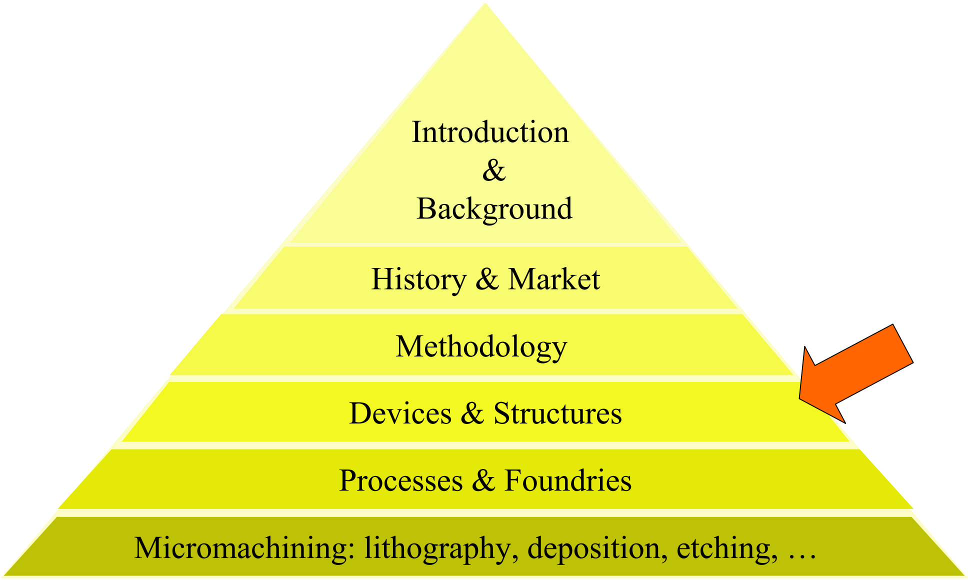
Introduction to Microeletromechanical Systems (MEMS)

Lecture 8 Topics

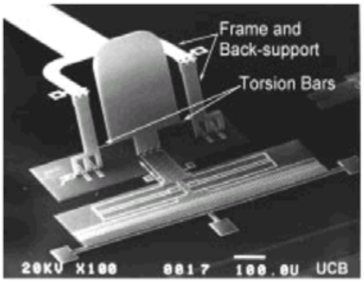
- MicroOptoElectroMechanical Systems (MOEMS)
  - Scanning 2D Micromirrors
  - TI Digital Light Projection Device
  - Basic Optics: Refraction and Diffraction
  - Related Applications

MEMS Overview

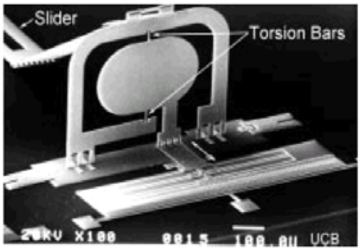


Scanning 2D Micromirrors

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



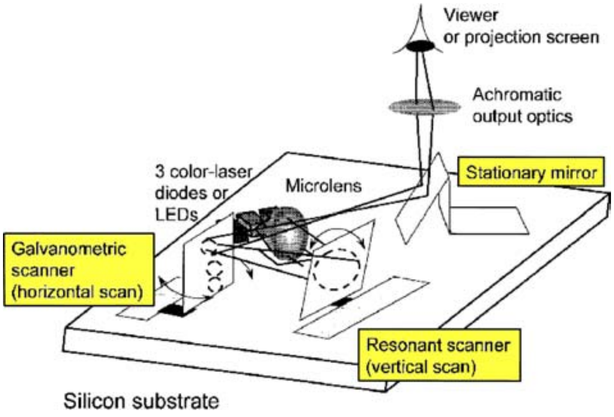
(a)

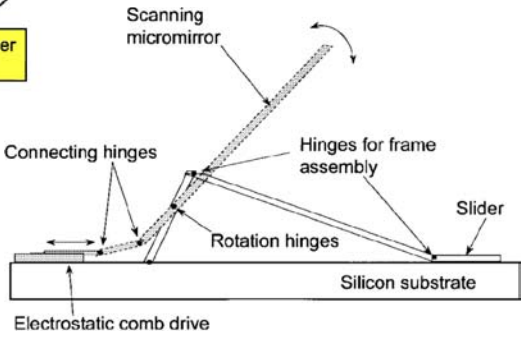


(b)

Kiang, Solgaard, Lam and Muller, JMEMS 1998]

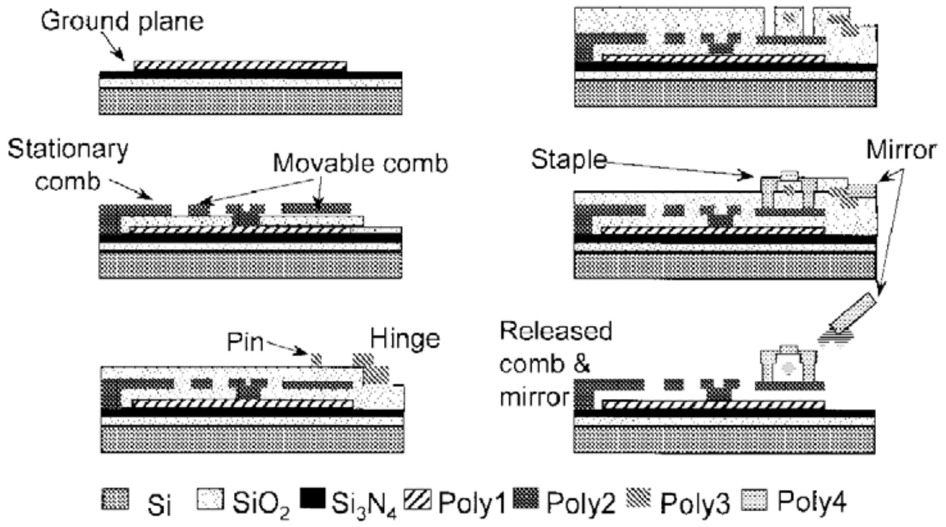
Scanning 2D Micromirrors





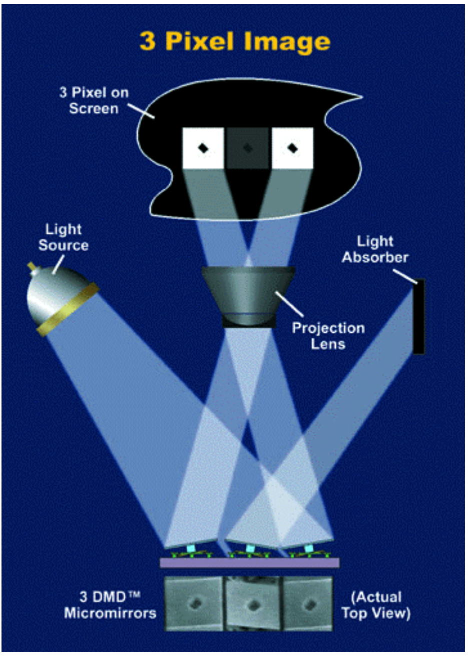
Scanning 2D Micromirrors

Fabrication: 4-layer poly MUMPs-like process



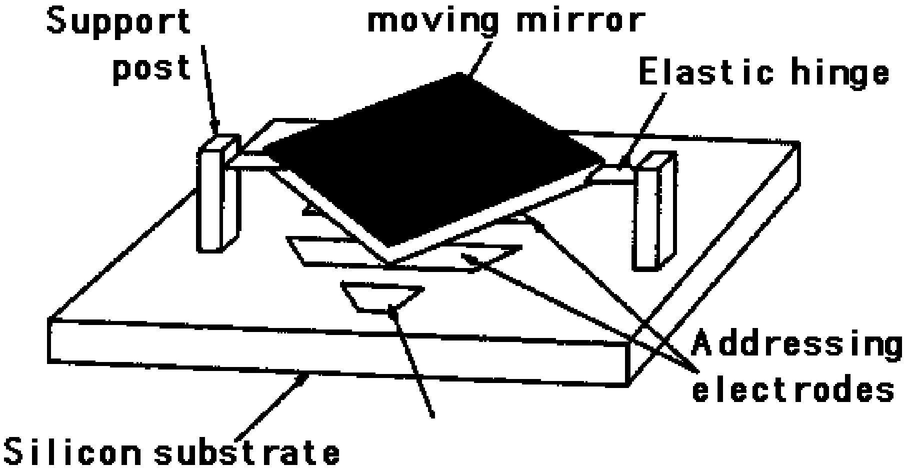
Digital Light Processing (DLP)

- ***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



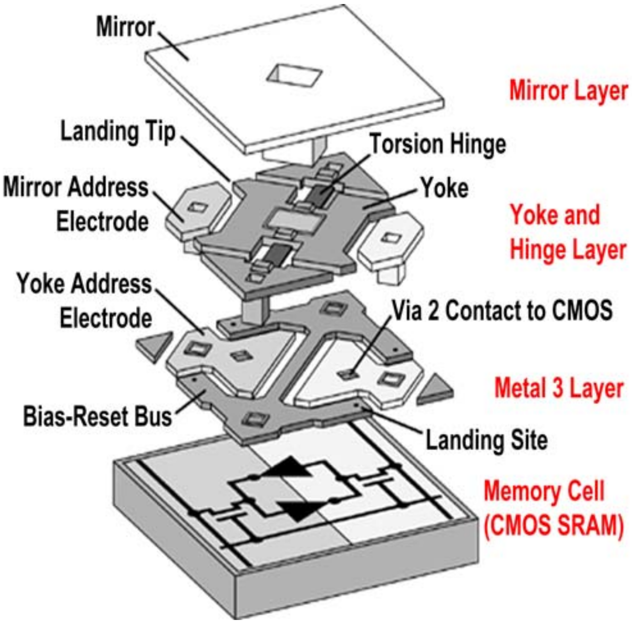
Digital Micro Mirror (TI)

DMD Principle



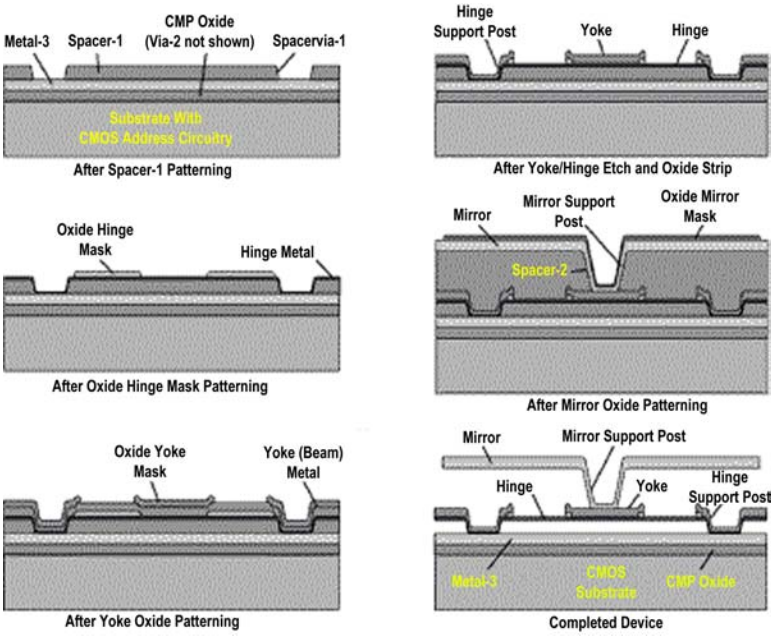
Digital Micro Mirror (TI)

DMD Components



Digital Micro Mirror (TI)

DMD Fabrication



After Spacer-1 Patterning

After Oxide Hinge Mask Patterning

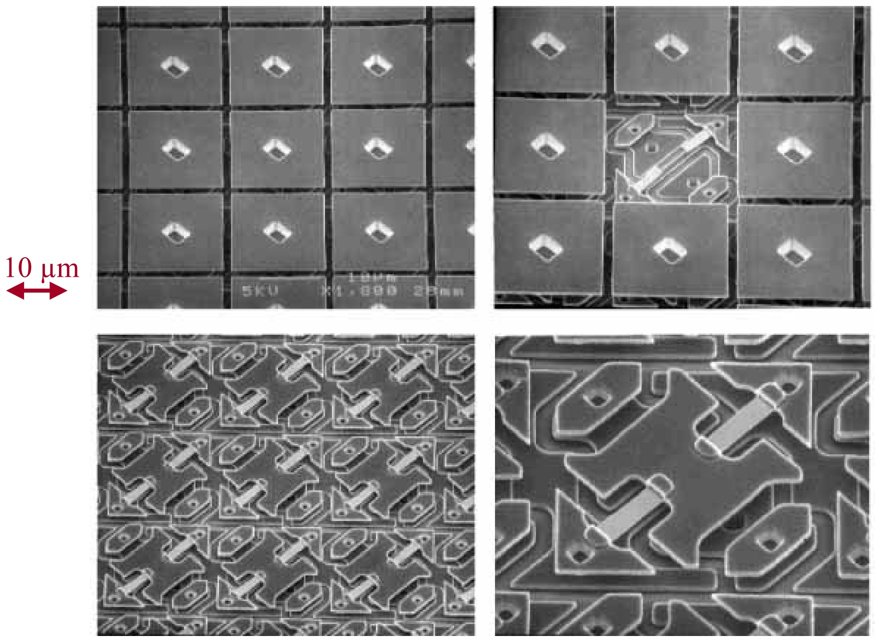
After Yoke Oxide Patterning

After Yoke/Hinge Etch and Oxide Strip

After Mirror Oxide Patterning

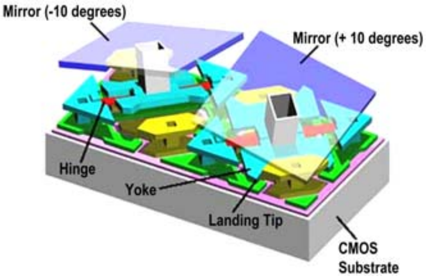
Completed Device

Digital Micro Mirror (TI)



Micro Optics

- Scanning laser micromirrors [Kiang et al., 1998] : size 300 μm × 400 μm or smaller
- TI DMD display: size per pixel 15 μm × 15 μm
- What is the size limitation? Is there a minimum size for micro optical components?



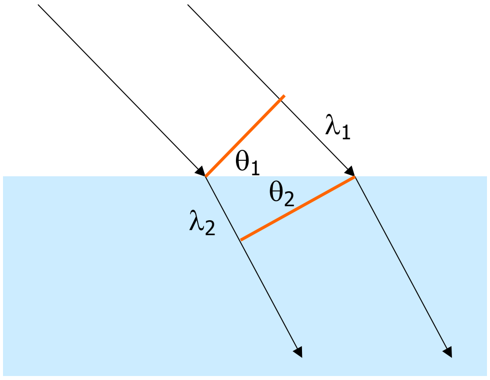
Refraction and Diffraction

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.

Refraction



2 wavefronts:

$\lambda_1 = c_1 / f$ 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: $n_1 = \dfrac{c}{c_1}$ and $n_2 = \dfrac{c}{c_2}$

c, c_1, c_2 speed of light

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

Refraction

Lens Maker's Equation:

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

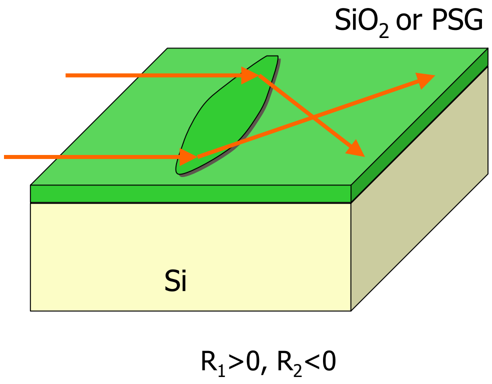
f focal length

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

relative refractive index

R_1 entrance radius of lens

R_2 exit radius of lens



Refraction

Limitations:

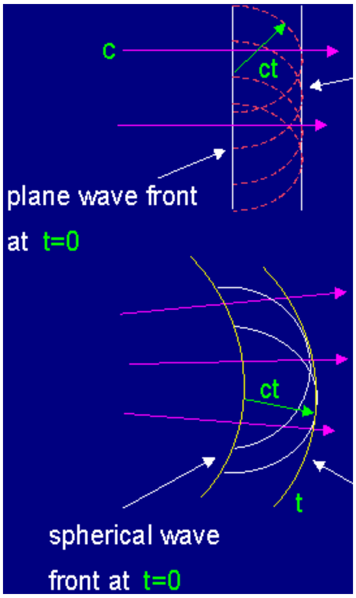
- Refractive surfaces are difficult to fabricate with micromachining techniques ("2.5 D design")
- Refraction angle is function of wavelength (**dispersion**)
- Refraction not practical for certain wavelengths (e.g. high UV, or x-rays)
- Small apertures and lenses are subject to **diffraction** or **interference**

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.

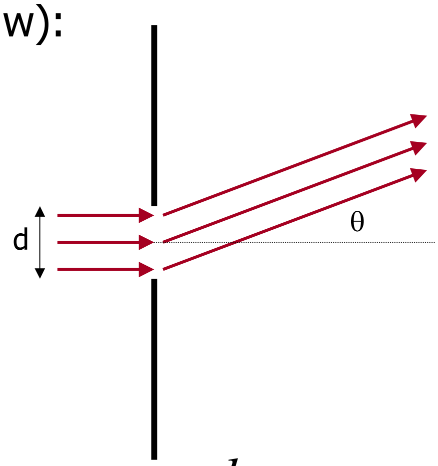
Huygens' principle was slightly modified by Fresnel to explain why no back wave was formed, and Kirchhoff demonstrated that the Huygens-Fresnel Principle could be derived from the Wave Equation.



Diffraction: Single Aperture

Intensity minima (Bragg's law):

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



Intensity as function of θ:

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

Example: Micro Mirrors

He-Ne laser (λ=633nm)

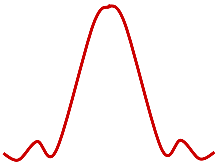
- **Micromirror scanner** [Kiang et al., 1998]

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

$$\theta_{\min,1} = 0.12°$$

$$\theta_{\min,2} = 0.24°$$

- **Digital Mirror Device** (TI)



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

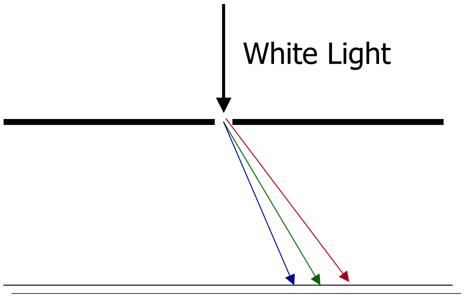
$$\theta_{\min,1} = 2.4°$$

$$\theta_{\min,2} = 4.8°$$

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: $\sin\theta \approx 3/2\ \lambda/d$

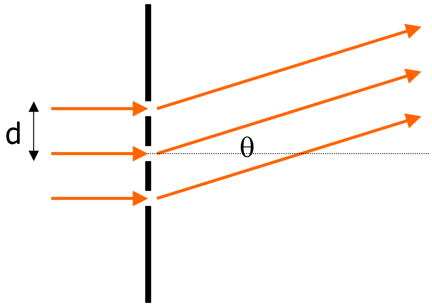


Aperture acts like prism

Diffraction: Multiple Apertures

Intensity maxima:

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

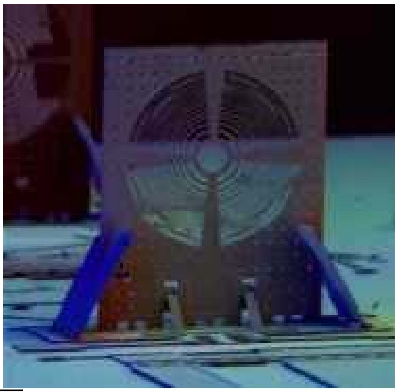


Intensity as function of θ:

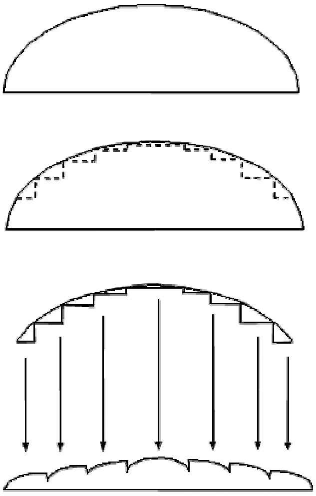
$$I = I_0\left(\frac{\sin N\Phi/2}{\Phi/2}\right)^2 \quad \text{where} \quad \Phi = 2\pi\frac{d}{\lambda}\sin\theta$$

Fresnel Lens

Diffractive



Refractive

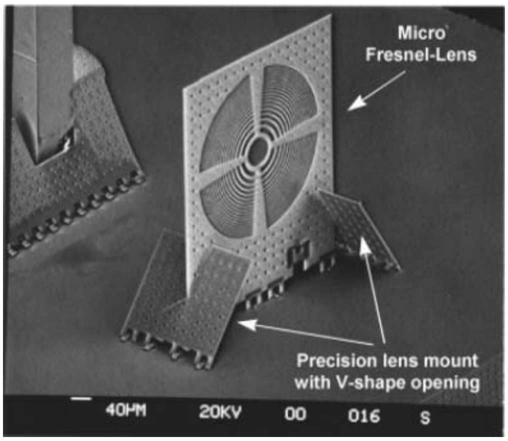


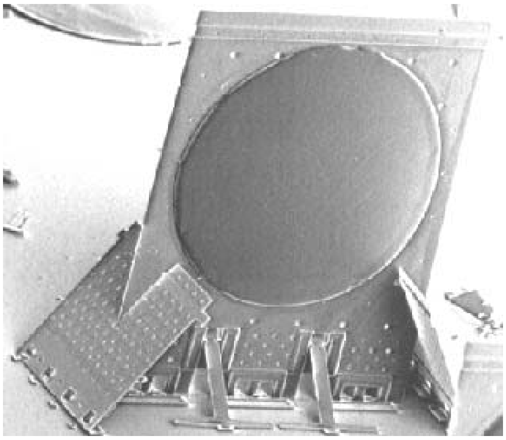
$R_n \approx \sqrt{nd\lambda}$ radius of Fresnel zone

d distance to aperture

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

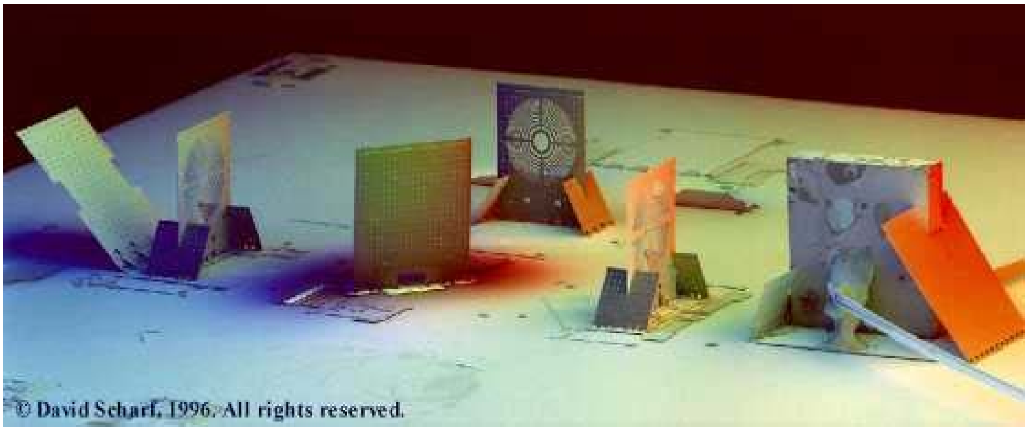
Integrated Micro Optics





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

Integrated Micro Optics



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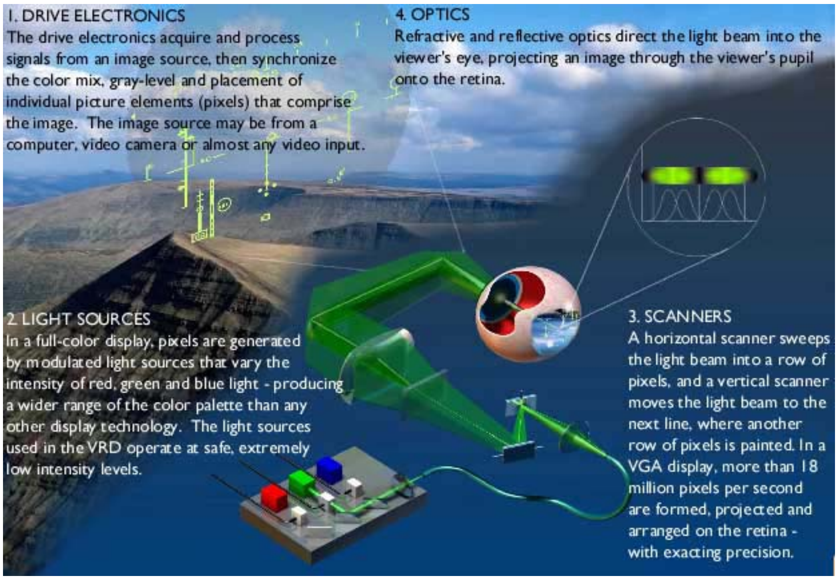
[Wu et al. (UCLA)]

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

Retinal Scanning Display



1. DRIVE ELECTRONICS
The drive electronics acquire and process signals from an image source, then synchronize the color mix, gray-level and placement of individual picture elements (pixels) that comprise the image. The image source may be from a computer, video camera or almost any video input.

4. OPTICS
Refractive and reflective optics direct the light beam into the viewer's eye, projecting an image through the viewer's pupil onto the retina.

2. LIGHT SOURCES
In a full-color display, pixels are generated by modulated light sources that vary the intensity of red, green and blue light - producing a wider range of the color palette than any other display technology. The light sources used in the VRD operate at safe, extremely low intensity levels.

3. SCANNERS
A horizontal scanner sweeps the light beam into a row of pixels, and a vertical scanner moves the light beam to the next line, where another row of pixels is painted. In a VGA display, more than 18 million pixels per second are formed, projected and arranged on the retina - with exacting precision.

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