Micro-Opto-Mechanical Systems

Contract No. FQ8671-9301675
Electronic Systems Technology Office
Advanced Research Projects Agency
Department of Defense
Program Manager: Dr. Kaigham J. Gabriel

Principal Investigators:
Prof. Mehran Mehregany
- e-mail: mehran@mems5.cwru.edu Tel: 216-368-6435

Prof. Frank Merat
- e-mail: merat@snowhite.eeap.cwru.edu Tel: 216-368-4572

Department of Electrical Engineering & Applied Physics
Fax: 216-368-2668

Opto-Mechanical Devices using MEMS Technology

Prof. Mehran Mehregany
- e-mail: mehran@mems5.cwru.edu Tel: 216-368-6435

Prof. Frank Merat
- e-mail: merat@snowhite.eeap.cwru.edu Tel: 216-368-4572

Department of Electrical Engineering & Applied Physics
Fax: 216-368-2668

ARPA MEMS PI meeting, Washington, D.C., July 1995 University

Outline

- motivation
- devices
- systems

Motivation

The ultimate goal of MOMS is to integrate coordinated motions of basic microactuators, passive/active optical components, microsensors, and microelectronics in order to realize a complete pre-assembled optical system that can be mass produced with low unit cost.

MOMS will allow the development of new families of microfabricated opto-mechanical systems which:

- do not need component alignment;
- can be mass produced (i.e., are on the order of dollars per unit device);
- have high packing density;
- can be directly integrated with electronics; and
- are low-power, small, and light weight.

Microelectromechanical Systems (MEMS)

We are at the device stage

- microscanners
- tunable laser diodes
- optical waveguides
- microrelays

ARPA MEMS PI meeting, Washington, D.C., July 1995 University

Where are are going?

- integrated systems especially for the telecommunications industry

Microelectromechanical Systems (MEMS)

Put individual devices into micro-optical-mechanical systems

- microscanners → optical switches, scanners, beam steering
- tunable laser diodes → communications systems
- microrelays → instrumentation

ARPA MEMS PI meeting, Washington, D.C., July 1995 University

Integrate individual devices to create micro-optical-mechanical systems

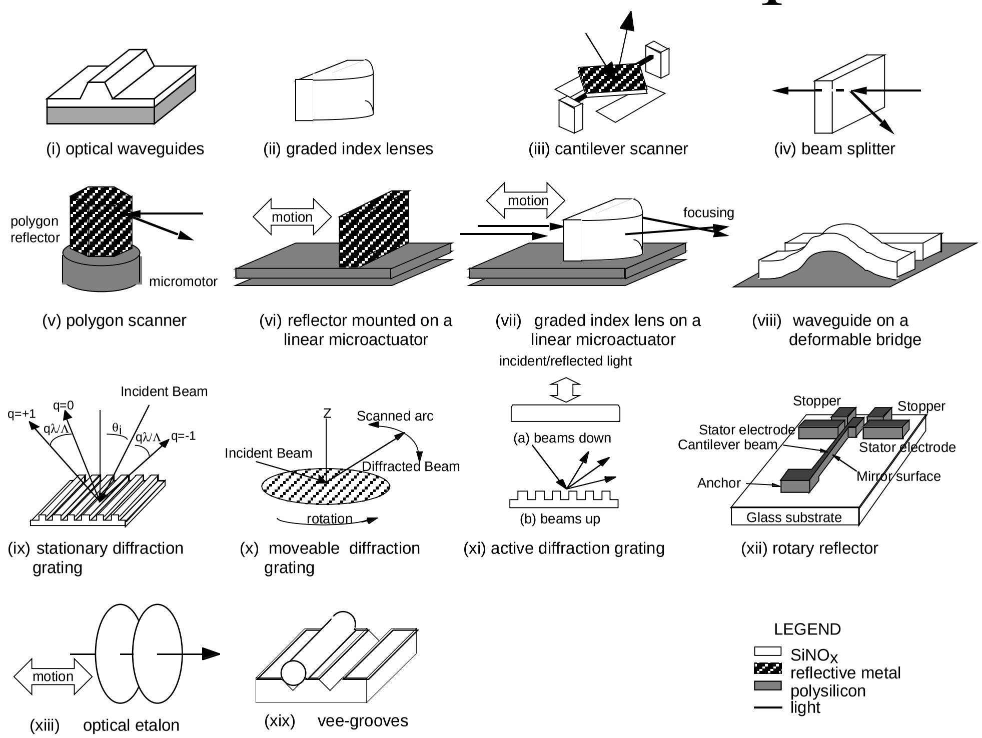
- optical waveguides are an enabling technology
- optical duplexer for subscriber loop services

MOMS critical to practical implementation of large numbers of fiber optic subscriber loops

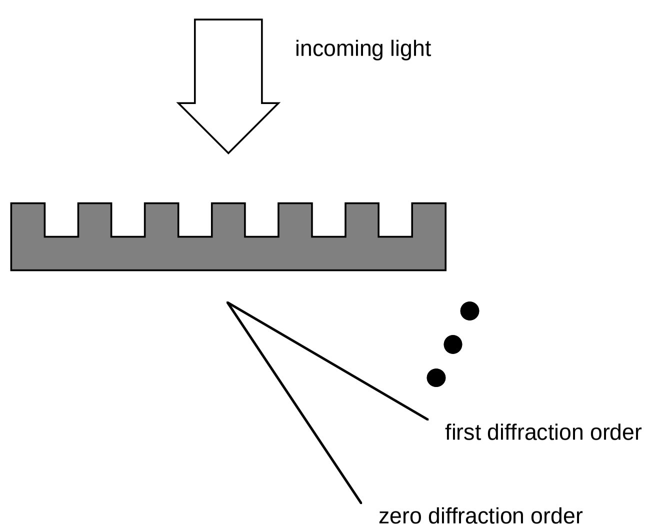
- optical microbenches that permit low-cost manufacture of pre-aligned, hybrid fiber optic systems (e.g., transmitters and receivers)

  Reliance Electric Comm-Tech has identified such an optical assembly microbench as one of the industry's most pressing short-term needs
- optical switches which permit in-situ testing of optical fibers
- low-cost, mass-produced frequency stabilized laser diode sources for WDM and other applications

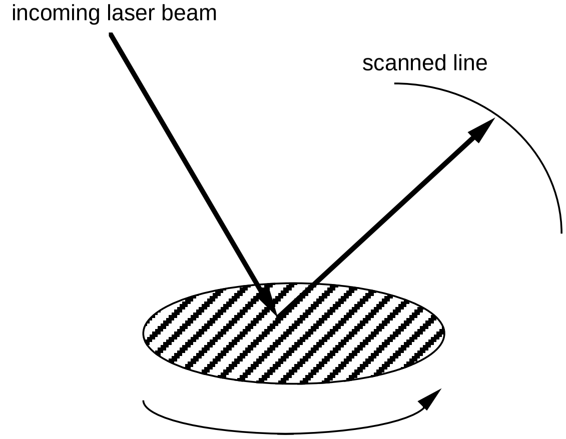
Set of basic MOM components



Diffraction grating

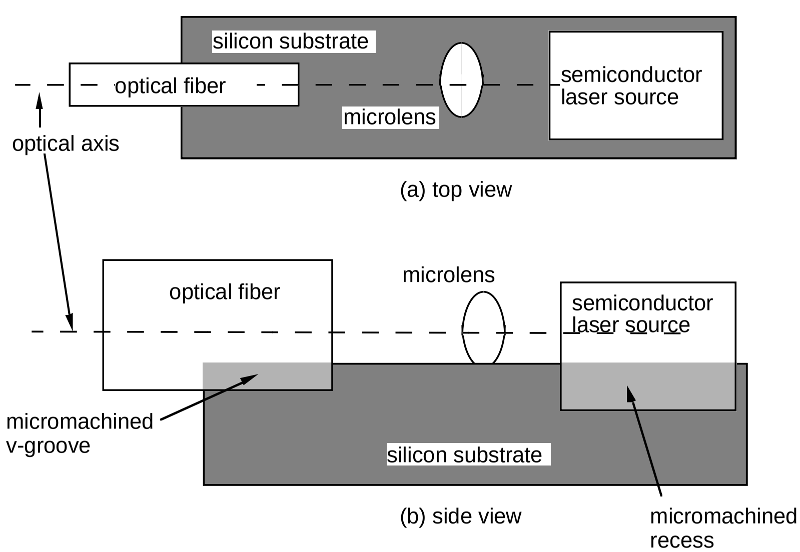


Schematic diagram of a rotating diffraction grating scanner.

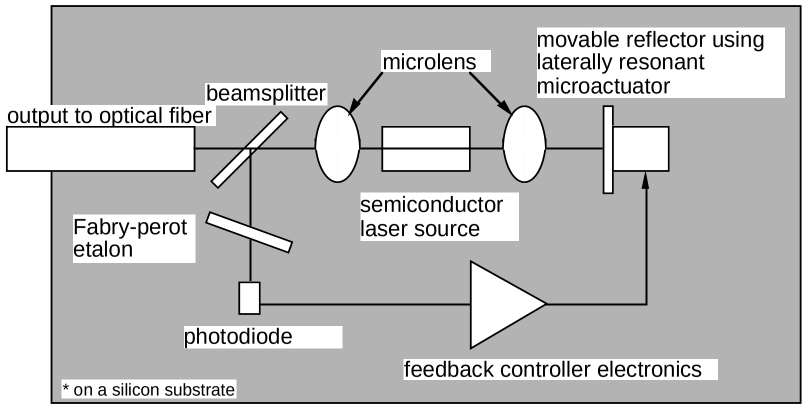


Note that the incident beam reflects from the entire rotor surface.

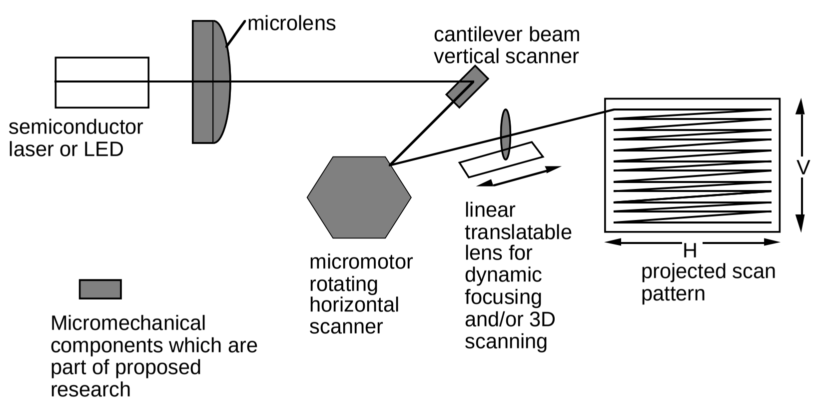
Schematic illustration of an optical microbench based on a silicon chip.



Conceptual external cavity frequency stabilized laser diode using a lateral resonant mirror translator



A microfabricated 3D scanner for miniature projection displays



The micromotor scanner will also be used for optical switches.

Our industrial partner, Reliance Electric

- Reliance Electric is genuinely interested in the technology being proposed and helped us in defining specific needs and applications. Our on-site interactions will result in a natural technology transfer path. In fact, their technical contacts will co-supervise the graduate students carrying out their research and will be directly involved as the program proceeds.
- The results of our basic research on enabling technologies, (generic) device designs, and prototype performance characteristics are not proprietary. However, in the course of the research, devices and applications with promising markets will be considered proprietary until appropriate patent protection is obtained by CWRU or Reliance Electric. The results of all portions of the program will be made available to ARPA for government use.

Collaboration with Reliance

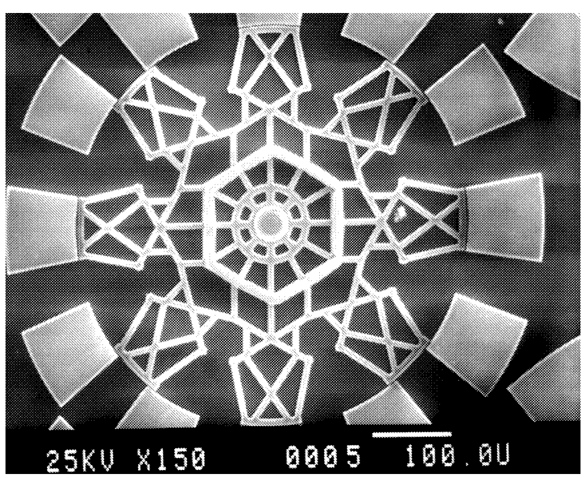
the fiber optic coupler

- a vee-groove multiple optical fiber coupler was identified as the short term application of the optical microbench technology
- Specifications for a commercial device were provided by Reliance Electric after several joint meetings
- a prototype device was designed and fabricated at CWRU
- this device was sent to Reliance telecommunications in Chicago for testing
- device passed AT&T coupler specifications

Continuing Collaboration with Reliance
the project team

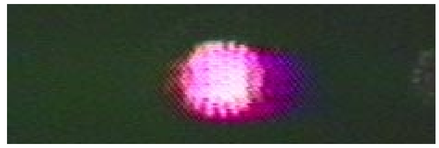
- Dr. Jim Harris, Fred Discenzo, Reliance Research
- Dr. George Ab-Bubu, Reliance Telecommunications
- Prof. Frank Merat, Prof. Mehran Mehregany, CWRU
- Shuvo Roy, Steve Smith, Azzam Yaseen, CWRU Ph.D. candidates

Polygon Microscanner



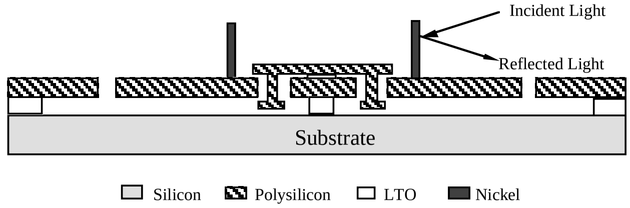
SEM photo of a rotating polygon optical microscanner made by electroless-plating of nickel reflecting surfaces on the rotor of a 500 micron diameter salient-pole micromotor. The thickness (height) of the nickel is 20 μm; the width of the nickel is 10 μm. The polygon itself is approximately 175 microns in diameter.

Scanner optical beam



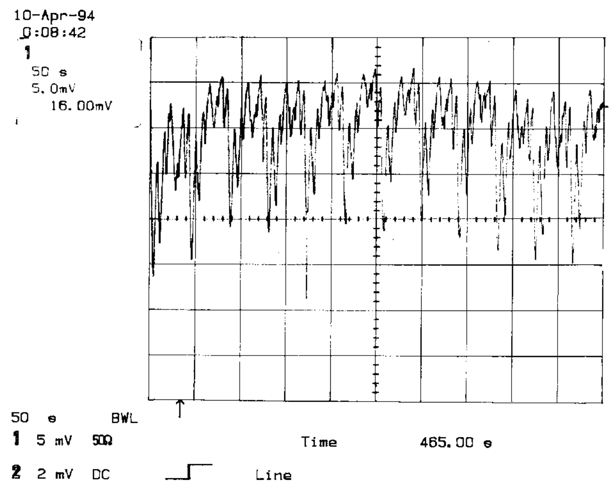
Digitized video image of a 633-nm laser beam reflecting from the polygon scanner. The image was recorded approximately 10 inches from the scanner using an ordinary TV camera.

Cross-sectional schematic of a typical polygon microscanner



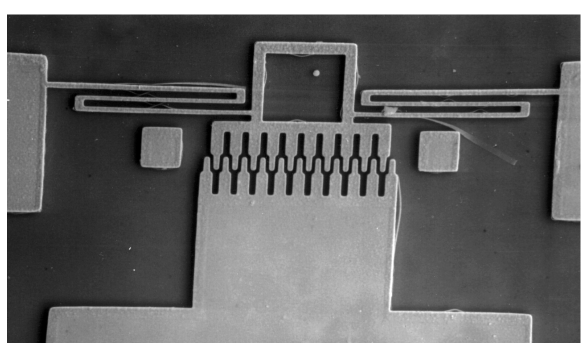
Typical microscanner after release showing illumination of the nickel surface with a laser beam. Note that if the reflector is too far from the rotor rim the beam will also reflect from the rotor surface.

Reflected signals from a spinning rotor with a constant rotor speed



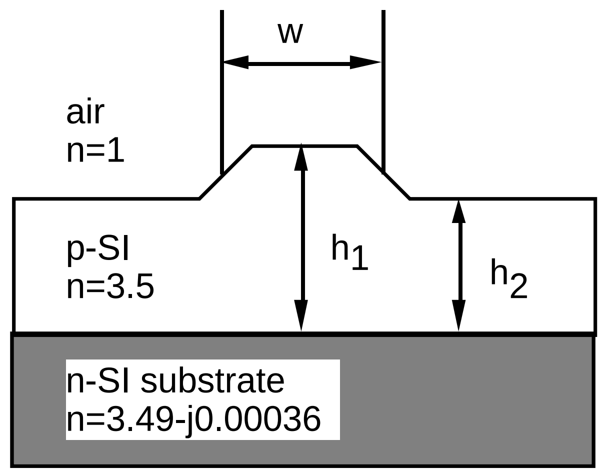
The complex shape of the reflection is caused by undesired reflections from the rotor. The low frequency variation of the reflectivity is hypothesized to be a low frequency wobble of the rotor about the axis of rotation.

Electrostatic drive lateral translational reflector.

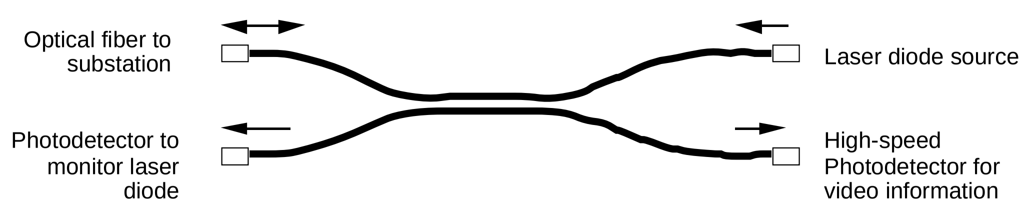


The sidewall of the surface at the top center of the image is nickel plated and will be used as an optical reflector.

Cross-sectional view of a rib waveguide in epitaxial silicon



Schematic diagram of optical duplexer chip

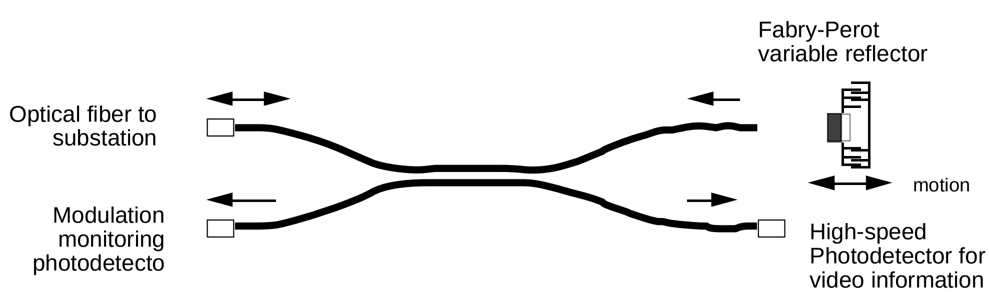


Single Mode Pigtailed 1.3/1.3 Duplexer

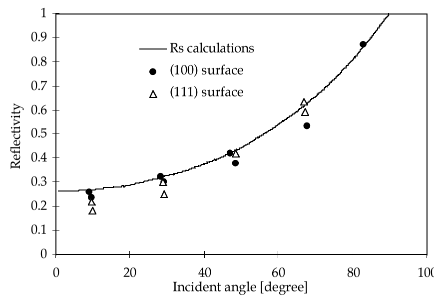
Item	Symbol	Conditions	MIN	MAX	Units
Operating case temp	Tc		-40	85	∞ C
Wavelength	lc	over Tc	1260	1350	nm
Output power into single mode fiber	Pout	over Tc	6	(see Pfth)	µW
Threshold power (Laser diode)	Pfth	over Tc		min Pout/30	µW
Crosstalk (Note 1)	Cr	over Tc		-29	dB
Tracking error (Note 2)	Er	over Tc	3, 0.5		dB
Receiver responsivity	R	over Tc	0.3		A/W
Receiver polarization dependence	Rp	over Tc		1	dB
Receiver capacitance	Cd	-5 V bias		1	pF
Receiver dark current	Id	over Tc, -5 V		10	nA
SC-PC connector loss	IL	over Tc		0.5	dB
Connector reflectance	Rc	over Tc		-33	dB
Backward reflectance	Rb	over Tc		-20	dB

Notes:
1. If total tracking error Er<0.5 dB, then crosstalk Cr<-24 dB
2. If total tracking error 0.5<Er<3.0 dB, then crosstalk Cr<-29 dB

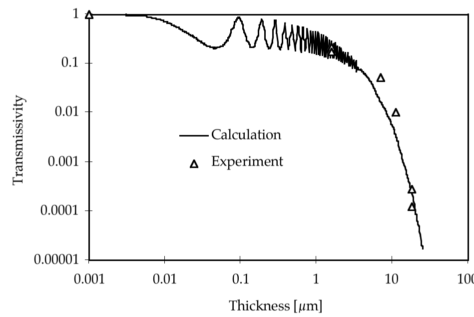
Optical duplexer using planar micromechanical light modulator to replace optical source.



Optical properties of high-aspect-ratio (111) silicon plates

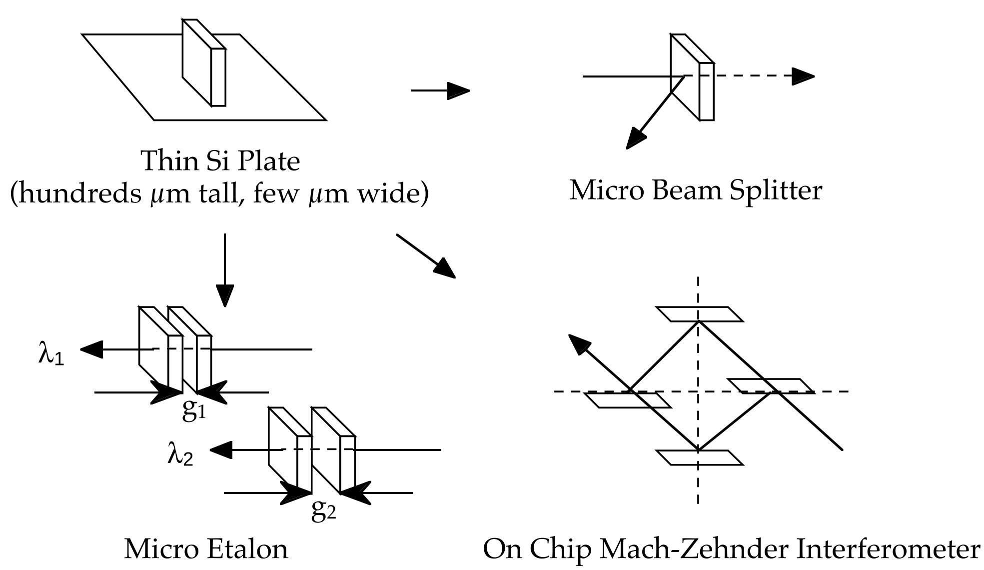


Reflectivity as a function of the light beam incident angle

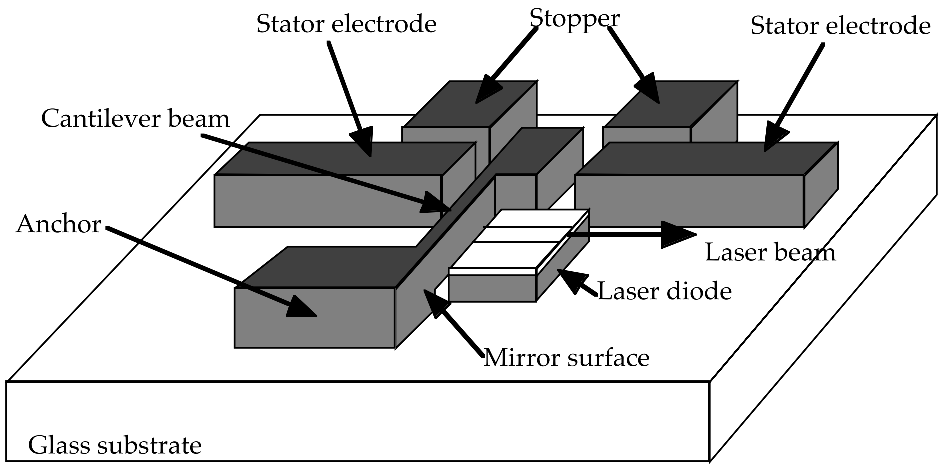


Transmissivity as a function of the thickness of the (111) silicon plate

Optical applications of high-aspect-ratio (111) silicon plates

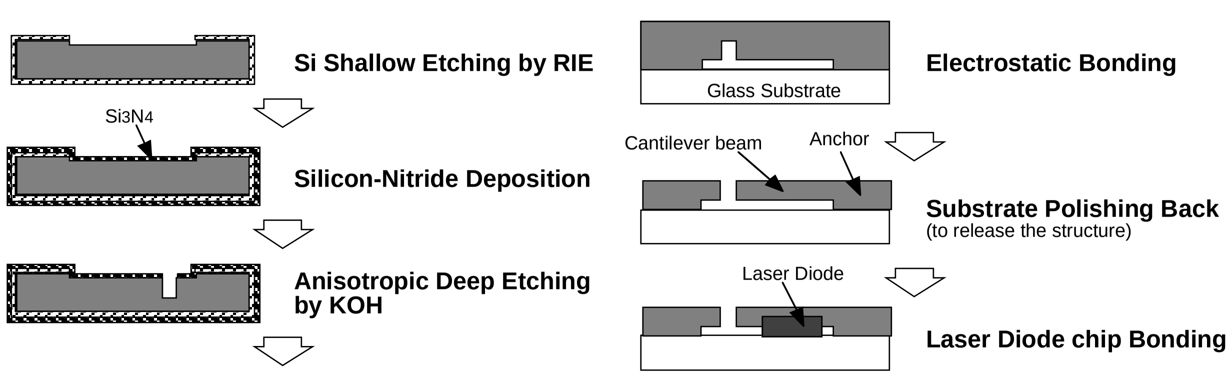


Schematic diagram of an integrated laser diode and micromirror



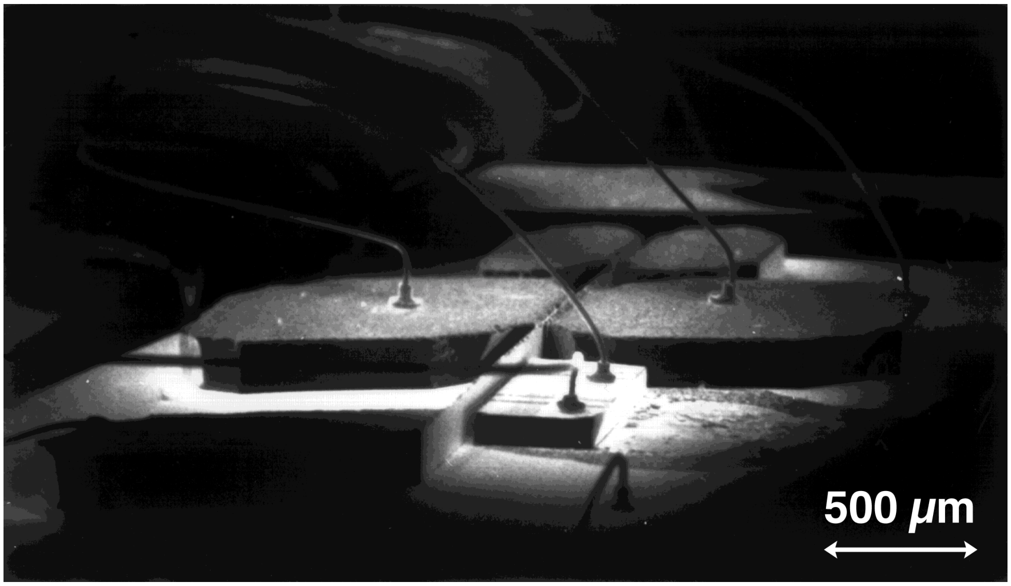
Microelectromechanical Systems (MEMS)

Fabrication process for the integrated laser diode/micromirror

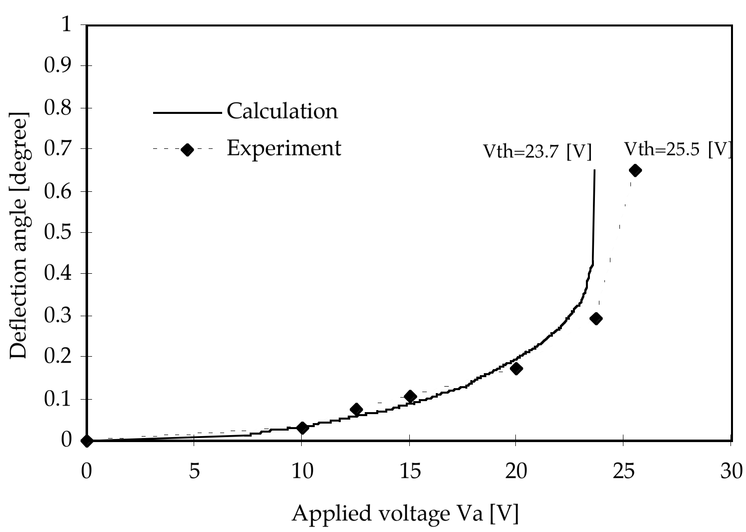


ARPA MEMS PI meeting, Washington, D.C., July 1995 University

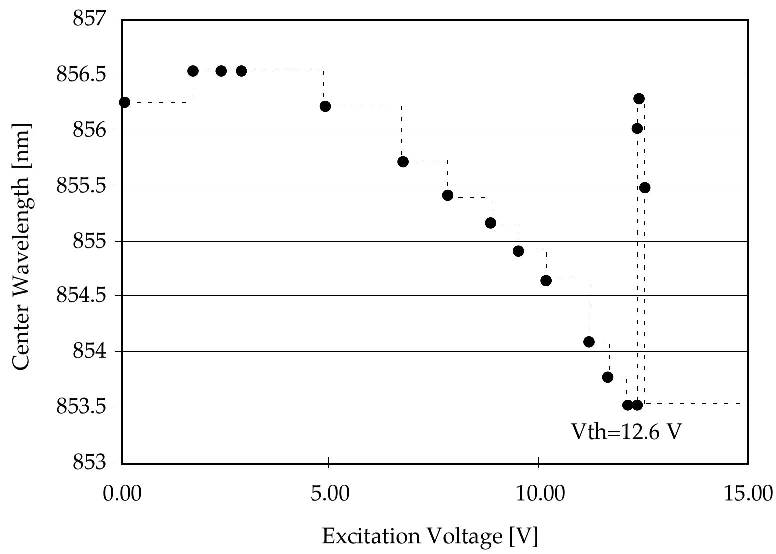
An SEM image of the integrated laser diode and micromirror.



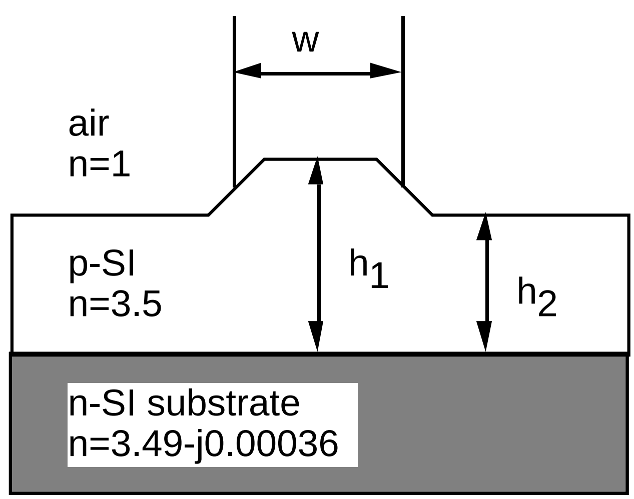
Micromirror deflection angle as a function of the applied voltage



Wavelength variation as a function of the excitation voltage of the mirror



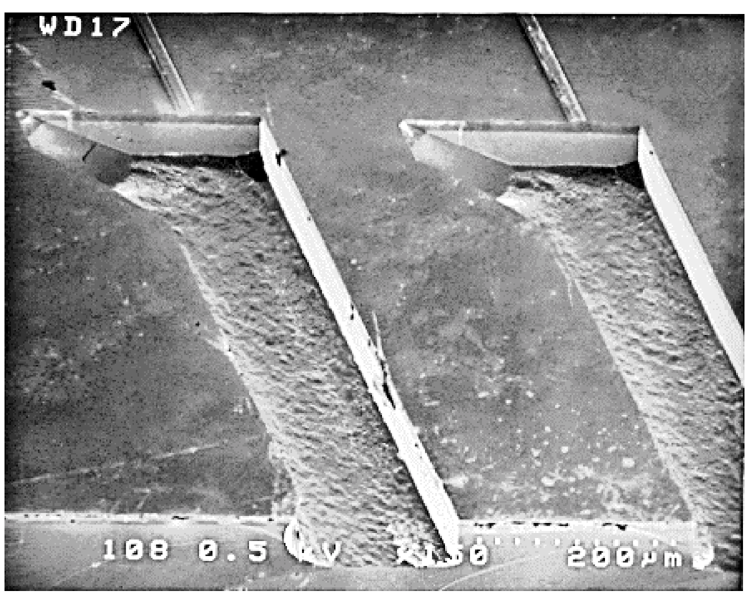
Cross-sectional view of a rib waveguide in epitaxial silicon



Anisotropically-etched waveguide end-face

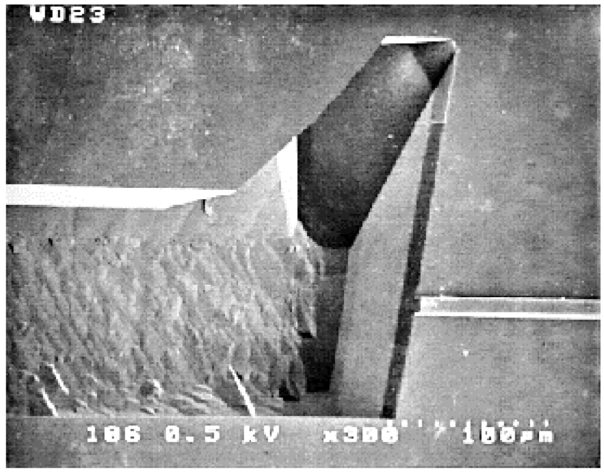
The dark layer is the region where light is guided and the light layer is the heavily doped silicon substrate

End view of bulk fabricated U-grooves



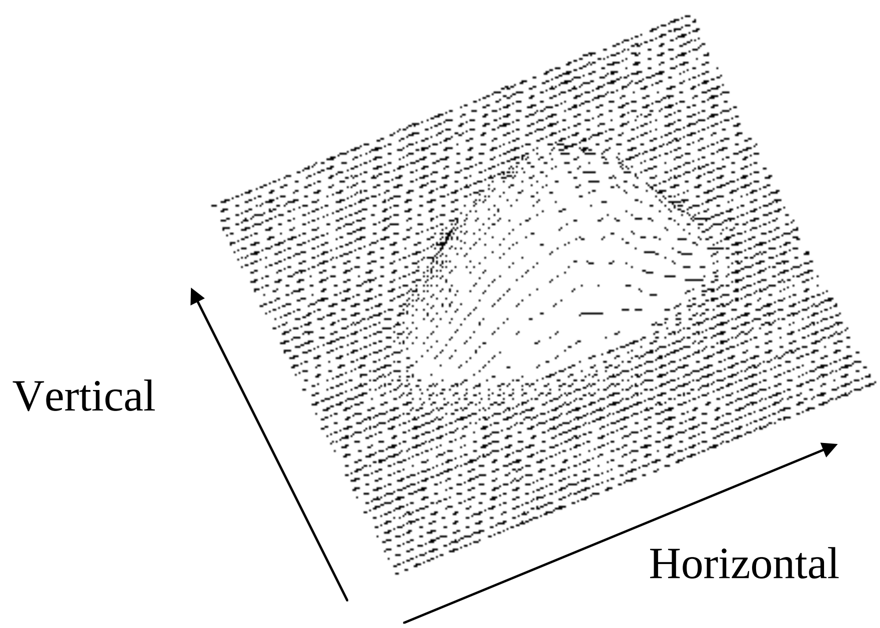
Note the rib waveguides positioned at the end of the grooves and the corner compensation structures

Detail of corner compensation structure of fiber guiding U-groove on a (110) silicon substrate

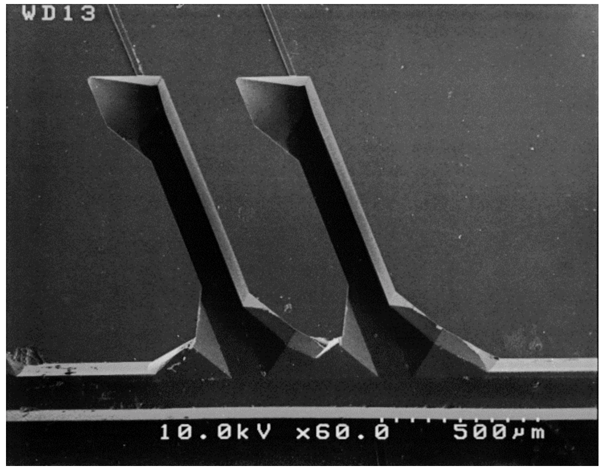


. Note the rib waveguide at the right end of the U-groove

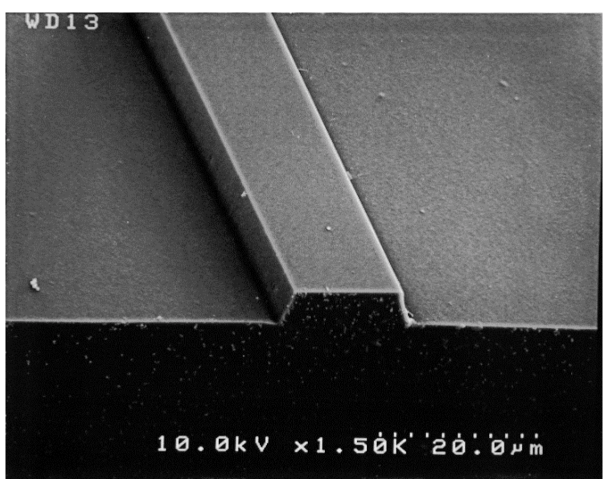
Three dimensional intensity profile from a large-area, all-silicon waveguide with a 10 µm wide rib



End view of bulk fabricated U-grooves using ultrasonic agitation

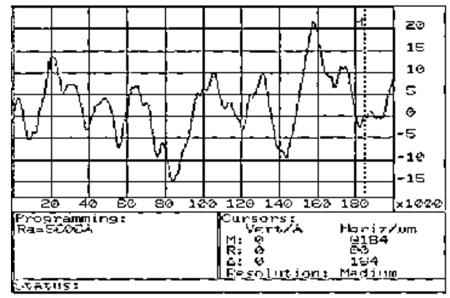


Anistropically etched rib waveguide with ultrasonic agitation

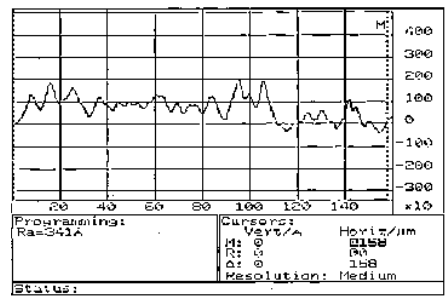


U-groove surface roughness

Decktak surface roughness of a typical U-groove bottom. The value of Ra is 5606Å.



Decktak surface roughness of a U-groove bottom produced with ultrasonic etching. The value of Ra is 341Å



Microrelays: Background and Motivation

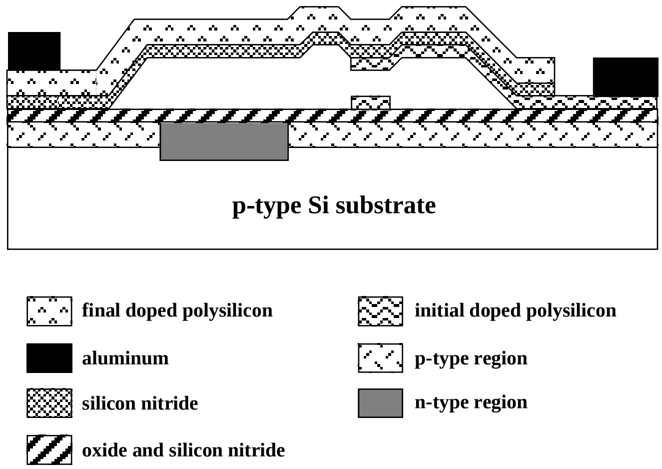
- Surface micromachining concept
- “Traditional” high-aspect-ratio microstructures

↓

- New Surface Micromachining Process
  - Mold characteristics
  - Structural material deposition

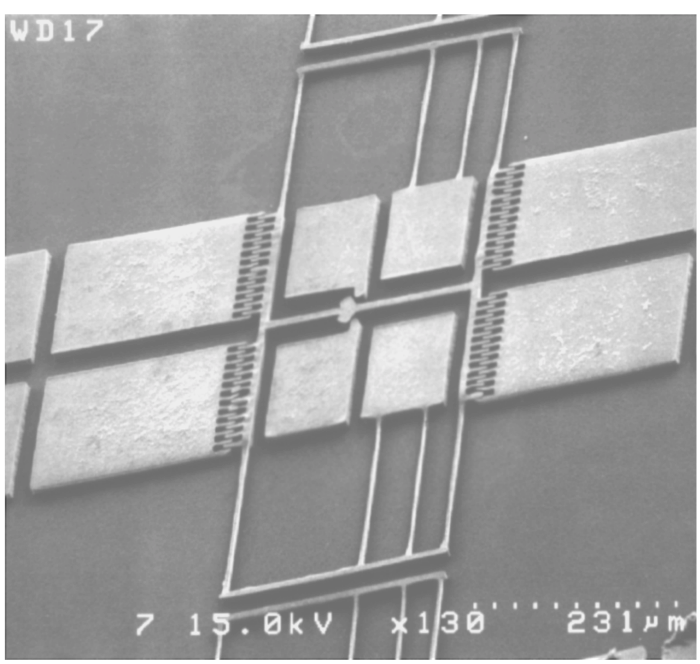
Polysilicon Surface–Micromachined Relay

(Gretillat et. al at MEMS ‘94)

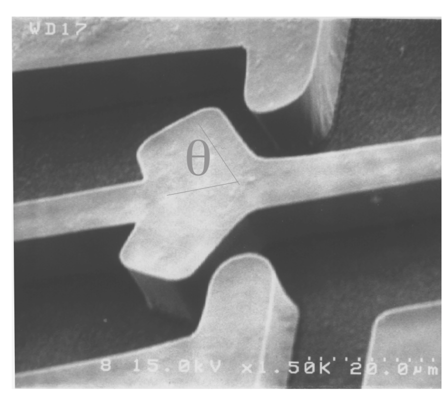


- Low current load ≈ 1 mA
- High contact resistance ≈ 10 kΩ

Nickel Microrelays



* Metallic contacts
- electrostatic actuation
- rubbing action
- stiff suspension



Microrelay Characterization

- Actuation voltages

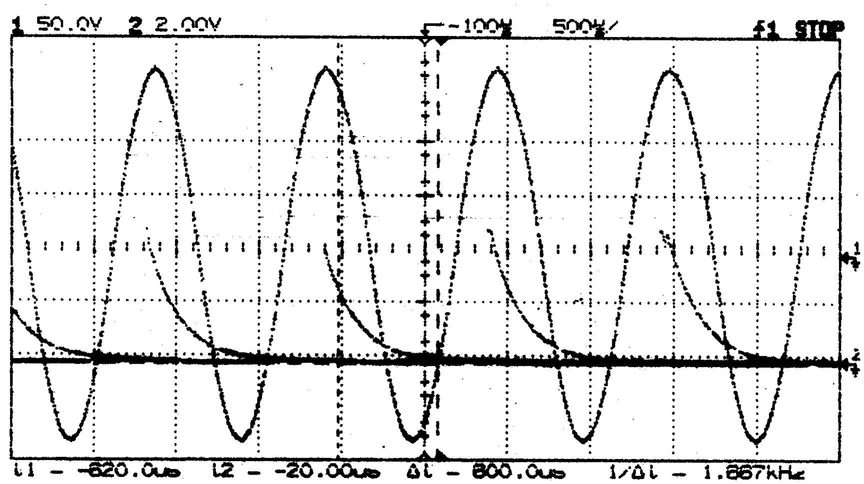
  ≈ 200 Volts
- Resonant frequencies

  5–20 kHz
- Current load

  ≈ 250 mA
- Contact resistance

  < 20 Ω

Microrelay Switching Operation



- frequency ≈ 1 kHz
- switched signal ≈ 5 Volts
- contact travel ≈ 2 µm
- contact force ≈ 20 µN