

# Micro-Opto-Mechanical Systems

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# Opto-Mechanical Devices using MEMS Technology

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# Outline

- motivation
- devices
- systems

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# Motivation

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

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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.

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## We are at the device stage

- microscanners
- tunable laser diodes
- optical waveguides
- microrelays

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## Where are we going?

- integrated systems especially for the telecommunications industry

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## Put individual devices into micro-optical-mechanical systems

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

## Integrate individual devices to create micro-optical-mechanical systems

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

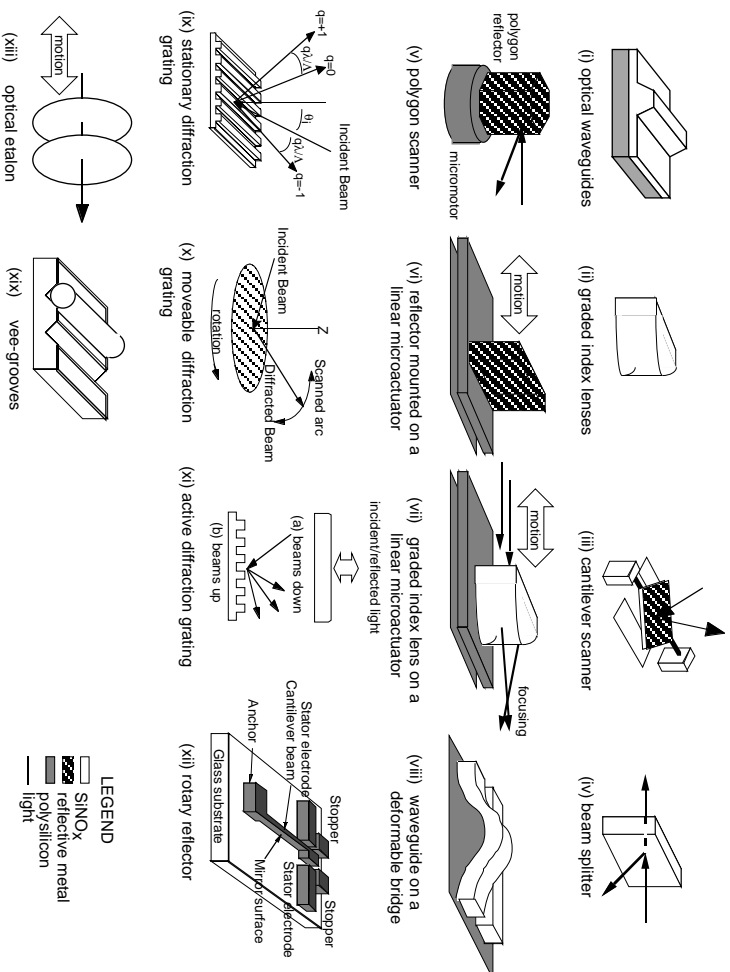
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MOMS critical to practical implementation of large numbers of fiber optic subscriber loops

- 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

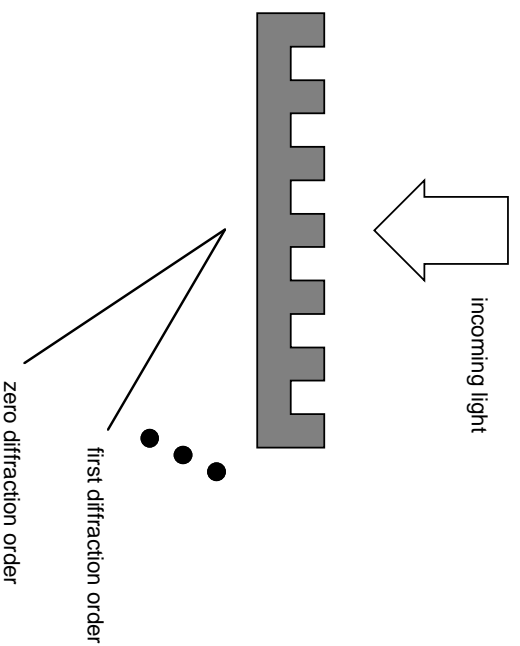
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# Set of basic MOM components



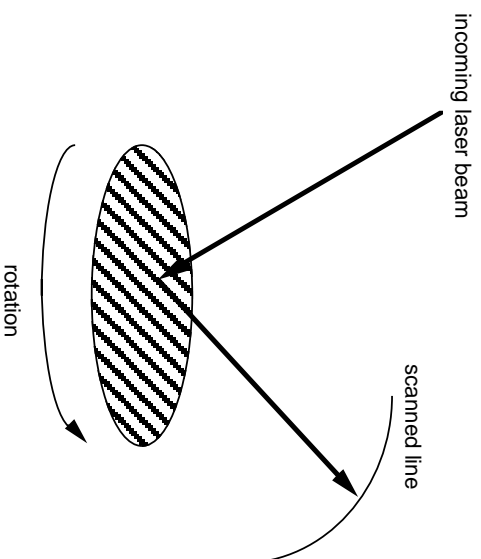
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# Diffraction grating



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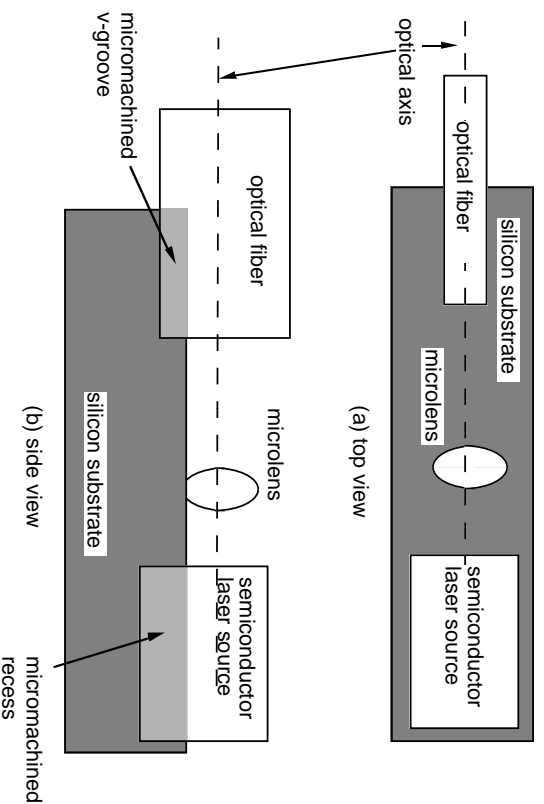
## Schematic diagram of a rotating diffraction grating scanner.



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

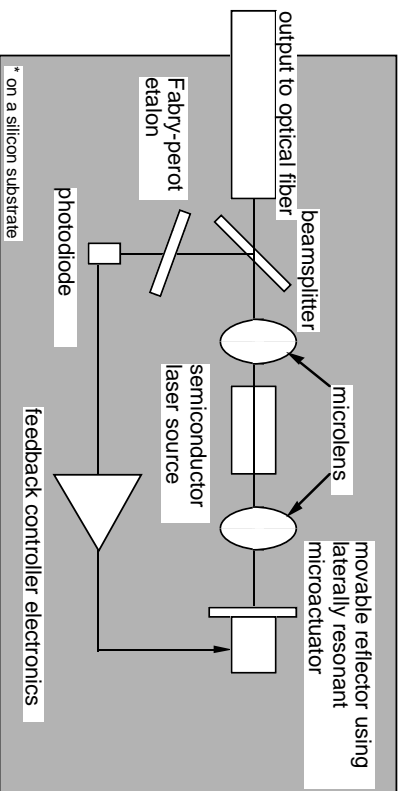
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## Schematic illustration of an optical microbench based on a silicon chip.



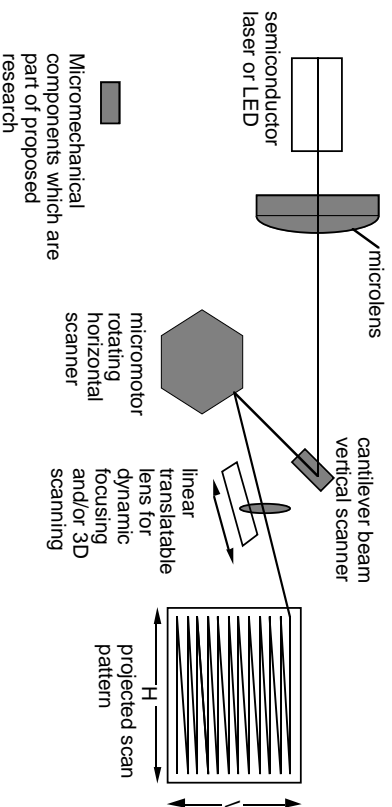
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## Conceptual external cavity frequency stabilized laser diode using a lateral resonant mirror translator



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## A microfabricated 3D scanner for miniature projection displays



The micromotor scanner will also be used for optical switches.

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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.

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## 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

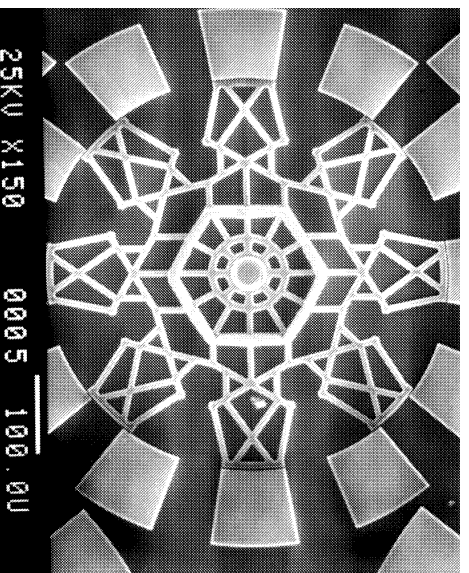
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## **Continuing Collaboration with Reliance *the project team***

- 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

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## **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  $\mu\text{m}$ ; the width of the nickel is 10  $\mu\text{m}$ . The polygon itself is approximately 175 microns in diameter.

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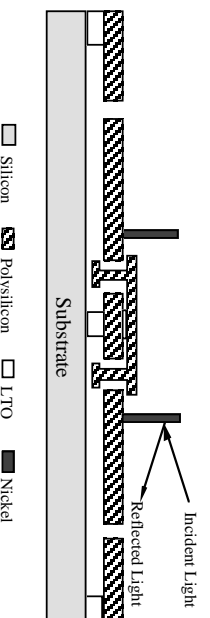
# Scanner optical beam



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.

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# Cross-sectional schematic of a typical polygon microscanner

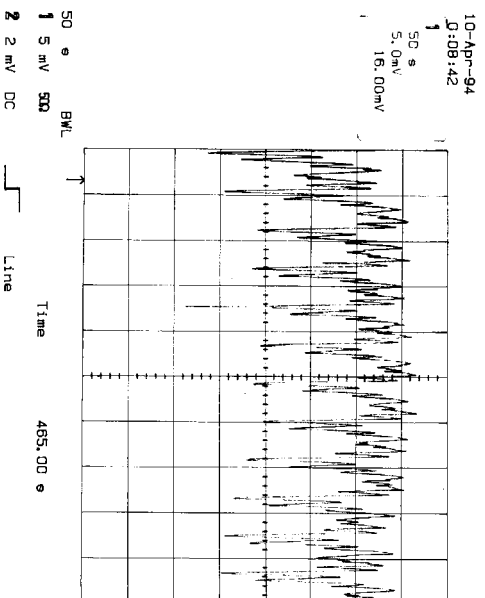


□ Silicon    ▨ Polysilicon    □ LTO    ■ Nickel

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.

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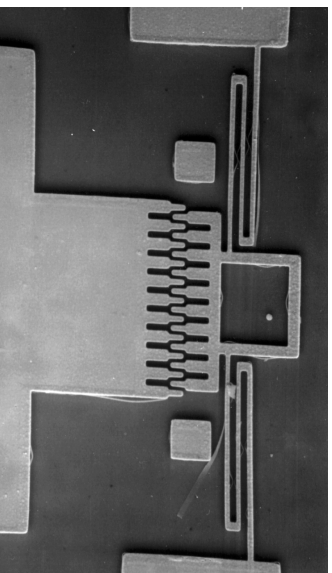
## Reflected signals from a spinning rotor with a constant rotor speed



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.

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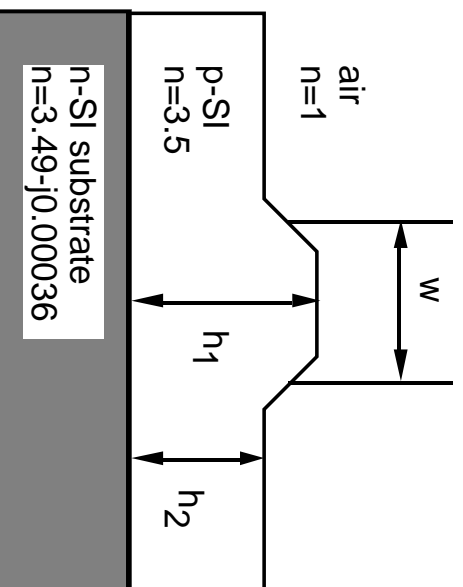
## Electrostatic drive lateral translational reflector.



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

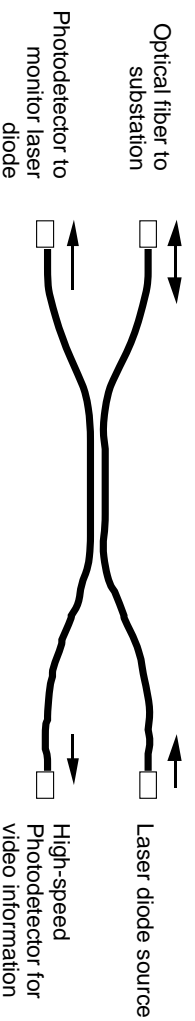
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## Cross-sectional view of a rib waveguide in epitaxial silicon



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## Schematic diagram of optical duplexer chip



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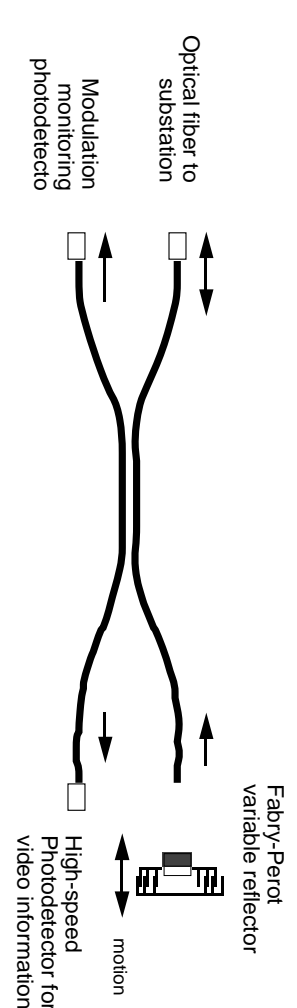
# Single Mode Pigtailed 1.3/1.3 Duplexer

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 Pth)	µW
Threshold power (Laser diode)	Pth	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

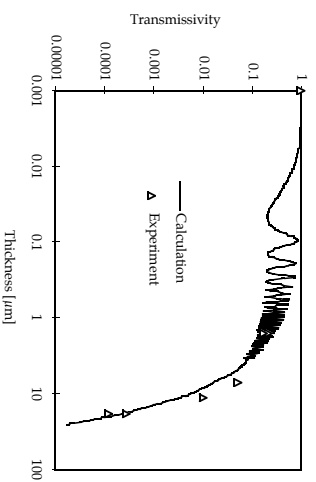
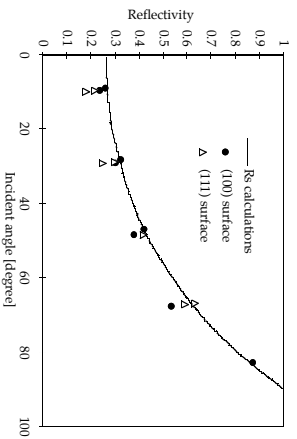
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# Optical duplexer using planar micromechanical light modulator to replace optical source.



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

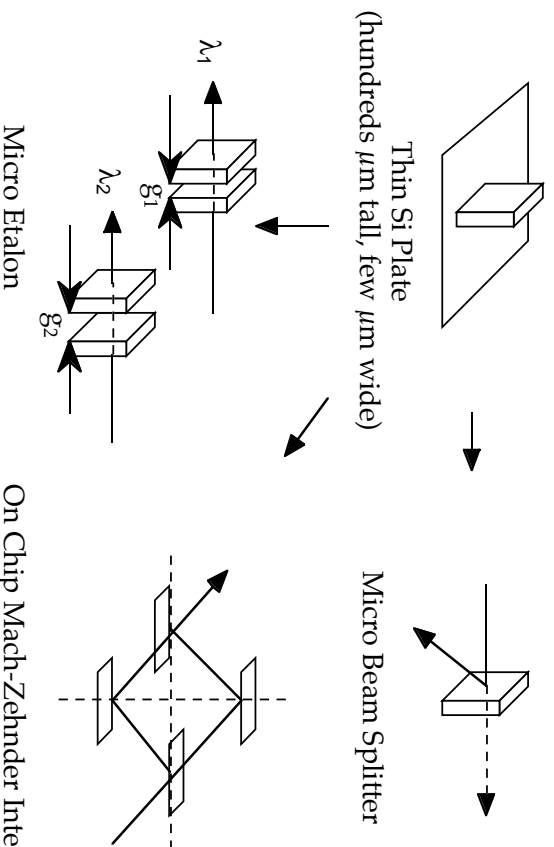


Reflectivity as a function of the light beam incident angle

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

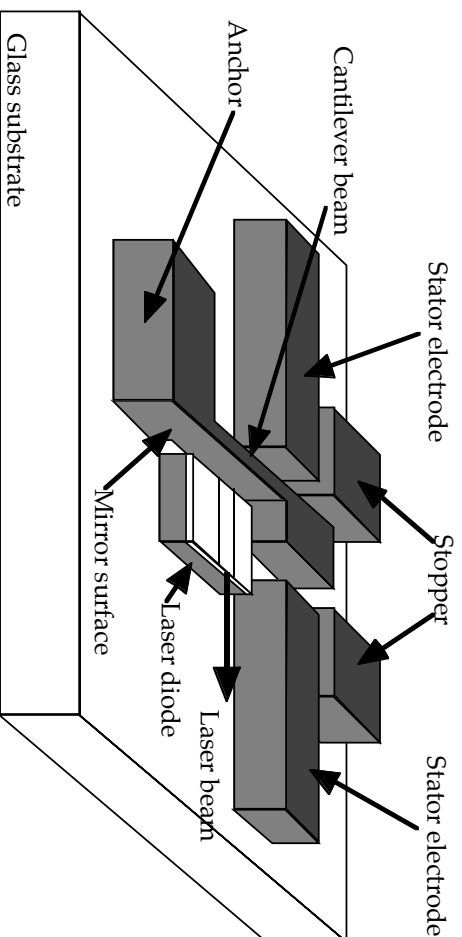
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# Optical applications of high-aspect-ratio (111) silicon plates



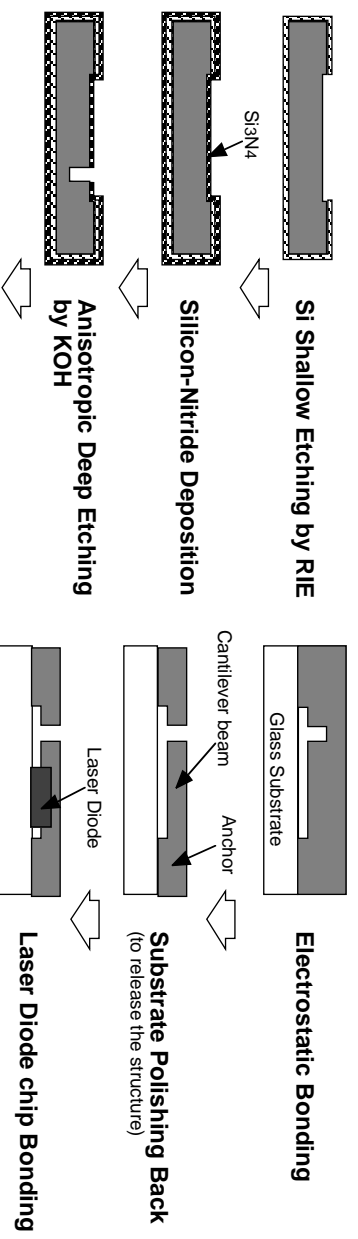
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# Schematic diagram of an integrated laser diode and micromirror



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## Fabrication process for the integrated laser diode/micromirror



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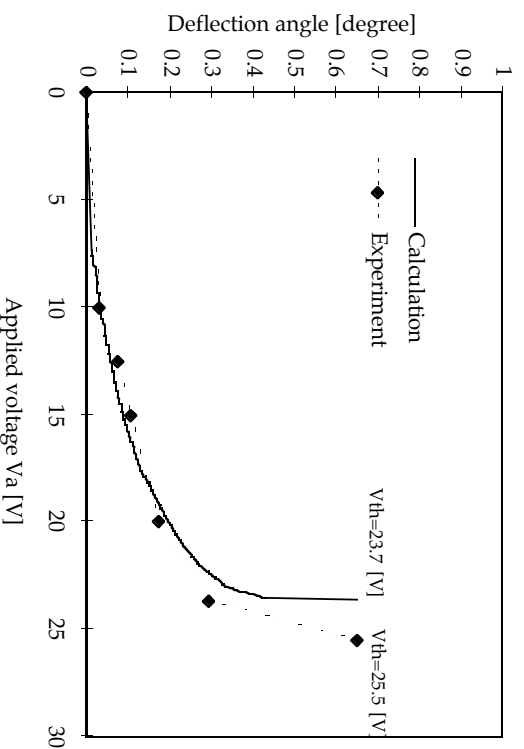


## An SEM image of the integrated laser diode and micromirror.



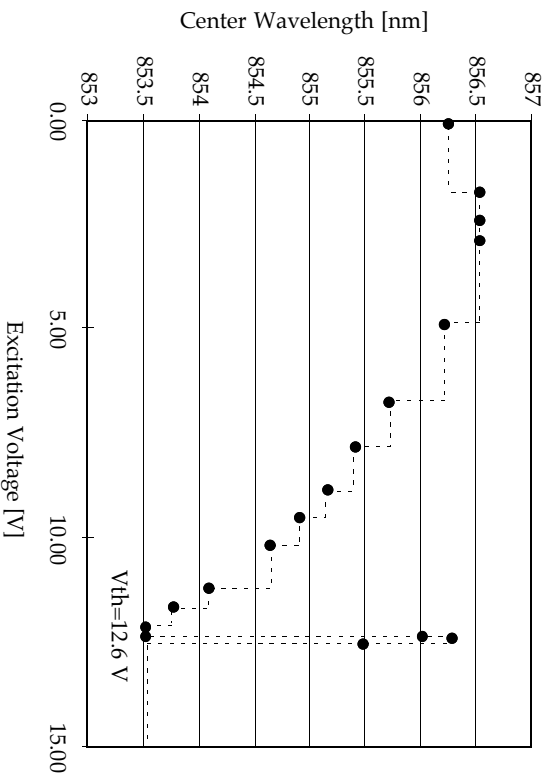
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## Micromirror deflection angle as a function of the applied voltage



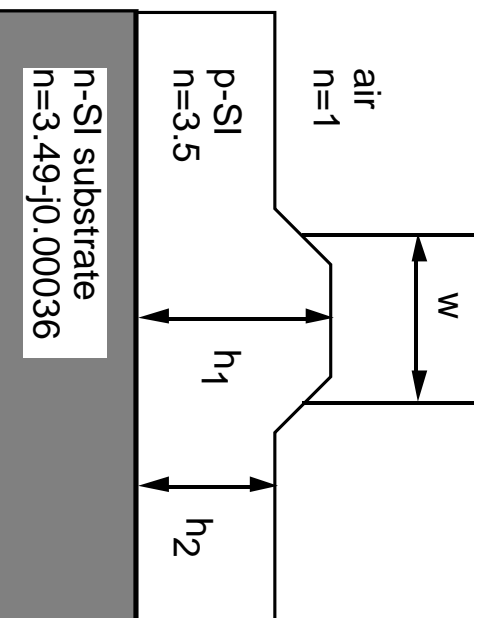
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## Wavelength variation as a function of the excitation voltage of the mirror



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## Cross-sectional view of a rib waveguide in epitaxial silicon



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## 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

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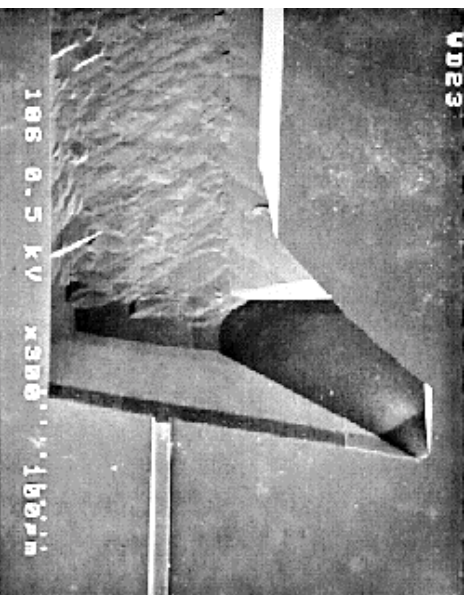
## End view of bulk fabricated U-grooves



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

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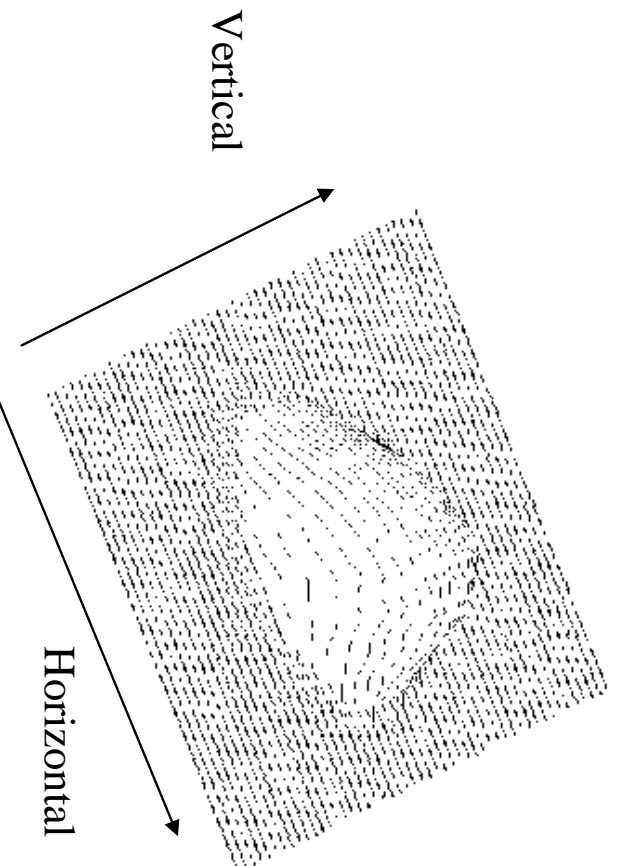
Detail of corner compensation structure of fiber guiding U-groove on a (110) silicon substrate



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

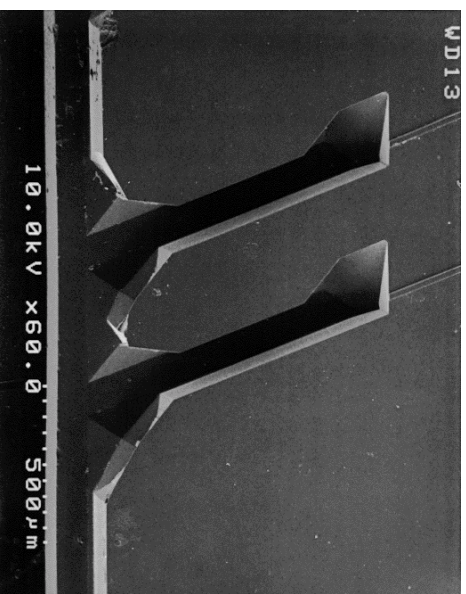
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Three dimensional intensity profile from a large-area, all-silicon waveguide with a 10  $\mu\text{m}$  wide rib



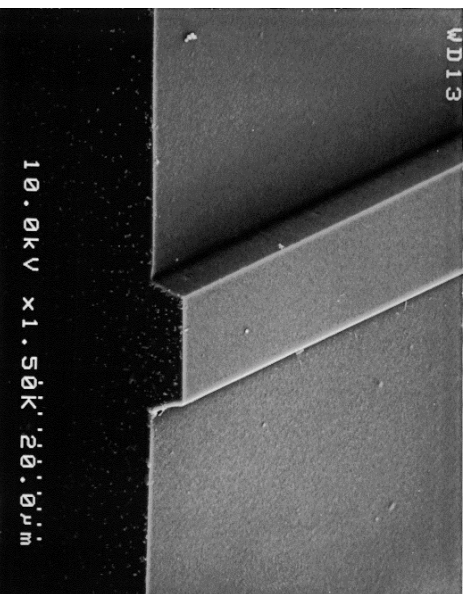
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## End view of bulk fabricated U-grooves using ultrasonic agitation



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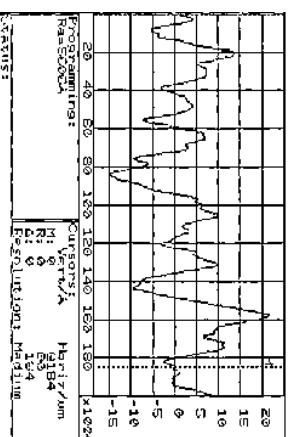
## Anisotropically etched rib waveguide with ultrasonic agitation



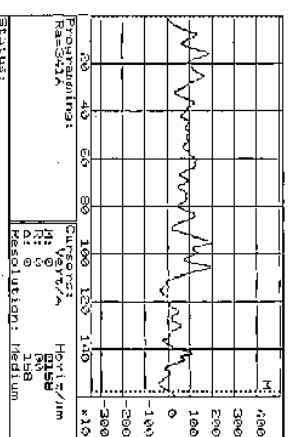
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# U-groove surface roughness

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



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## Microrelays:

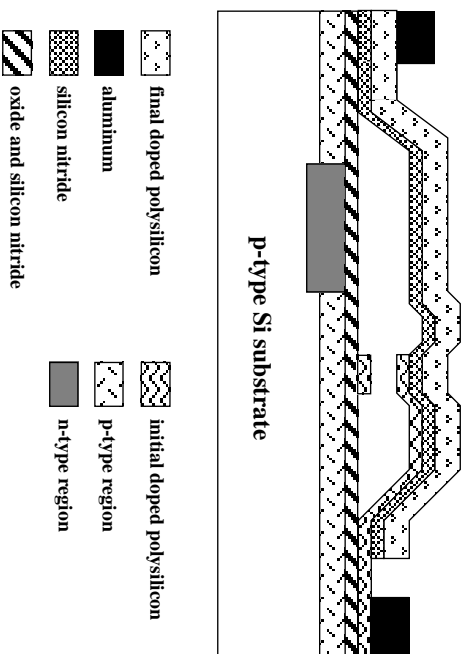
### Background and Motivation

- 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)



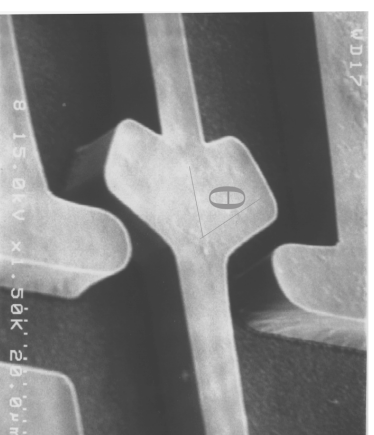
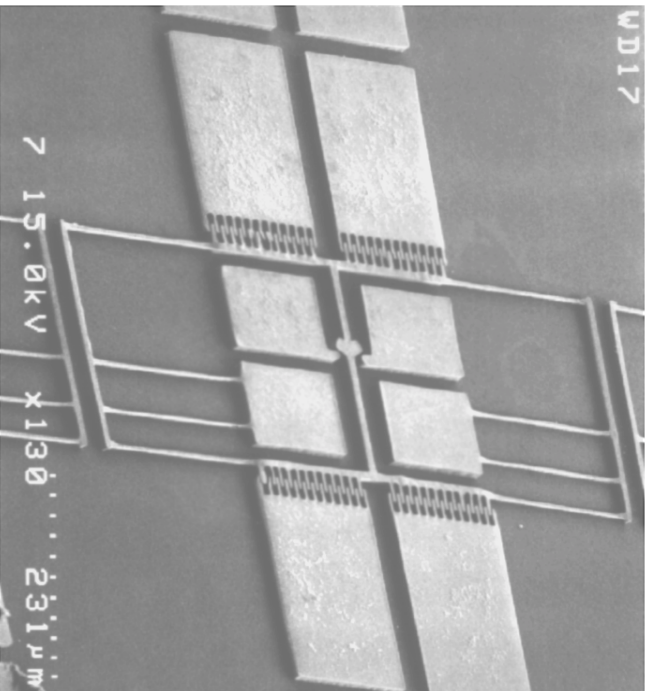
- Low current load  $\approx 1$  mA
- High contact resistance  $\approx 10$  k $\Omega$

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# Nickel Microrelays

\* Metallic contacts

- electrostatic actuation
- rubbing action
- stiff suspension



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# Microelectromechanical Systems (MEMS) — Microrelay Switching Operation

