


**Wright State University**



EE480/680  
**Micro-Electro-Mechanical Systems (MEMS)**  
 Summer 2006

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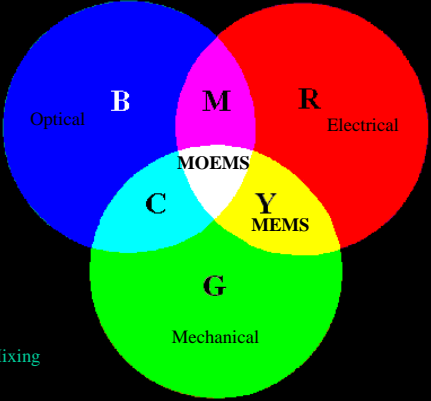



**Optical MEMS**

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**Optical MEMS: MOEMS**

- Micro-Opto-Electro-Mechanical Systems (MOEMS)

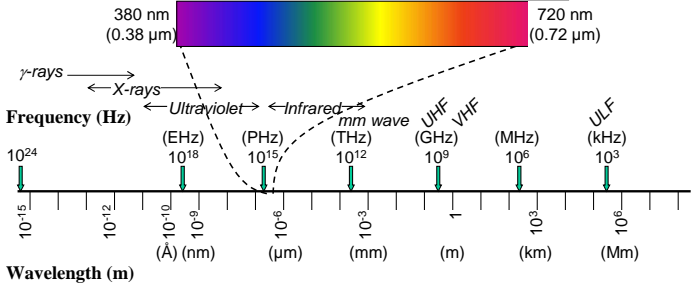


Additive Color Mixing

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**Optical MEMS**

- Electromagnetic Spectrum
  - Energy of a quantum of electromagnetic radiation:
    - $E = hf = hc/\lambda$



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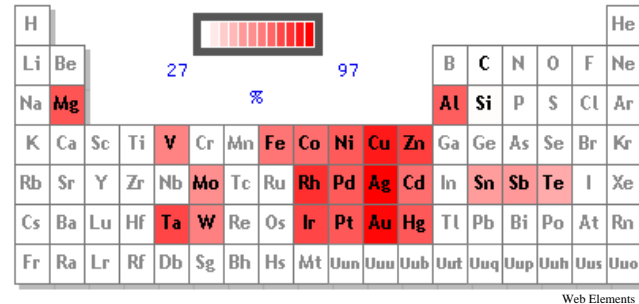
## Overview

- Mirrors & Mirror Arrays
  - Beam Steering
    - Simple Reflection
    - Corner Cube Reflector
    - Grating
    - Blazed Grating
    - Phased Array
- Lenses
  - Refractive
  - Diffractive
- Systems



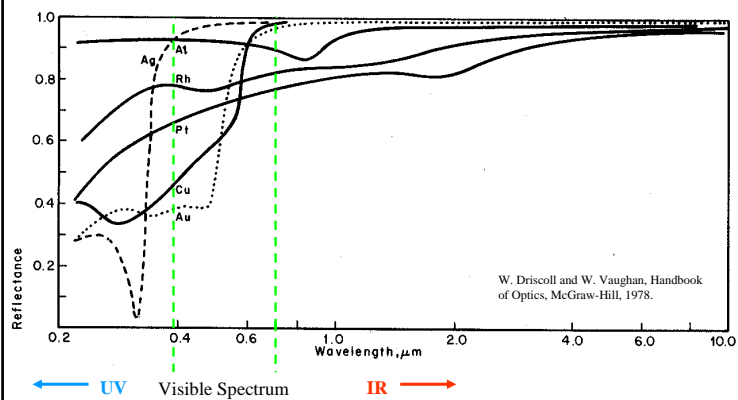
## Mirrors

- Different materials reflect different wavelengths with varying efficiency -- almost anything can be a form of mirror.
  - Reflectivity: the percentage light reflected from a surface at a given wavelength
    - ex. elemental comparison at 1  $\mu\text{m}$  wavelength

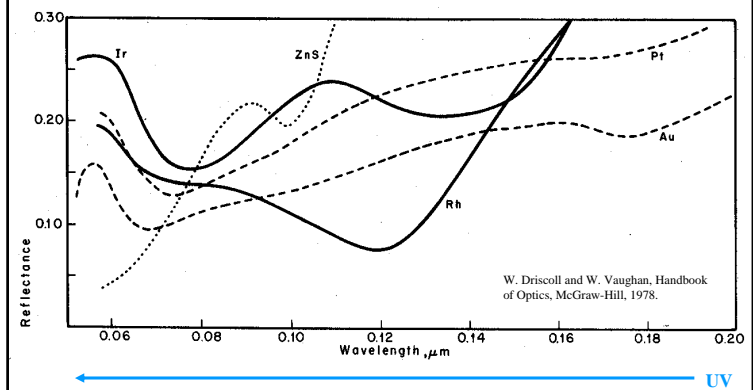


Web Elements

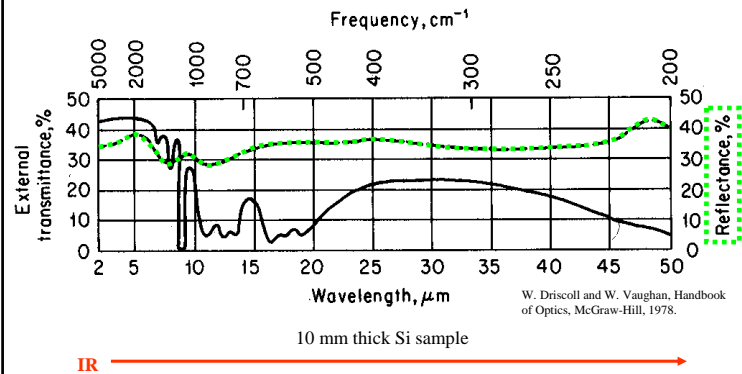
## Mirrors: Reflectance



## Mirrors: UV Reflectance



## Mirrors: IR Reflectance Si

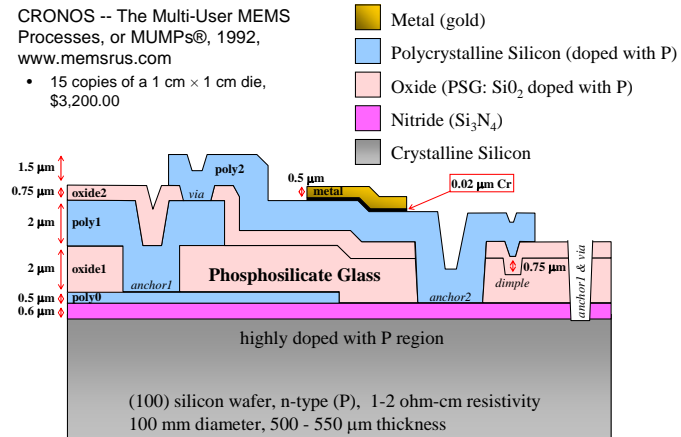


## Mirrors: Distortion

- Most mirrors are fabricated from surface micromachining
- Some drawbacks causing distortion in reflected image include:
  - Deposited layers conform to the topology of lower layers, therefore, embossing the mirror surface.
  - Residual stress in deposited layers or combinations of layers can deform the mirror surface
- Solutions include:
  - Thinner reflective coatings
  - Stiffer mirror structures
  - Avoid topology under mirror by design
  - Use backsides of layers through assembly
  - Use fabrication processes with planarized layers
  - More appropriate combinations of multi-layer materials
  - Different fabrication processing conditions

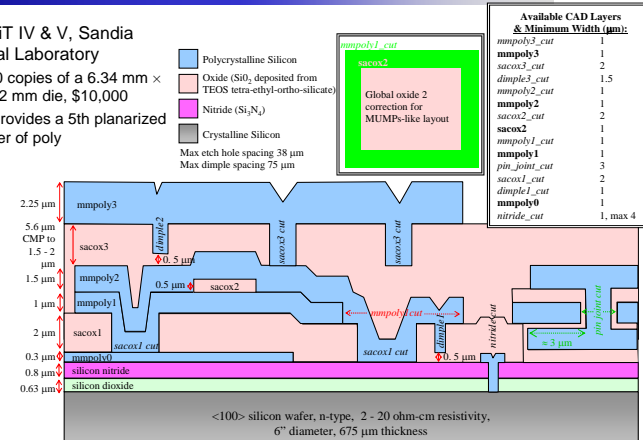
## Mirrors: Fabrication

- CRONOS -- The Multi-User MEMS Processes, or MUMPs®, 1992, www.memrsus.com
- 15 copies of a 1 cm × 1 cm die, \$3,200.00



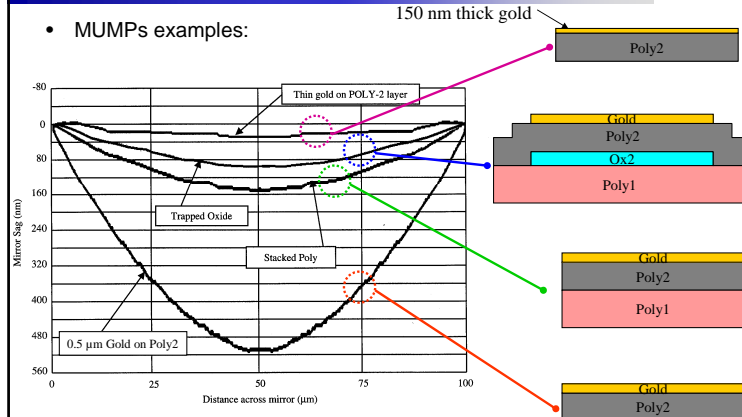
## Mirrors: Fabrication

- SUMMIT IV & V, Sandia National Laboratory
- 100 copies of a 6.34 mm × 2.82 mm die, \$10,000
- V provides a 5th planarized layer of poly



## Mirrors: Residual Stress

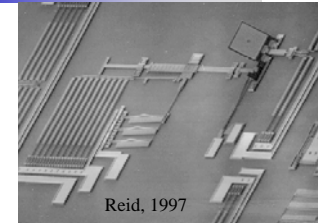
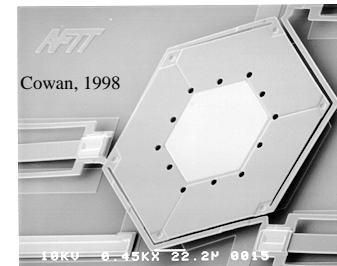
- MUMPs examples:



D. Burns, *Microelectromechanical Optical Beam Steering Systems*, AFIT Dissertation, 1998.

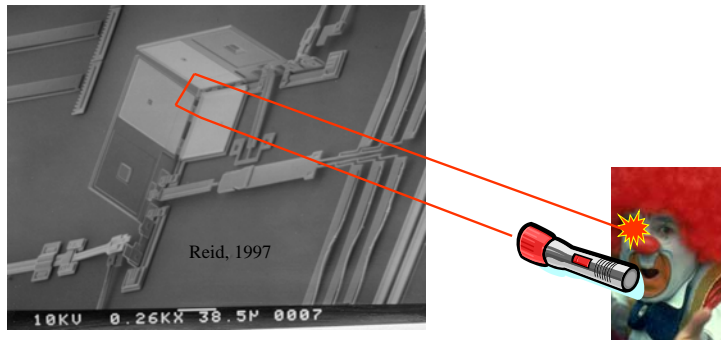
## Mirrors: Beam Steering

- Simple Reflection



## Mirrors: Beam Steering

- Corner Cube Reflector
  - Modulation device -- signal always returns to source if mirrors are orthogonal to each other.

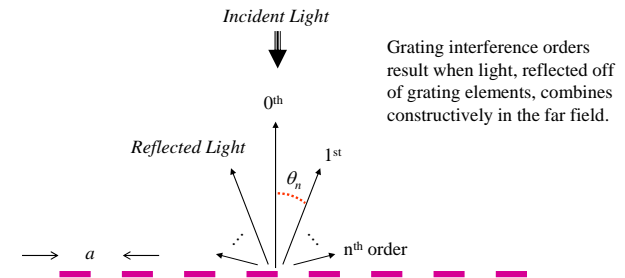


## Mirrors: Beam Steering

- Diffraction Gratings
  - Scatter reflected in discrete directions:

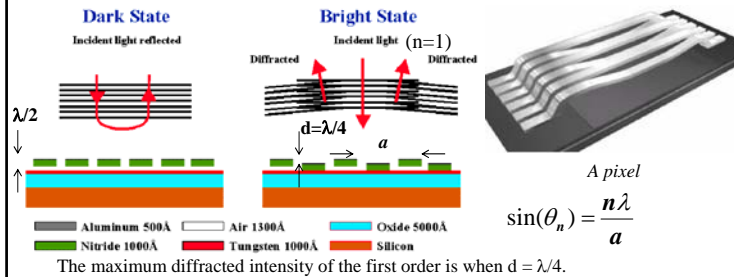
$$\sin(\theta_n) = \frac{n\lambda}{a}$$

- where  $n$  is the discrete order,  $\theta_n$  is the order direction,  $\lambda$  is the wave length, and  $a$  is the period of the grating elements.



## Mirrors: Beam Steering

- Grating Light Valve (GLV) by Silicon Light Machines
  - Destructive interference attenuates 0<sup>th</sup> order.



The maximum diffracted intensity of the first order is when  $d = \lambda/4$ .

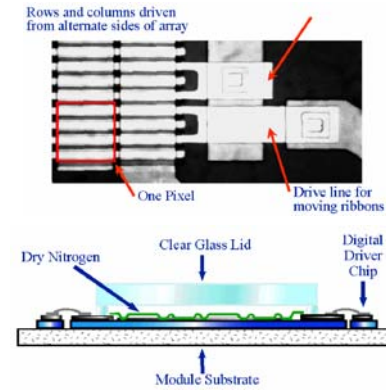
For same  $\theta$ , but different colors, choose a different  $a$  such that  $\lambda/a$  is same.

-or-

Build one pixel for "red" and deflect the same pixel less for green and blue.

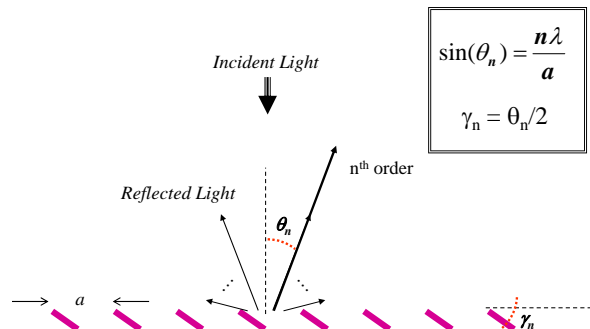
## Mirrors: Beam Steering

- Grating Light Valve (GLV) by Silicon Light Machines



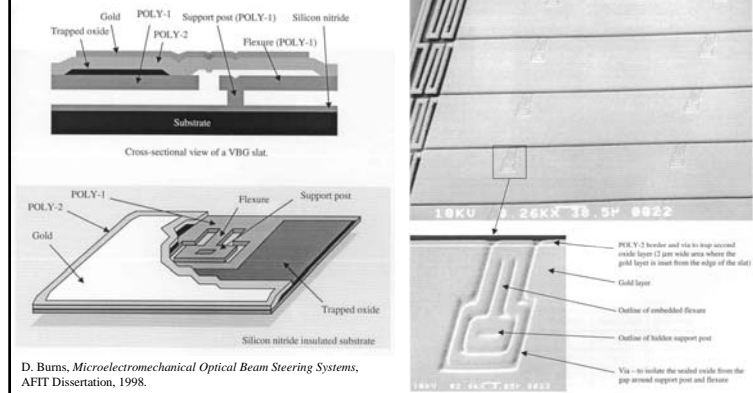
## Mirrors: Beam Steering

- Blazed Grating
  - Gratings can be angled to direct the 0<sup>th</sup> order intensity into the direction of a higher order, therefore, enhancing the higher order direction.



## Mirrors: Beam Steering

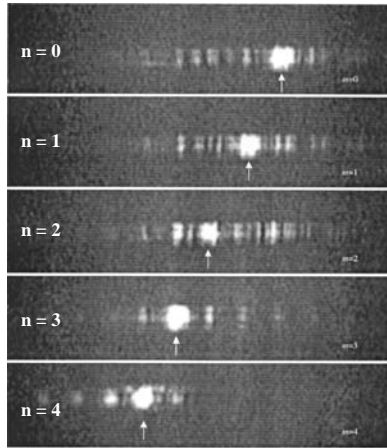
- Blazed Grating



## Mirrors: Beam Steering

- Blazed Grating

Diffraction order	Blaze angle	Steering angle	Drive voltage
0	0°	0°	0
1	0.23°	0.45°	13.4
2	0.46°	0.91°	22.9
3	0.68°	1.36°	26.6
4	0.91°	1.81°	29.4



D. Burns, *Microelectromechanical Optical Beam Steering Systems*, AFTT Dissertation, 1998.

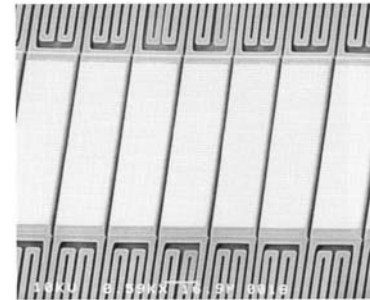
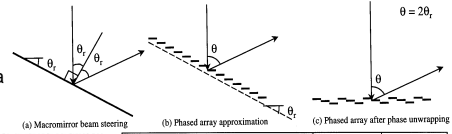
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## Mirrors: Beam Steering

- Phased Array
  - A digital approximation of beam steering with a single tilted mirror.



	4 <sup>th</sup> Generation	5 <sup>th</sup> Generation
MUMPs Fabrication Run	15	19
Number of Elements	128	10
Vertical Range of Motion* (µm)	2.0	2.0
Array Period (µm)	30.0	30.0
Linear Fill Factor (%)	63.33	93.33
Number of Flexures	4**	4
Flexure Length (µm)	85.0**	243.0
Flexure Width (µm)	1.75	2.0
Surface Area Above Bottom Electrode (µm <sup>2</sup> )	3,294.0	2,912.0
Width of Element's Gold Layer (µm)	19.0	28.0
Curvature Across Width (peak to valley) (nm)	9.0	13.7
Curvature Across Length (peak to valley) (nm)	65.5	104.4
Bottom Electrode Construction	Substrate	Substrate
Calculated Pull Down Voltage (V)	23.1	6.3
Measured Pull Down Voltage (V)	24.5	5.5

D. Burns, *Microelectromechanical Optical Beam Steering Systems*, AFTT Dissertation, 1998.

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## Overview

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    - Diffraction Gratings
    - Blazed Grating
    - Phased Array
- Lenses
  - Refractive
  - Diffraction
- Systems

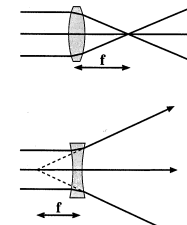
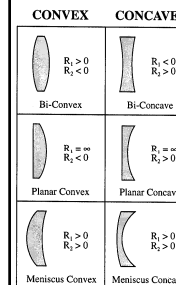


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## Lenses: Refractive



$$\frac{1}{f} = (n_1 - n_m) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)$$

where,  
 $n_1$  = refractive index of the lens material  
 $n_m$  = refractive index of the medium (for air,  $n_m = 1$ )  
 $R_1$  = entrance radius of lens  
 $R_2$  = exit radius of lens

Material	Refractive Index (n = c/v)
Air (0°C, 1 atm)	1.0002926
Liquid Nitrogen	1.21
Ice	1.31
Methanol	1.326
Water (20°C)	1.333
Acetone	1.357
Bismut	1.339
Fused Silica (SiO <sub>2</sub> )	1.438
Hoya QZ Quartz Glass	1.46
Thermal Silicon Dioxide (TF)	1.46
PECVD Silicon Dioxide (TF)	~ 1.47 (may vary)
Corning 7740 Pyrex™ Glass	1.473
Benzene	1.498
Plexiglas™ (PMMA)	1.5014
Borosilicate Glass	1.517
Phosphate Crown Glass	1.518
Hoya SL (70% SiO <sub>2</sub> , 3% Na <sub>2</sub> O, 9% K <sub>2</sub> O, 13% Refractory Metal Oxides)	1.52
Sodium Chloride	1.53
Hoya LE (Aluminosilicate)	1.53
Light Flint Glass	1.581
Flint Glass	1.620
PECVD Silicon Nitride (TF)	1.8 to 2.3
LPCVD Silicon Nitride (TF)	2.01
Gallium Nitride (ordinary-stay)	2.35
Diamond	2.38
Gallium Arsenide	3.32
Silicon	3.415
Germanium	4.001

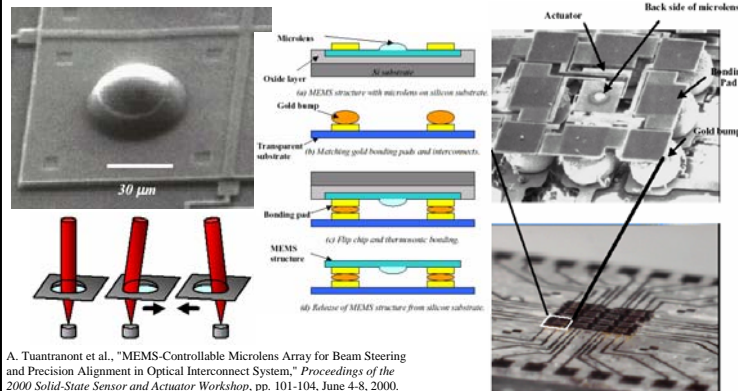
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## Lenses: Refractive

- Reflowed BCB lens for VCSEL de-centered lens beam steering



A. Tuantranont et al., "MEMS-Controllable Microlens Array for Beam Steering and Precision Alignment in Optical Interconnect System," *Proceedings of the 2000 Solid-State Sensor and Actuator Workshop*, pp. 101-104, June 4-8, 2000.

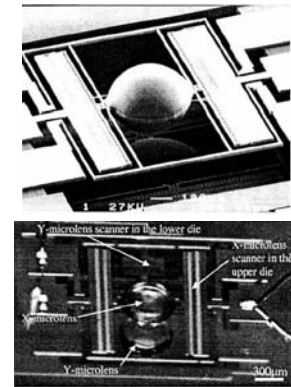
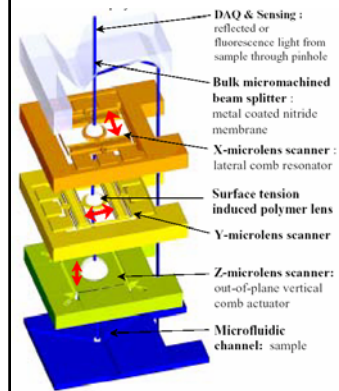
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## Lenses: Refractive

- UV curable polymer lenses for 2-D scanning



S. Kwon et al., "Stacked Two Dimensional Micro-Lens Scanner for Micro Confocal Imaging Array," 2002.

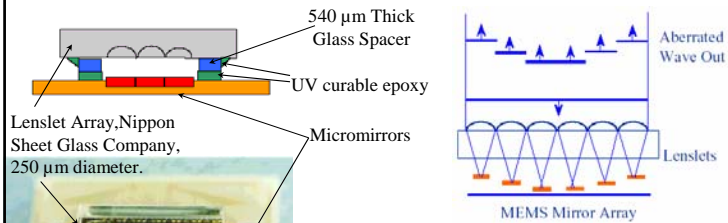
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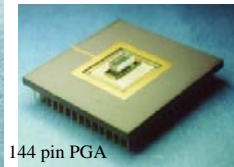
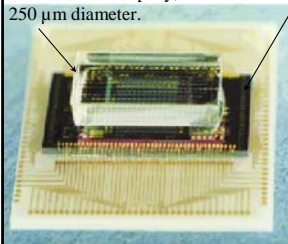
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## Lenses: Refractive

- Lenzlet arrays with piston micromirrors for aberration correction using phase alteration.



Lenzlet Array, Nippon Sheet Glass Company, 250 μm diameter.



144 pin PGA

A. Tuantranont et al., "Packaging of Lenzlet Array on Micromirrors," *Proceedings of the SPIE '99*, vol. 3631, pp. 156-164, 1999.

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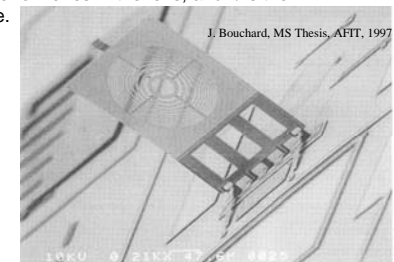
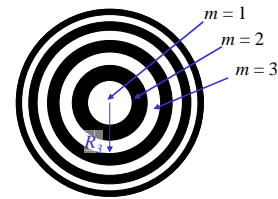
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## Lenses: Diffractive

- Fresnel Lens
  - Diffraction and constructive interference shape the near-field light beam exiting the lens.

$$f = \frac{R_m^2}{m\lambda}$$

- where  $f$  is the focal length,  $R_m$  is the radius of the outer zone,  $m$  is the largest integer number of zones in the lens, and  $\lambda$  is the wavelength of the source.



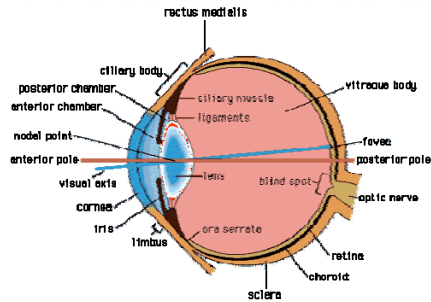
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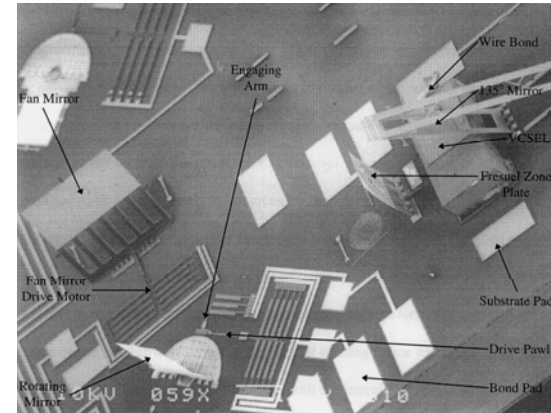
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## Optical Systems

- Surface micromachined VCSEL scanning system

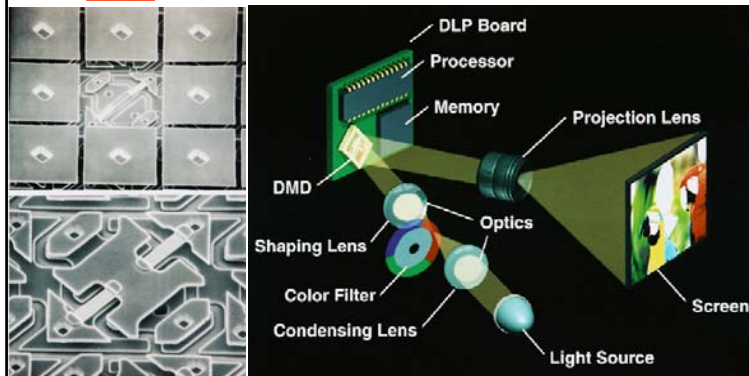


J. Bouchard, MS Thesis, AFIT, 1997

## Optical Systems

- Texas Instruments Digital Micromirror Device™

16 μm



## Optical Systems

- 3-Chip, Texas Instruments Digital Micromirror Device™

