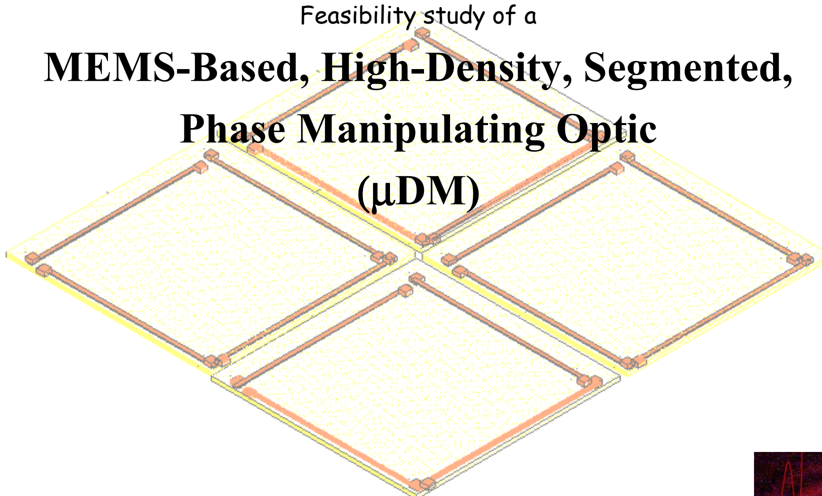
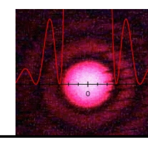
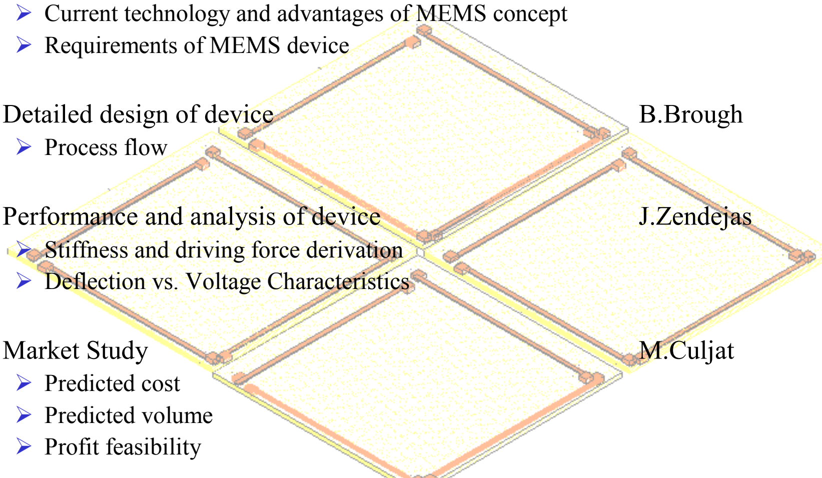
Feasibility study of a

MEMS-Based, High-Density, Segmented, Phase Manipulating Optic (μDM)





Outline



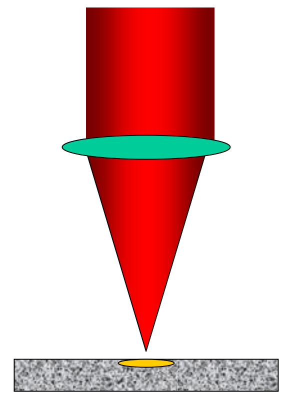
- Introduction to the problem and solution concept — C.Adams
  - Current technology and advantages of MEMS concept
  - Requirements of MEMS device
- Detailed design of device — B.Brough
  - Process flow
- Performance and analysis of device — J.Zendejas
  - Stiffness and driving force derivation
  - Deflection vs. Voltage Characteristics
- Market Study — M.Culjat
  - Predicted cost
  - Predicted volume
  - Profit feasibility

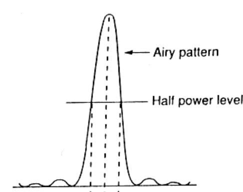
- 10 slides is insufficient to describe problem/system completely

Introduction to the problem

- As light propagates, diffraction effects cause intensity distributions to deviate from geometric ray trace values
  - Diffraction causes "blurring" of the image (far field spot) when ray are brought to a focus
  - This blurring causes poor image quality and should be be minimized
    - Larger diameter of input beam/optic
    - Flat wave front
- Wavefront is the distribution of the spatial phase of an optical beam in a plane normal to it's axis
  - Deviation from constant phase is known as wavefront error (WFE)
- Far field quality can be mathematically calculated
  - Spot is less "focused" with increasing WFE
  - Apodization can "improve" this
  - Prediction methods
    - Fraunhofer/Far field
    - Fresnel/Near field

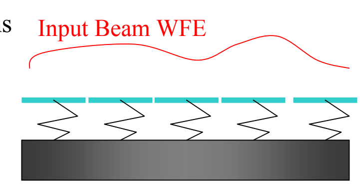
$$U_p = C \int\int e^{ik\Phi} dA$$

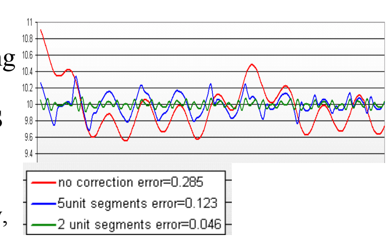




Solution Concept

- Wavefront error is intrinsic to all optical systems
  - Atmospheric effects
  - Optical misfigure
- Image quality increases if WFE is minimized
  - Current technology is deformable mirrors
    - Use continuous face sheet actuated by piezo stacks (hand assembled, low density)
    - Actuated segments (large ~cm)
- WFE can be minimized with localized pistoning of the optical surface
  - Effect increases with actuator density→ MEMS
  - Simplified control system
  - No piston-tilt coupling
  - Can be used to remove static WFE using a slow, active, control system
- Concept is applicable to all imaging/focusing systems
  - High end telescopes





Predicted Strehl number improvement with correction

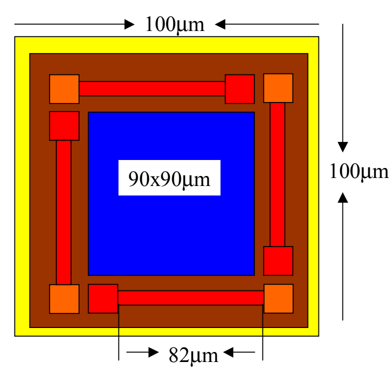
No correction	α 0.920
5 unit	α 0.985
2 unit	α 0.998

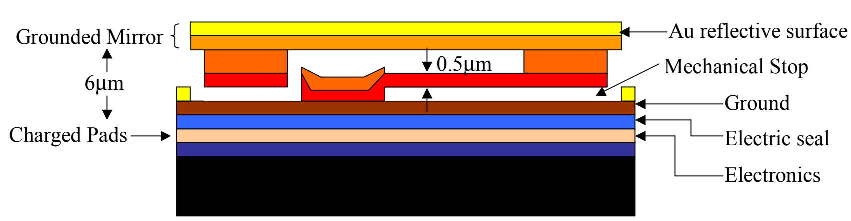
MEMs Advantage and Device Requirements

- Clear advantage to MEMS is the VLSI style fabrication possibility.
  - Large number of “tiny” actuators
  - Implies high actuator density
  - Small and accurate displacements
  - Relatively small cost for large number of actuators
- Requirements for a “useable” MEMS device
  - Must be comparable to current technology
  - Must be applicable to solving the problem
  - Many optical systems deal with wavelengths from near IR (~2 μm) through visible (down to 0.4 μm)
    - **Useable actuator throw > 2 μm with stability to 1% (.02 μm)**
  - System power source requirements must be reasonable
    - Current DMs use up to 100 Volts
    - **Voltage required < 100 Volts**
  - System cost must be reasonable
    - **Cost must be comparable to current deformable mirror (DM) systems**
  - > 98% Effective area
    - Small impact on Strehl

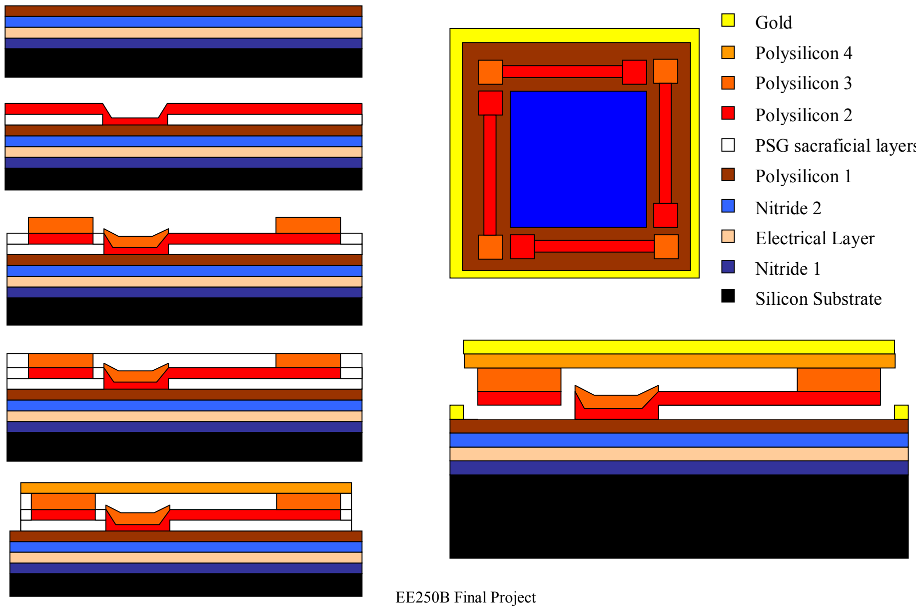
Device Basic Characteristics

- Device complies with specified requirements:
  - Mirror size = 100 x 100 μm
  - “Capacitor” size = 90 x 90 μm
  - Gap between mirrors = 1 μm
  - Implies ~2% loss in effective area
  - Pull-in gap = 2 μm
  - Pull-in voltage = 16.4 Volts





Process Flow



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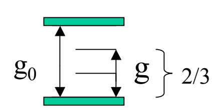
Device Analysis

- Desired throw movement:
  - Required swing 2µm

$$g = \frac{2}{3} g_0 \longrightarrow g = 6\mu m$$



- Mechanical properties of a cantilever beam:
  - Spring constant

$$k = \frac{Ewt^3}{l^3} \longrightarrow k = 0.075 N/m$$

  - 4 beams $\longrightarrow$ $k_{total} = 0.30 N/m$

- Electrostatic actuator properties and requirements:
  - Voltage controlled electrostatic gap closing actuator force

$$Force = \frac{-\partial w^*(V,g)}{\partial g} = \frac{\varepsilon A V^2}{2g^2}$$

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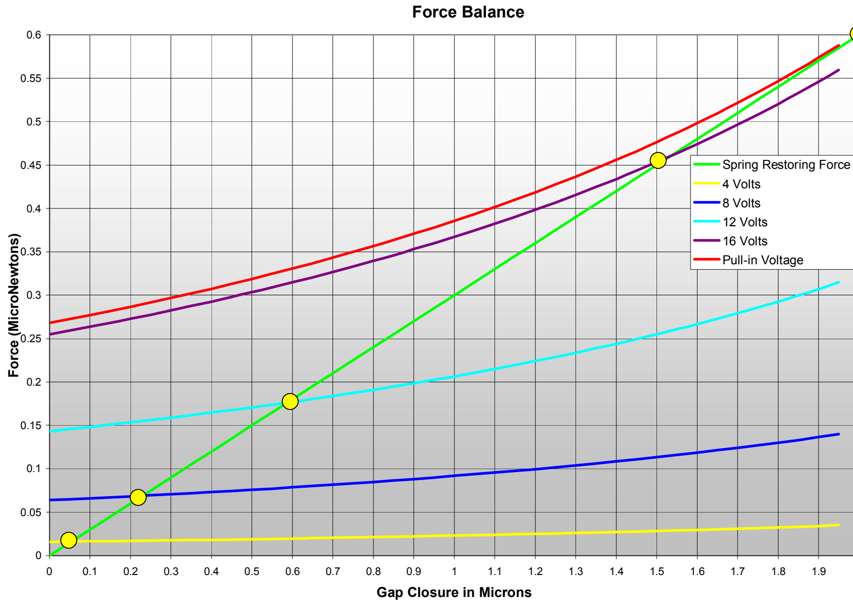
Force Balance Plot



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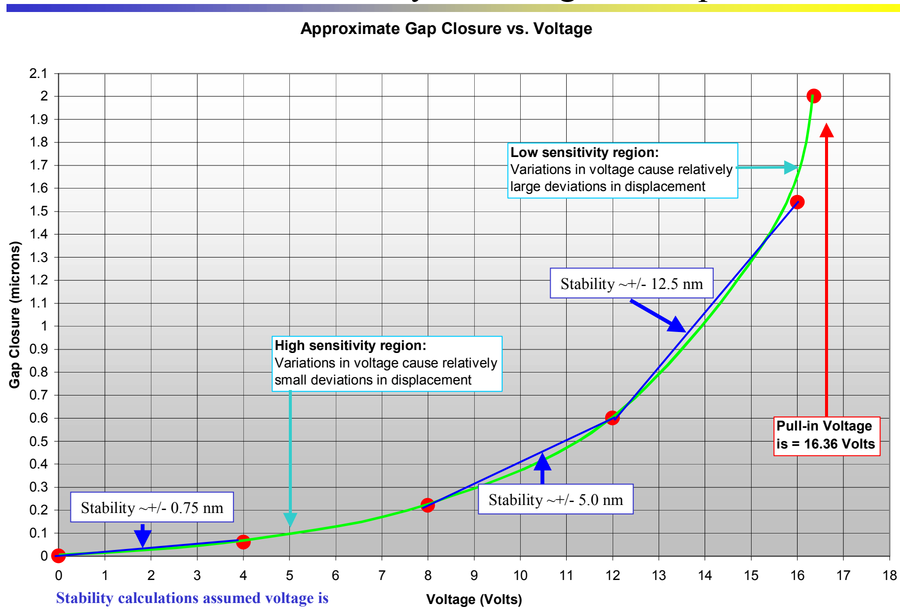
Performance and Stability… Voltage vs. Gap Closure



Stability calculations assumed voltage is stable to +/- 0.05V (conservative)

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Market Information

- Current market allows for ~ $1000 per actuator
  - e.g., 10 x 10 array on 6 inch mirrors = $100K per device
  - Based on data from Xinetics
- Our device:
  - Can use a MUMPS-like process - $10K per wafer
  - Additional processing ~ $10K per wafer
  - 100% markup
    - Total cost per wafer ≈ $50K
  - 500 x 500 array of mirrors on 4 inch wafer
    - 25,000 actuators
- Market Volume
  - ~45 large optical telescopes, 10 more under construction
  - Medical imaging, Satellite imaging, Military