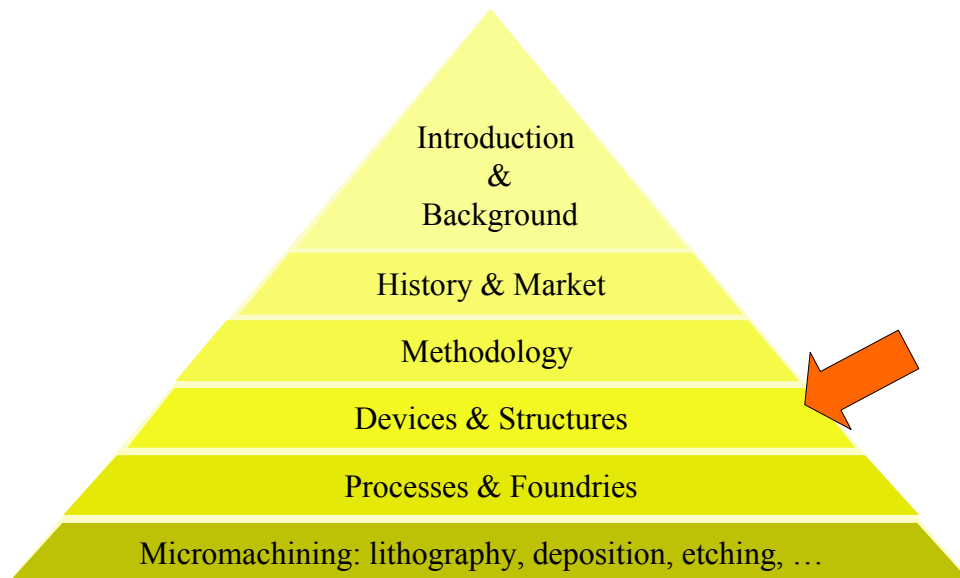


Introduction to Microelectromechanical Systems (MEMS)

Lecture 8 Topics

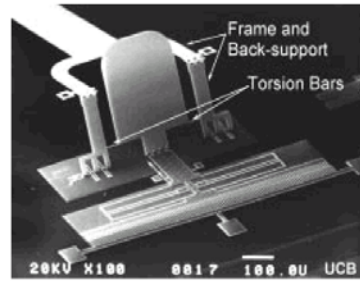
- MicroOptoElectroMechanical Systems (MOEMS)
 - Scanning 2D Micromirrors
 - TI Digital Light Projection Device
 - Basic Optics: Refraction and Diffraction
 - Related Applications

MEMS Overview

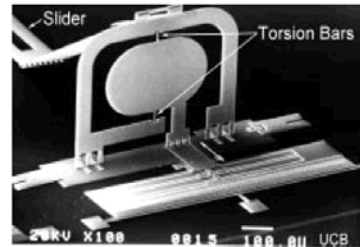


Scanning 2D Micromirrors

- MUMPs-like process for high resolution scanning or projection of 2D surface
- Two mirrors in sequence
 - Galvanometric mirror (low frequency)
 - Resonant mirror (high frequency)



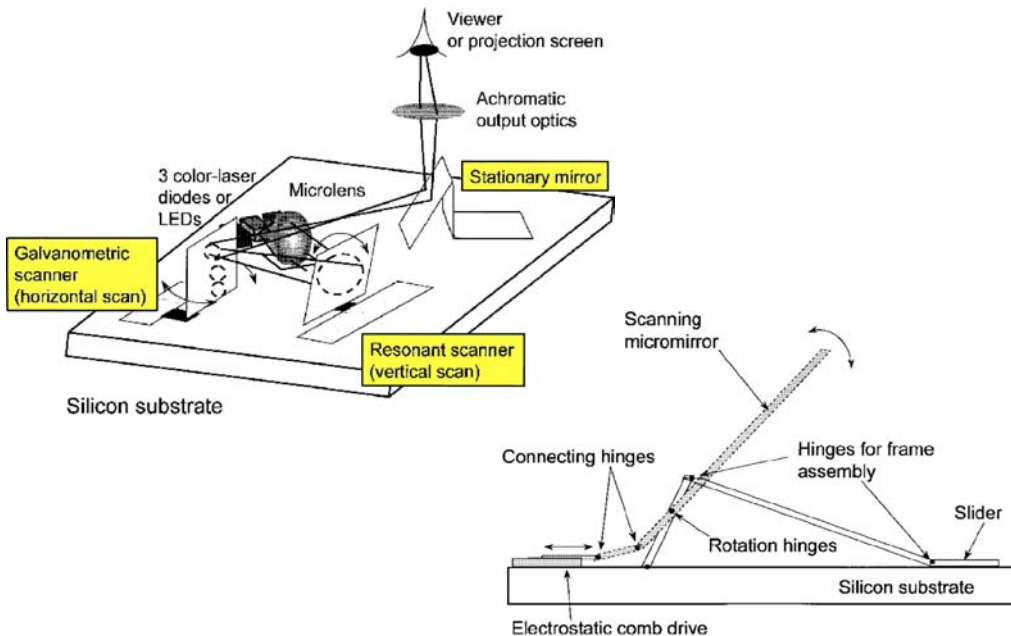
(a)



(b)

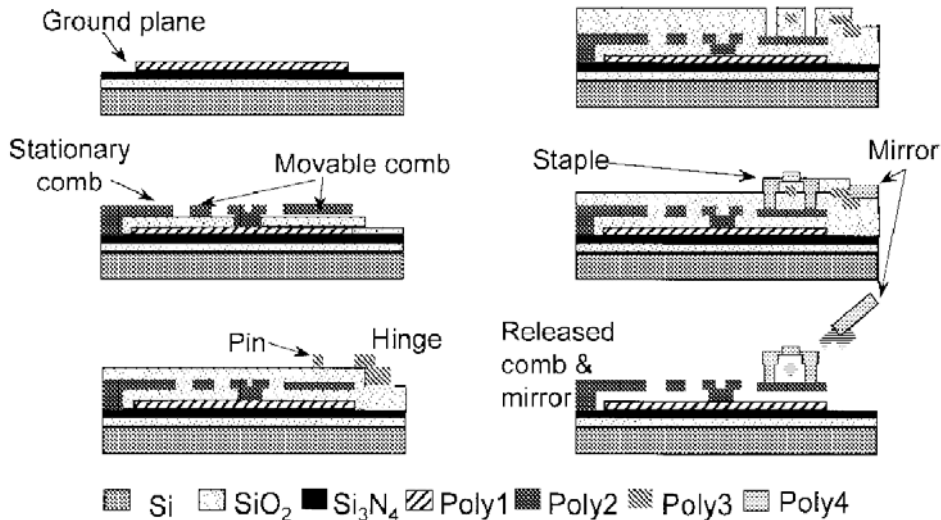
Kiang, Solgaard, Lam and Muller, JMEMS 1998]

Scanning 2D Micromirrors



Scanning 2D Micromirrors

Fabrication: 4-layer poly MUMPs-like process



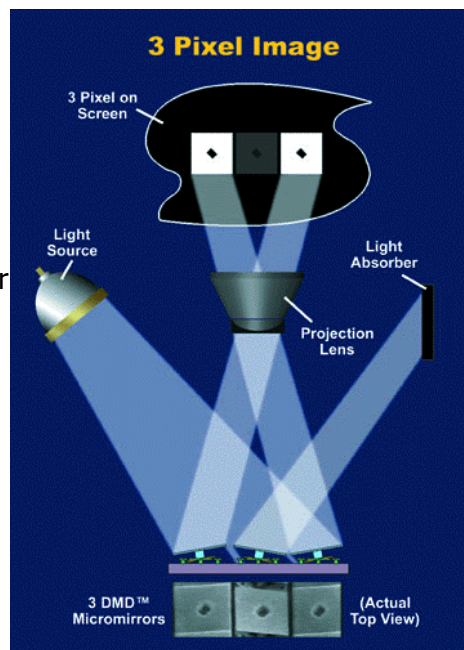
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Digital Light Processing (DLP)

- Basic Idea**
 Digital Video Projection:
 MEMS micromirror array with 1 or 3 mirrors per pixel
 - Gray scale by "duty cycling"
 - Color by multiple light sources or color wheel
- Extended Idea**
 "Digital Cinema": movie production, distribution, and presentation completely digital
- www.ti.com/dlp



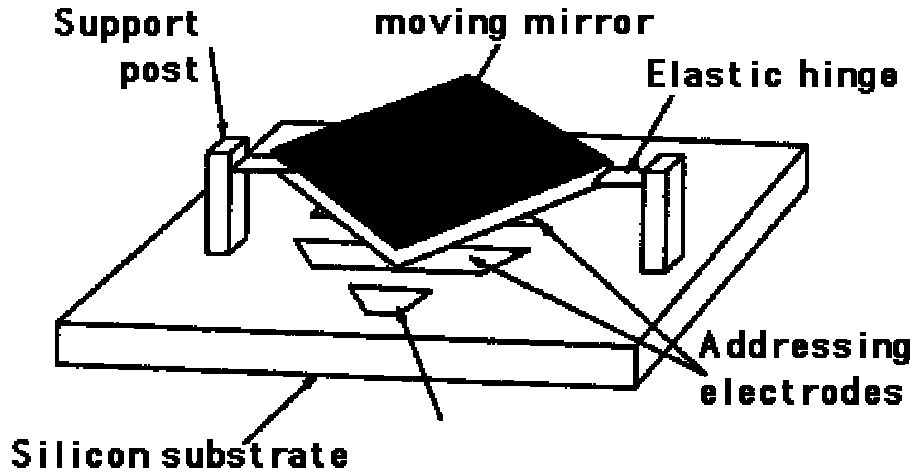
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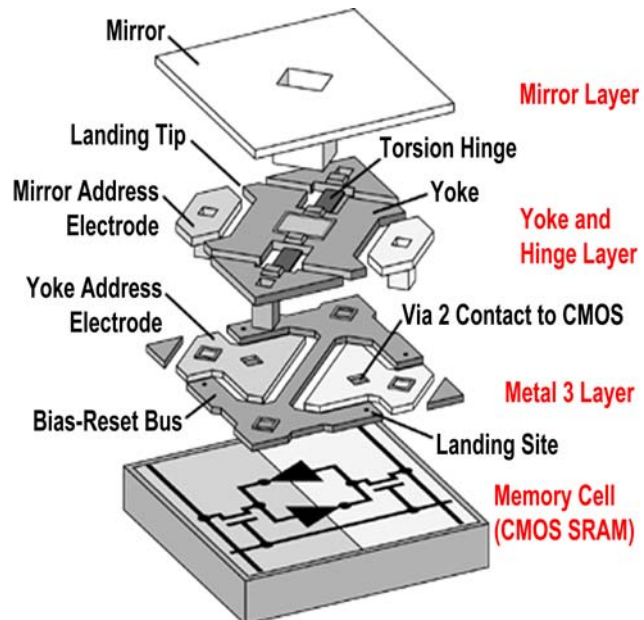
Digital Micro Mirror (TI)

DMD Principle



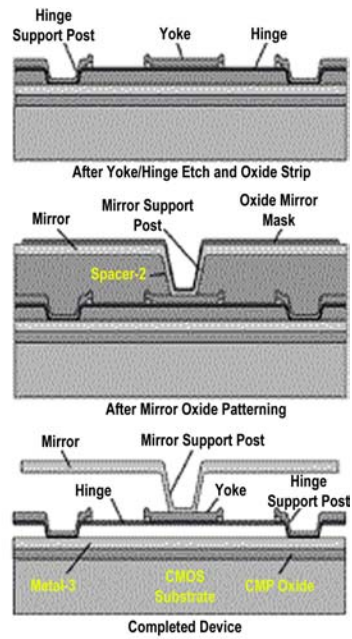
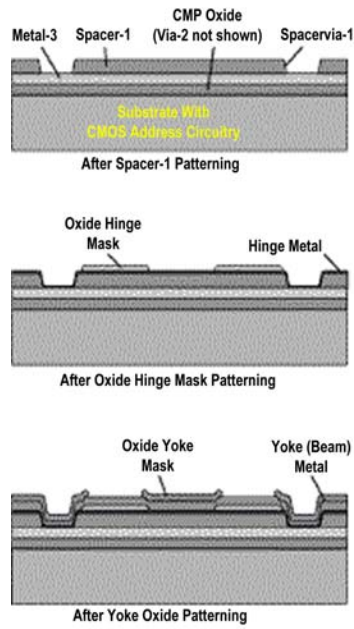
Digital Micro Mirror (TI)

DMD Components



Digital Micro Mirror (TI)

DMD Fabrication



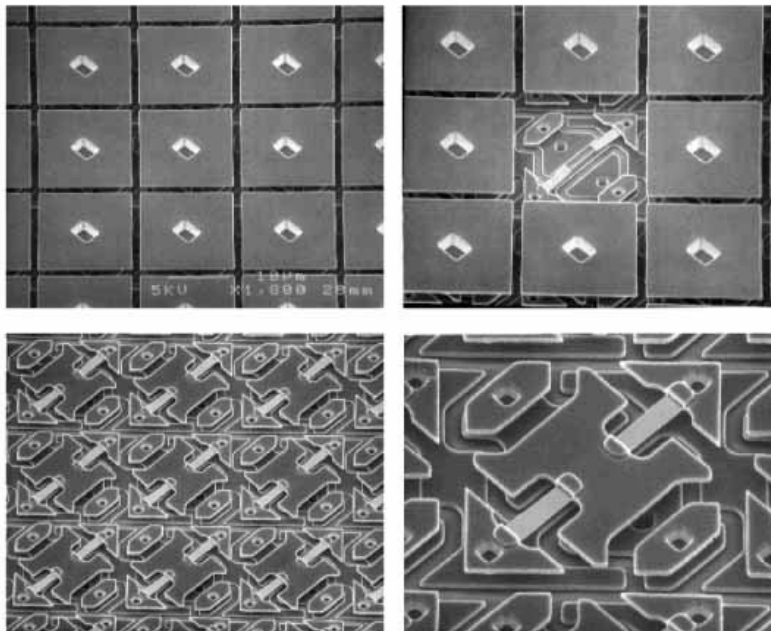
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Digital Micro Mirror (TI)

10 μm



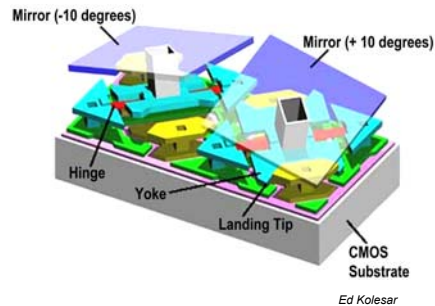
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Micro Optics

- Scanning laser micromirrors [Kiang et al., 1998] : size $300\ \mu\text{m} \times 400\ \mu\text{m}$ or smaller
- TI DMD display: size per pixel $15\ \mu\text{m} \times 15\ \mu\text{m}$
- What is the size limitation? Is there a minimum size for micro optical components?



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Refraction and Diffraction

Refraction: “bending” of light that passes through optical elements (usually at the **border** between two different materials)

Diffraction: forming of multiple wavefronts from incident light by constructive and destructive **interference**.

Both types have similarities (e.g., focal lengths, dispersion), but underlying principles are different, and may be combined to cancel out some of the effects.

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Refraction

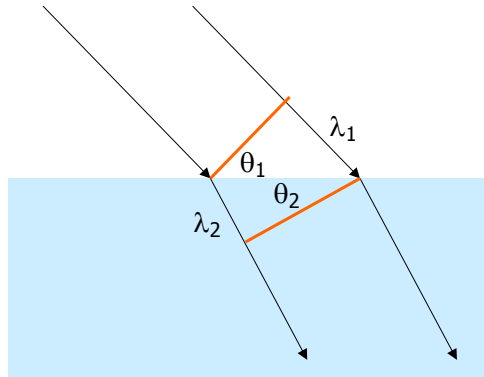
2 wavefronts :

$$\lambda_1 = c_1/f \text{ and } \lambda_2 = c_2/f$$

change in direction :

$$\frac{\lambda_1}{\lambda_2} = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2} = \frac{n_2}{n_1}$$

refractive index : $n_1 = \frac{c}{c_1}$ and $n_2 = \frac{c}{c_2}$



c, c_1, c_2 speed of light

in vacuum / medium 1 / medium 2 (note also that $n_i = \sqrt{\epsilon_{r_i} \mu_{r_i}}$)

Refraction

Lens Maker's Equation:

$$\frac{1}{f} \approx \Delta n \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

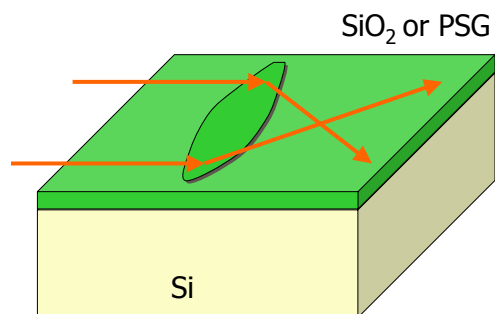
f focal length

$$\Delta n = (n_{\text{lens}} - n_{\text{medium}})$$

relative refractive index

R_1 entrance radius of lens

R_2 exit radius of lens



$$R_1 > 0, R_2 < 0$$

Refraction

Limitations:

- Refractive surfaces are difficult to fabricate with micromachining techniques (“2.5 D design”)
- Refraction angle is function of wavelength (**dispersion**)
- Refraction not practical for certain wavelengths (e.g. high UV, or x-rays)
- Small apertures and lenses are subject to **diffraction** or **interference**

Diffraction

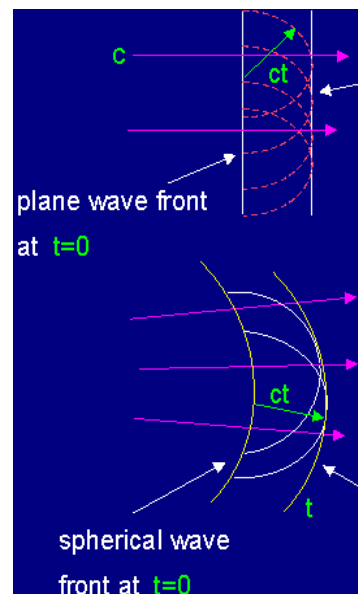
Interference and diffraction

describe the same physical phenomenon:

Huygens' Principle (1678):

Every point on a primary wavefront serves as the source of spherical secondary wavelets such that the primary wavefront at some later time is the envelope of these wavelets.

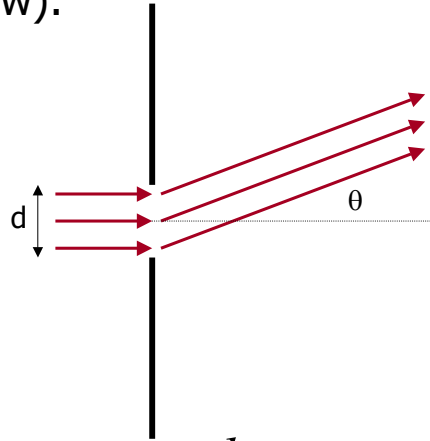
Huygens' principle was slightly modified by Fresnel to explain why no back wave was formed, and Kirchhoff demonstrated that the Huygens-Fresnel Principle could be derived from the Wave Equation.



Diffraction: Single Aperture

Intensity minima (Bragg's law):

$$\sin \theta_{\min,n} = n \frac{\lambda}{d} \text{ for } n \geq 1$$



Intensity as function of θ :

$$I = I_0 \left(\frac{\sin \Phi/2}{\Phi/2} \right)^2 \text{ where } \Phi = 2\pi \frac{d}{\lambda} \sin \theta$$

Example: Micro Mirrors

He-Ne laser ($\lambda=633\text{nm}$)

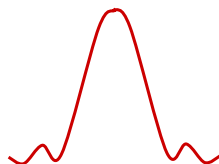
- **Micromirror scanner**
[Kiang et al., 1998]

$$\sin \theta_{\min,n} = n \frac{\lambda}{d} = n \frac{0.633}{300}$$

$$\theta_{\min,1} = 0.12^\circ$$

$$\theta_{\min,2} = 0.24^\circ$$

- **Digital Mirror Device (TI)**



$$\sin \theta_{\min,n} = n \frac{\lambda}{d} = n \frac{0.633}{15}$$

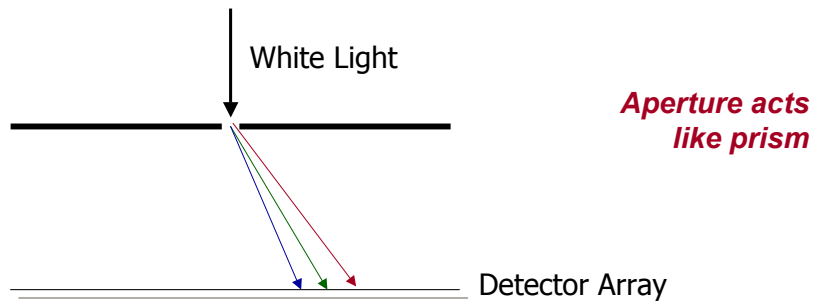
$$\theta_{\min,1} = 2.4^\circ$$

$$\theta_{\min,2} = 4.8^\circ$$

Dispersive Spectrometer

Spectrometer: device to examine the different wavelength components of light (e.g., for chemical sensors, for thermal sensors, or to quantify color).

Note that diffraction depends on wavelength location of first non-central maximum: $\sin \theta \approx 3/2 \lambda/d$



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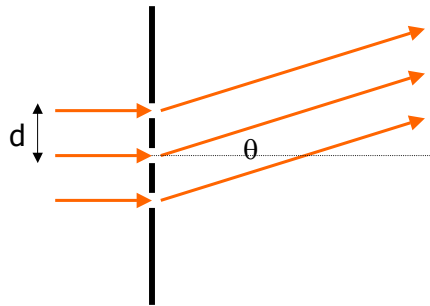
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Diffraction: Multiple Apertures

Intensity maxima:

$$\sin \theta_{\max, n} = n \frac{\lambda}{d} \text{ for } n \geq 0$$



Intensity as function of θ :

$$I = I_0 \left(\frac{\sin N \Phi/2}{\Phi/2} \right)^2 \text{ where } \Phi = 2\pi \frac{d}{\lambda} \sin \theta$$

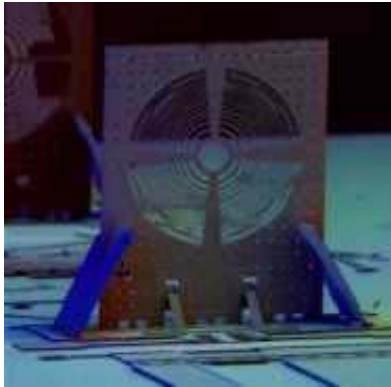
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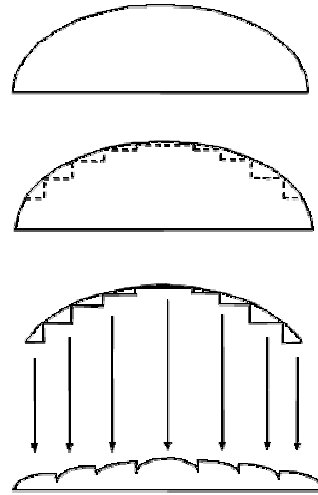
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Fresnel Lens

Diffractive



Refractive



$R_n \approx \sqrt{nd\lambda}$ radius of Fresnel zone
 d distance to aperture

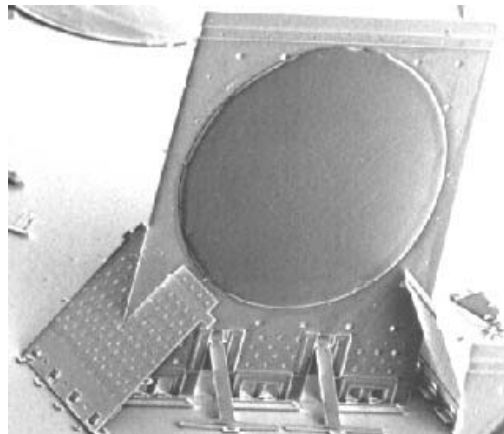
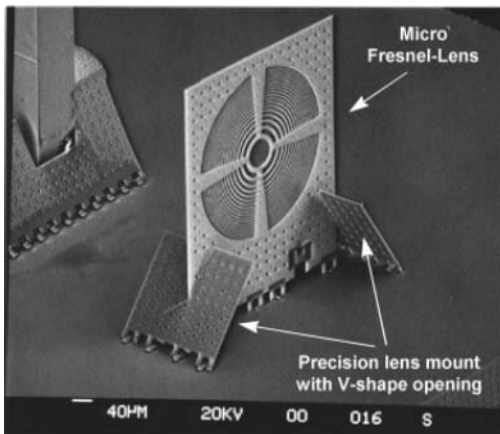
$N \approx \frac{R^2}{d\lambda}$ number of Fresnel zones

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Integrated Micro Optics



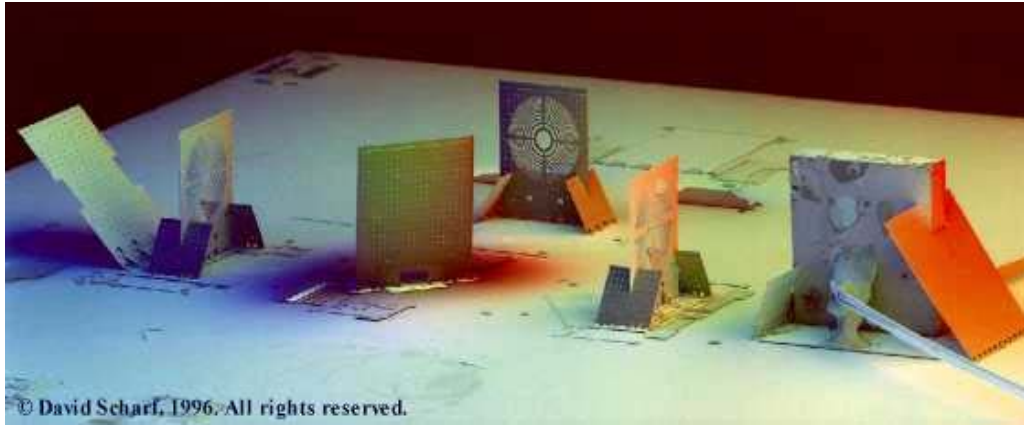
[C. R. King, L. Y. Lin and M. C. Wu 1996]

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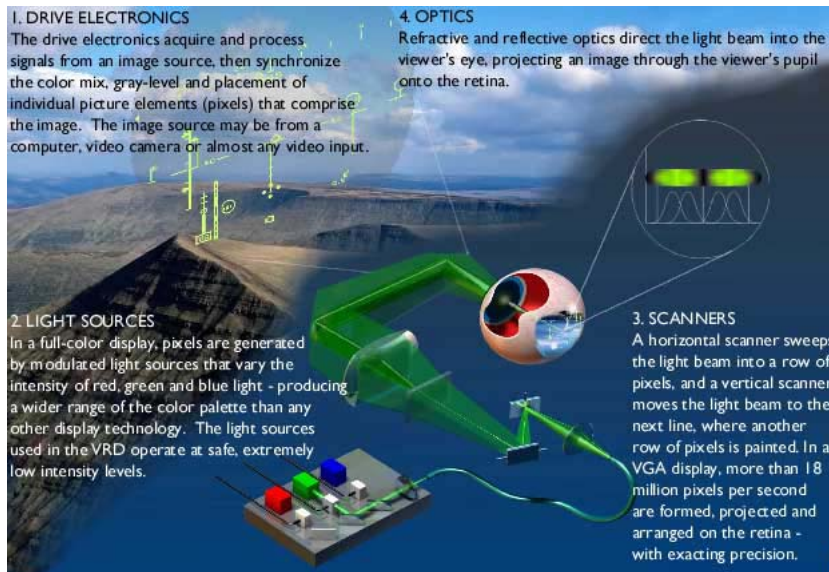
Integrated Micro Optics



[Wu et al. (UCLA)]

Optical components for integrated free-space micro optics:
laser, beam splitter, fresnel lens, mirror, photosensor, ...

Retinal Scanning Display



Microvision (Bothell, WA) www.mvis.com
Originated from HIT lab, University of Washington