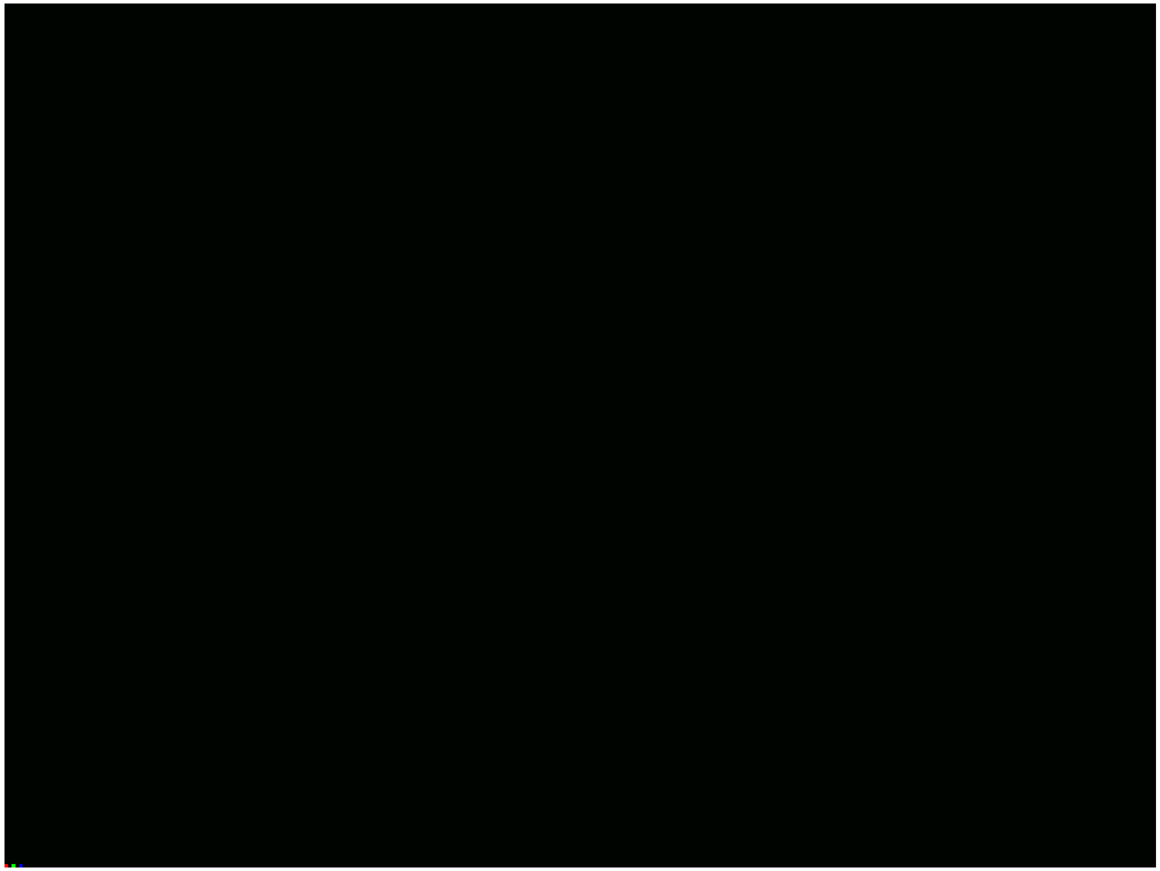
suspended components



1st latched mode 30 kHz | 2nd latched mode 76 kHz | 1st unlatched mode 30 kHz | 2nd unlatched mode 50 kHz

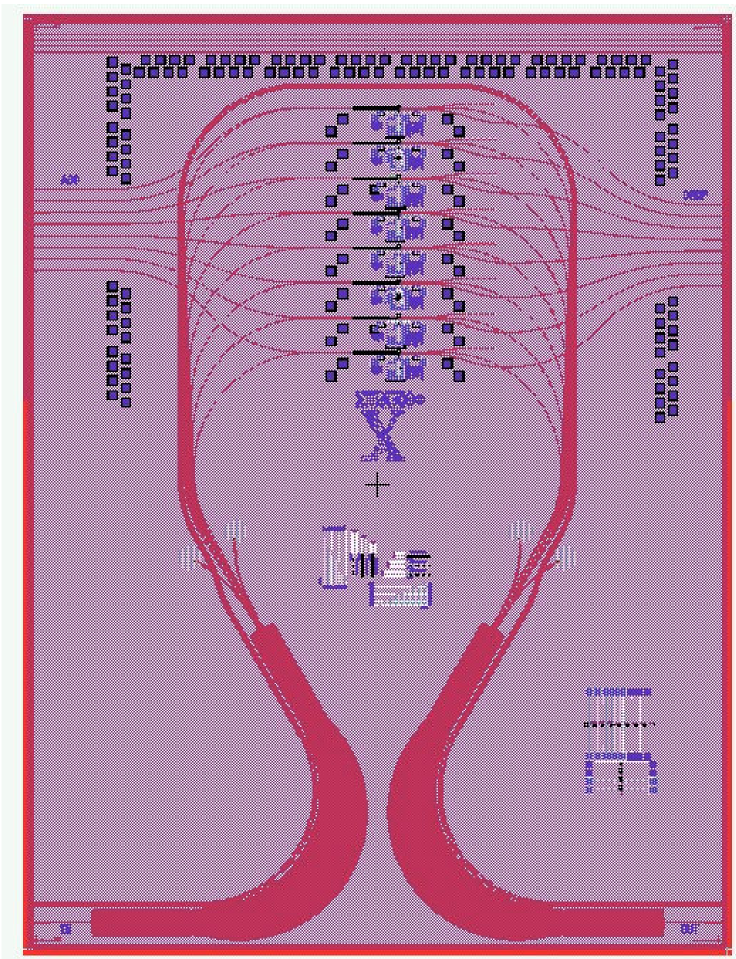
(arbitrary depicted amplitudes)

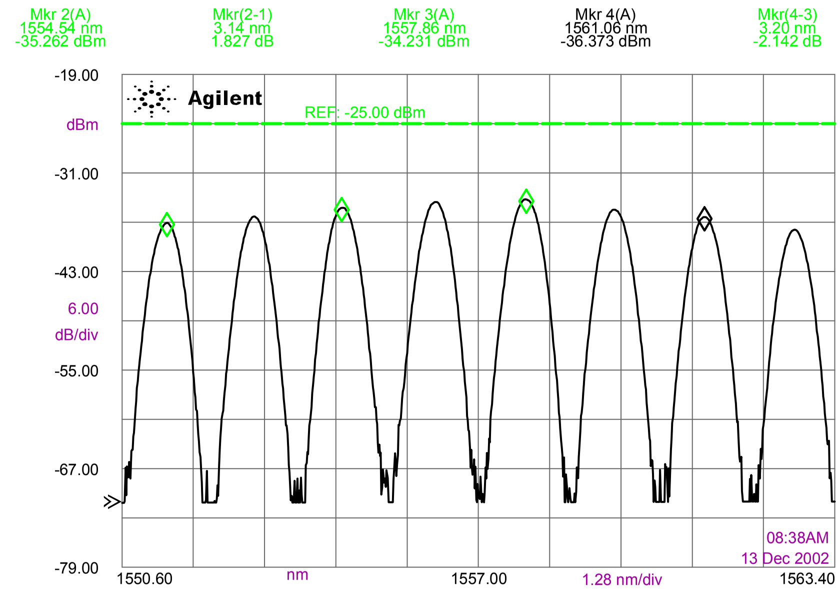
Latching waveguide switch in action



Life tested to over 17 million changes of state

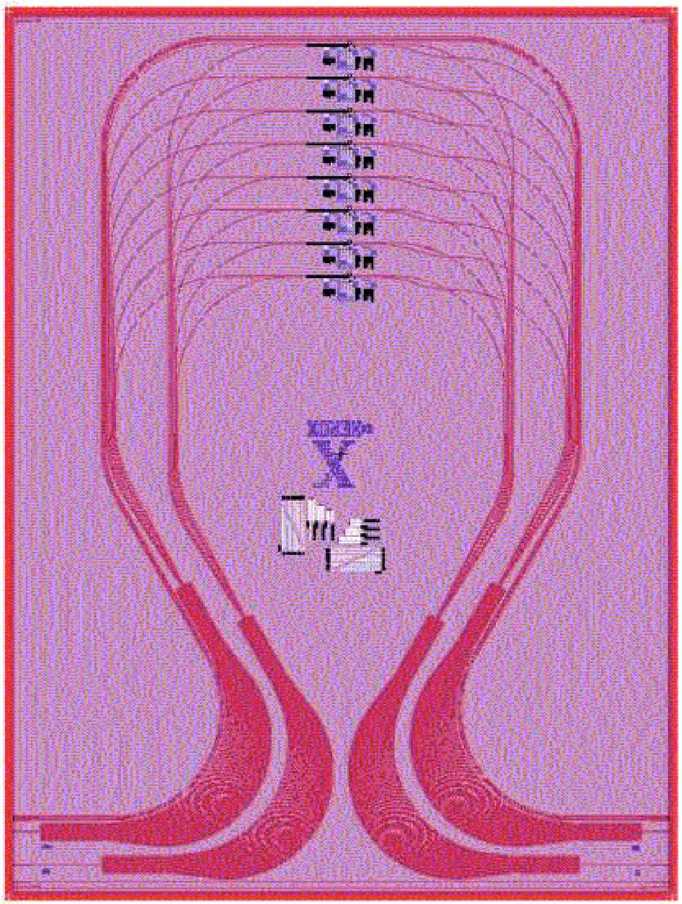
Reconfigurable OADM Performance

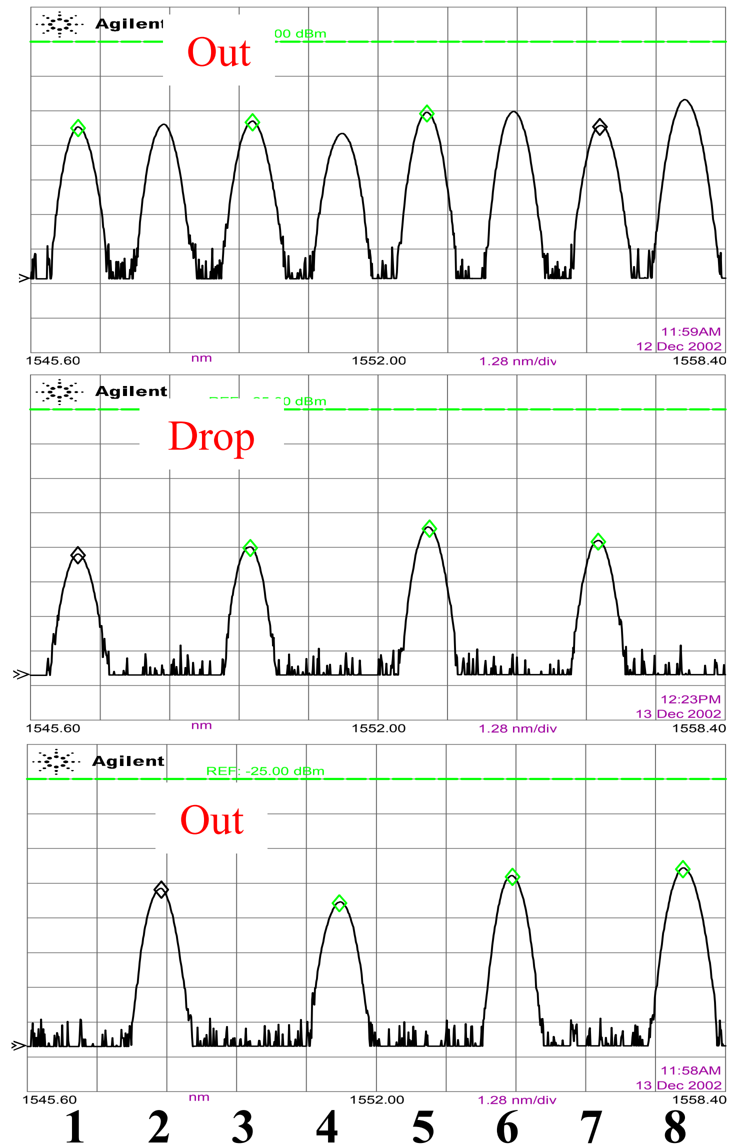




In→ Out output spectrum

Reconfigurable λ-Router Performance





Pass:
All Channels

All Switches
Unlatched

Drop:
Odd Channels

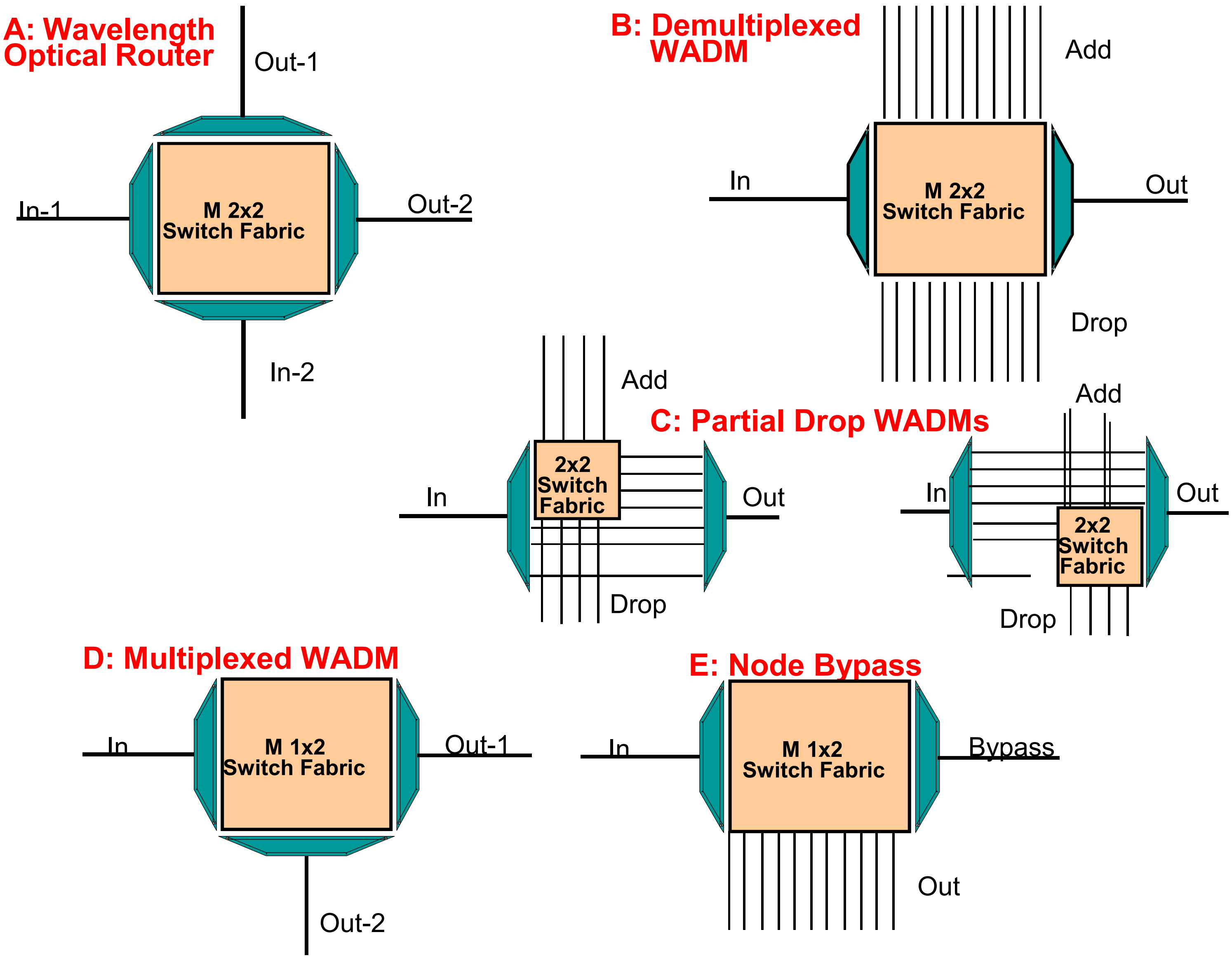
Switches
1, 3, 5, 7
Latched

Pass:
Even Channels

Switches
2, 4, 6, 8
Unlatched

Real time switching of R-OADM

Examples of component reuse



Prototype Specs and Product Targets

R-OADM System	**Achieved**	**Target**
Insertion Loss (IL)	19 dB	12 dB
IL Uniformity (ILU)	4 dB	2 dB
Adjacent Cross Talk (AXT)	>25 dB	✓
Adjacent Cross Talk (AXT)	>30 dB	✓
Extinction Ratio	40 dB	✓
Return Loss (RL)	??	50 dB
Polarization (PDL)	??	0.5dB
Power (mW)	~ 800 pulsed	~ 500 pulsed
Speed (msec)	12	10
Latching	Yes	✓
Lifetime (state changes)	>17 M	✓

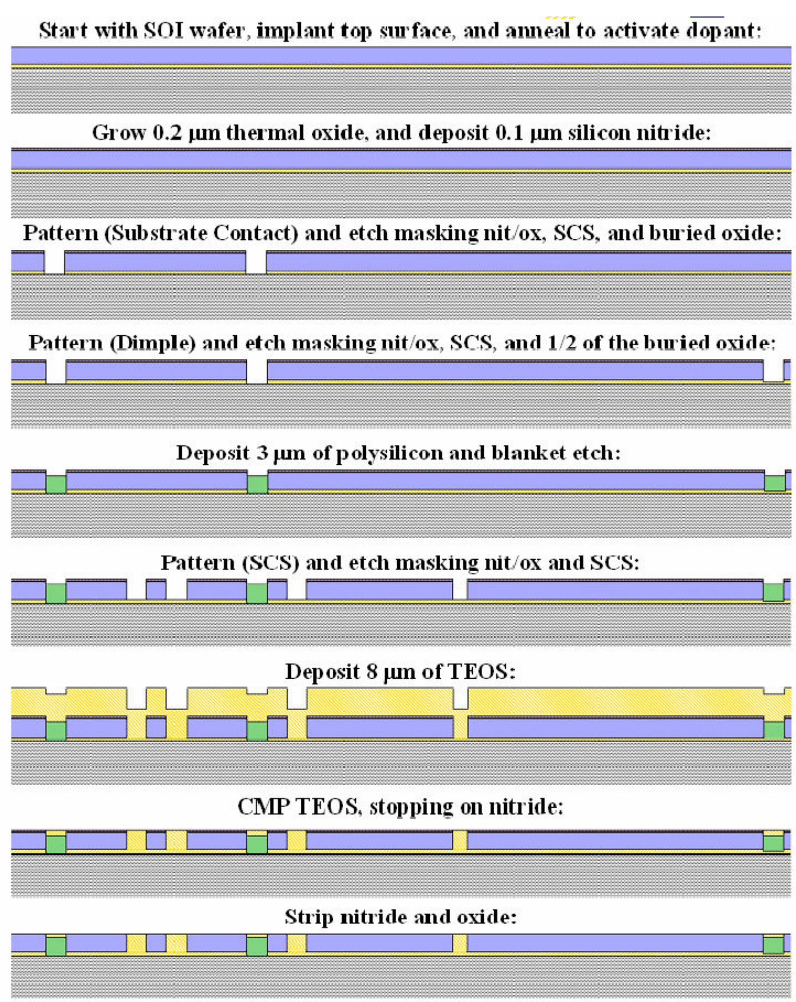
Fabrication Process

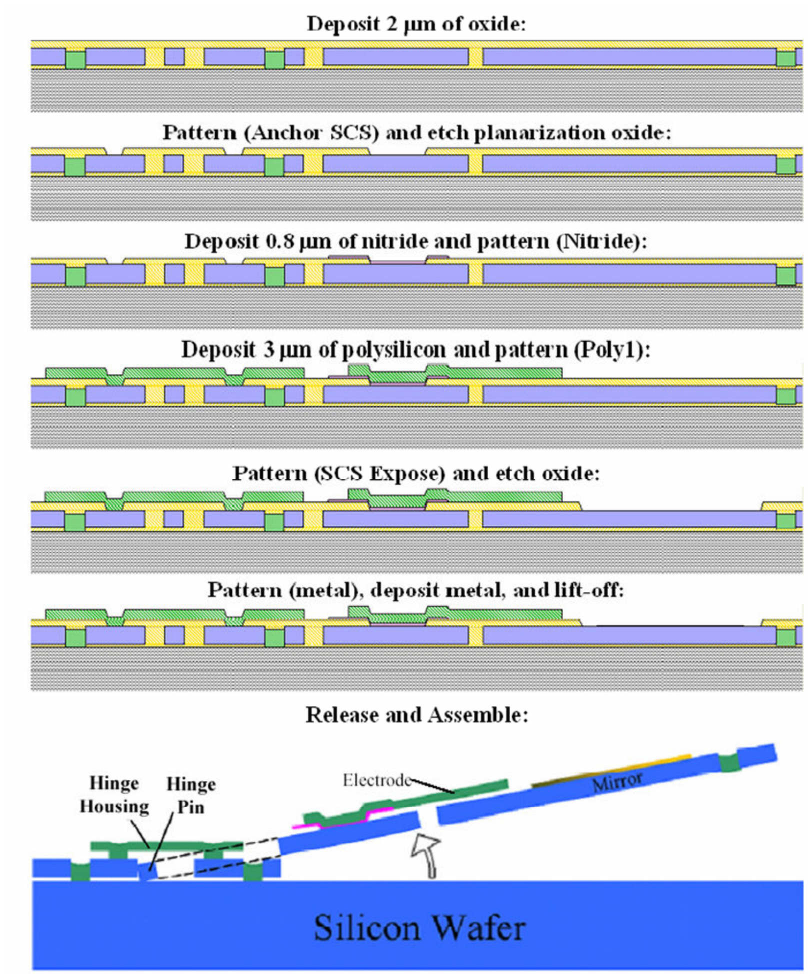
- Process developed under the auspice of the NIST Advanced Techology Program (ATP)
- Broadly enabling in the area of free space and guided wave MicroOptoElectroMechanical Systems (MOEMS)
- Hybrid integration capabilities included for active optical elements
- Developed in partnership with Coventor, Corning IntelliSense Corp., and MicroScan Systems
- Prototypes employed a subset of the full process for quick proof of concept demonstration

Hybrid SOI Micromachine Process

For details see:

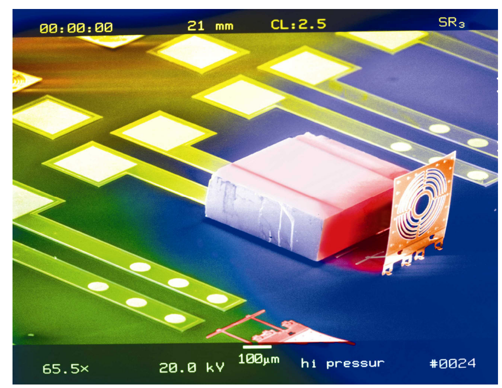
www.infotonics.org → fabrication → device technologies → foundation process





Extensibility to higher levels of integration

- Process is extensible to hybrid integration techniques such as flip chip bonding (NIST ATP)
  - Photodetectors
  - Power amplifiers
- Silicon enables further monolithic integration
  - VOA for equalization
  - GHz modulation
  - On chip electronics, controls, logic
  - Silicon laser on the horizon



Next Steps

- Decrease IL (sidewall roughness, AR coatings on facets)
- Pursue higher levels of integration, device optimization, reconfiguration and/or packaging pending customer traction

INFOTONICS technology center

Center of Excellence in Photonics & Microsystems

- Not for profit organization
- Promote photonics and microsystems
- Cooperative sponsorship of industry, academia, and government
- MEMS prototype, pilot plant, packaging capabilities under development

Summary

- On chip integration of SOI MEMS latching optical waveguide switches with PLCs can reduce size and cost of optical network devices
- Prototypes have demonstrated the feasibility of this approach to compact affordable integration
- Switches and PLC components can be reconfigured to make many network devices
- Hybrid integration can further extend the SOI MEMS platform to devices that require active optical components
- Advances in adiabatic mode coupling technology address issues of low loss fiber attachment

Acknowledgements

Process work performed under Cooperative Agreement #70NANB8H4014, National Institute for Standards and Technology Advanced Technology Program, ATP Project Managers Thomas Lettieri and Carlos Grinspon.