CECD Applied MEMS Research for Navy Anti-Torpedo Torpedo

CECD
CENTER FOR ENERGETIC CONCEPTS DEVELOPMENT

Kevin Cochran, Gabe Smith, Lawrence Fan, NSWC

Don DeVoe, UMD

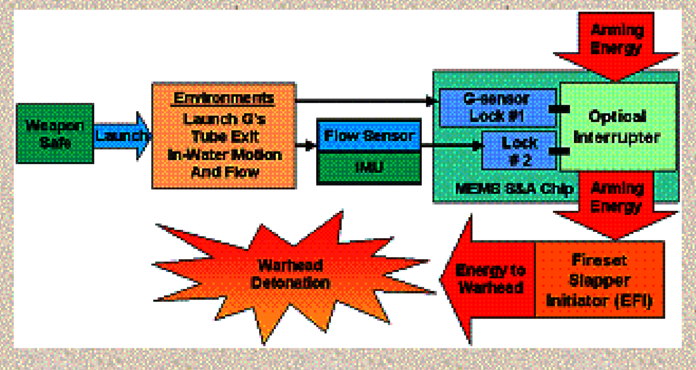
United States Naval Academy

University of Maryland 1856

NAVSEA Indian Head Surface Warfare Center Division

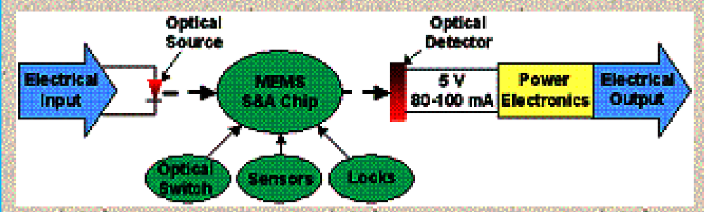
CCAT Applied MEMS

DRIE MEMS S&A Chip



- Prevents weapon arming until two unique post-launch environments are sensed
- Must operate in a fail-safe manner

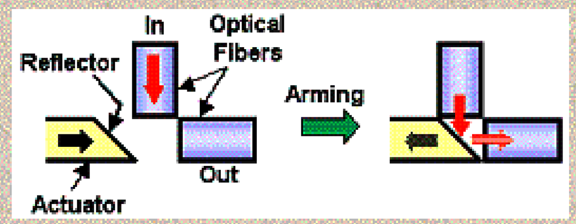
Optical Charging System



- MEMS S&A chip is an optical interrupter
- Provides a fail-safe activation and termination of an optical path between a low-power source and a high-power discharge capacitor

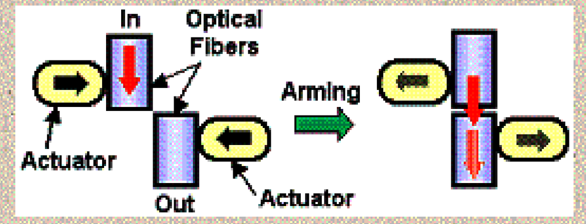
MEMS Optical Switch Approaches

Moving Reflector Design



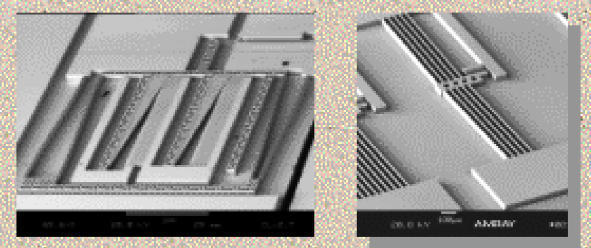
- Movable micromachined reflector
- High displacement actuator required
- Possibly poor optical efficiency

Moving Fiber Design



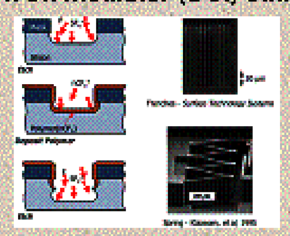
- Directly actuated optical fibers
- High force + displacement actuator required
- Very good optical efficiency

High Force / Displacement Micro Actuators

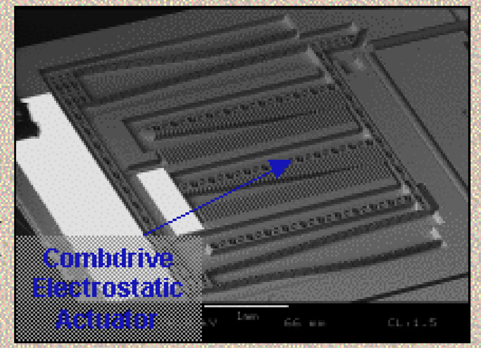


Fabrication

- Deep Reactive Ion Etching (DRIE)
- Silicon on Insulator (SOI) substrates



Moving Reflector Optical Switch



Switching Concept

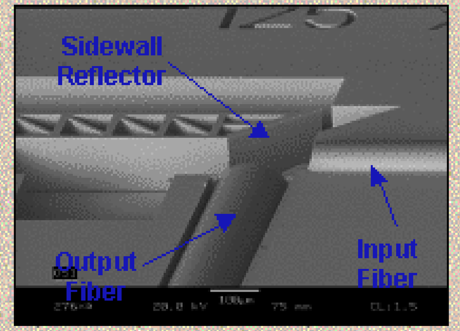
- Input and output optical fibers placed in etched alignment channels
- Reflector is actuated into the optical path between the input and output fibers
- Actuator
  - 116 μm required displacement
  - No force required
- Reflector
  - Etched sidewall surface
  - Sidewall reflector is gold coated to increase reflectivity

System Optical Components

- Input Fiber: 50 / 125 μm core / cladding
- Output Fiber: 105 / 125 μm core / cladding
- Optical Input: 2000 mW, 810 nm laser diode

Optical Analysis

- Optical losses
  - Fiber longitudinal misalignment
  - Fresnel reflections
  - Sidewall reflector properties
- Predicted optical efficiency: 50-70% (dependent upon sidewall surface roughness)



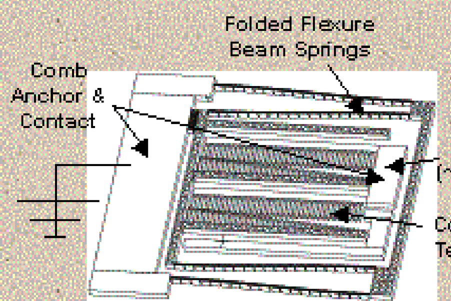
Combdrive Electrostatic Actuator

Actuator Description

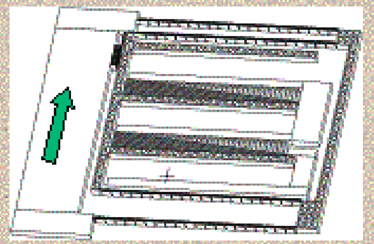
- The combdrive structure actuates through electrostatic attraction of inter-digitated comb teeth.
- This attraction is induced by an applied voltage between the fixed and free anchors
- Advantages
  - High displacement
  - Low current
- Disadvantages
  - Low force
  - Relatively high voltage

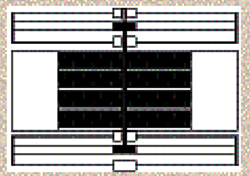
Design Specifications

- 200 μm max. displacement
- Size: currently 2.5 mm x 2 mm



As Fabricated


Actuated


Conventional Design


New Design

Measured Results

- 200 μm displacement
- 50 V DC drive signal
- Stable movement over full actuation range

Revised Design

- 4 to 1 size reduction (right) over conventional designs
- More robust flexures & comb teeth
- Increased stability

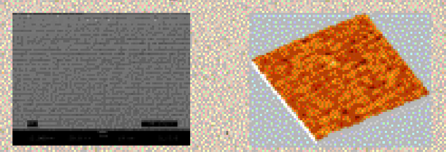
Moving Reflector Switch Performance

Measured Results Summary

Actuator Drive	V	50
Optical Input	mW	1000
Optical Efficiency	%	48 - 67
Max. Power Transfer	mW	670
Switch Time	ms	8 - 10
Max. Frequency	Hz	60
Channel Isolation	dB	30

Measured Results

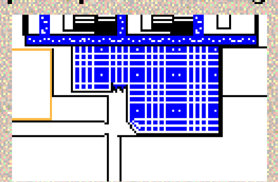
- Reflector surface topology resulted in decreased reflectivity
- Reflector surface
  - Scalloping due to Bosch process DRIE
  - Measured roughness: 51 nm RMS



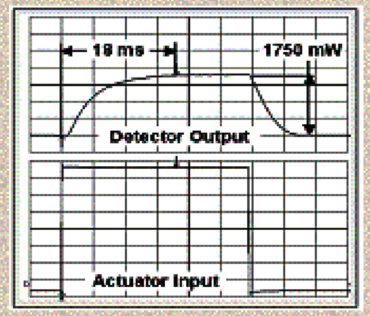
- Relatively fast switching time
- Some reflector failures due to thermal breakdown

Design Improvements

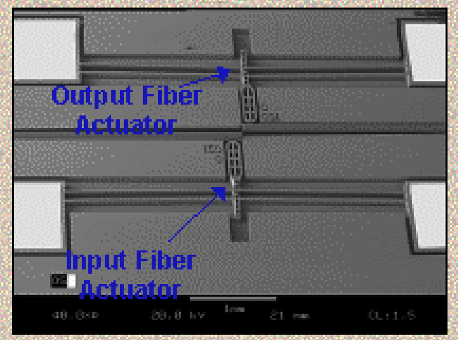
- AR coated optical fibers will increase optical efficiency ~5%
- Revised reflector design (below)
  - Larger thermal heat sink
  - Better optical power handling capability



Optical Output vs. Actuator Input



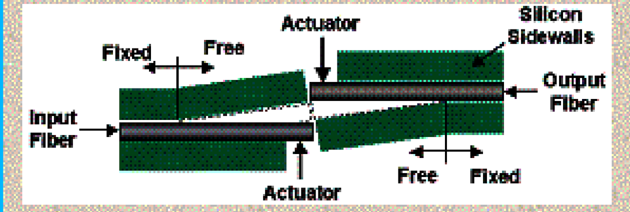
Moving Fiber Optical Switch



. . .

Switching Concept

- Input and output optical fibers placed in etched alignment grooves in an out-of-line position
- "Cantilevered" fibers directly actuated to an in-line position by v-beam thermal actuators

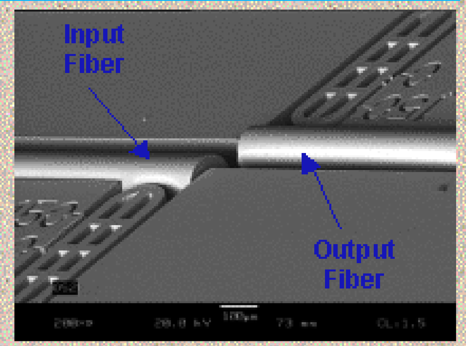


System Optical Components

- Input Fiber: 105 / 125 μm core / cladding
- Output Fiber: 105 / 125 μm core / cladding
- Optical Input: 2000 mW, 810 nm laser diode

Optical Analysis

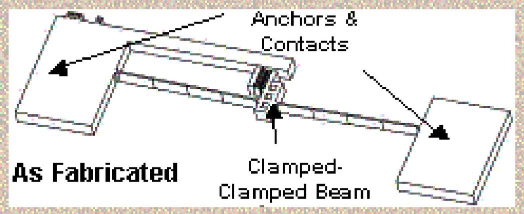
- Optical losses
  - Fiber longitudinal misalignment
  - Fresnel reflections
- Predicted optical efficiency: 90-91% (dependent upon final fiber separation)



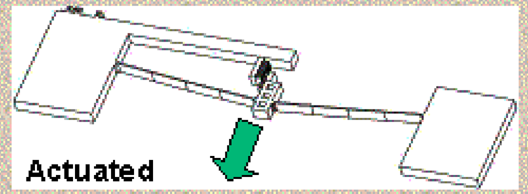
V-Beam Thermal Actuator

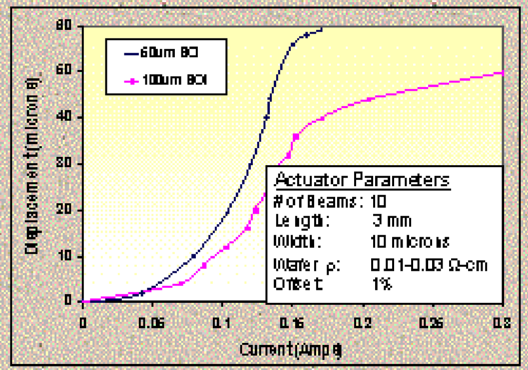
Actuator Description

- Clamped-clamped beam with a slight central offset
- Current is applied across the beam; Joule heating causes the beam to expand and deflect in the direction of the offset
- Advantages
  - High force
  - Extremely rugged from dual cantilever anchors
- Disadvantages
  - Relatively high power
  - Lower displacement than other actuator



As Fabricated


Actuated



Measured Results

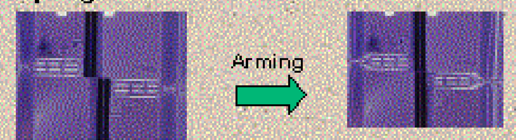
- Displacement roll-off at higher current is due to the silicon material intrinsic point
- Multiple beam actuators
  - Several beams can be placed in parallel to increase actuator force output
  - Benefit from co-heating of closely spaced, parallel beams
  - Maximum displacement is reduced by "weakest link" effect
- Most power efficient design is a long, single beam actuator

Moving Fiber Switch Performance

Input / Output Core	μm	105 / 105
Actuator Current	mA	190
Optical Input	mW	2000
Optical Efficiency	%	87 - 88
Max. Power Transfer	mW	1760
Switch Time	ms	16 - 21
Max. Frequency	Hz	35
Channel Isolation	dB	55

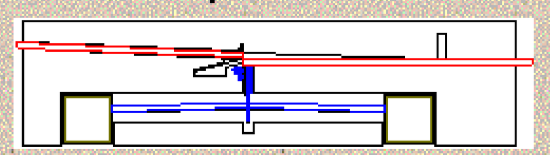
Measured Results

- Fiber assembly
  - Fibers secured with epoxy
  - Fiber end faces can be brought to within 10 μm of each other
- Excellent optical efficiency
- Fiber reliably returns to out-of-line position under its own spring force



Design Improvements

- AR coated optical fibers will increase optical efficiency ~5%
- Revised designs require less current (currently being fabricated)
- Alternate layout: actuation of input fiber only (below)
  - Lower overall current
  - Smaller footprint



Optical Output vs. Actuator Input