GLIMMERGLASS

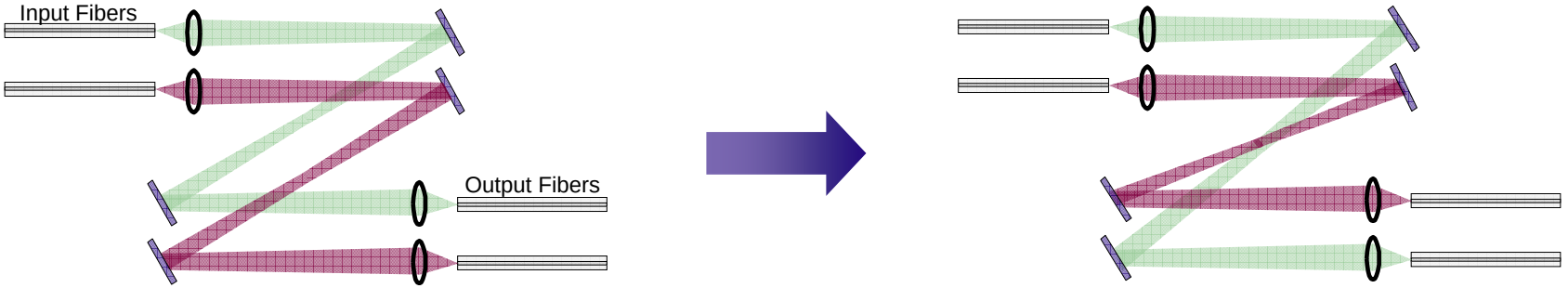
Modular MEMS for an 80x80 Optical Cross-Connect Switch

W. E. Owens, A. Fernandez,
B. P. Staker, and Bill Banyai

October 4, 2005

Problem: Transparent Fiber to Fiber Switching

- Required Performance
  - Fast Response (10 ms)
  - Low-Loss (<3 dB)
- Required Architecture
  - Non-Blocking (Only Switched Fibers Interrupted During Switching)
  - Scalable (16x16 to 160x160)

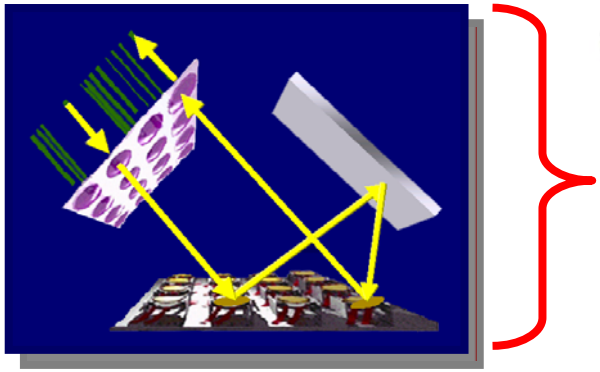


Transparent Fiber Switching with Actuated Micro-Mirrors and Micro-Optics

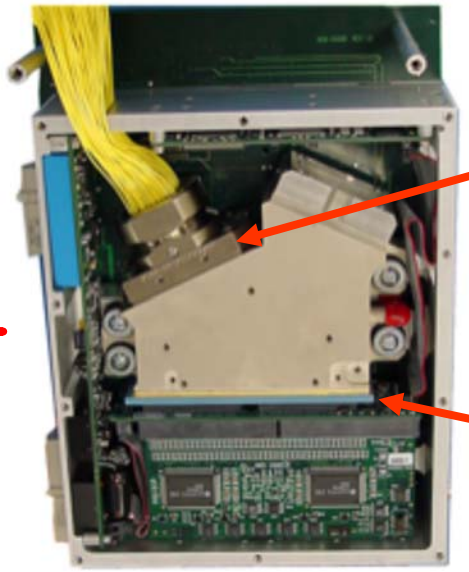
- No Conversion to Electrical Signals

- Supports All Data Rates and Protocols

Solution: 3D-MEMS Switch

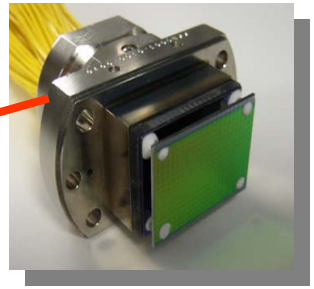


3D-MEMS
Architecture



Switching
Module
(2” x 6” x 7”)

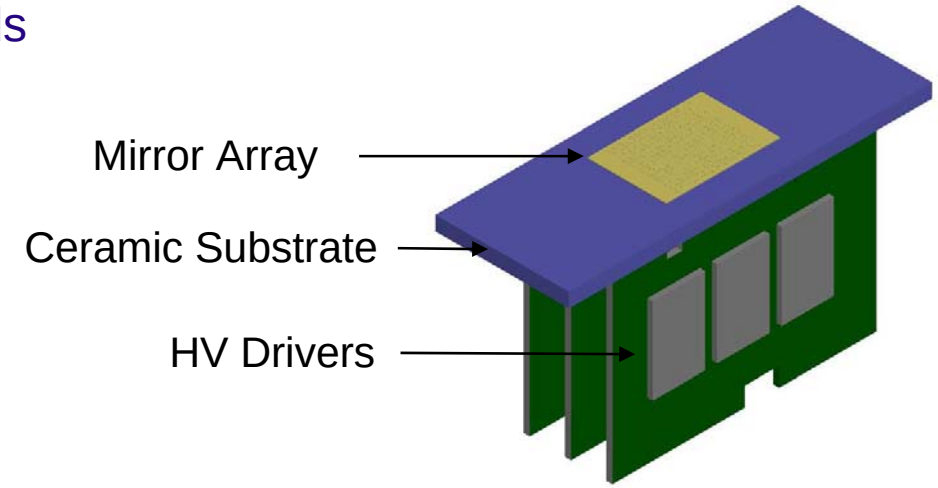
Micro-Optics
Module



MEMS
Micro-Mirror
Module

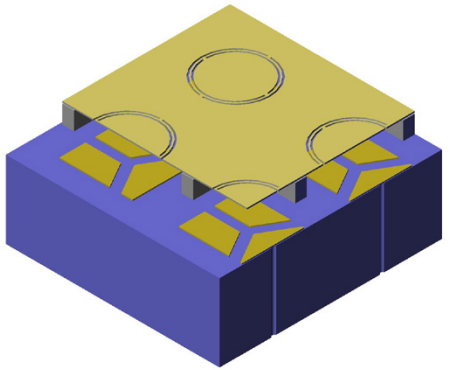
Modular Approach

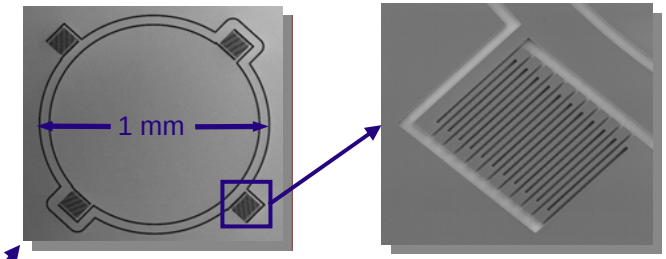
- System Design
  - Divide Into Sub-Units
  - Parallel Component Development
  - Distributed Fabrication Risks
- MEMS design
  - Mirror Array
  - Multi-Layer Ceramic Substrate
  - High-Voltage Driver Cards

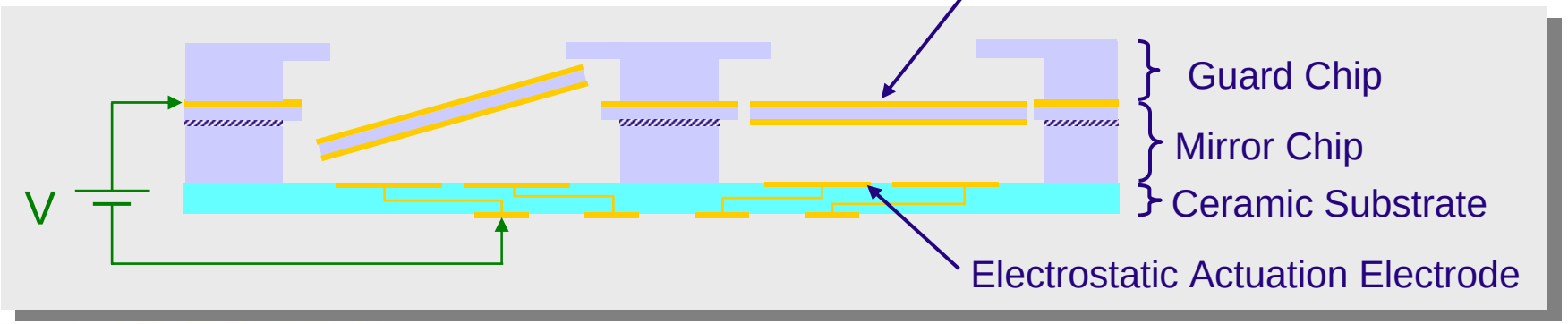


Mirror Design

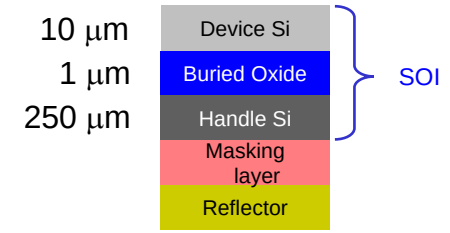
- Gimbaled Structure
- 3-Electrode Electrostatic Actuation
- Electrostatic Snap-Down Guard
- Bulk Micro-Machined Single-Crystal Silicon
- Double-Sided Gold Coating For Thermal Stability



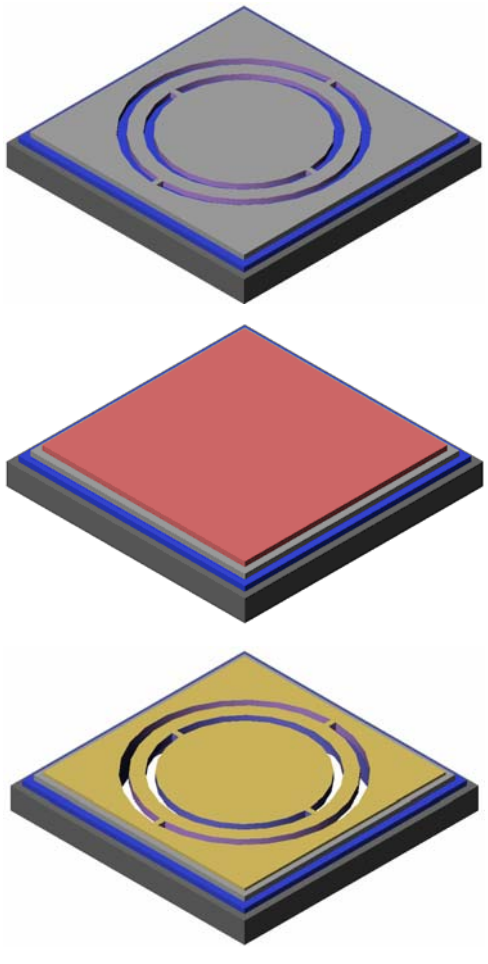




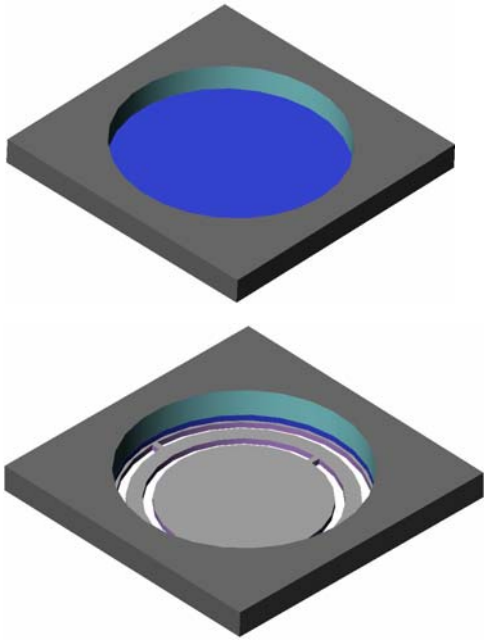
Mirror Fabrication



1. Hinge lithography and DRIE
2. Hinge protection layer
3. Cavity lithography and DRIE
4. Buried oxide release
5. Hinge protection layer strip
6. Blanket reflector deposition

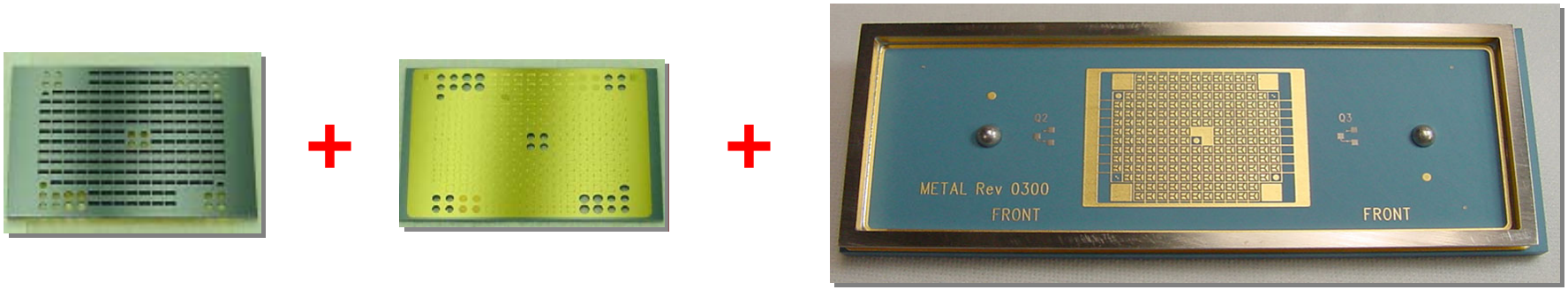


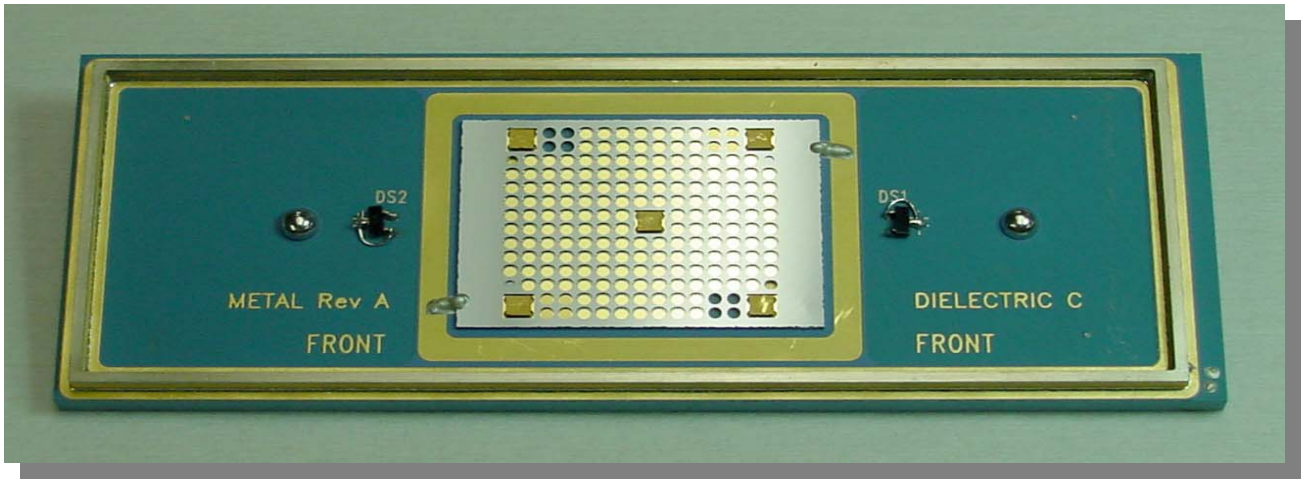
Device Side



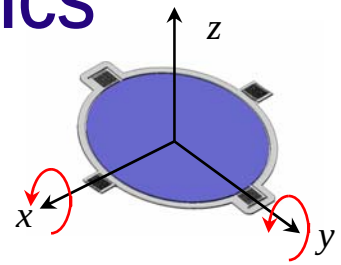
Handle Side

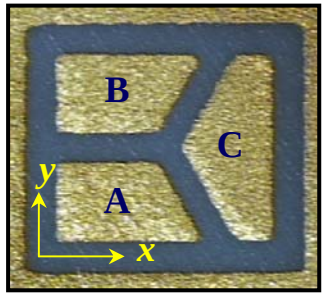
Snap-Guard / Mirror / Ceramic Assembly



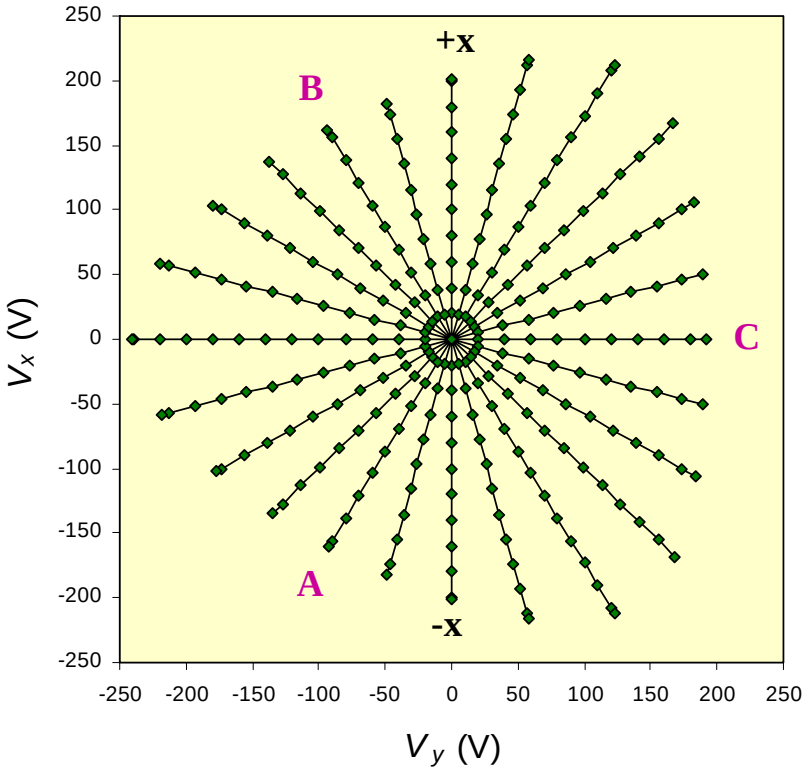


Mirror Deflection Characteristics

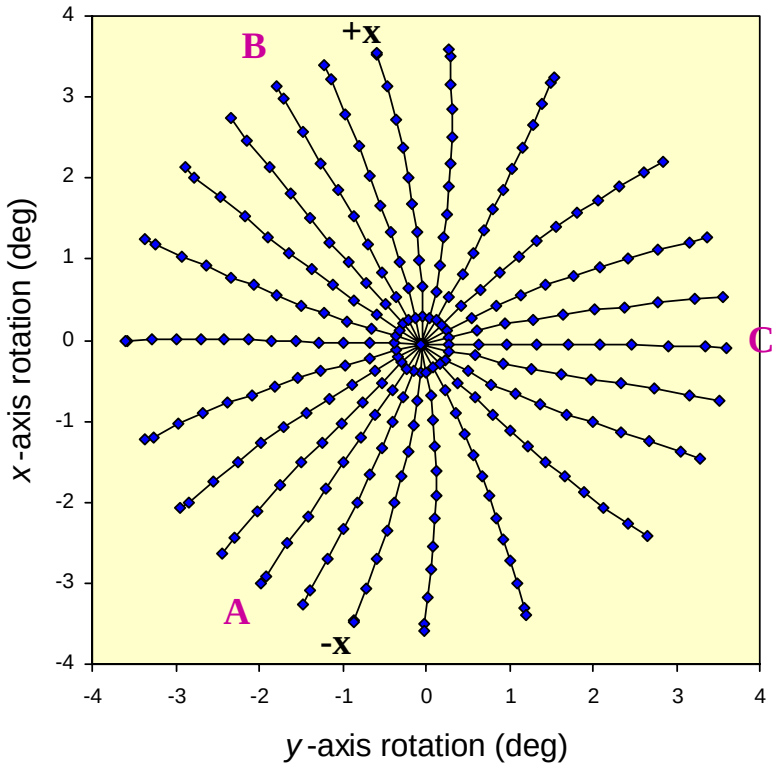




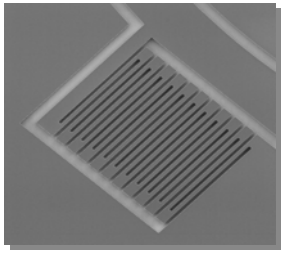
Applied voltage



Mirror tilt state



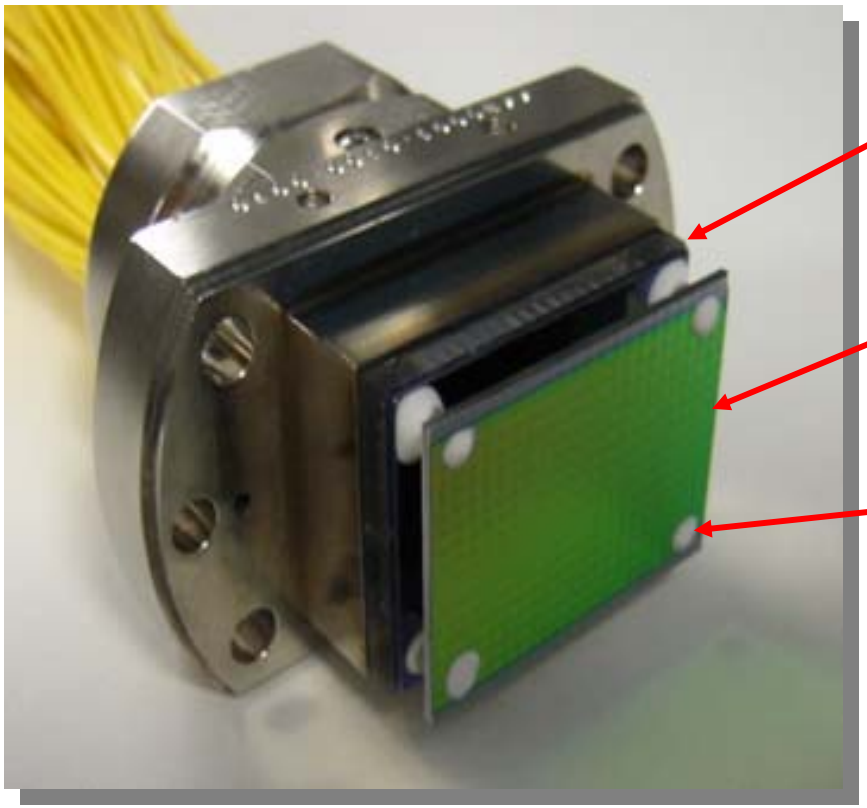
MEMS Reliability



- Mirrors
  - Testing Conditions
    - ±3° Cycling at Resonance
    - 56 Devices Tested Over 36 Days (0.5 Billion Cycles/Device)
    - 28 Billion Cumulative Cycles
  - Results
    - No Failures
    - Single Mirror FIT(60%) = 0.64 for 10M switches in 20 years

- HV Drivers
  - Testing Conditions
    - Stress Temperature = 125C (Acceleration Factor = 198)
    - 89 Devices Tested For 1000 Hours Each
  - Results
    - No Failures
    - Fit(60%) = 52

REFLEXION Optics Module



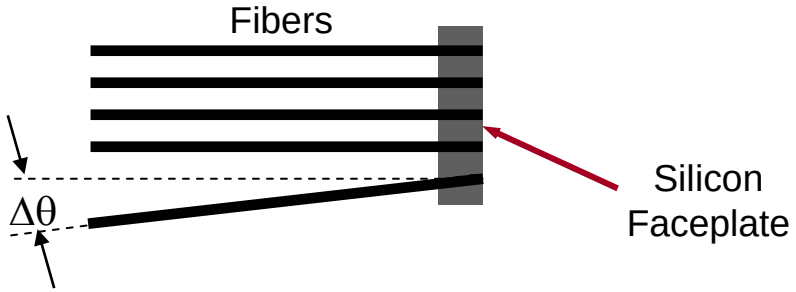
Two-Dimensional
Fiber Array

Two-Dimensional
Lens Array

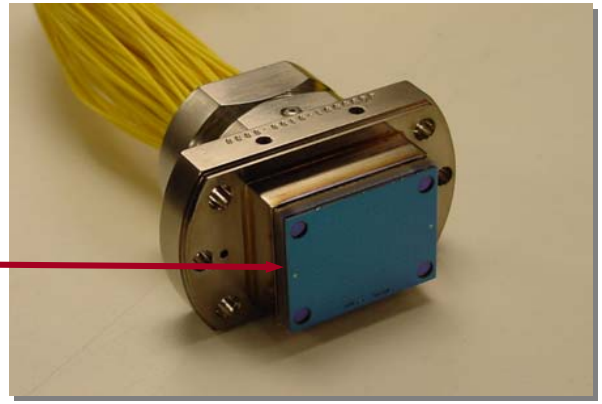
Epoxy-Bonded
Fused Silica Standoff

Critical Optics Specs

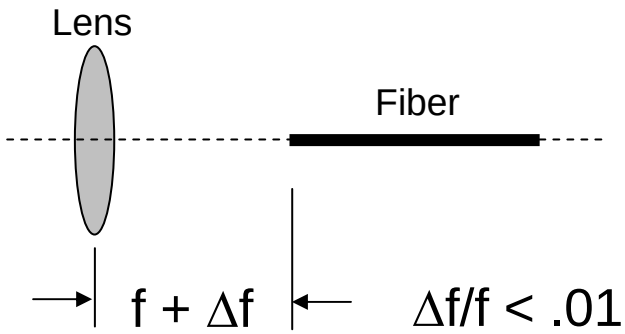
- Fiber Pointing

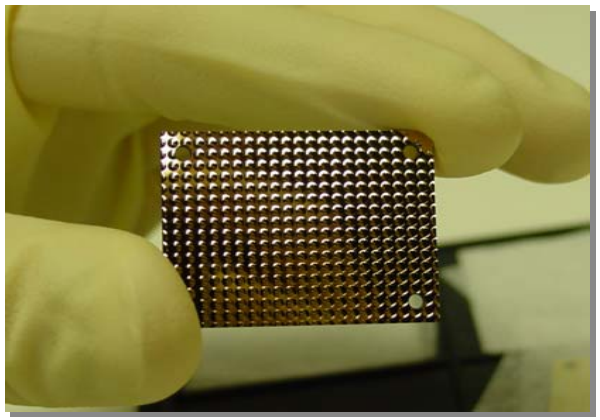


$\Delta\theta < 10$ mRadian

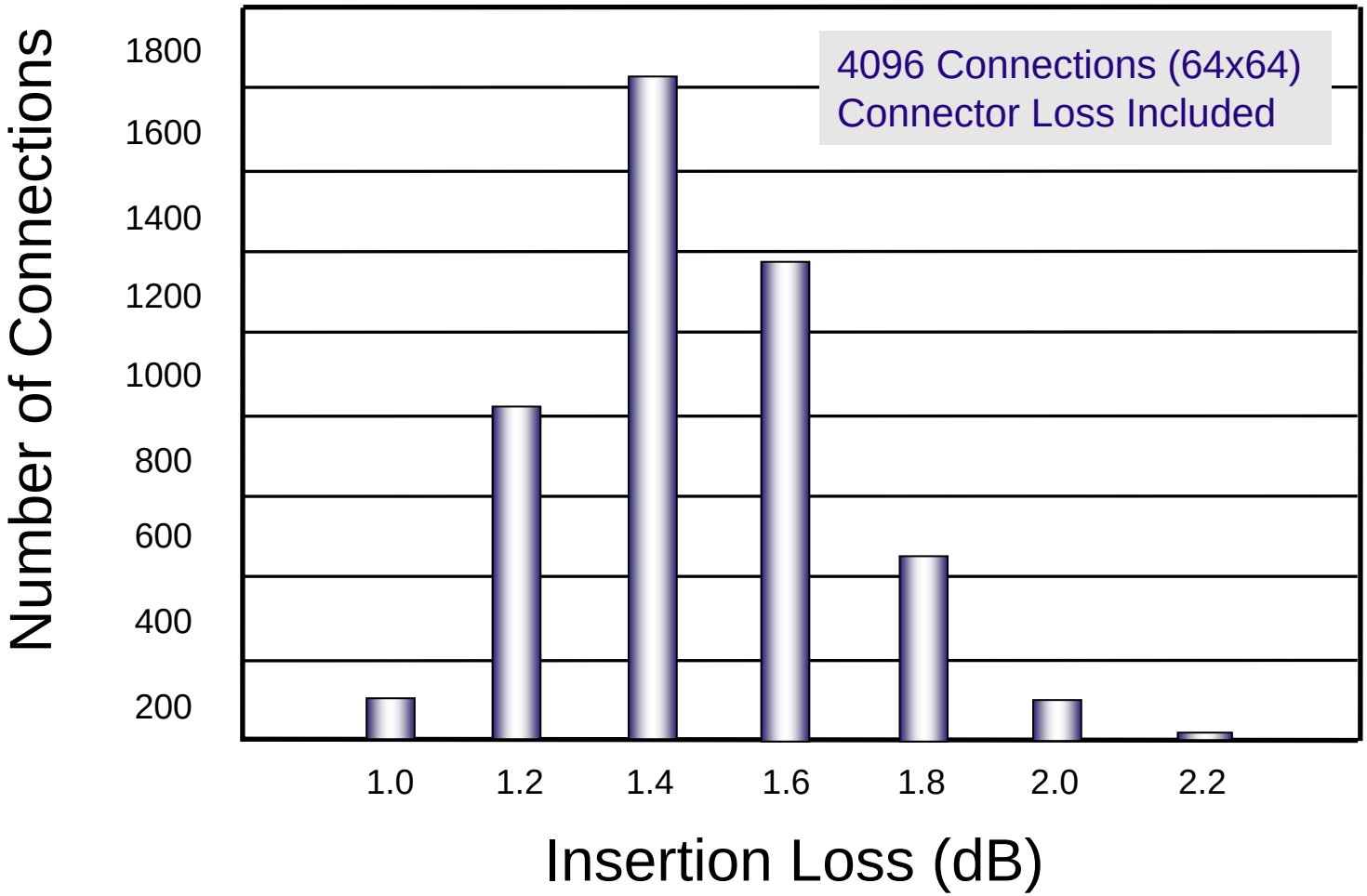


- Lens Focal Length Variation



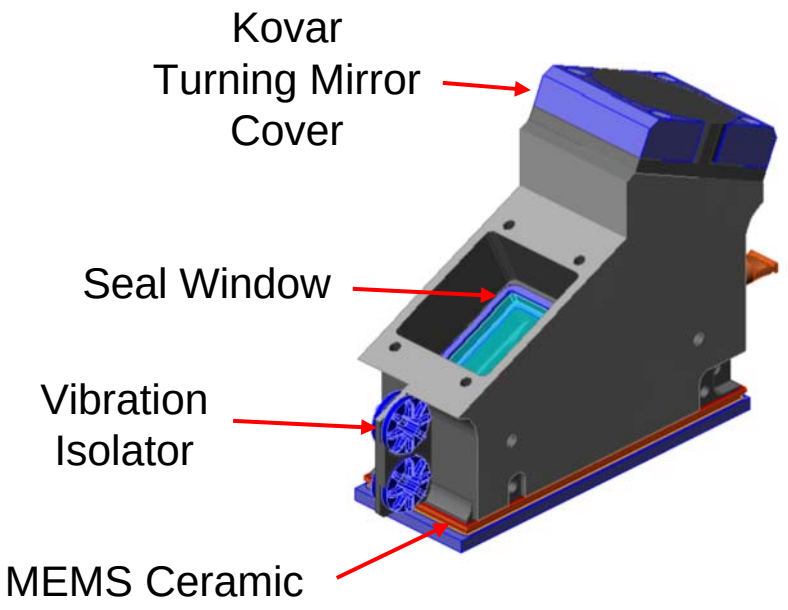


Typical Optical Insertion Loss Distribution



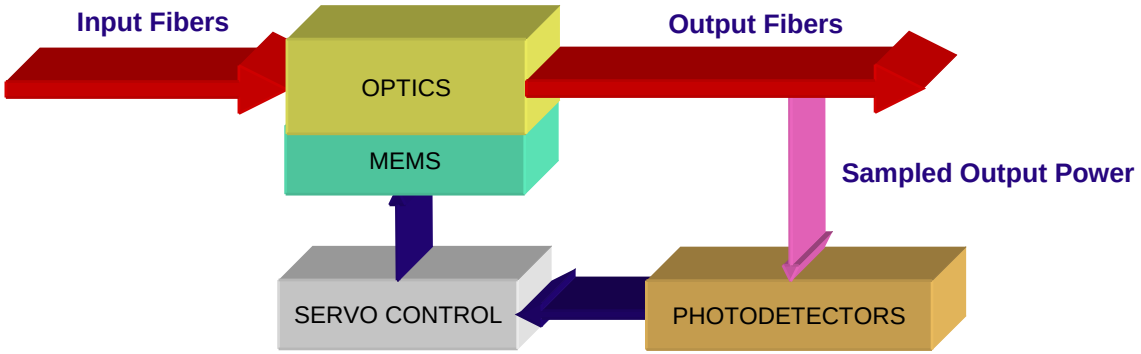
Hermetic Housing

- Kovar Housing
  - Coefficient of Thermal Expansion Matched to Ceramic and Glass
- MEMS Ceramic Has Braze Ring
  - Allows Metal to Metal Laser Weld
- Seal Window Soldered Into Frame
  - Frame Laser Welded to Housing
- Bake-Out and Dry N_2 Refill
  - Metal to Metal Pinch Tube Seal



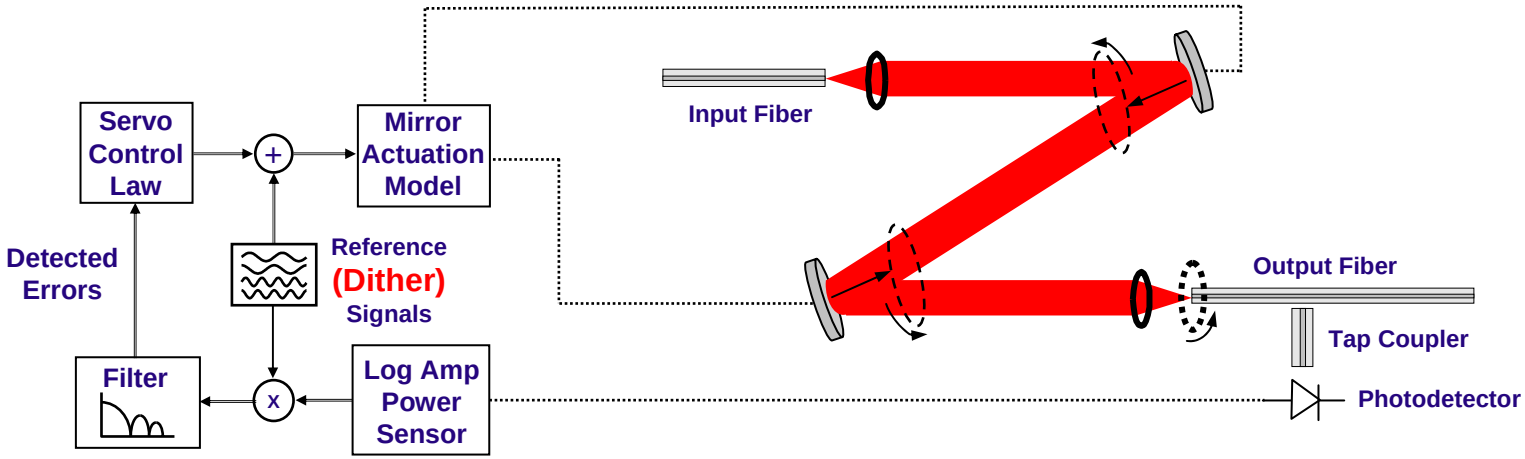
Control System Design

- Factory Calibration
  - Electrode Voltages for All Connections Stored in Flash Memory
  - Minimum Insertion Loss and Switching Time
- Every Connection Can Have Closed-Loop Servo Control
  - Compensates for All Mirror-Pointing Degradation Mechanisms
  - Enables Operation Over Large Temperature Range

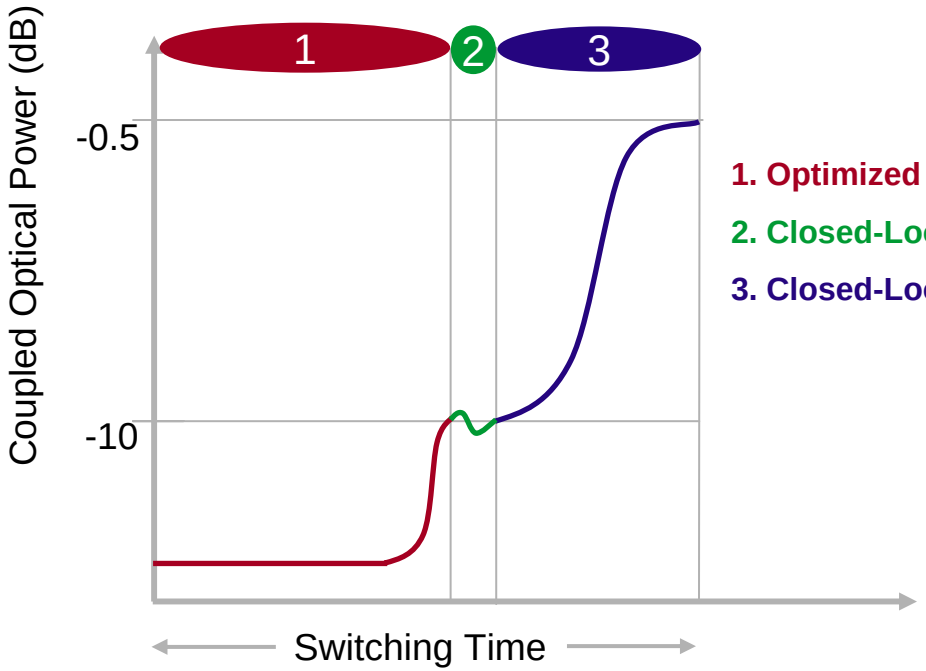


Pointing-Error Correction Via Synchronous Detection

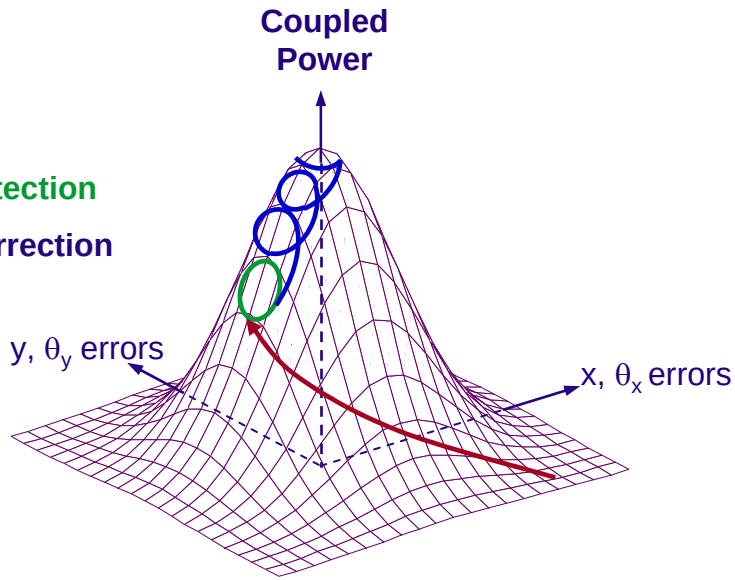
- **Dither Mirrors to Orbit Beam at Output Fiber**
  - … Results in DC Coupled Power Offset (0.1 dB)
- **Mirror Pointing Errors Perturb Orbit**
  - … Results in AC Coupled Power Variations
- **Synchronously Detect Errors**
  - … Correct Errors to Null AC Coupled Power Variations



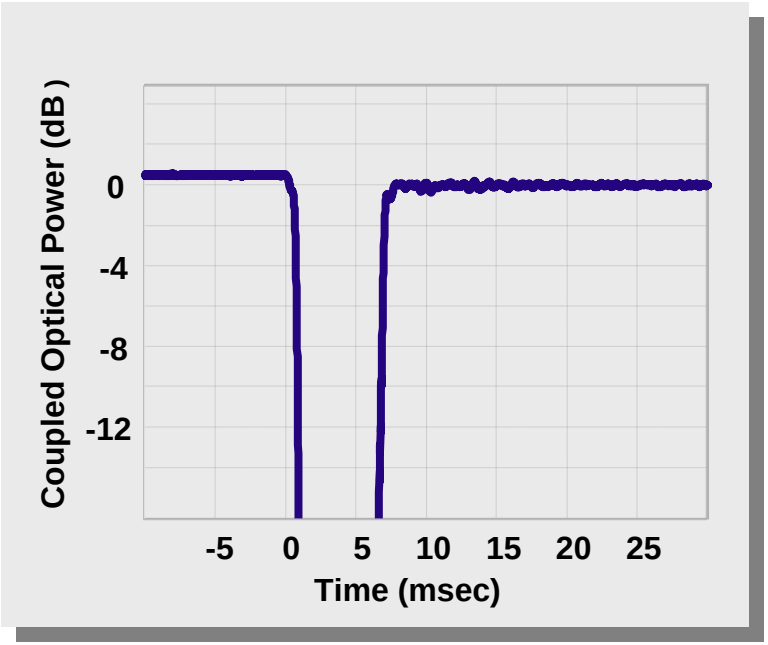
REFLEXION Switching Model



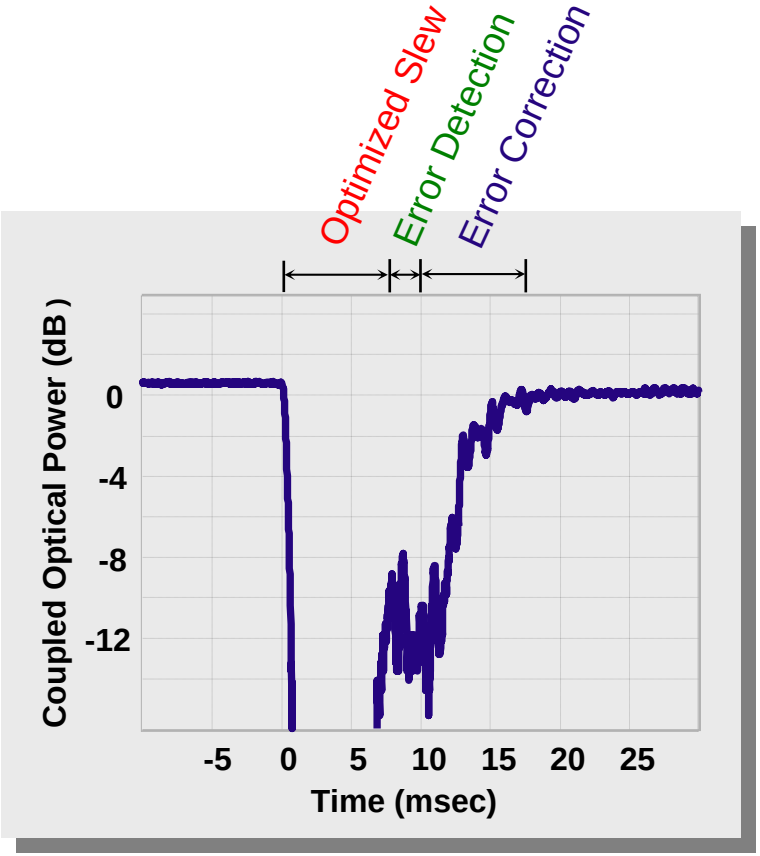
1. Optimized Slew
2. Closed-Loop Error Detection
3. Closed-Loop Error Correction



REFLEXION Switching Measurements



Factory Calibrated



With Simulated
End-Of-Life Drift

System Reliability

- Testing Conditions
  - Uniform Deployment Rate: 96 Units / 34 Months
  - Time = $\sum_{N=1}^{34} N * (96 \text{ Units} / 34 \text{ Months}) = 1.2\text{M Hours}$
- Results
  - 14 Corrective Action Reports - All Design Flaws
  - FIT(60%) = 772

Summary

- Transparent Optical Switch Based on 3D MEMS Architecture
- Modular MEMS Allows for Independent Component Development
- Ongoing Reliability Program