WORCESTER POLYTECHNIC INSTITUTE
MECHANICAL ENGINEERING DEPARTMENT

Optical Metrology and NDT
ME-593n/ ME-5304, C'2025

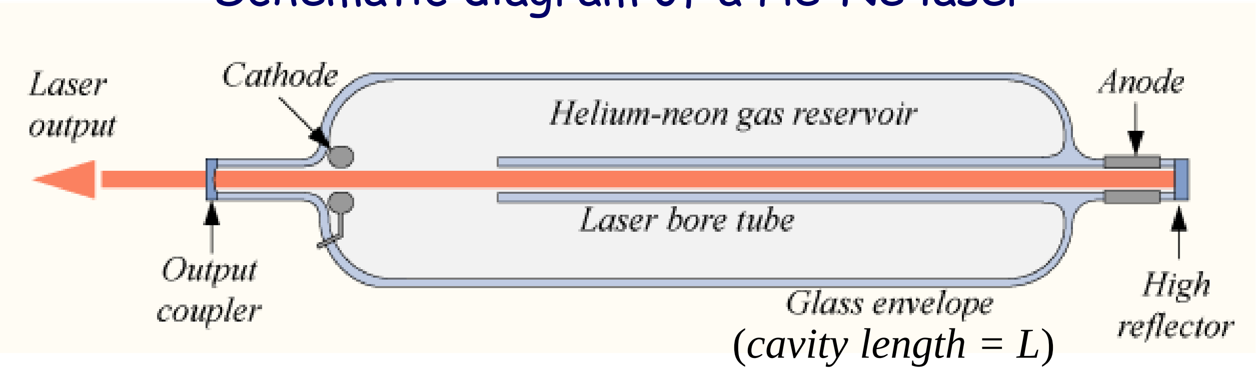
Lecture 03

January 2025

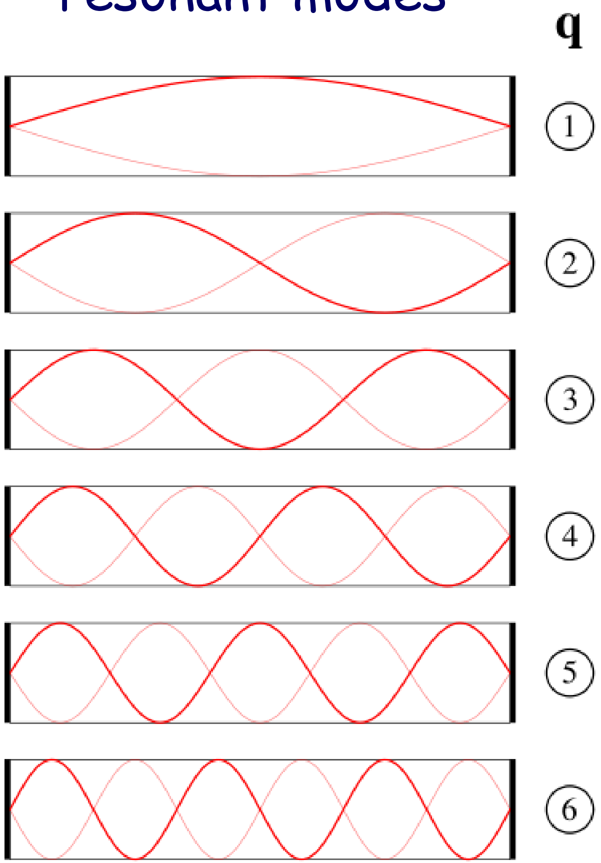
Lasers sources

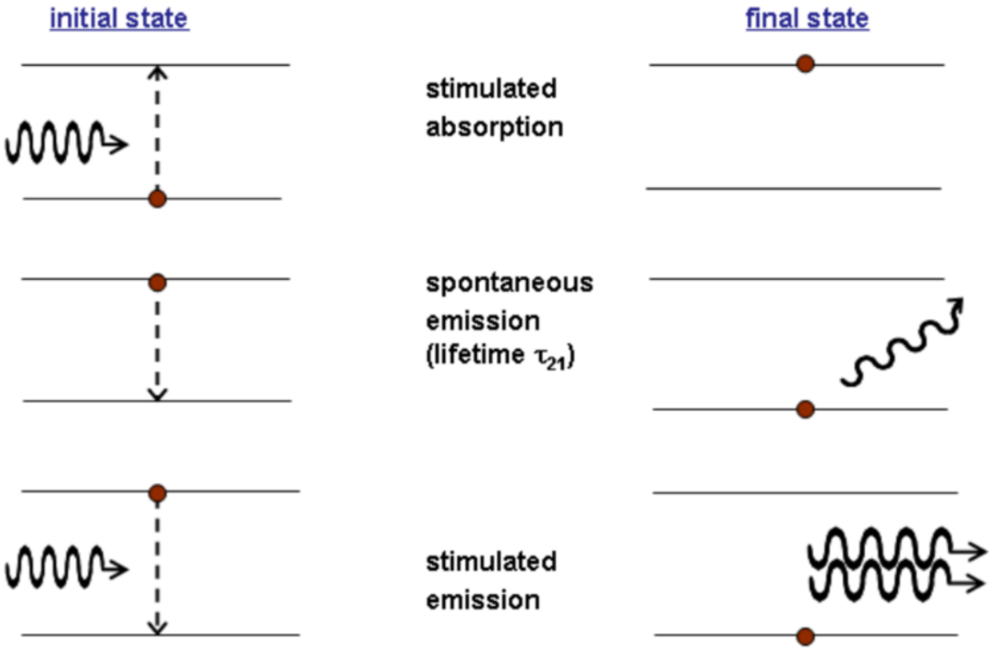
Some operating characteristics: *laser modes*

Schematic diagram of a He-Ne laser



Possible **longitudinal** resonant modes

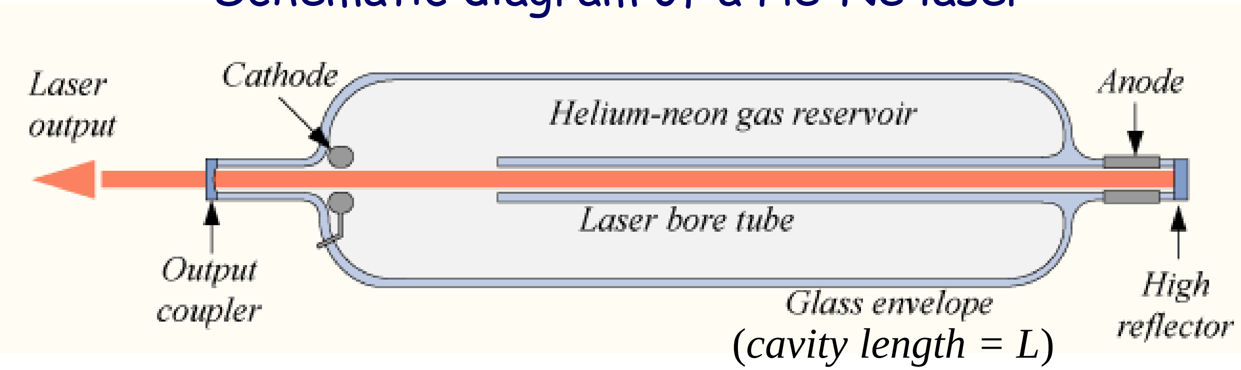




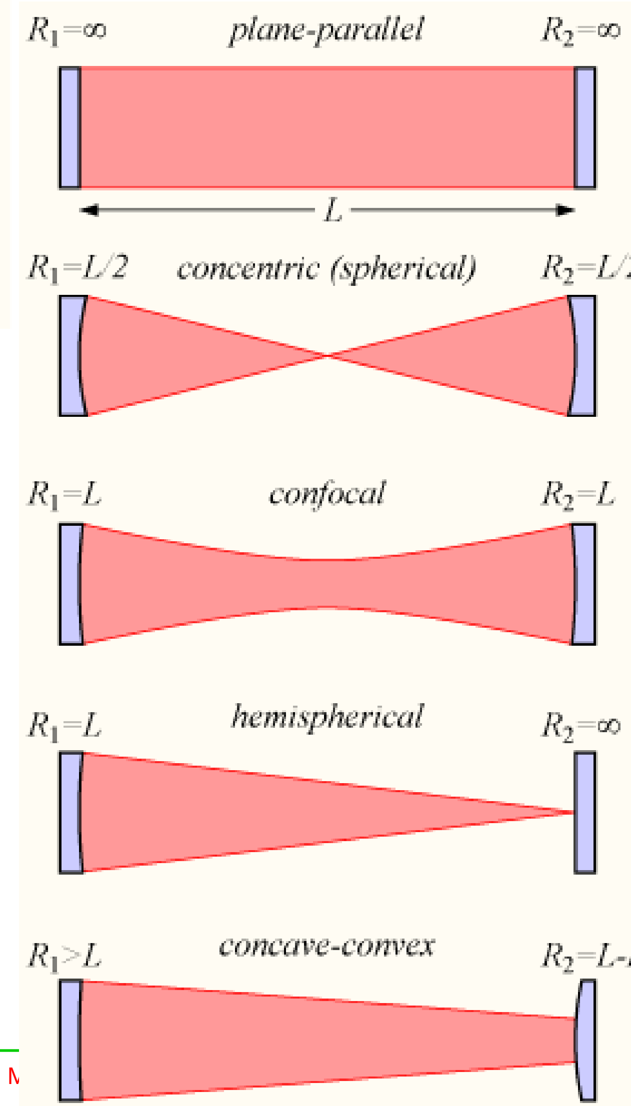
Lasers sources

Some operating characteristics: *laser modes*

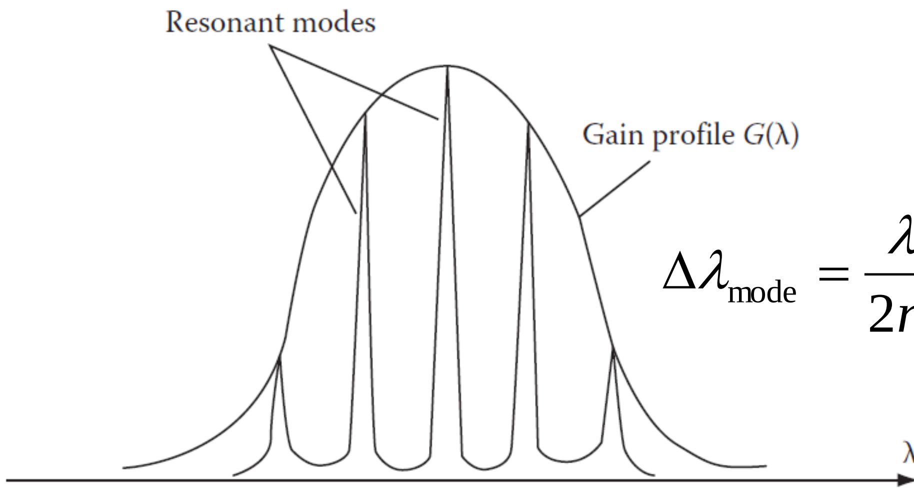
Schematic diagram of a He-Ne laser



Laser cavity configurations



Possible **longitudinal** resonant modes

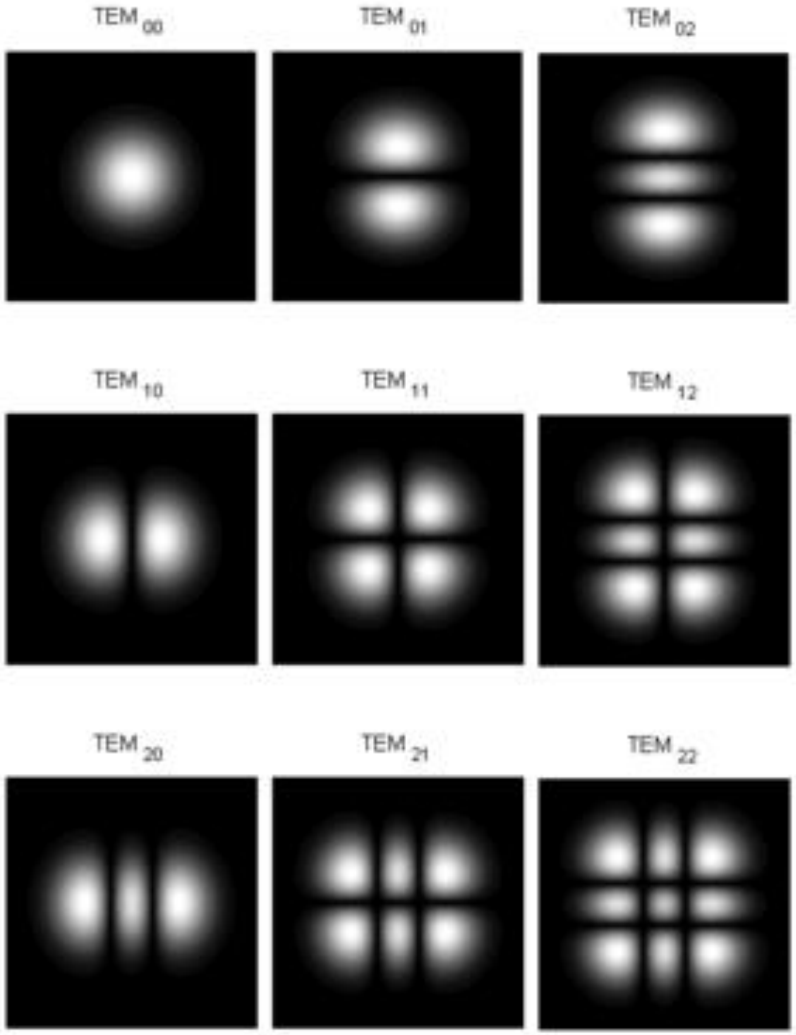


$$\Delta\lambda_{mode} = \frac{\lambda^2}{2nL}$$

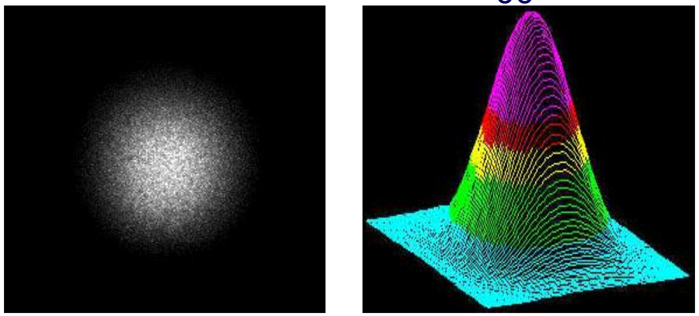
Lasers sources

Some operating characteristics: *laser modes*

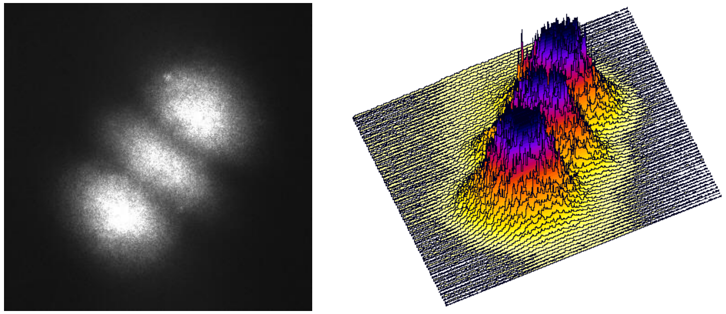
Possible **transversal** resonant modes



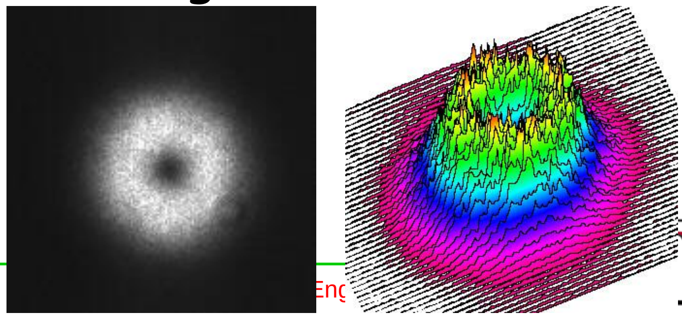
Gaussian TEM_{00}



Hermite-Gaussian TEM_{02}



Laguerre-Gaussian



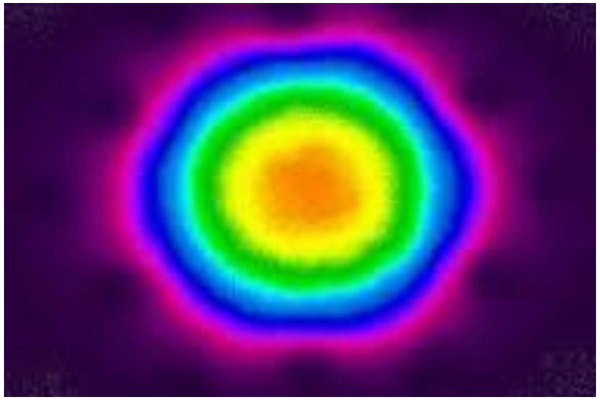
WPI

Lasers sources

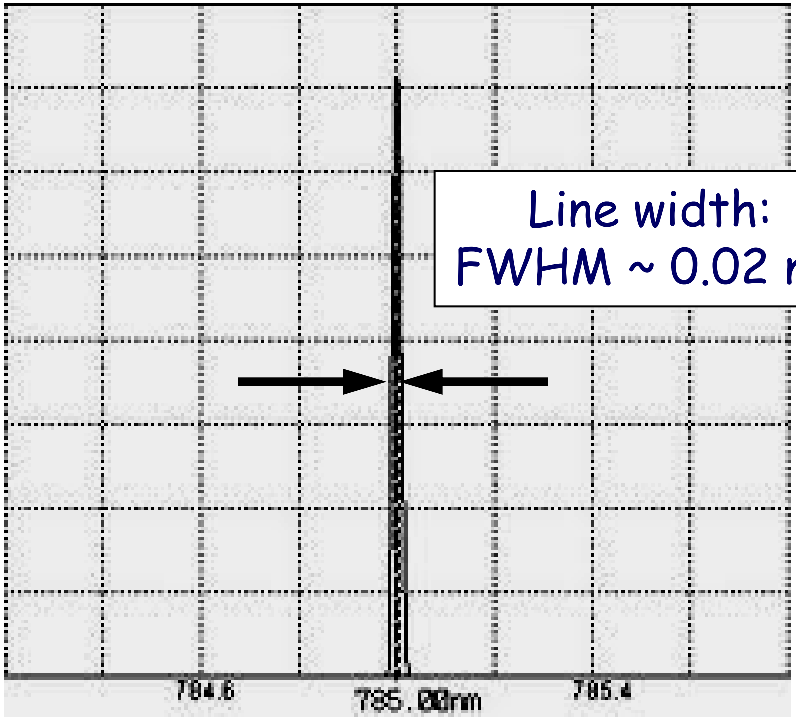
Some operating characteristics: *continuous & pulsed*

Near IR **continuous** laser

Transversal mode



Output wavelength:
narrow bandwidth



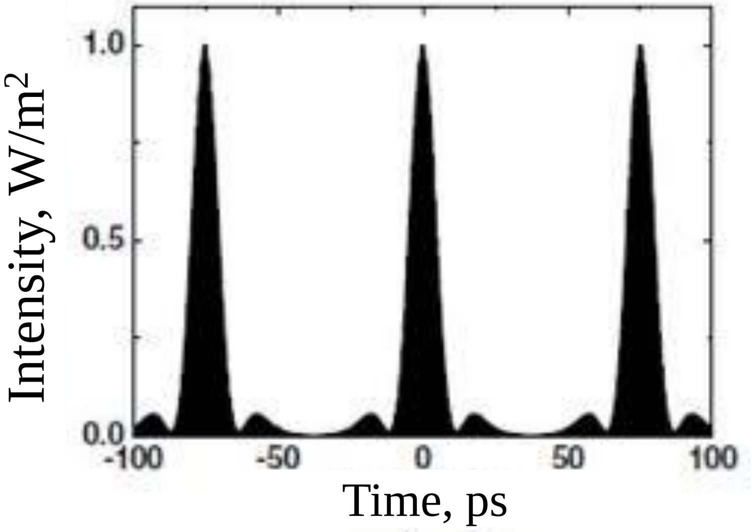
Line width:
FWHM ~ 0.02 nm

Lasers sources

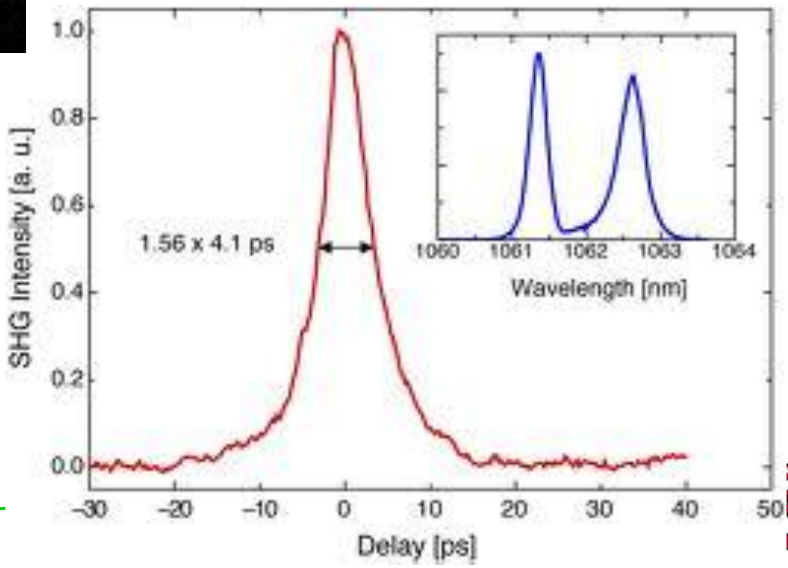
Some operating characteristics: *continuous & pulsed*

Picosecond **pulsed** laser

Typical pulsetrain



Individual pulse characteristics

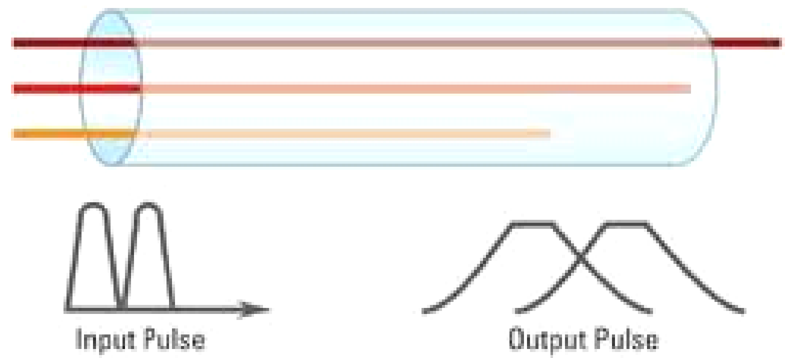


Lasers sources

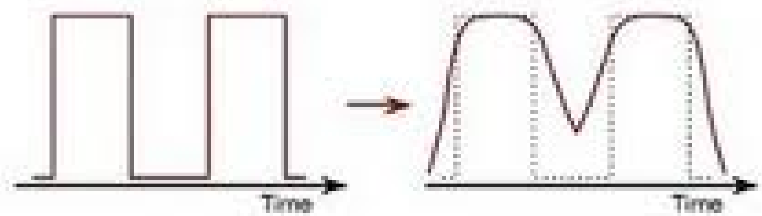
Some operating characteristics: *continuous & pulsed*

Picosecond **pulsed** laser

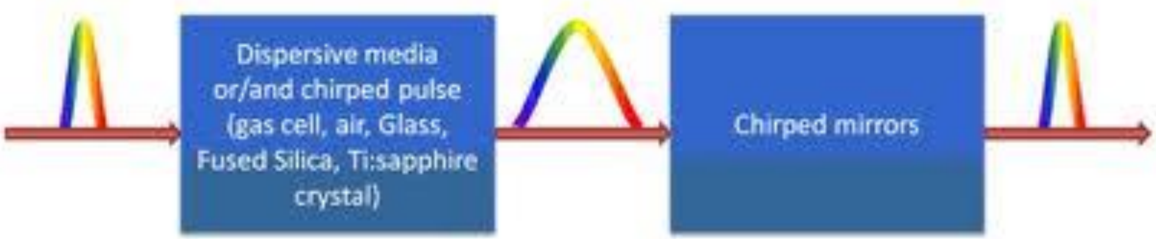
Pulse dispersion through media

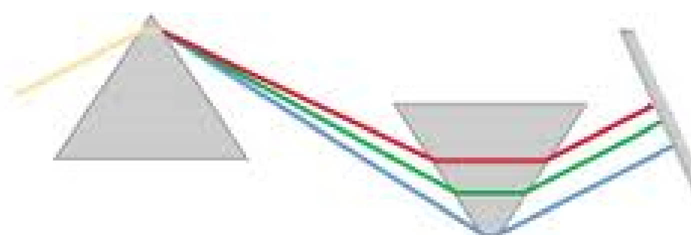


Dispersion in optical fibers



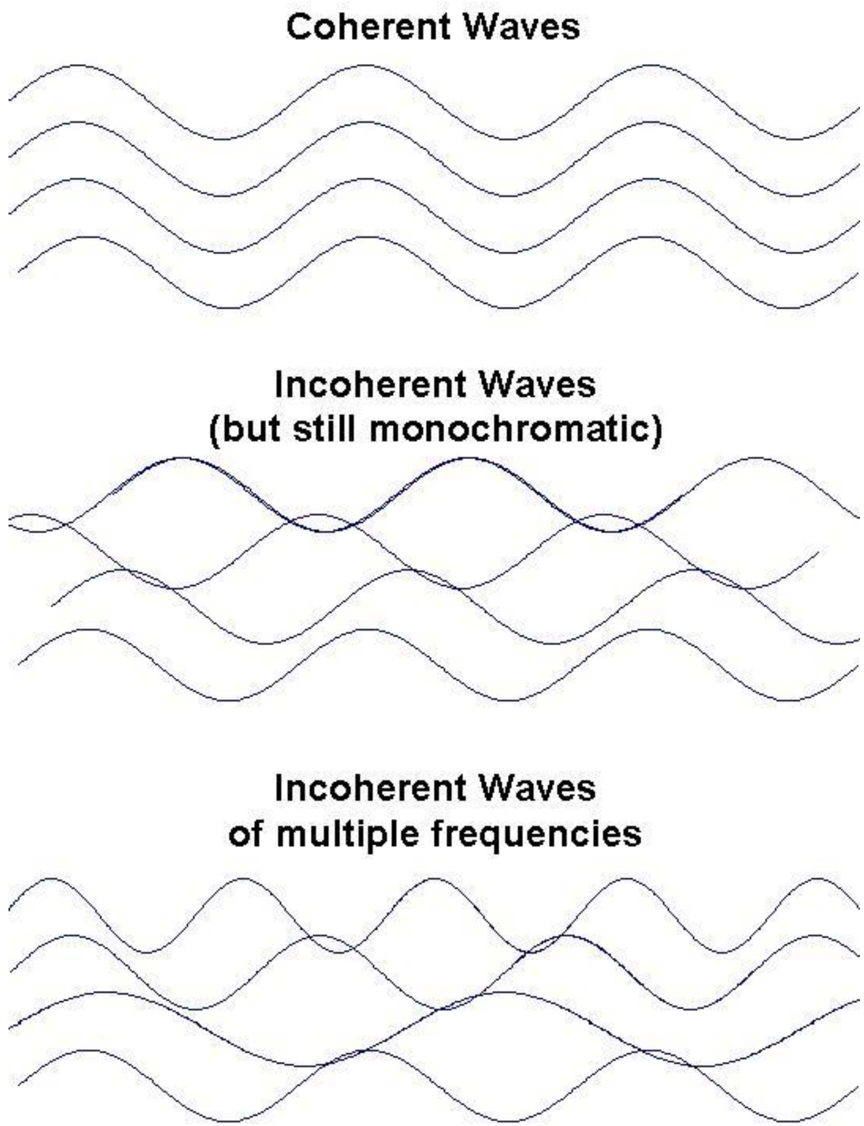
Dispersion compensation





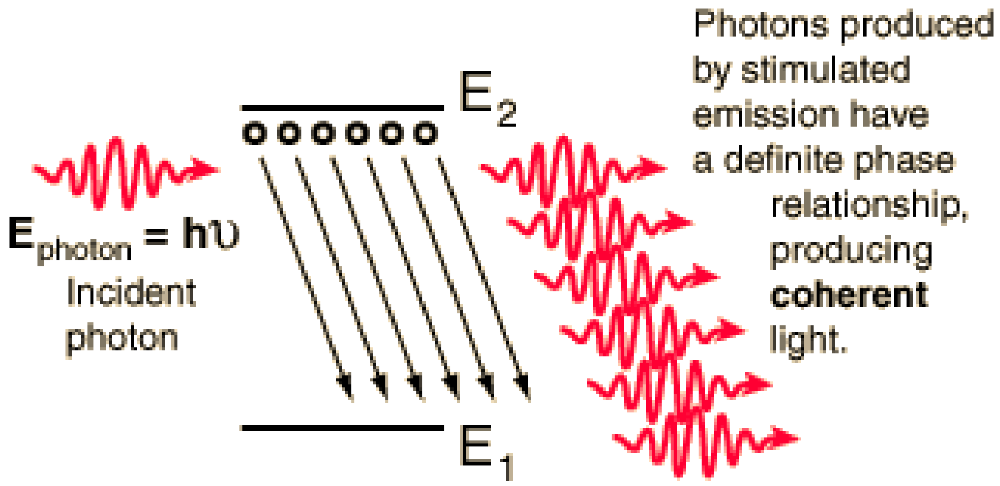
Lasers sources

Some operating characteristics: *temporal coherence*



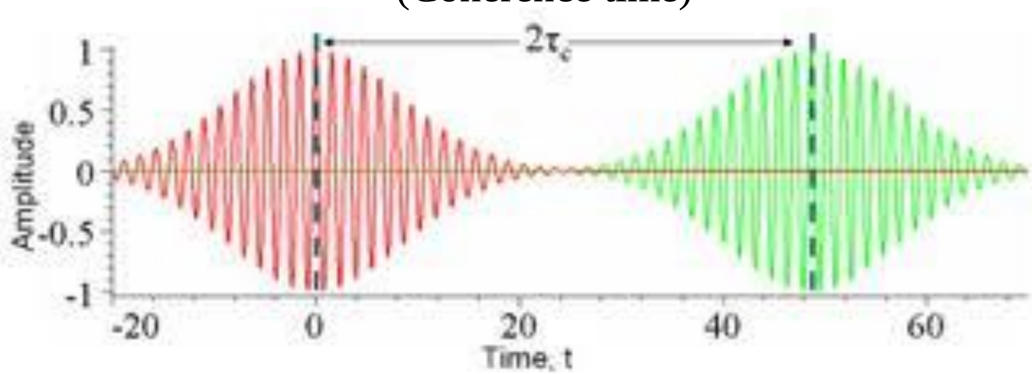
Lasers sources

Some operating characteristics: *temporal coherence*



Packets of emitted light

(Coherence time)

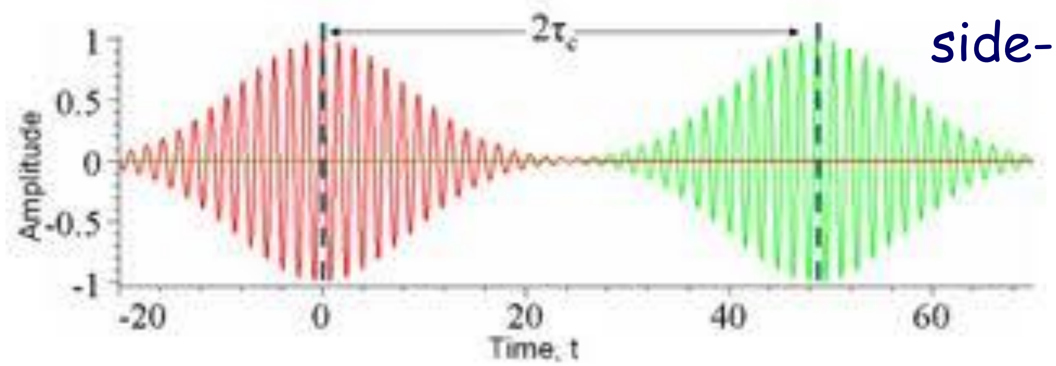


Lasers sources

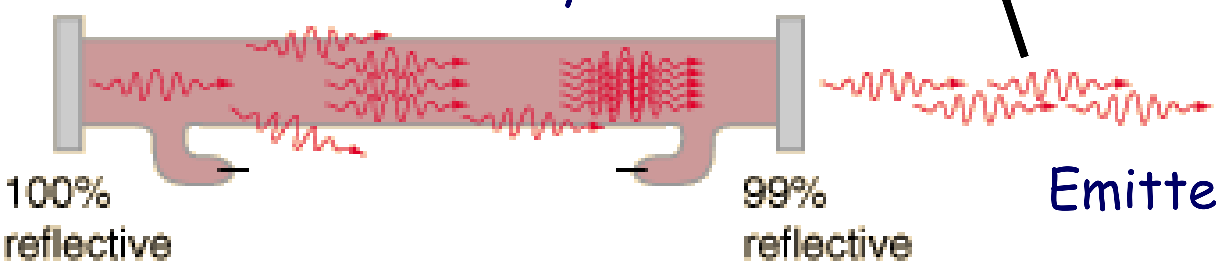
Some operating characteristics: *temporal coherence*

Coherence time

Two emissions side-by-side



Laser cavity



Emitted packets

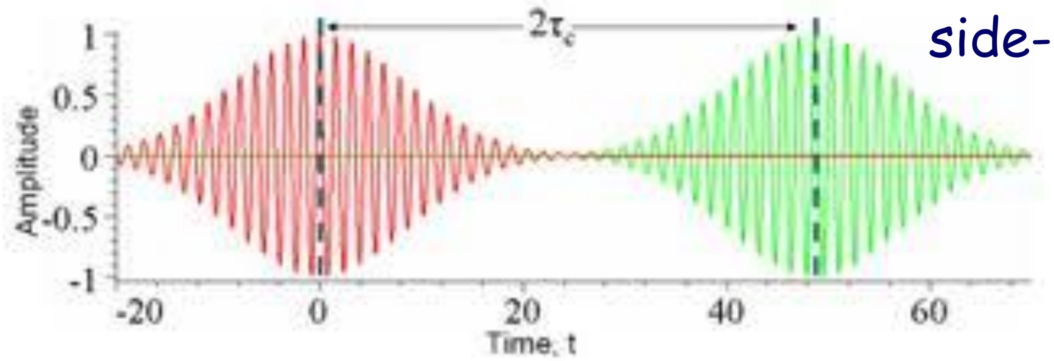
Lasers sources

Some operating characteristics: *temporal coherence*

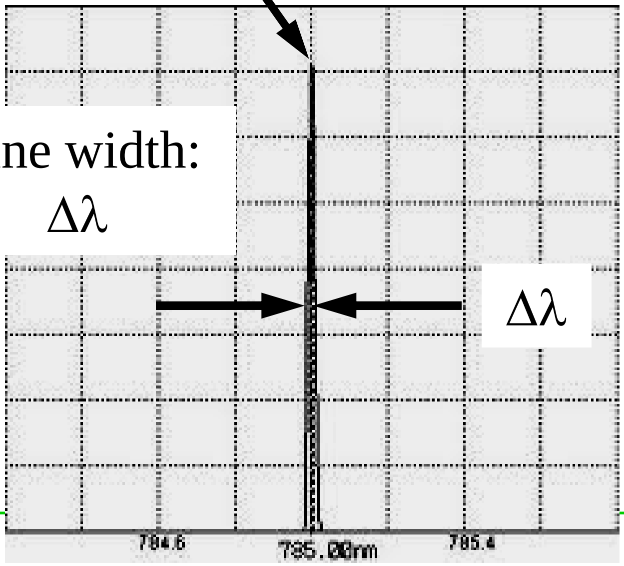
Temporal coherence length contributes to <u>interference</u> ability

Coherence time

Two emissions side-by-side



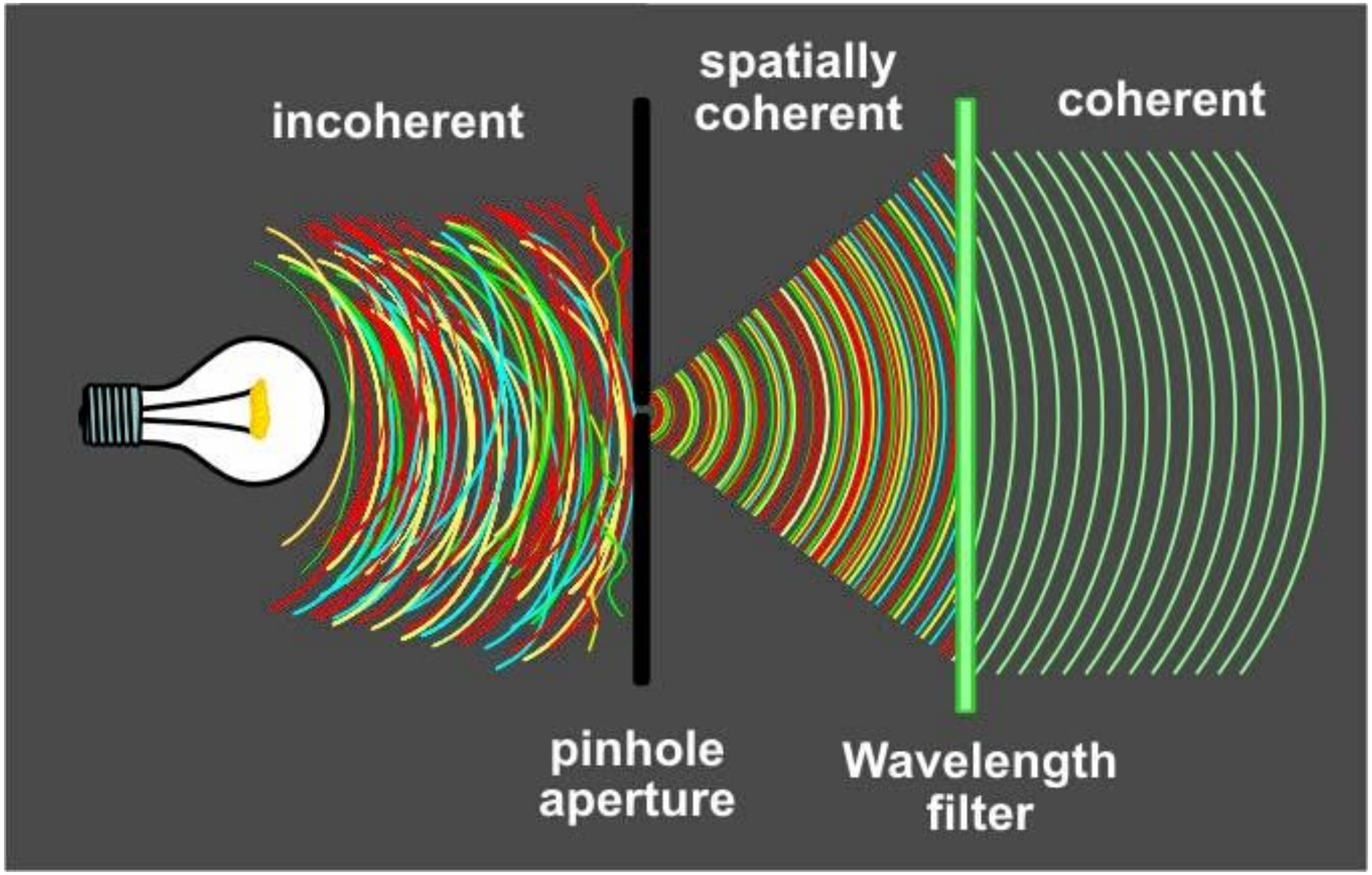
Central wavelength: λ



Coherence length: $l_c = \sqrt{\frac{2 \cdot \ln(2)}{\pi}} \frac{\lambda^2}{\Delta\lambda}$

Lasers sources

Some operating characteristics: *spatial coherence*

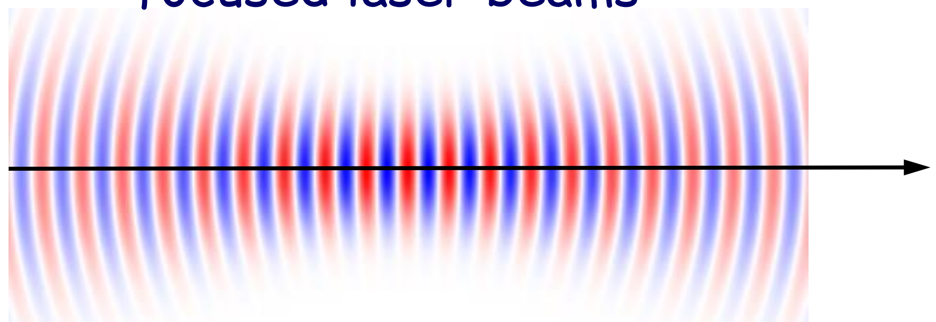


Lasers sources

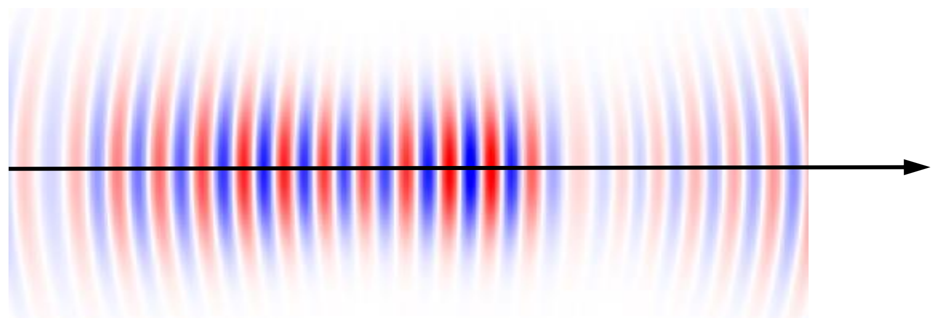
Some operating characteristics: *temporal & spatial coherence*

Electric fields of
focused laser beams

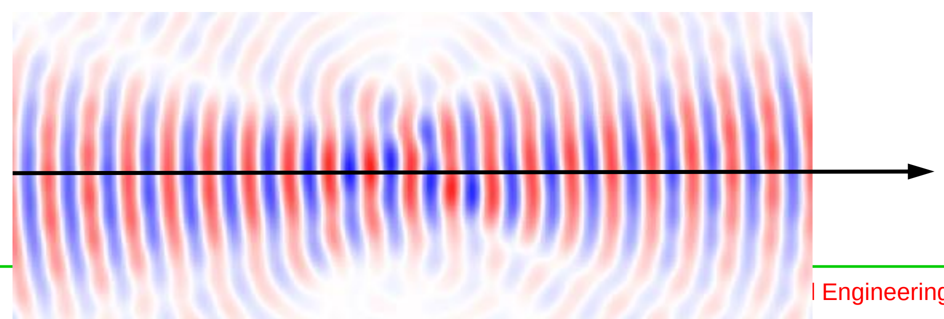
Good temporal
&
Good spatial
coherence



Poor temporal
&
Good spatial
coherence



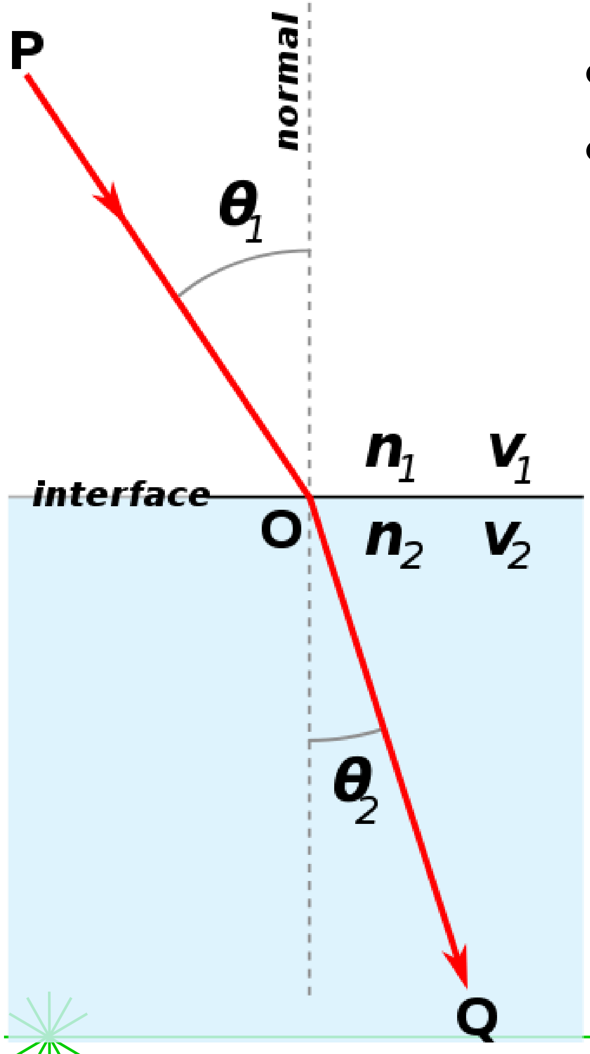
Good temporal
&
Poor spatial
coherence



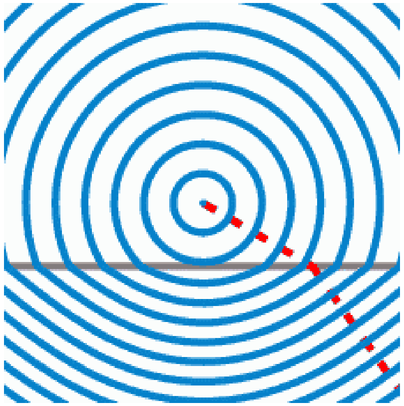
Lenses

Snell's law

Light ray propagating through two media



- n_1 and n_2 are refractive indexes
- v_1 and v_2 are velocities of light



Light wavefronts

$$n_1 \cdot \sin\theta_1 = n_2 \cdot \sin\theta_2$$

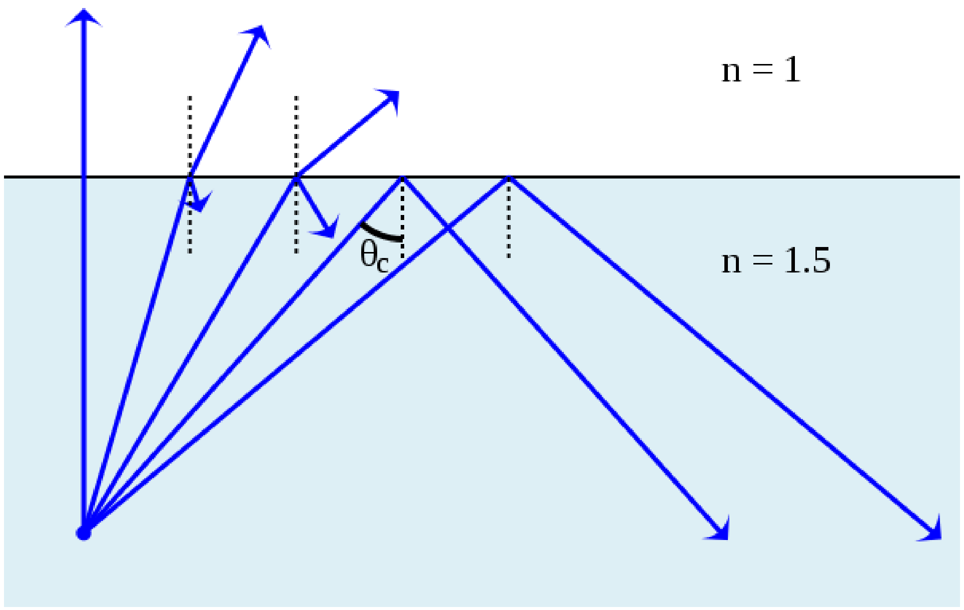
and

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

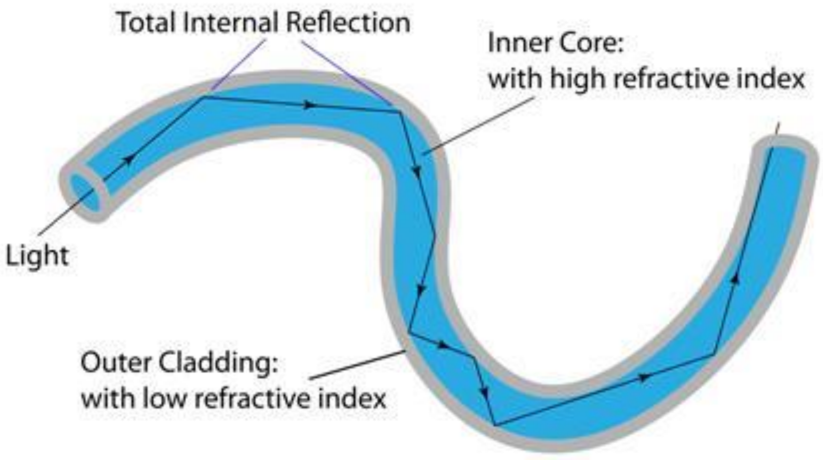
Lenses

Snell's law & total internal reflection

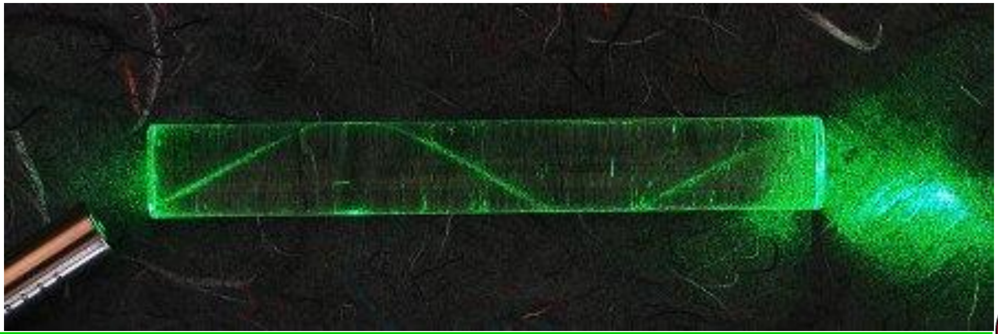
Angle of incidence and internal reflections:



Fiber optics

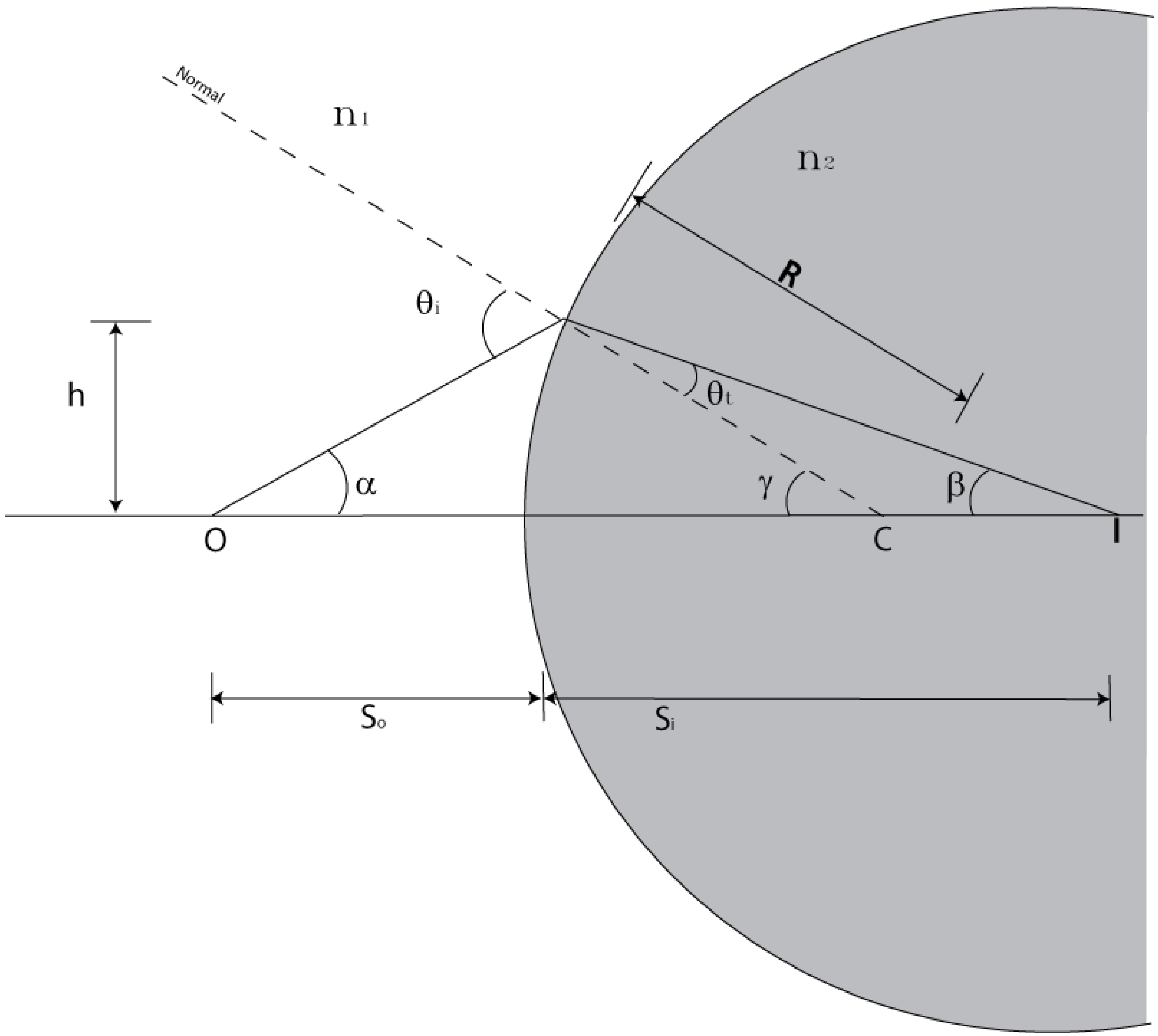


Laser in fiber



Lenses

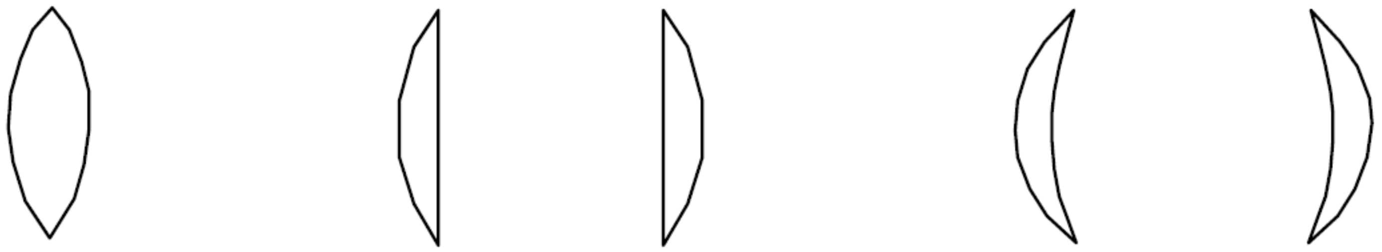
Snell's law: refraction at a spherical interface



Lenses

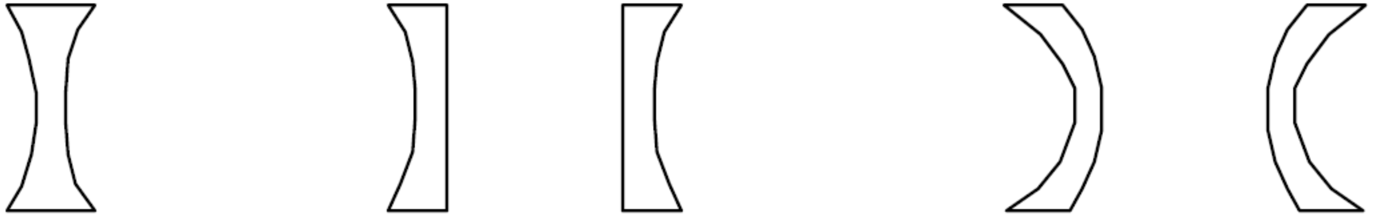
Types

Convergent lenses



double convex planoconvex convex meniscus

Divergent lenses

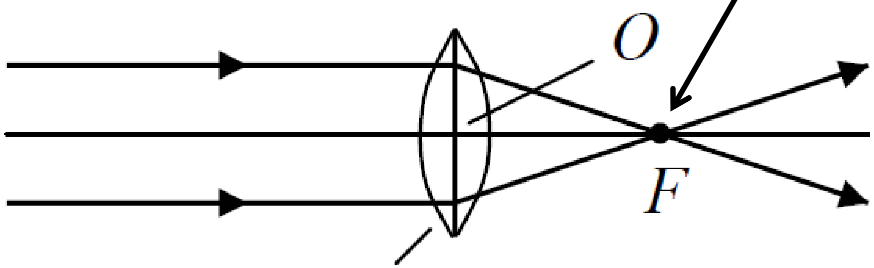


double concave planoconcave concave meniscus

Lenses

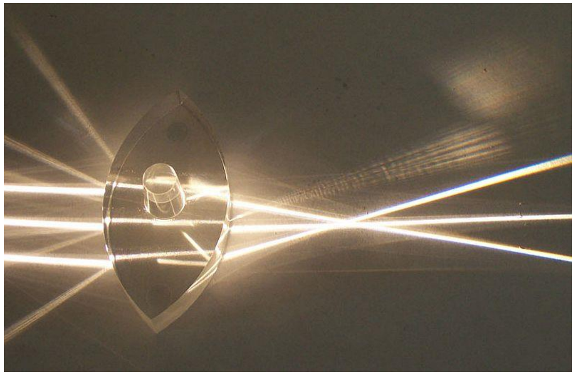
Types

Focal point

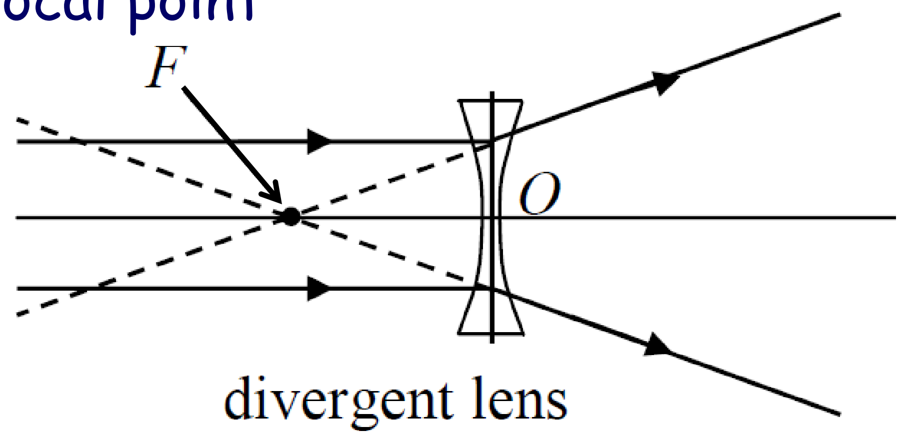


convergent lens

$(f = \overline{OF} > 0)$

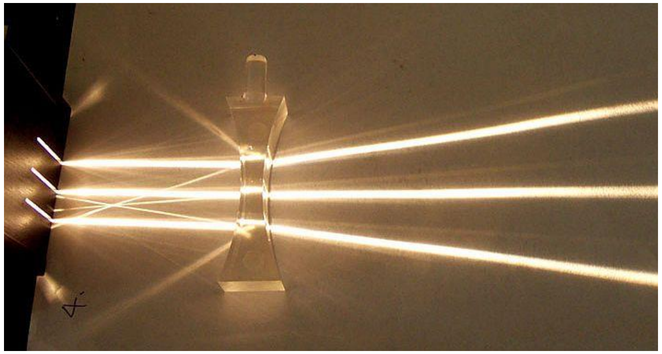


Virtual focal point



divergent lens

$(f = -\overline{OF} < 0)$

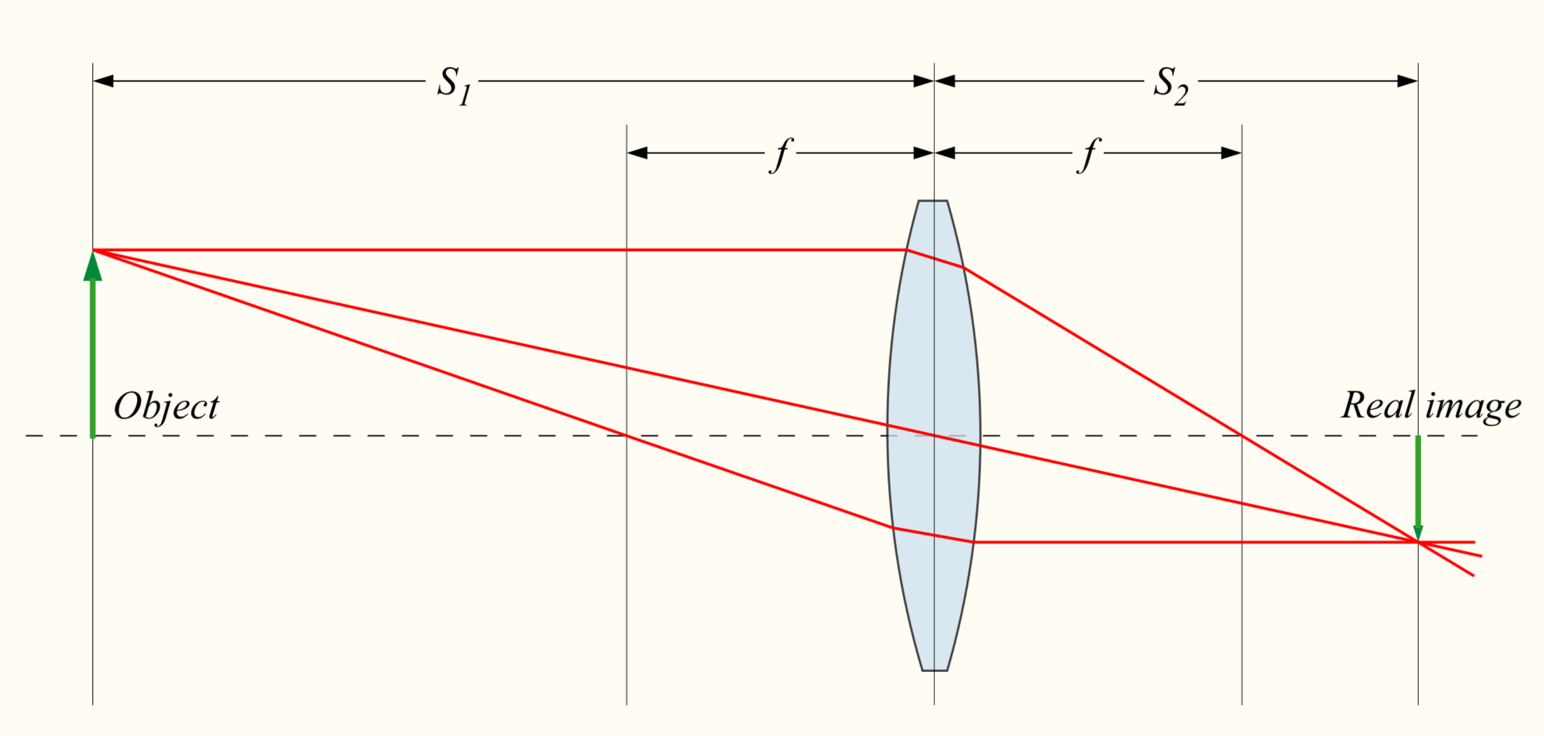


Lenses

Imaging properties: real image

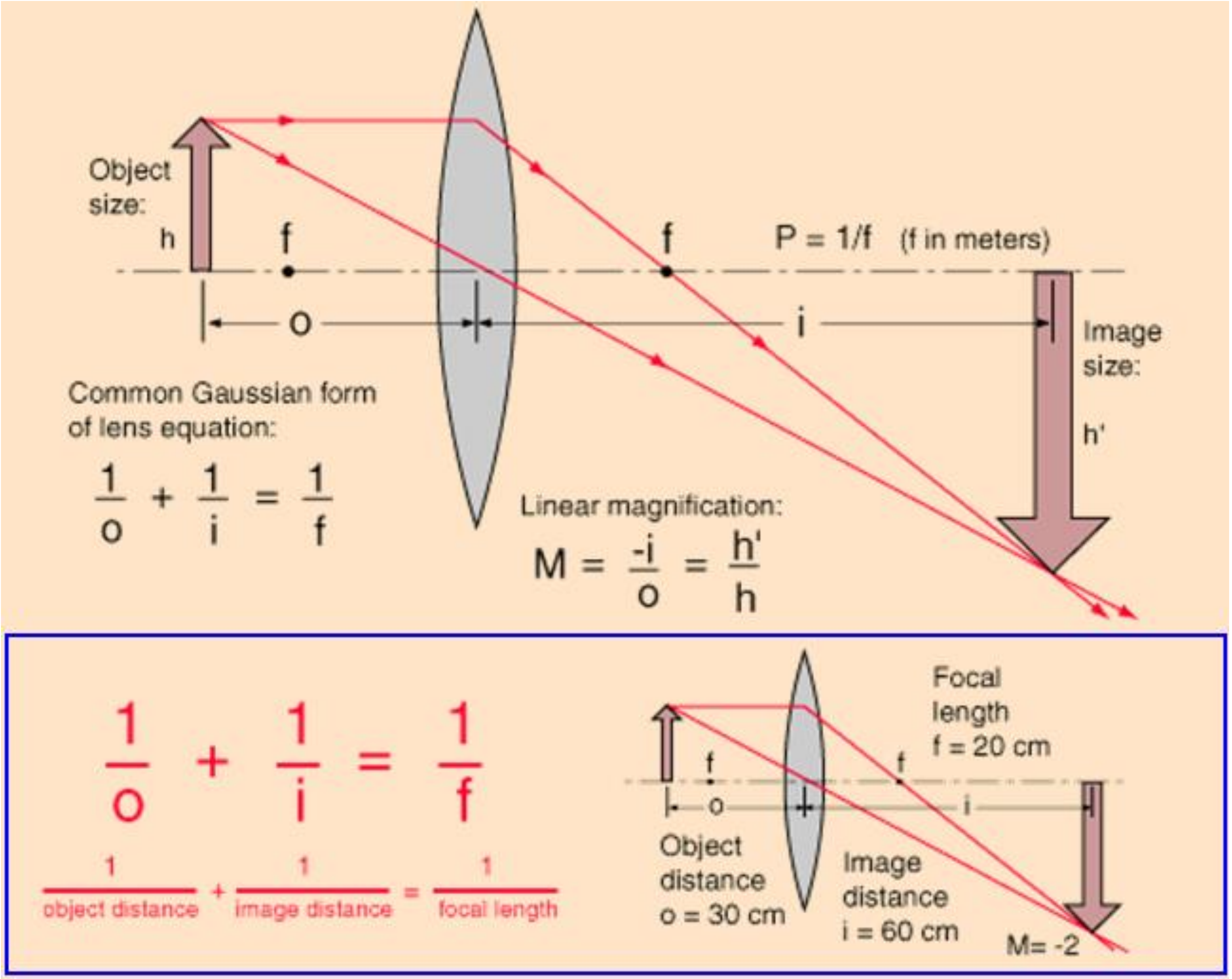
$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f};$$

Magnification: $M = -\frac{S_2}{S_1} = \frac{f}{f - S_1}$



Lenses

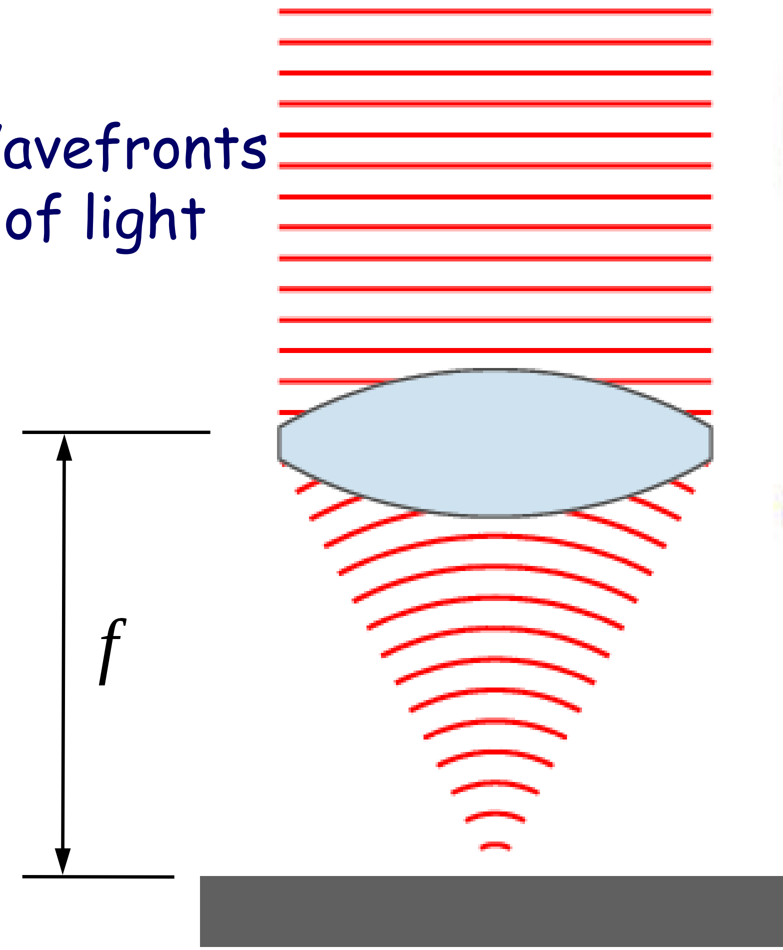
Imaging properties: real image formation



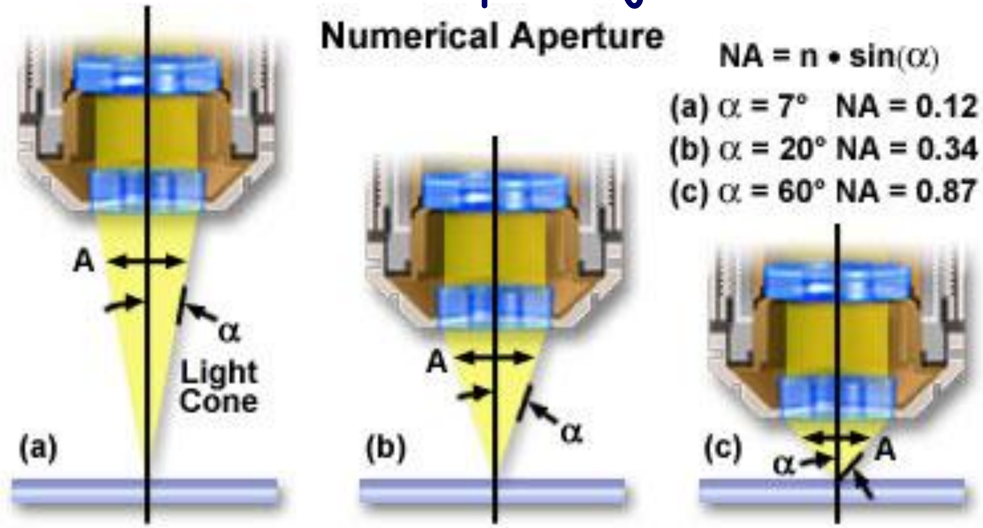
Lenses

Imaging properties: real image formation

Wavefronts of light



Microscope objectives



60x Plan Apochromat Objective

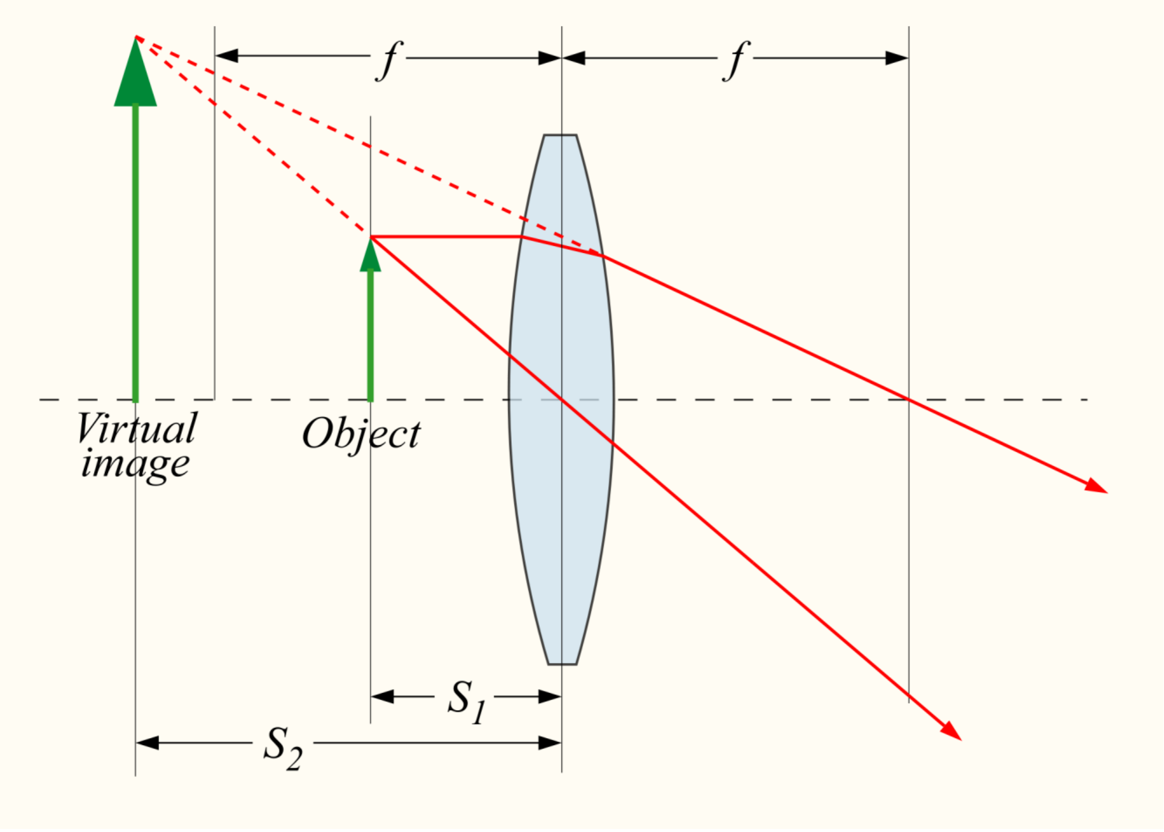
WPI

Lenses

Imaging properties: virtual image

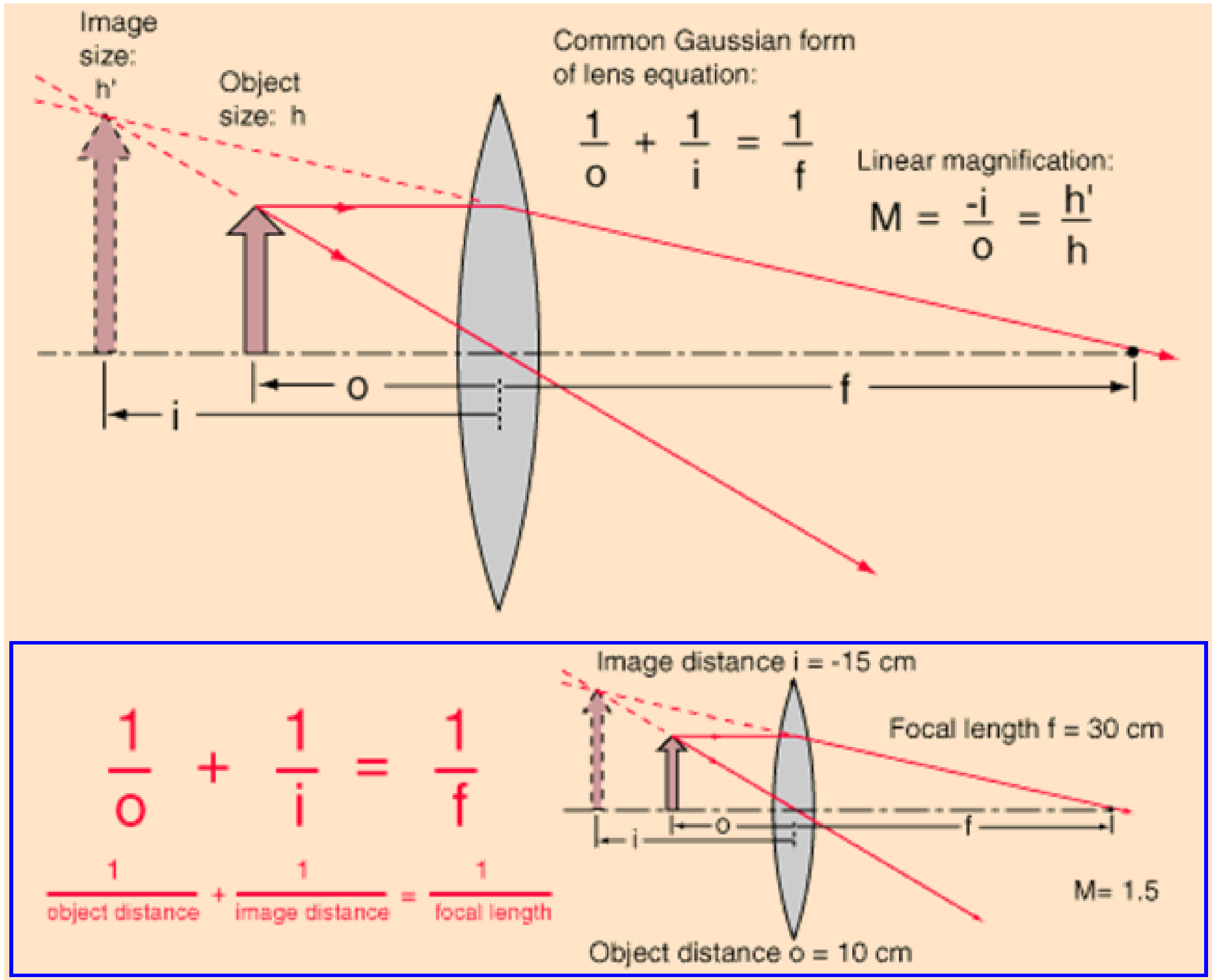
$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

for $S_1 < f$



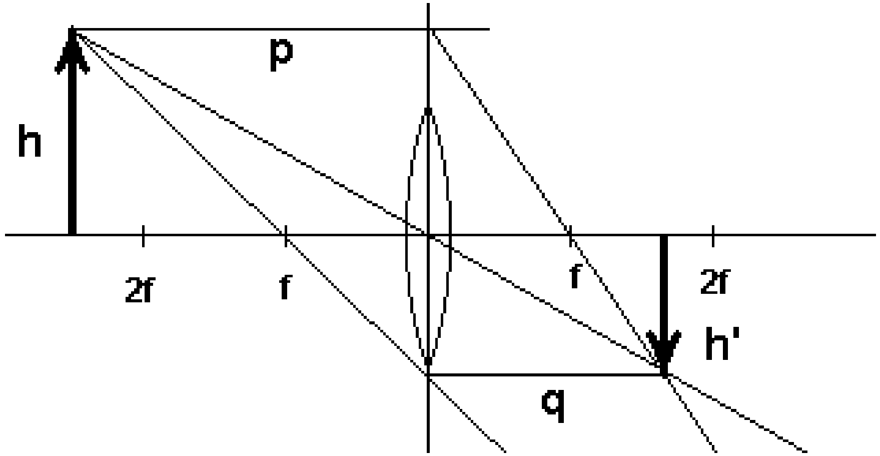
Lenses

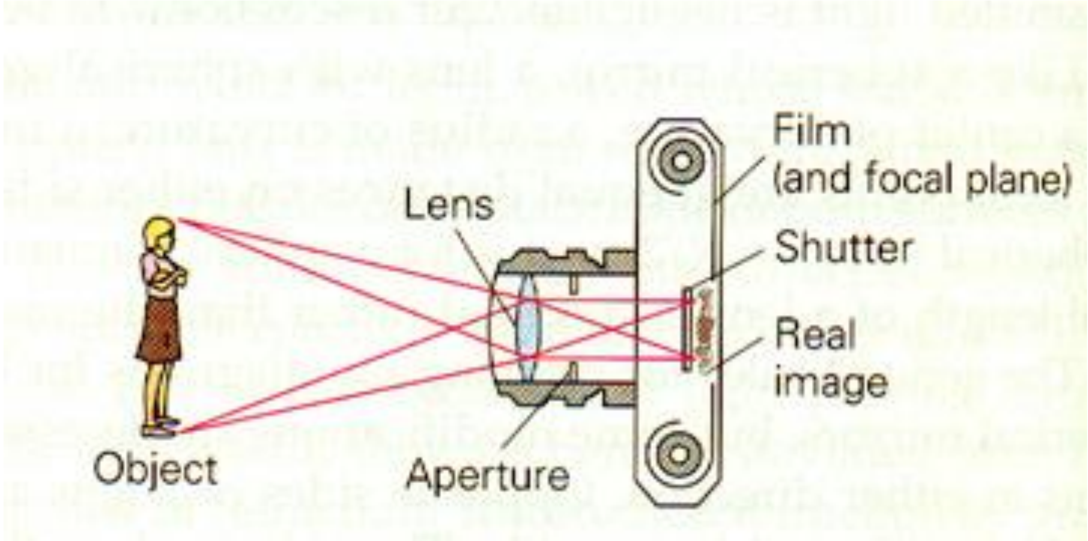
Imaging properties: virtual image

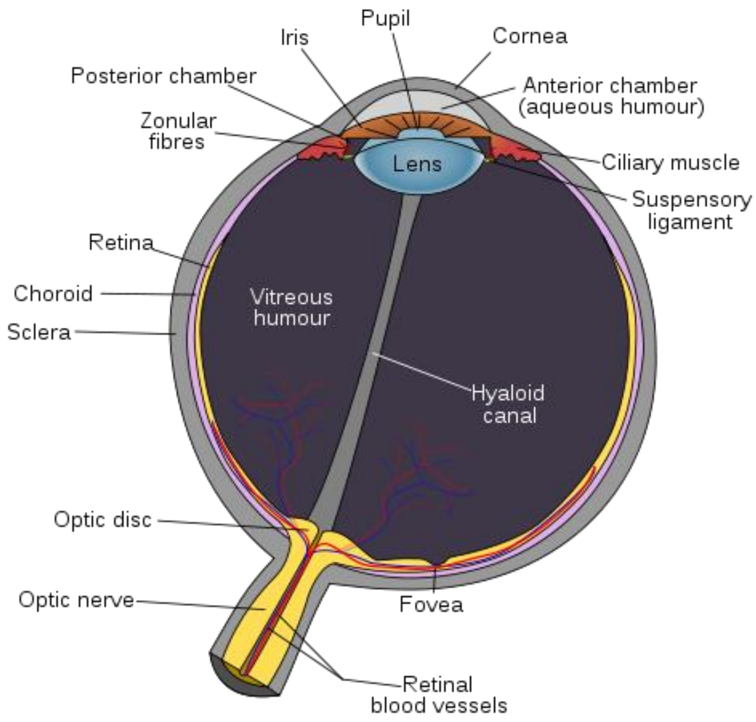


Lenses

Imaging properties: real image formation

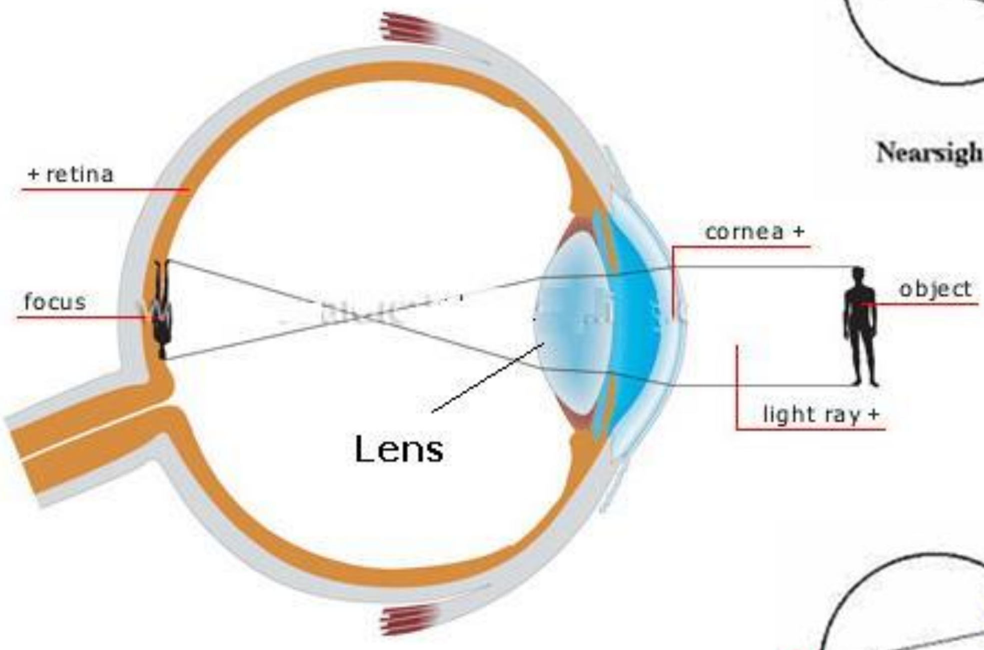


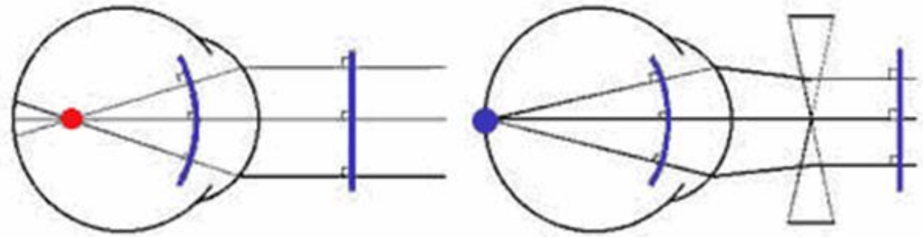




Lenses

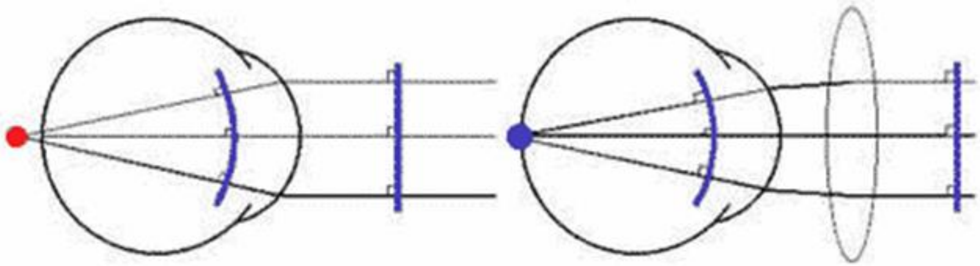
Imaging properties: real image formation





Nearsighted eye - Uncorrected

Nearsighted eye - Corrected with a NEGATIVE (diverging) lens

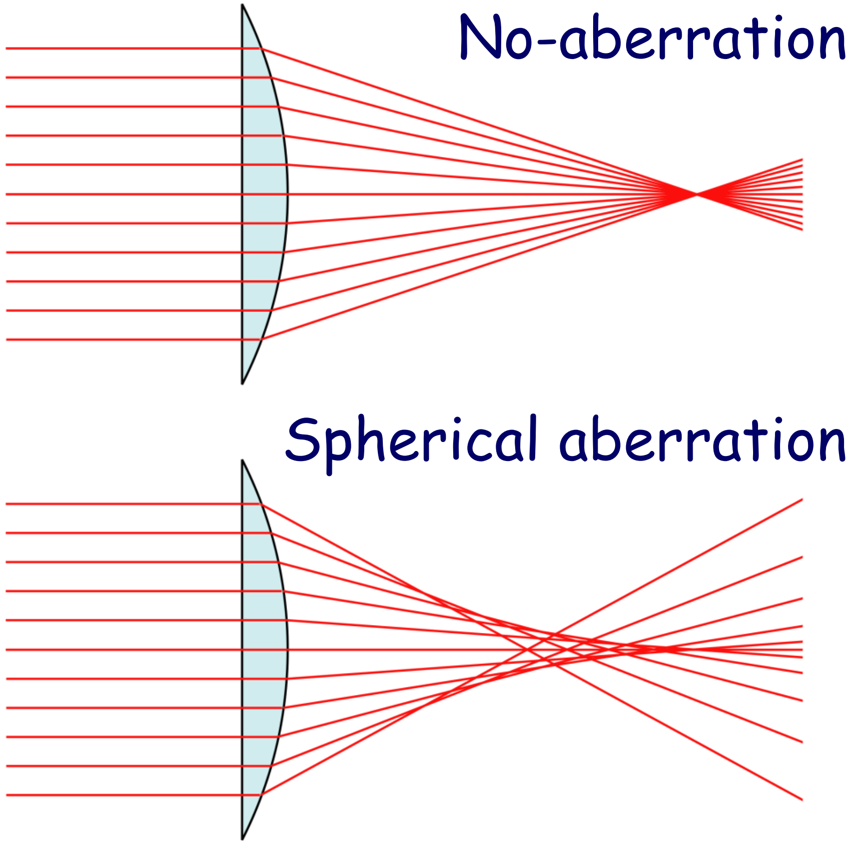


Farsighted eye - Uncorrected

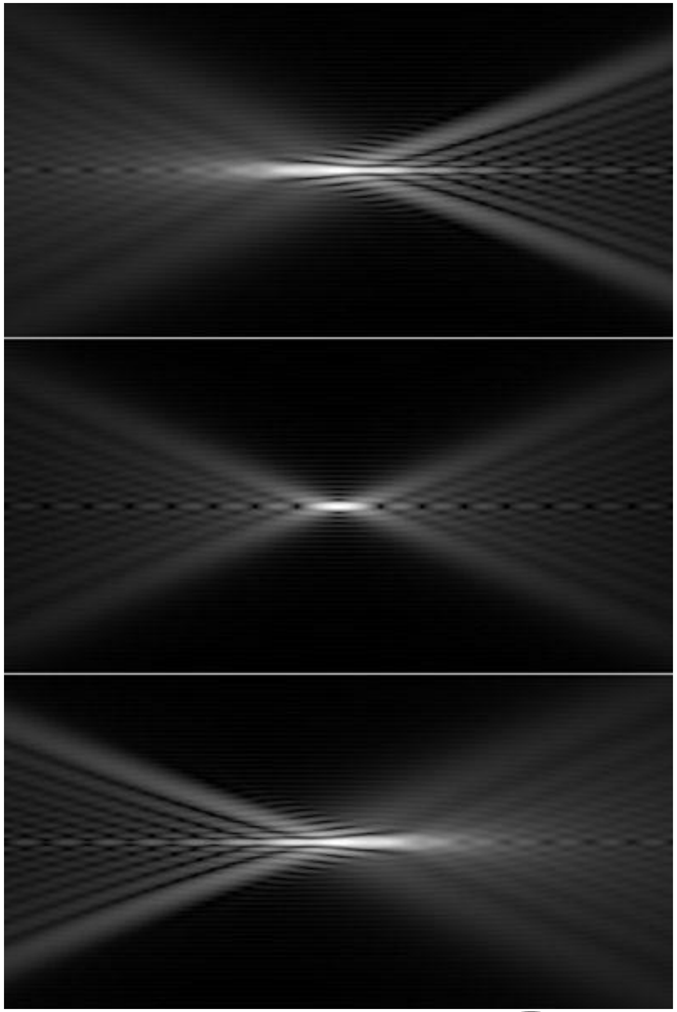
Farsighted eye - Corrected with a POSITIVE (converging) lens

Lenses

Some optical aberrations: *spherical*

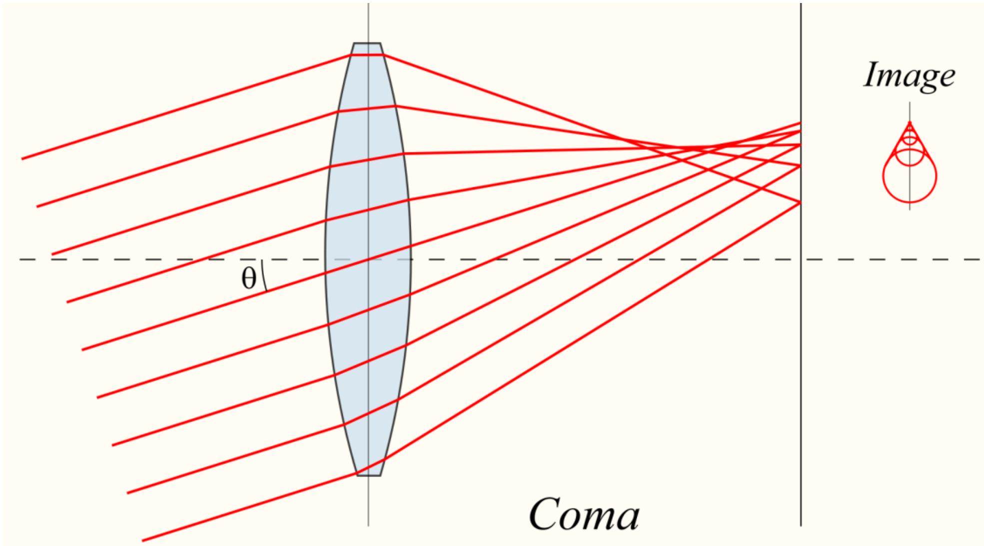


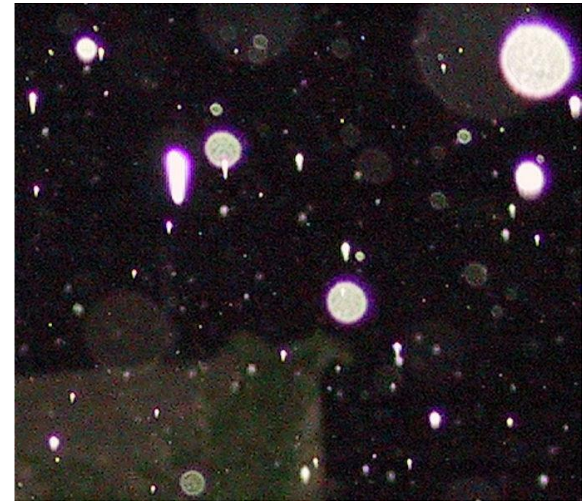
Spherical aberration

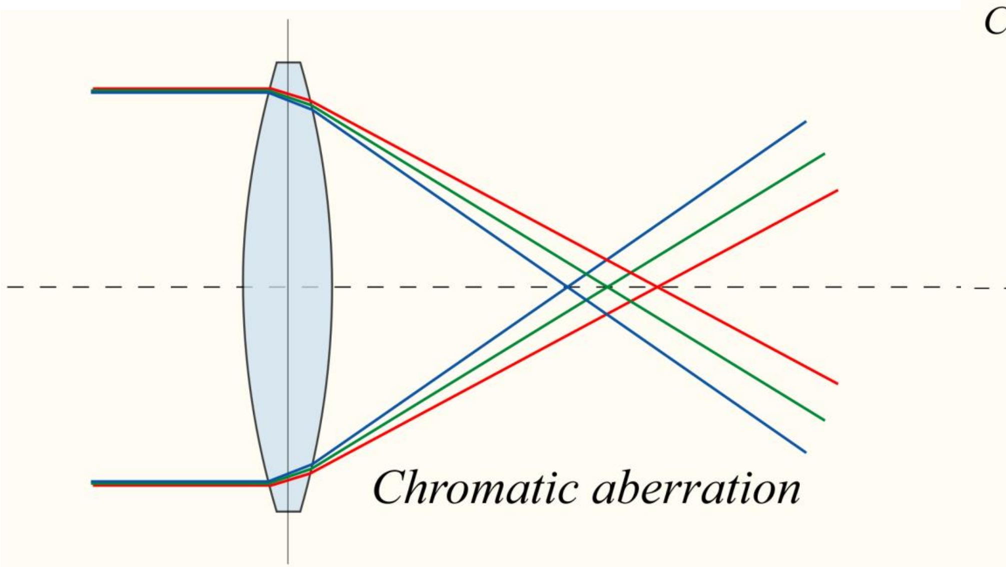


Lenses

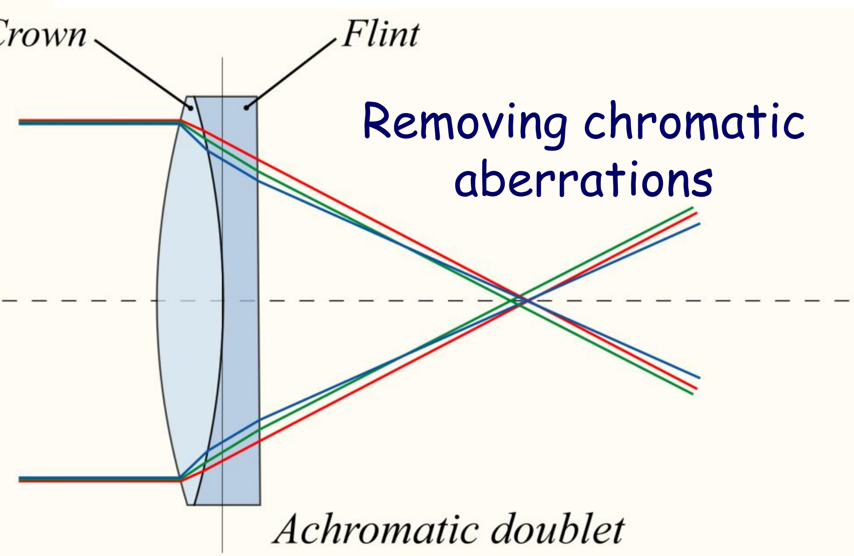
Some optical aberrations: *coma & chromatic*







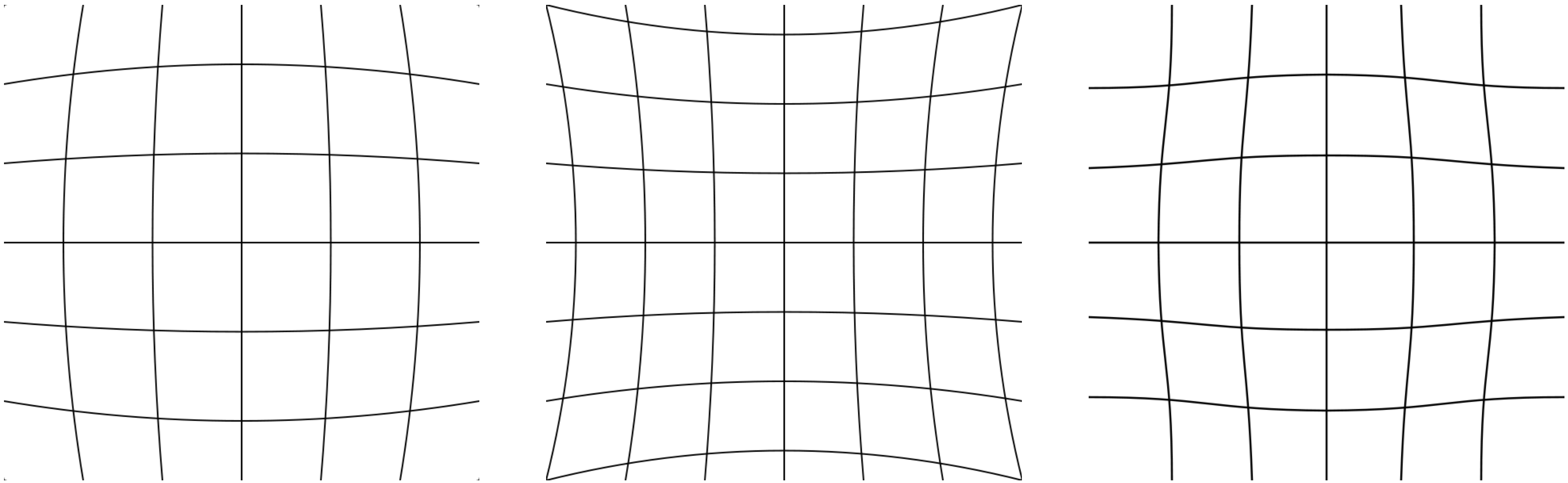
Removing chromatic aberrations



Lenses

Some optical aberrations: *distortion (need for "camera" calibration and software)*

Barrel Pincushion Mustache



Potential Course Projects
Overview: lab visit

- Ultra-high speed imaging: DIC
- Shearography: NDT
- Fringe Projection: Shape measurements & NDT
- MEMS metrology: Shape/deformation measurements & NDT
- Digital holography
- Other…

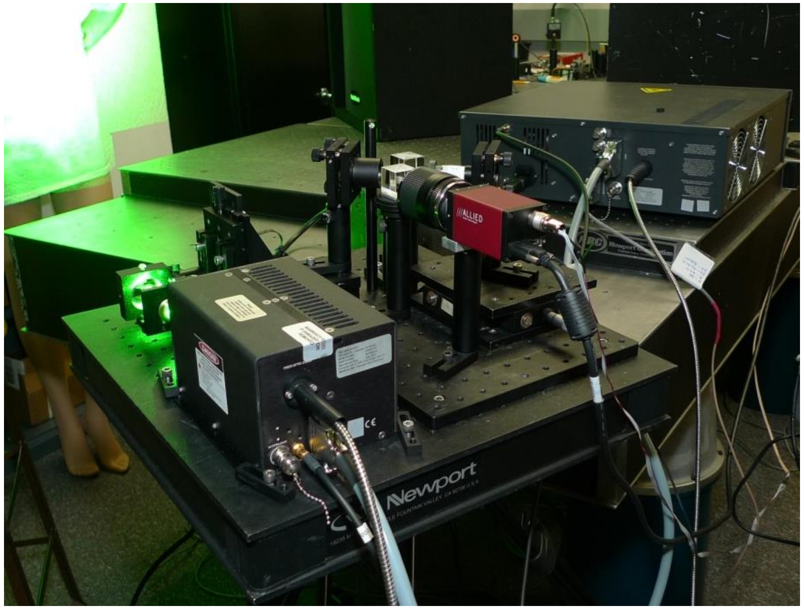
Potential Course Projects

Overview: shearography

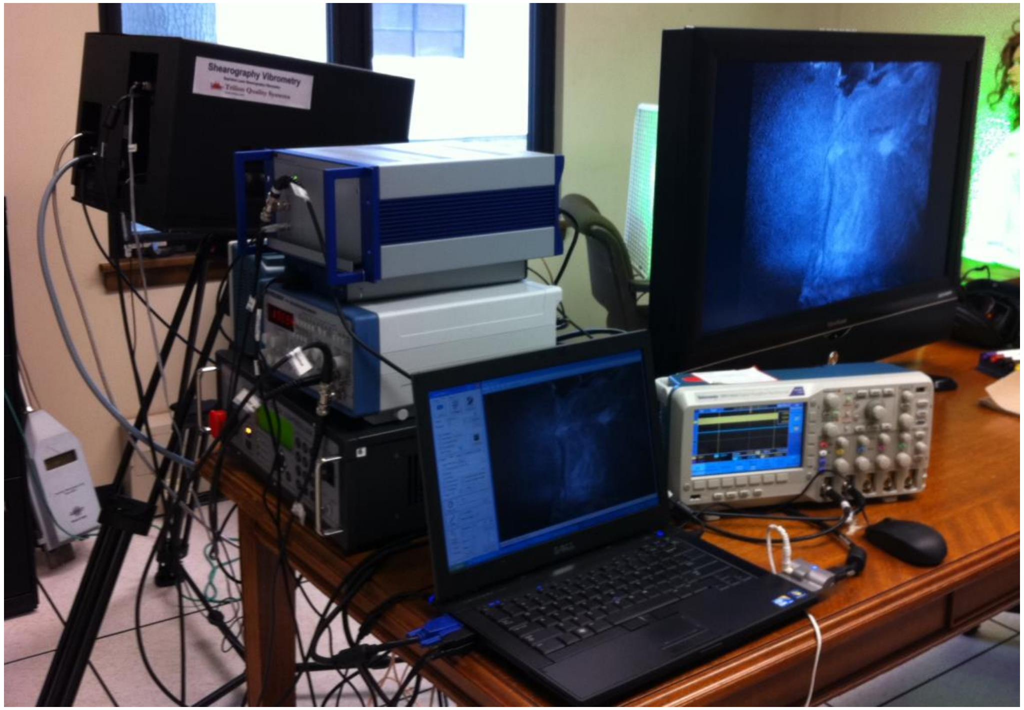
Nondestructive testing: standoff detection

Internal defect detection & measurements

Realized opto-electronic head with pulsed laser

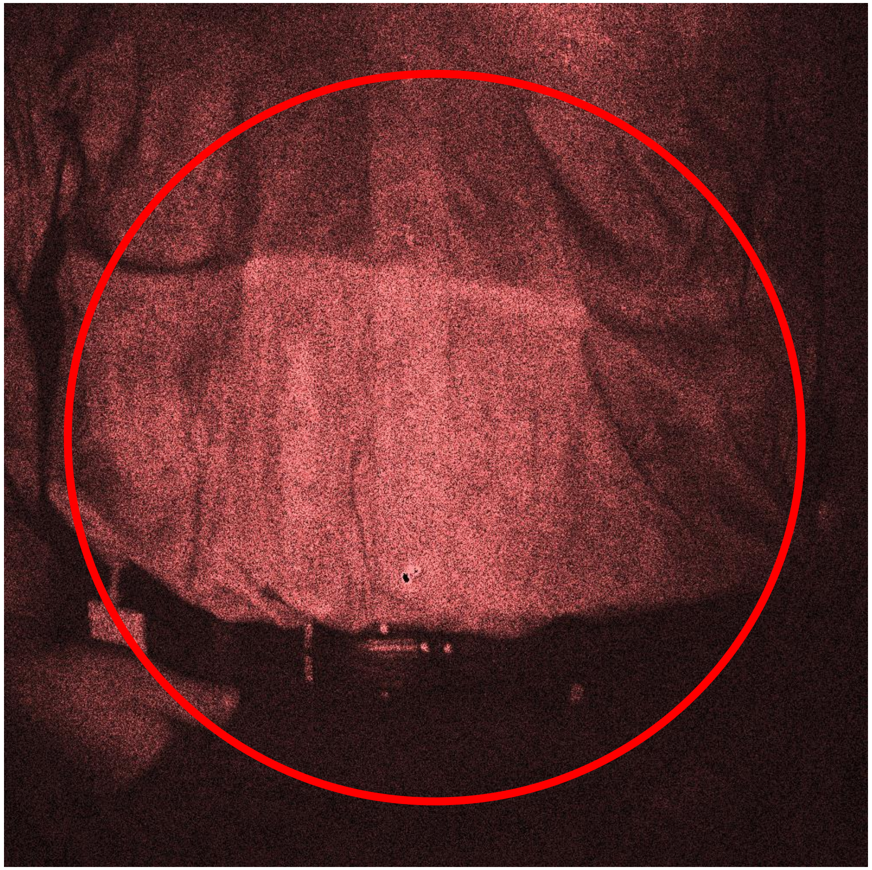


Developed holographic system in the field

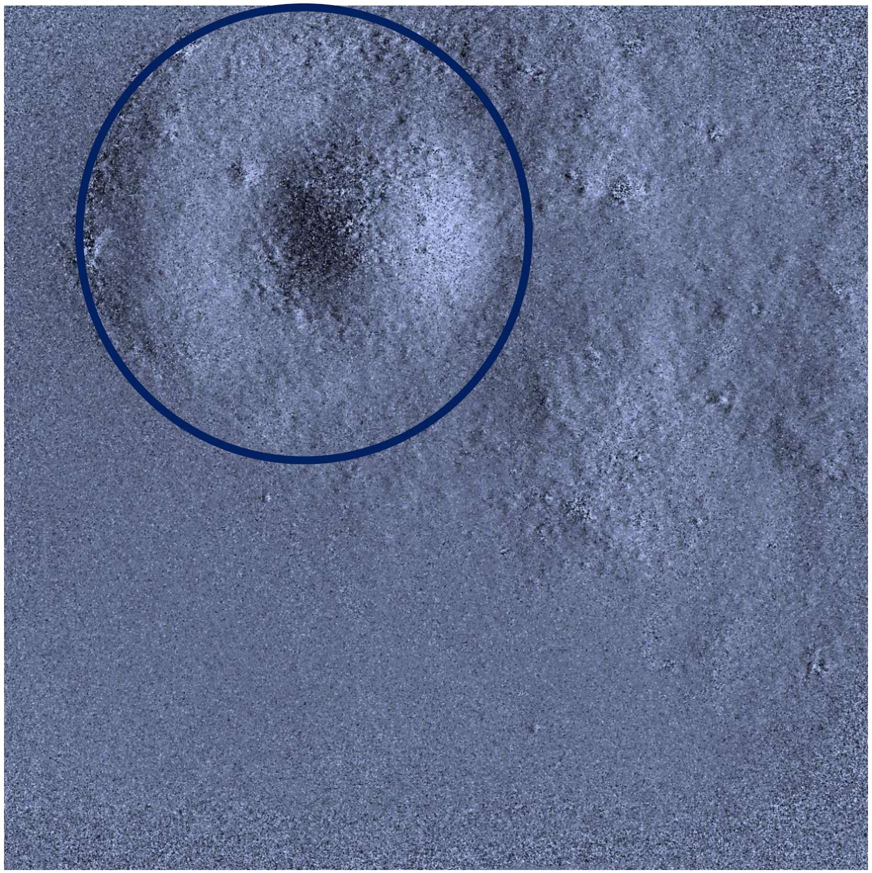


Nondestructive testing: standoff detection
Internal defect detection & measurements

Hidden object under person's shirt



Detected defect an inside object

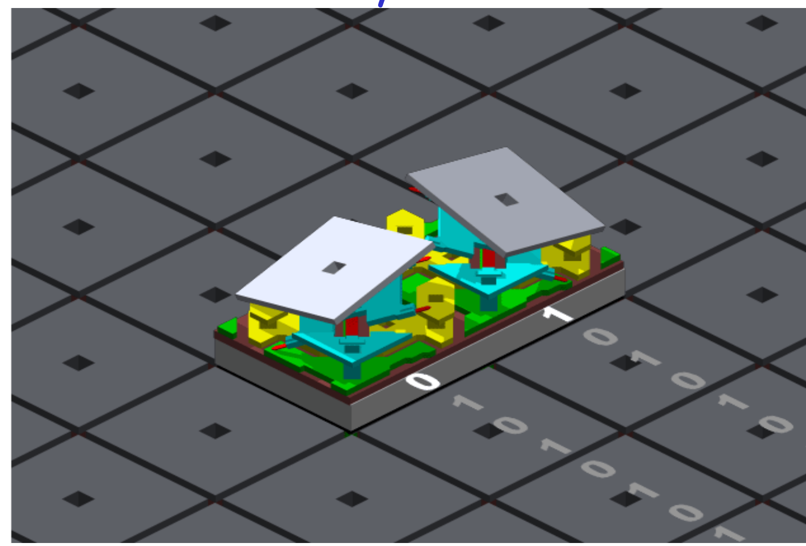


Course Projects

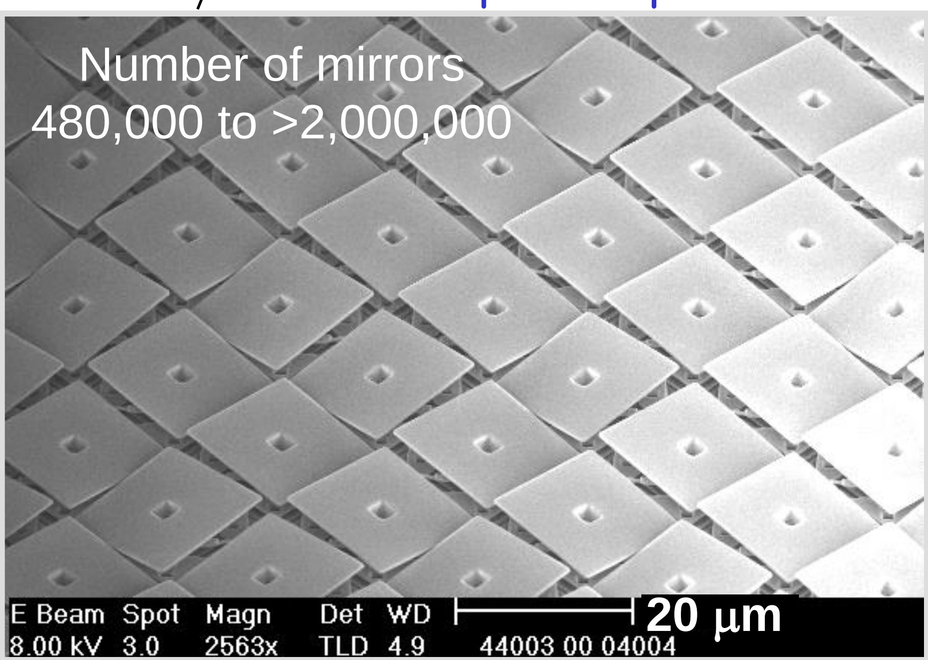
Overview: Fringe Projection for Shape measurements & NDT

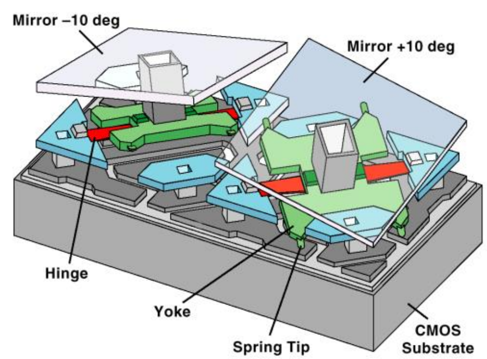
Texas Instrument's DMD

Each mirror of the DMD is individually addressable



Close-up of chip surface

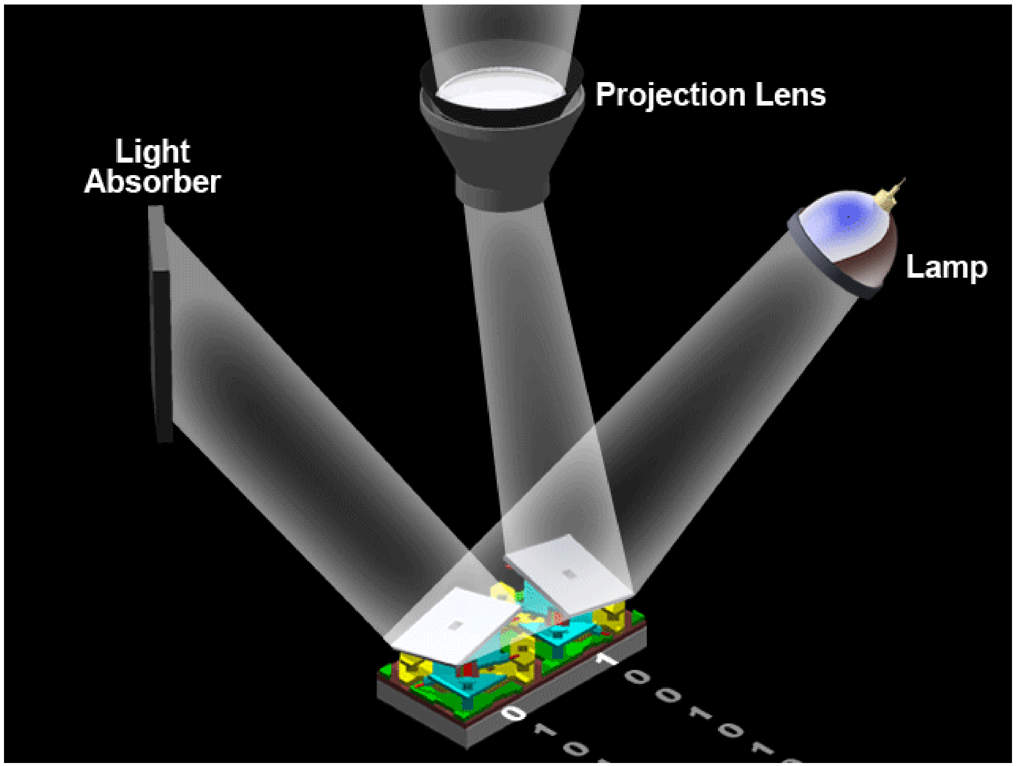


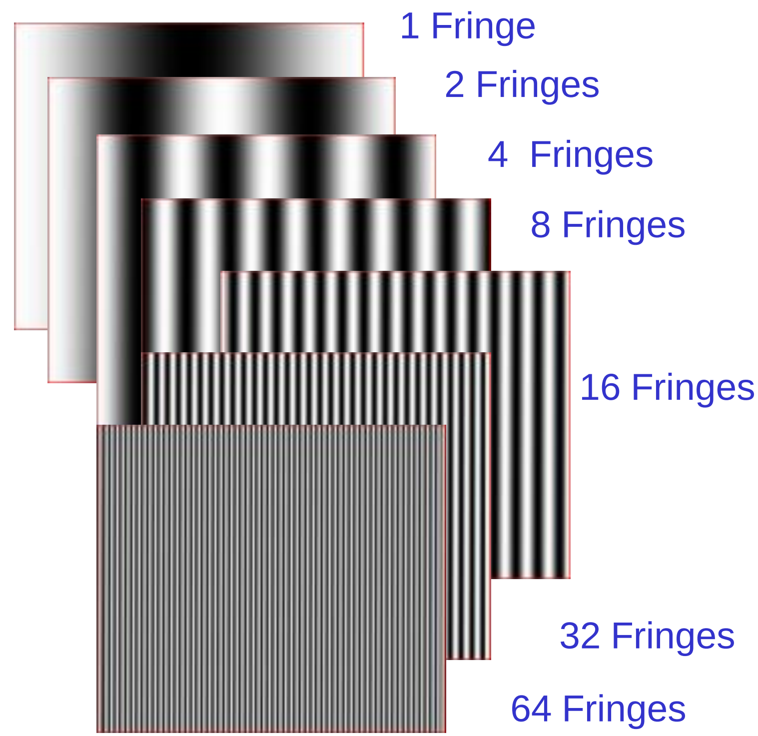


MEMS in optoelectronic metrology

High-speed measurements based on holographic interferometry principles

Use of computer generated holograms

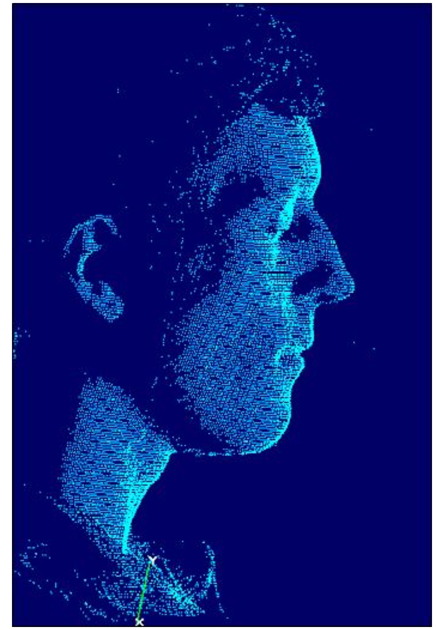


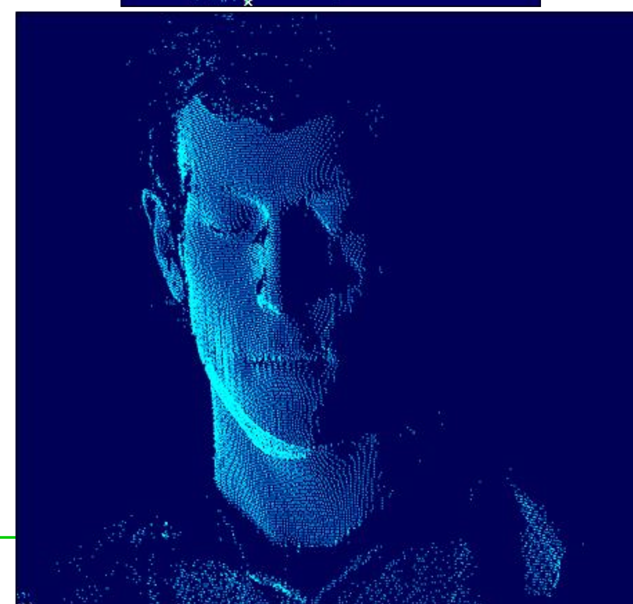


MEMS in optoelectronic metrology

High-speed measurements based on holographic interferometry principles

Shape measurements in '3D inspection applications'



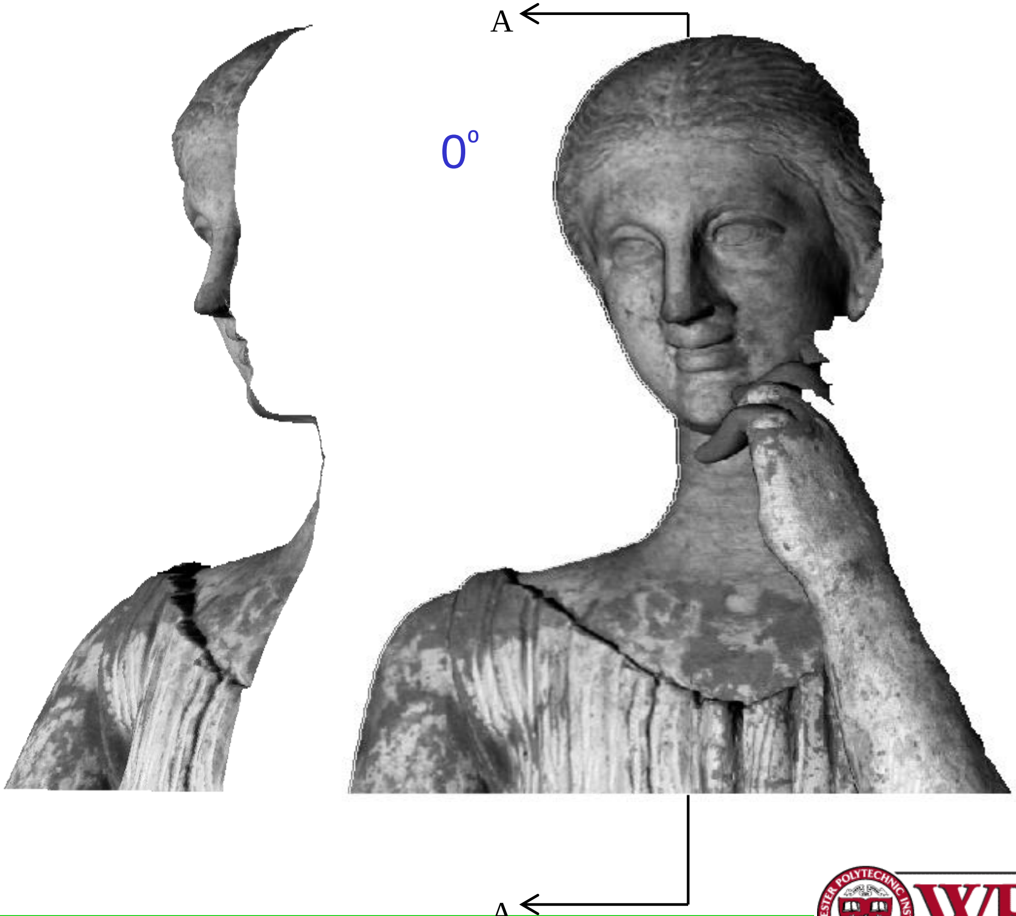


MEMS in optoelectronic metrology: art-conservation

High-speed measurements based on holographic interferometry principles

Worcester Art Museum: Sculpture titled "Funeral of a Young Maiden" Casona, South Italy. Late 4th Century BCE

Representative Measurements

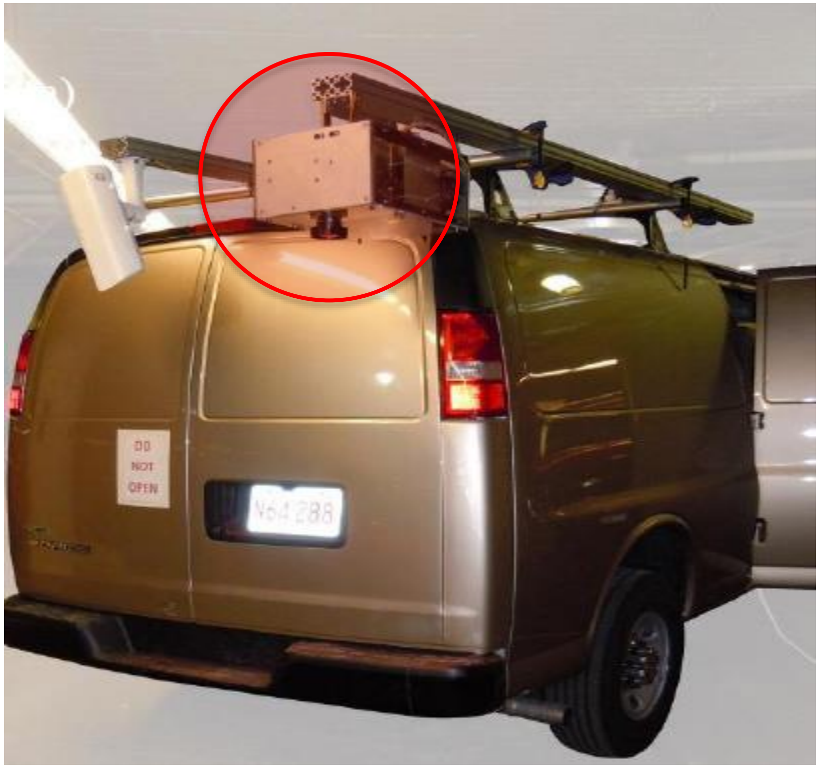


MEMS in optoelectronic metrology: road shape

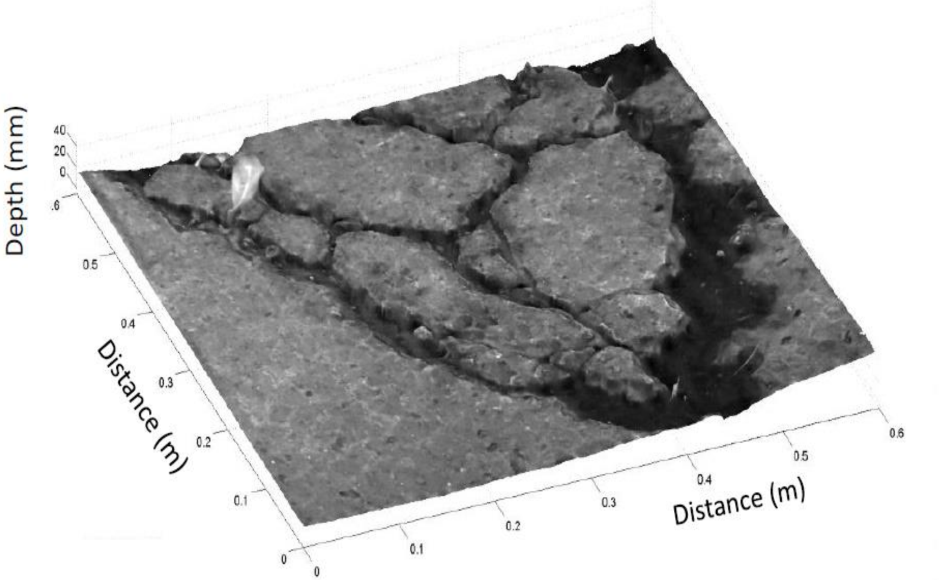
High-speed measurements based on holographic interferometry principles

- A prototype system has been developed and applied to road surface analysis
- We are currently designing a robust, low-cost, projection system that can be deployed in the field for measurements at up 60 mph driving speeds

Prototype projector on a vehicle

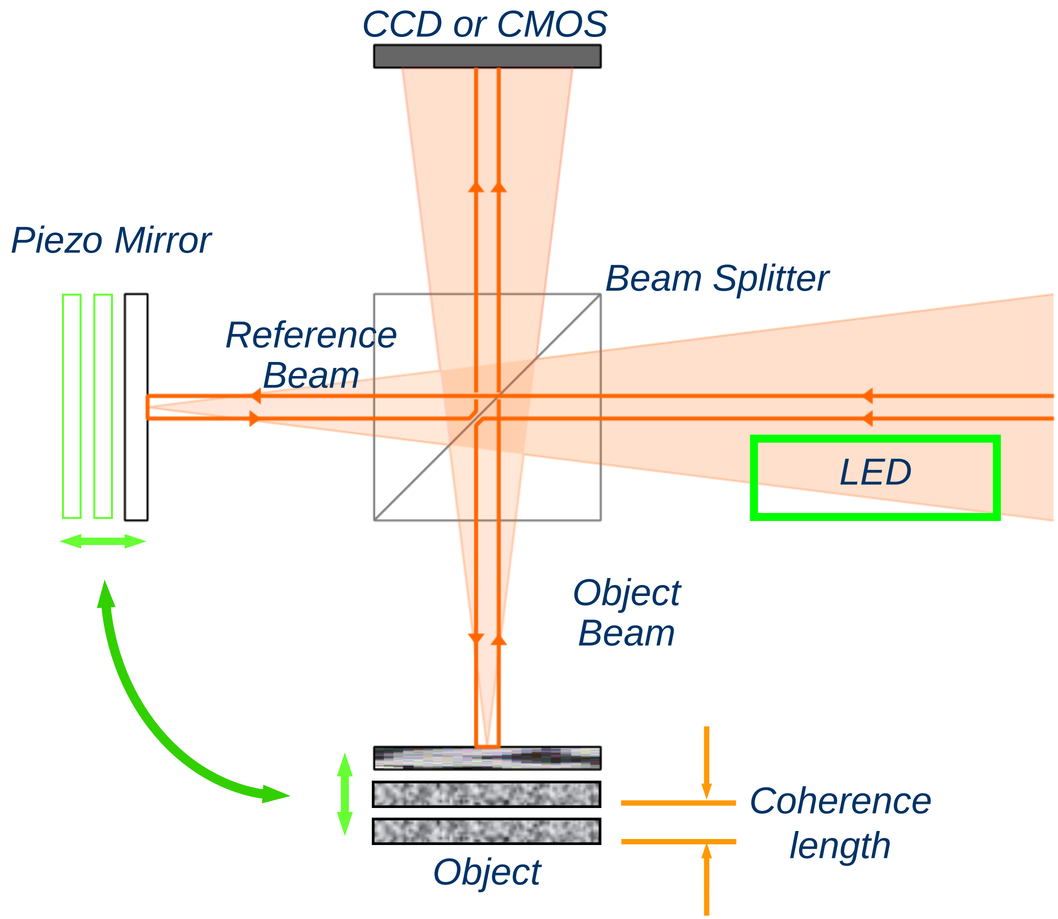


Typical surface road measurements



Course Projects

Overview: MEMS metrology for Shape/deformation measurements & NDT

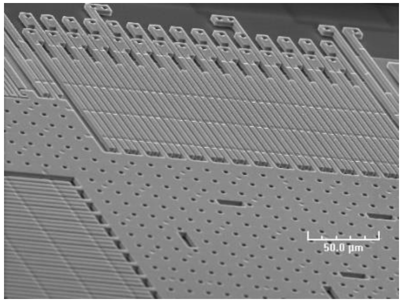


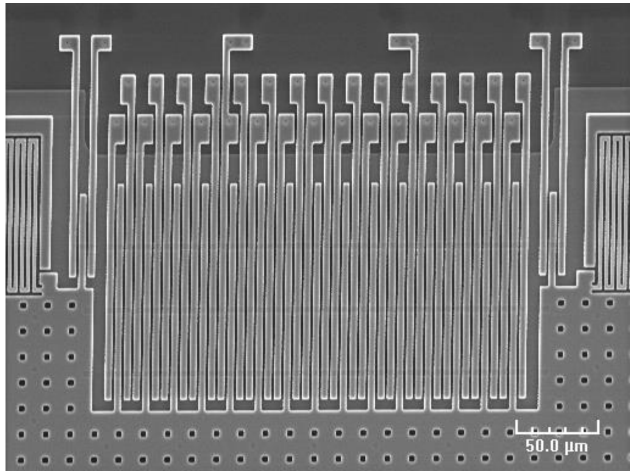
- High-power LED's: 470, 520, 620, 680 nm
- FWHM ≈ 25 nm
- Coherence length: ≈ 10 μm (620 nm)
- Matching of the OPLD within coherence length
- T and I modulation: rise and fall time of 175 nsec

Course Projects

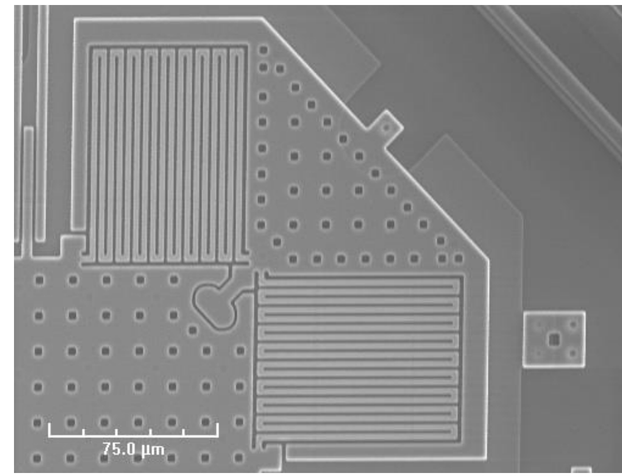
MEMS accelerometers: shape/deformation/NDT

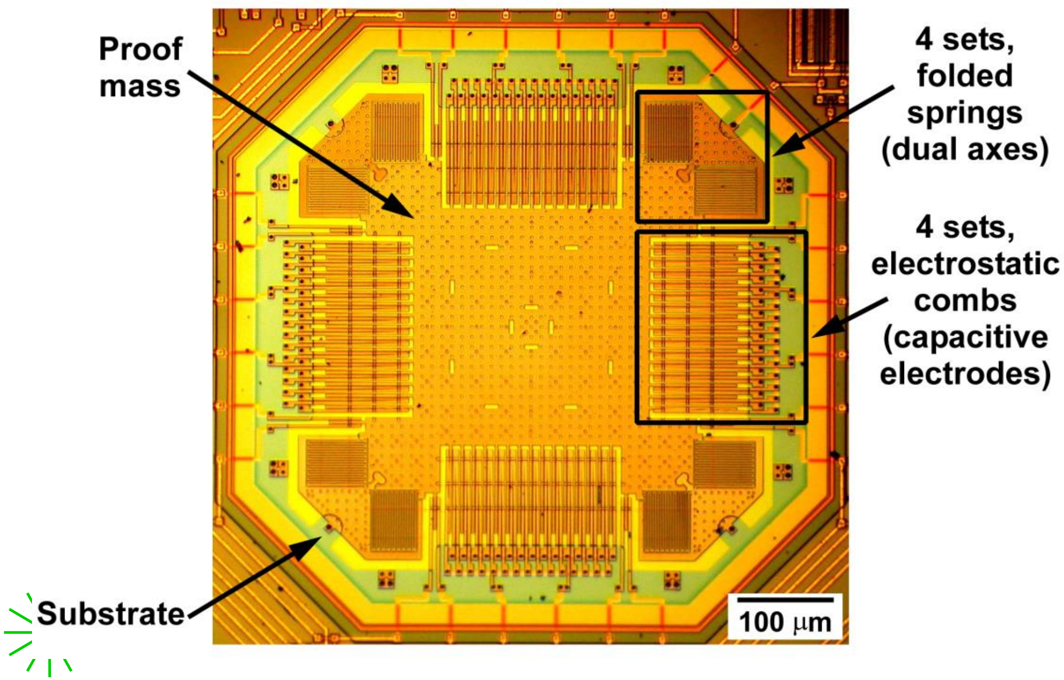
Electrostatic combs

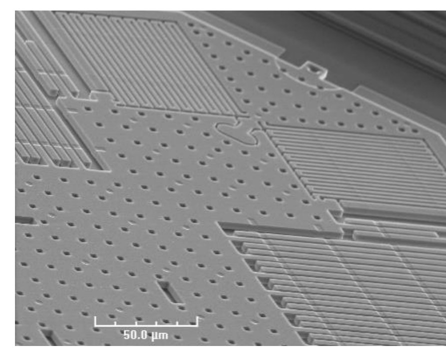




Folded springs



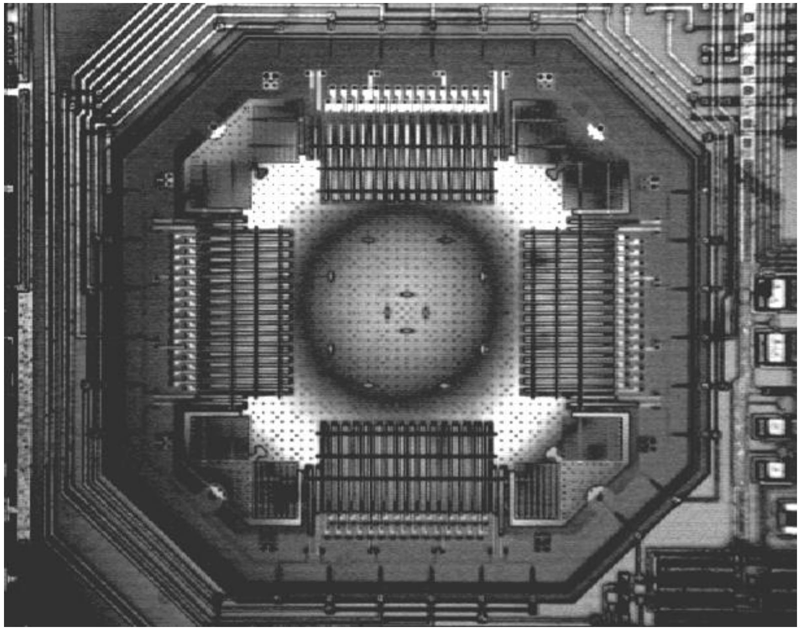




Full-field-of-view characterization of mode shapes of vibration

Fundamental frequency is related to the measuring accuracy of the MEMS device

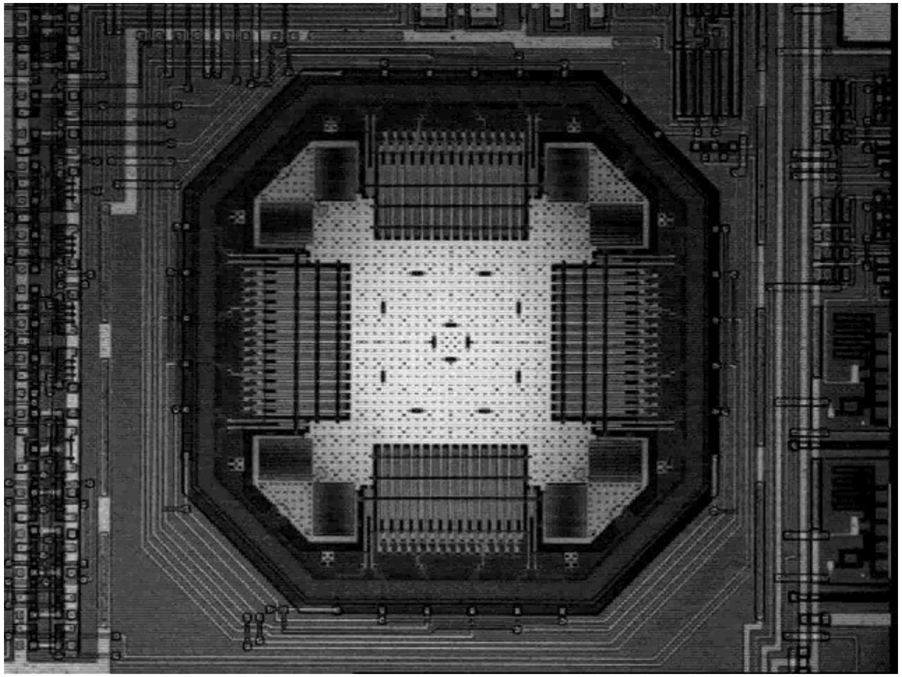
Observed fundamental mode at 10.65 KHz



100 µm

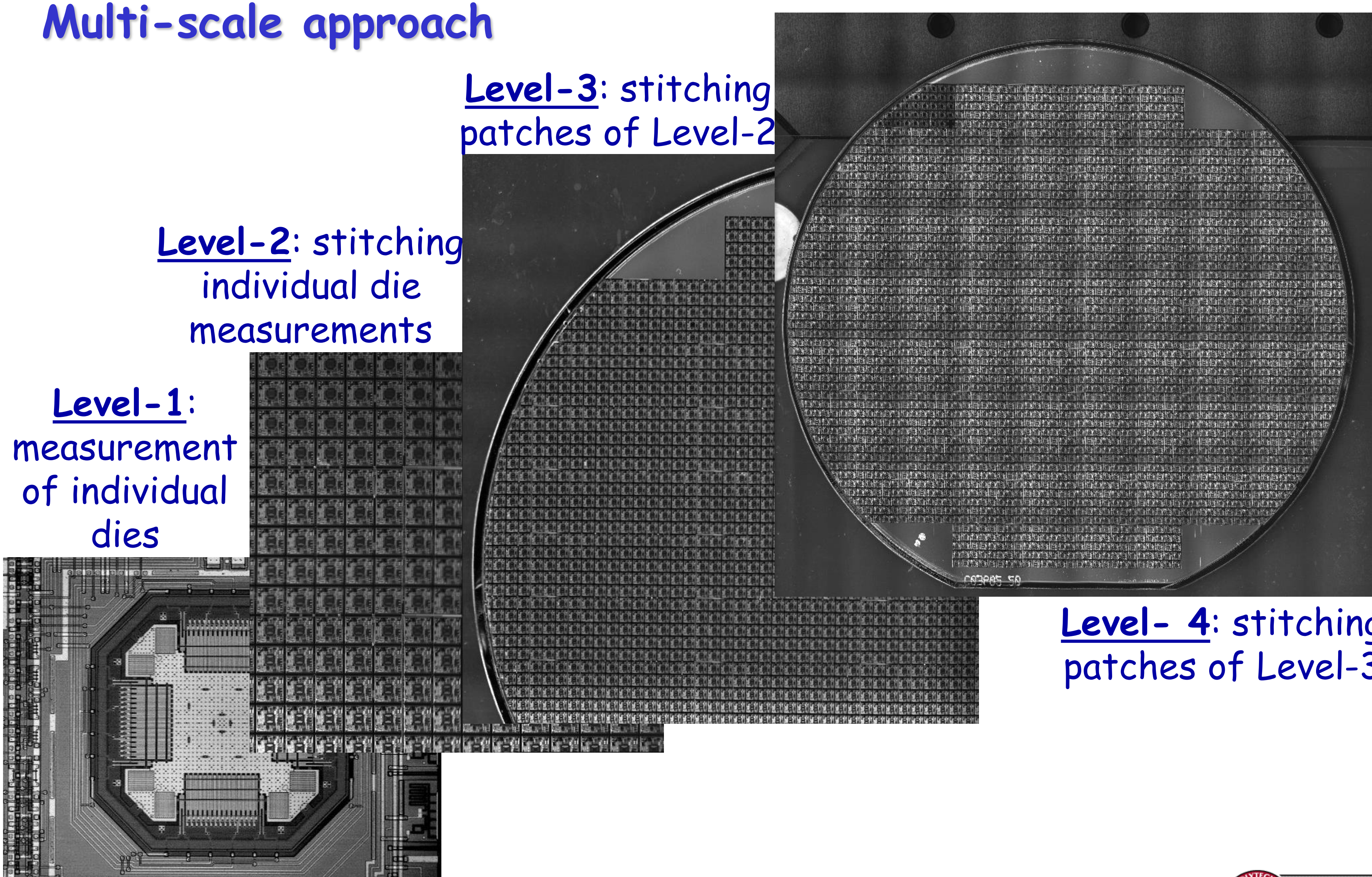
Continuous full-field-of-view measurements

Frequency scan: 10 kHz – 11 kHz



Testing at the wafer level: inspecting an ADXL202 wafer

Multi-scale approach



Announcements

- Homework distributed soon in class/web
- Project for this class: list of topics (CF) and teams, for example:
  - Modal analysis by (a) digital holography; (b) shearography; and (c) DIC. Modal analysis supported by analytical and computational work.