Basic Optics : Microlithography Topics Book pages171- 183

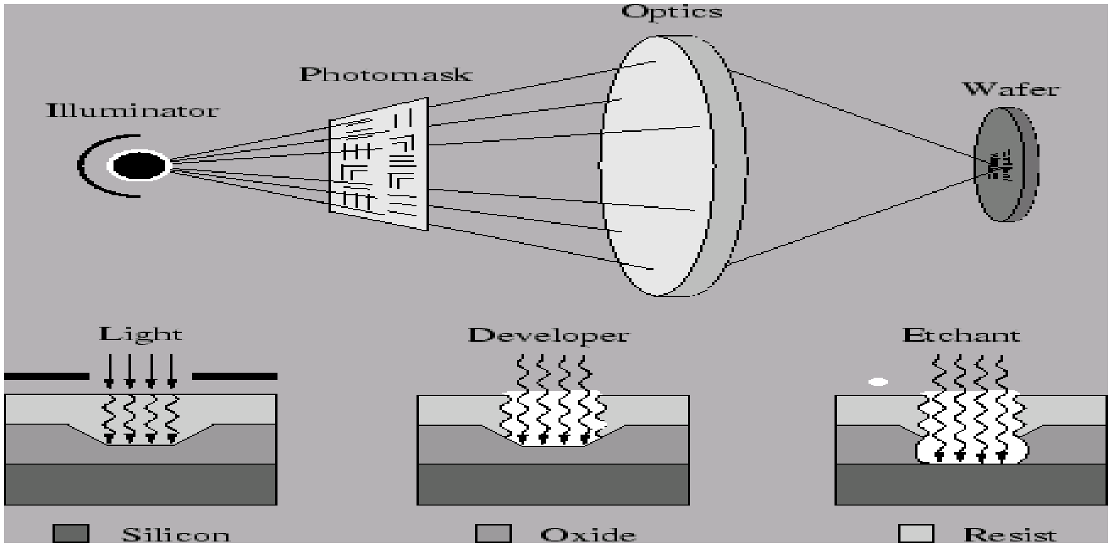
- **1. Electromagnetic Radiation**
- **2. Refractive Index and refraction**
- **3. Optical Path length**
- **4. Lens Basics**
- **5. Geometrical Optics**
- **References**
- *** Elements of Modern Optical Design, Donald C. O'Shea, John Wiley and Sons 1985**
- **ISBN 0-471-07796-8**
- **Optics, Eugene Hecht, Addison-Wesley Publishing Co., 1987, ISBN 0-201-11609-X**
- *** Fundamentals of Optics, Jenkins and White, McGraw-Hill 1976; ISBN 0-07-032330-5**
- **Websites:**
- http://www.ece.arizona.edu/~dial/ece425/notes8.pdf
- http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

Basic Optics : Microlithography Topics

http://www.iue.tuwien.ac.at/publications/PhD%20Theses/kirchauer/node17.html#fig::PRprosys

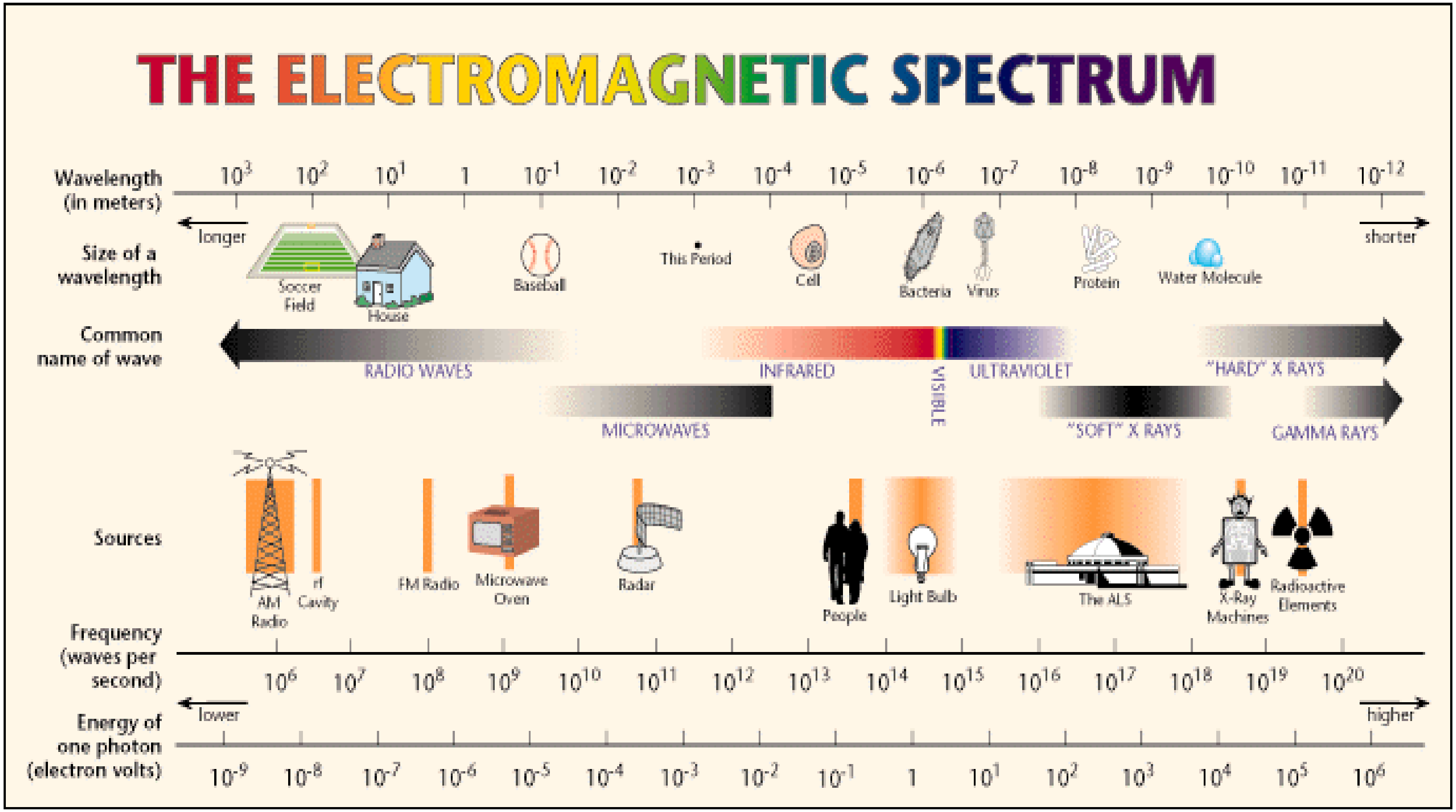
Need to know basic optics to understand how light propagates through optic system to form an image in photoresist.

Figure 2.3: An optical lithography tool generally consists of an illuminator, a photomask, an optical system, and the photoresist spinned on top of the wafer. The lithography process is based on the ability of the photoresist to store a replica of the photomask that is used for subsequent processing steps, e.g., etching, deposition or implantation.



Basic Optics : Microlithography

1. Electromagnetic radiation



Basic Optics : Microlithography

1. Electromagnetic radiation

- **Light Sources**

- Light used in lithography is monochromatic with wavelengths of 436 nm and 365 nm ranging in the *ultraviolet (UV)*, 248 nm and 193 nm belonging to *deep UV (DUV)*, and 13 nm and below settled in the *extreme UV (EUV)*. The monochromaticity stems from the fact that high quality optics can only be fabricated for a single wavelength. The type of the light source depends on the used wavelength:
- **High-pressure arc lamps.** A typical arc lamp is filled with mercury (Hg) or mercury-xenon (Hg-Xe) mixtures at a pressure of 30-40 atm. The distribution of the emitted spectrum depends on the partial pressures of Hg and Xe as well as of the total pressure of the discharge plasma. The dominating wavelengths range in the UV domain. The most prominent ones are the G-line at 436 nm used for features sizes down to 0.8 m, and the I-line at 365 nm with a maximal resolution of 0.35 m. At the moment I-line printing is the state of the art technology in industry. Other wavelengths of the spectrum have to be filtered out. Thereby the beam intensity is reduced and the exposure time is increased.

Basic Optics : Microlithography

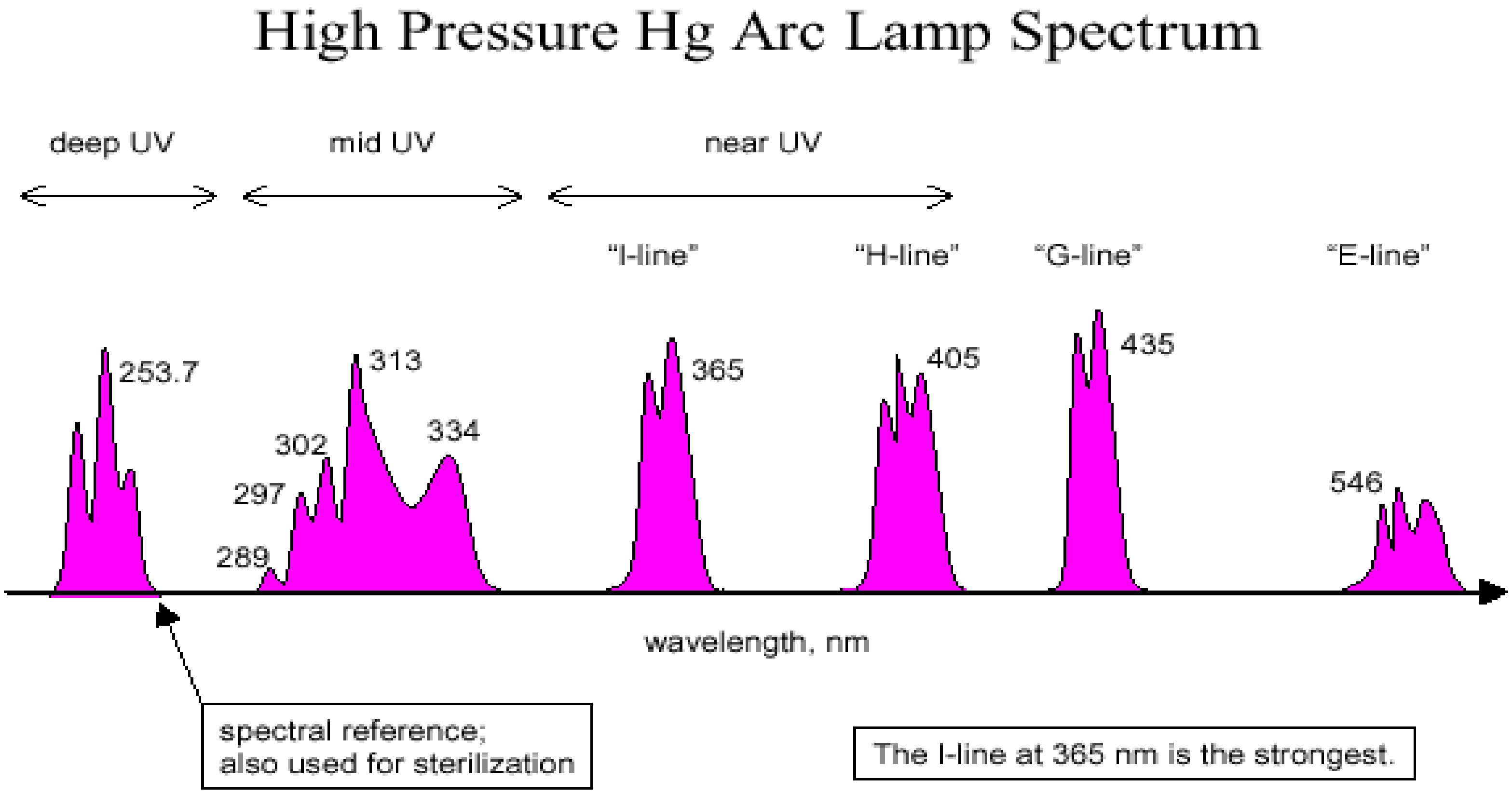
1. Electromagnetic radiation

- **Light Sources**

- **Excimer lasers.** For DUV lithography excimer lasers are the most powerful and brightest light sources. A noble gas, e.g., Krypton (Kr) or Argon (Ar), is excited and reacts with a molecule composed of two identical atoms like Fluorine (F).[b] Laser emission occurs through transitions from a metastable excited state to an unstable ground state. Excimers have a bandwidth of about 1 nm and emit strongly in a multimode fashion with relatively poor spatial coherence. This is a crucial advantage for lithography applications, because it avoids or at least relaxes the problem of ``speckle.'' Speckle means printing of a random pattern caused by phase variations of a narrow linewidth laser due to a nonideal optical system. The high-power pulses of excimer lasers allow extremely short exposure times (10-20 ns), which increases the throughput. The two most attractive wavelengths are 248 nm and 193 nm emitted from a KrF- and ArF-laser, respectively.
- ... Fluorine (F).[b]
  - **A molecule with two atoms of the same element is called dimer. The name ``excimer'' combines the two words ``excited'' and ``dimer.''**

Basic Optics : Microlithography

1. Electromagnetic radiation



High Pressure Hg Arc Lamp Spectrum

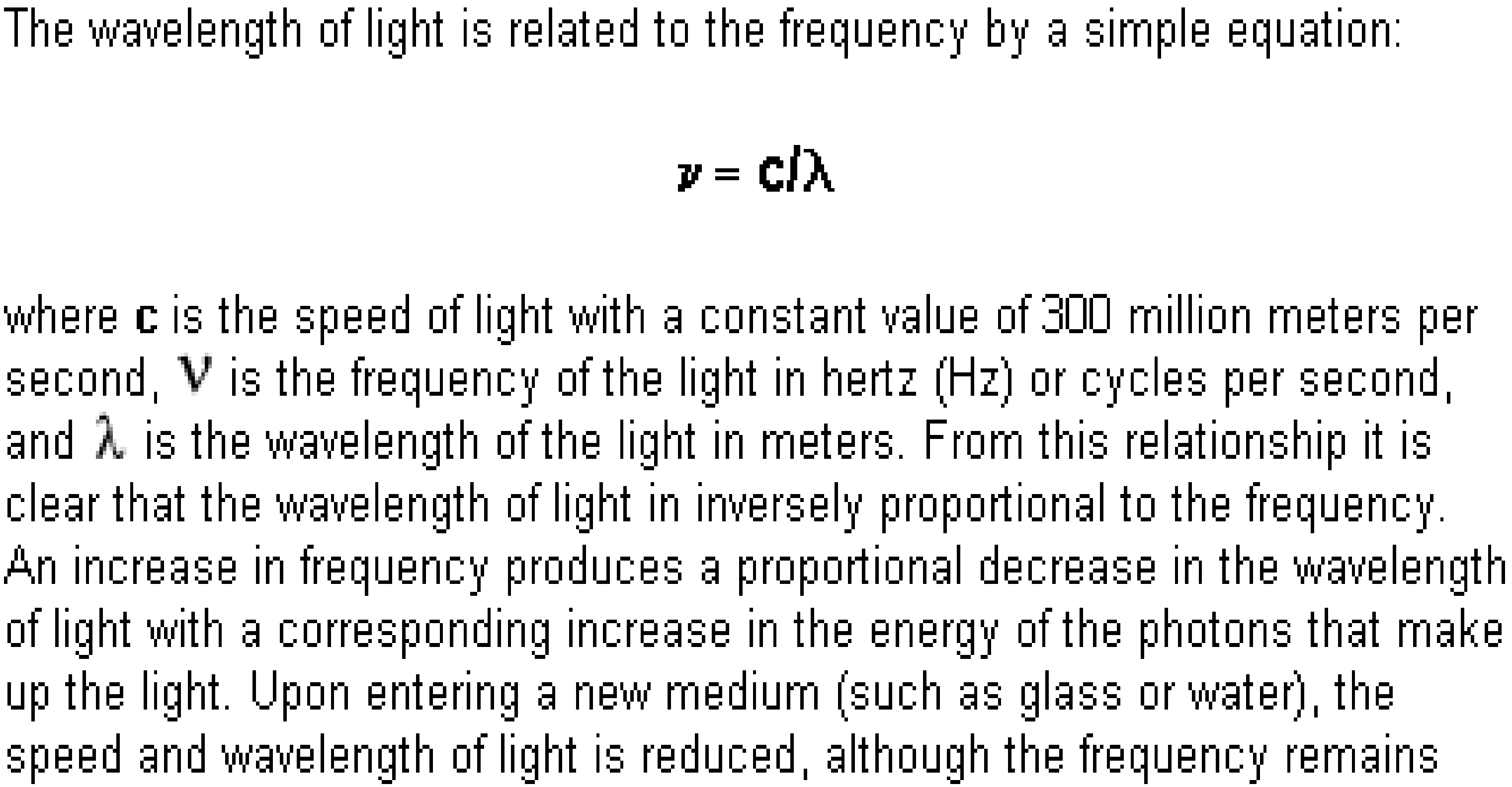
spectral reference;
also used for sterilization

The I-line at 365 nm is the strongest.

Basic Optics : Microlithography

1. Electromagnetic radiation

http://micro.magnet.fsu.edu/primer/lightandcolor/frequency.html



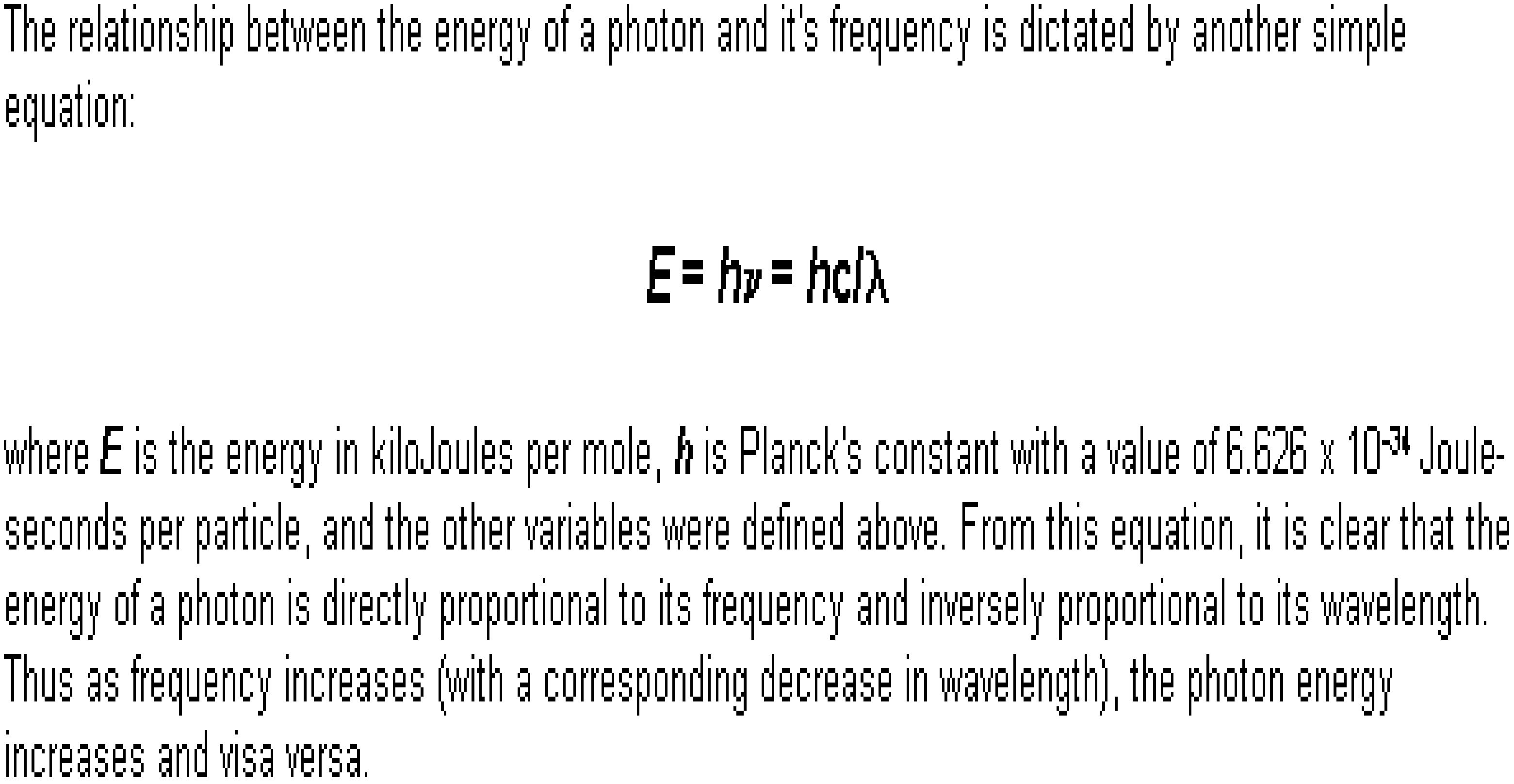
The wavelength of light is related to the frequency by a simple equation:

$$\nu = c/\lambda$$

where **c** is the speed of light with a constant value of 300 million meters per second, ν is the frequency of the light in hertz (Hz) or cycles per second, and λ is the wavelength of the light in meters. From this relationship it is clear that the wavelength of light in inversely proportional to the frequency. An increase in frequency produces a proportional decrease in the wavelength of light with a corresponding increase in the energy of the photons that make up the light. Upon entering a new medium (such as glass or water), the speed and wavelength of light is reduced, although the frequency remains

Basic Optics : Microlithography

1. Electromagnetic radiation



The relationship between the energy of a photon and it's frequency is dictated by another simple equation:

$$E = h\nu = hc/\lambda$$

where E is the energy in kiloJoules per mole, h is Planck's constant with a value of 6.626 x 10^{-34} Joule-seconds per particle, and the other variables were defined above. From this equation, it is clear that the energy of a photon is directly proportional to its frequency and inversely proportional to its wavelength. Thus as frequency increases (with a corresponding decrease in wavelength), the photon energy increases and visa versa.

Basic Optics : Microlithography

1. Electromagnetic radiation

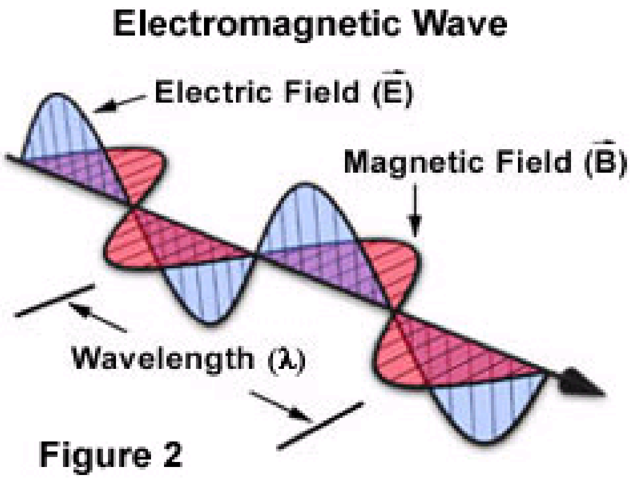


Figure 2

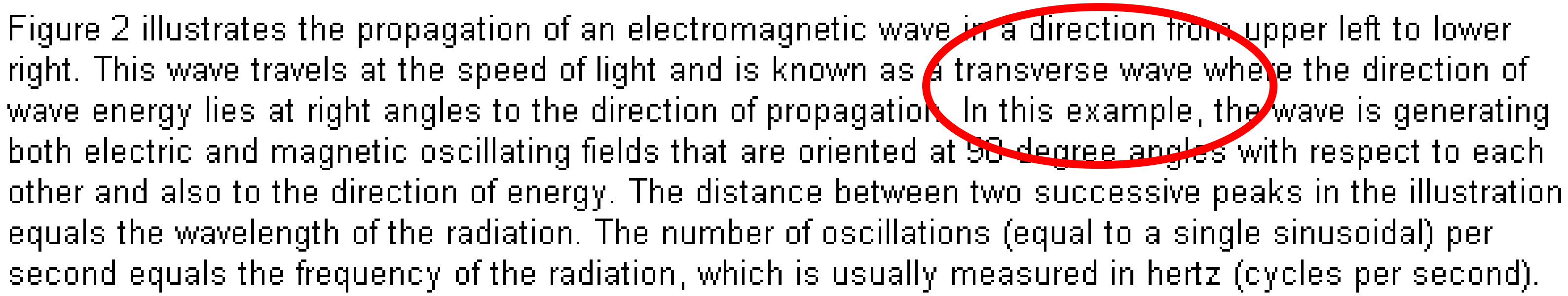


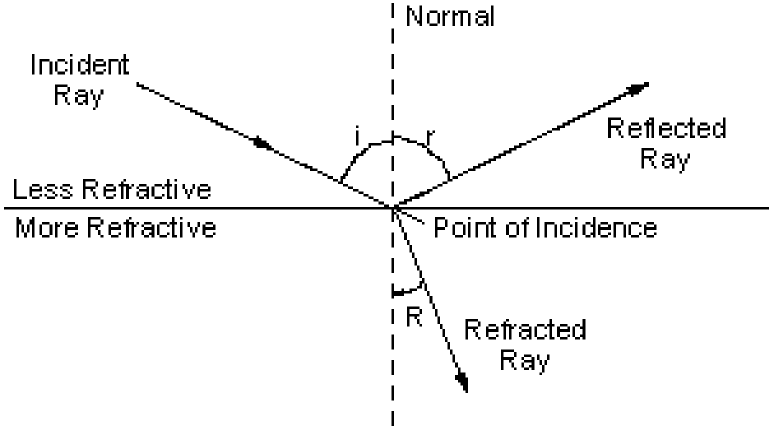
Figure 2 illustrates the propagation of an electromagnetic wave in a direction from upper left to lower right. This wave travels at the speed of light and is known as a transverse wave where the direction of wave energy lies at right angles to the direction of propagation. In this example, the wave is generating both electric and magnetic oscillating fields that are oriented at 90 degree angles with respect to each other and also to the direction of energy. The distance between two successive peaks in the illustration equals the wavelength of the radiation. The number of oscillations (equal to a single sinusoidal) per second equals the frequency of the radiation, which is usually measured in hertz (cycles per second).

Basic Optics : Microlithography

2. Refractive Index and refraction

- Excellent Interactive Java Website: **http://micro.magnet.fsu.edu/primer/java/scienceopticsu/refraction/index.html**

- **Refraction Theory** describes how light bends when passing from one medium to another **.** Definitions: rare medium = smaller refractive index medium; dense medium = larger refractive index medium;



Both Reflection and Refraction occur when the light is incident on a more refractive medium.

Basic Optics : Microlithography

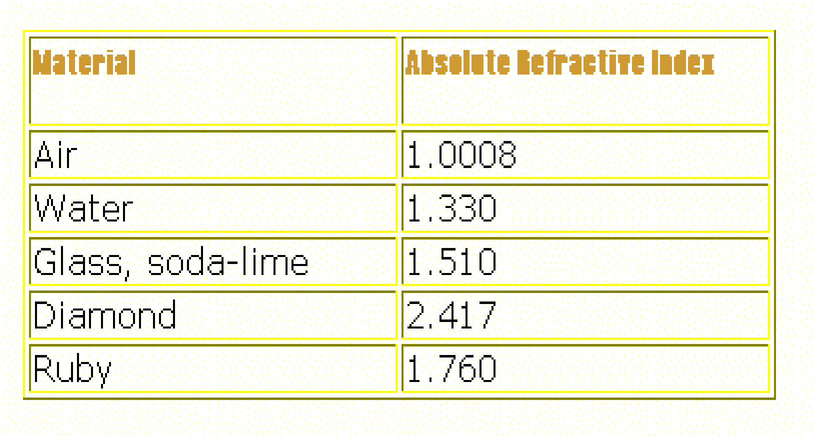
2. Refractive Index and refraction

- **Refractive Index:** The velocity of light slows down when in enters a denser medium. The wavelength λ decreases and the frequency ϖ remains constant as;
-
  $\lambda * \varpi = c$ and $\lambda_m * \varpi = v$ meters*cycles/sec =meters/sec = velocity of hυ
-
- **Refractive Index: $n = c/v = \lambda/\lambda_m$**
-
- **C = velocity of light in vacuum; v = velocity of light in medium of refractive index n; λ= wavelength in vacuum; λ_m = wavelength in medium**

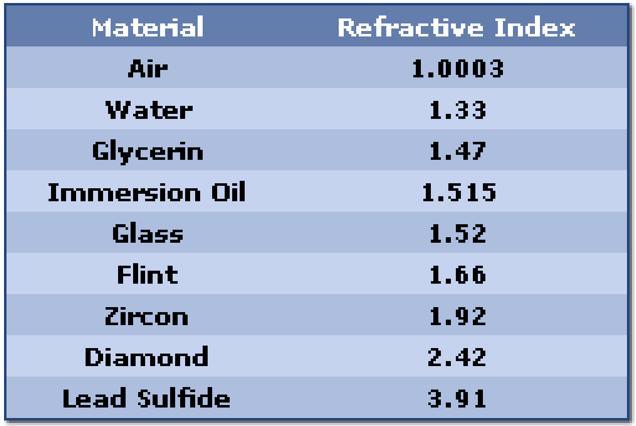
Basic Optics : Microlithography

2. Refractive Index and refraction

- Light slows down when it enters a substance, so the refractive index will always be greater than 1. Most minerals have refractive indices between 1.32 and 2.40, with values between 1.50 and 1.80
- **KEY IDEA: Refraction indices discussed here are assuming no Absorption I.e: $n = n_r = ik$ (no k extinction coefficient) The real part only!**
- **Absorption coefficient: $\alpha = 4\pi k/\lambda$**
- See website for table: http://www.geology.wisc.edu/~jill/ri.html



Material	Absolute Refractive Index
Air	1.0008
Water	1.330
Glass, soda-lime	1.510
Diamond	2.417
Ruby	1.760



Material	Refractive Index
Air	1.0003
Water	1.33
Glycerin	1.47
Immersion Oil	1.515
Glass	1.52
Flint	1.66
Zircon	1.92
Diamond	2.42
Lead Sulfide	3.91

Basic Optics : Microlithography

2. Refractive Index and refraction

- **HOWEVER!!**... the refractive index of a mineral is not necessarily the same in all directions. characterized by the number of crystallographic axes, and the relationship of the axes to one another.
- The internal symmetry of a mineral is a reflection of the **orientation of atoms into layers**.... the arrangement of the atoms determines how light interacts with the crystal!!
- Two basic types of behaviour are exhibited:

1. ***Isotropic*** - same properties (refractive index) in all directions exhibit the same physical properties regardless of where the light enters the crystal material include glasses (e.g., volcanic glass) and all isometric minerals.
2. ***Anistropic*** - different properties (different refractive index) in different directions

Related to birefrigence Anisotropic minerals are divisible into two types:

uniaxial - have two refractive indices (tetragonal and hexagonal system minerals);

biaxial - characterized by three refractive indices (triclinic, monoclinic and orthorhombic system minerals).

QUESTION: Where are crystals used in photolithography?

Basic Optics : Microlithography

2. Refractive Index and refraction

Snells law: (Dutch 1621) defines refection at an interface of two mediums with different refractive indices. Very key equation used in optical design and ray tracing:

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

Light Refraction Through Glass and Water

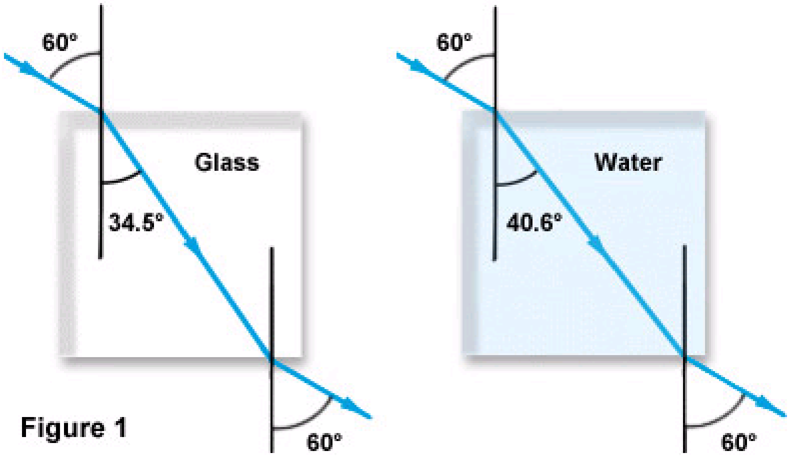
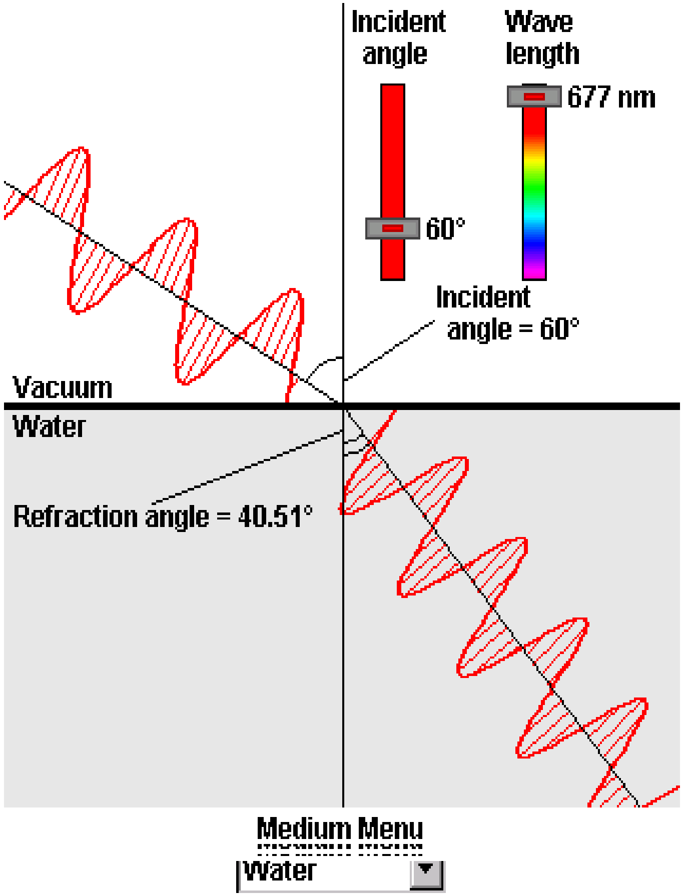


Figure 1

Basic Optics : Microlithography

2. Refractive Index and refraction

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

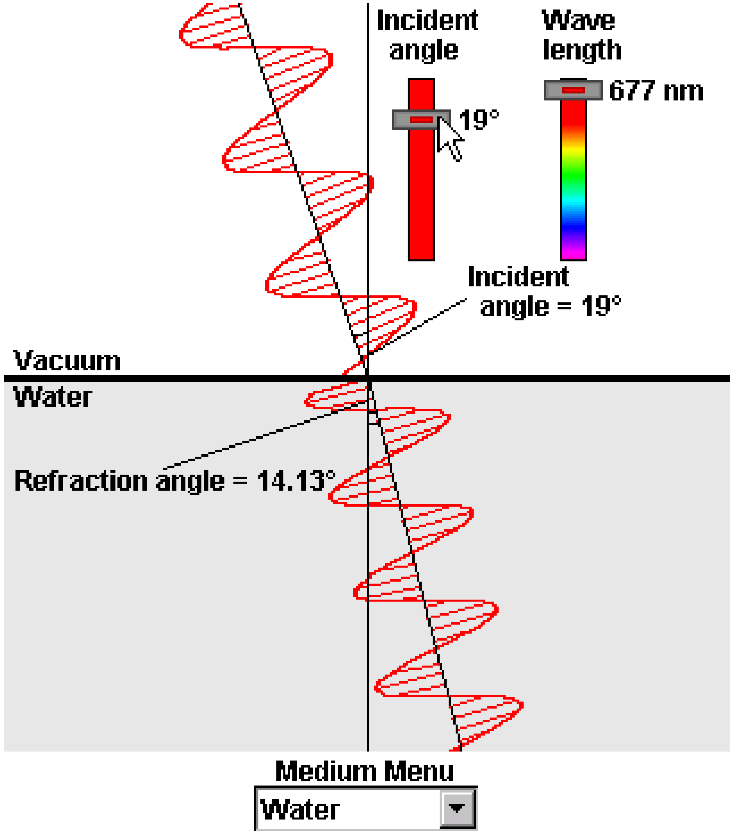


Incident angle = 60°

Refraction angle = 40.51°

Wave length 677 nm

Medium Menu: Water



Incident angle = 19°

Refraction angle = 14.13°

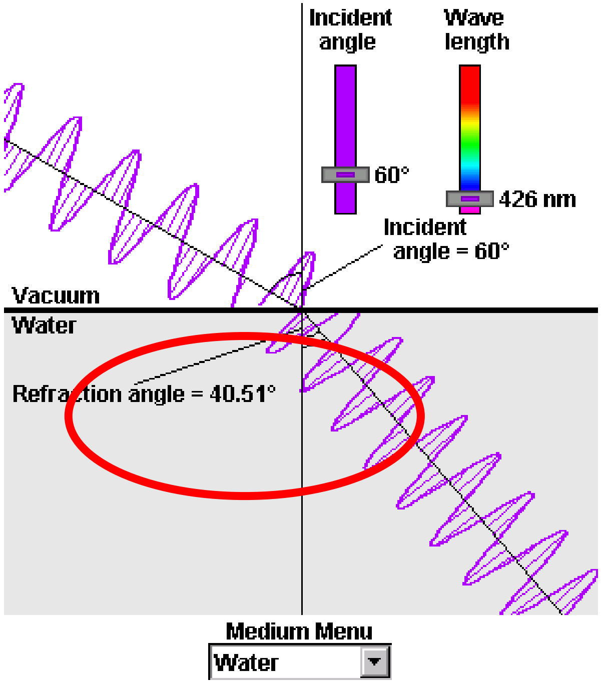
Wave length 677 nm

Medium Menu: Water

Basic Optics : Microlithography

2. Refractive Index and refraction

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

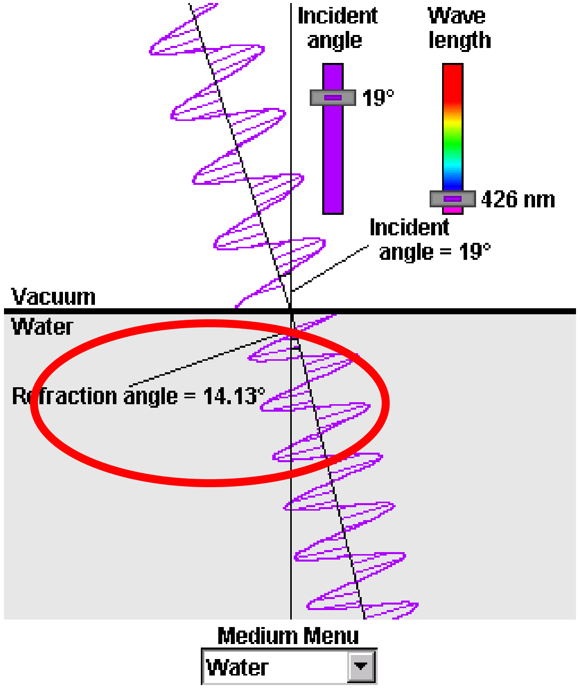


Incident angle = 60°

Refraction angle = 40.51°

Medium Menu

Water



Incident angle = 19°

Refraction angle = 14.13°

Medium Menu

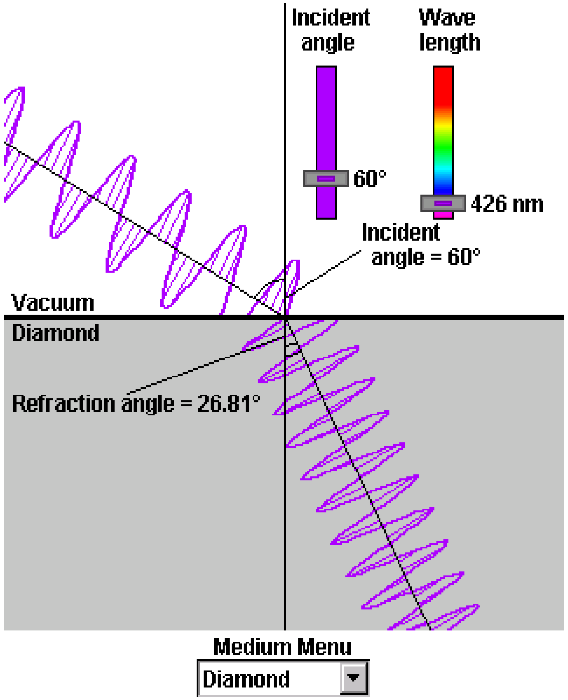
Water

Do you see any problems here?

Basic Optics : Microlithography

2. Refractive Index and refraction

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html



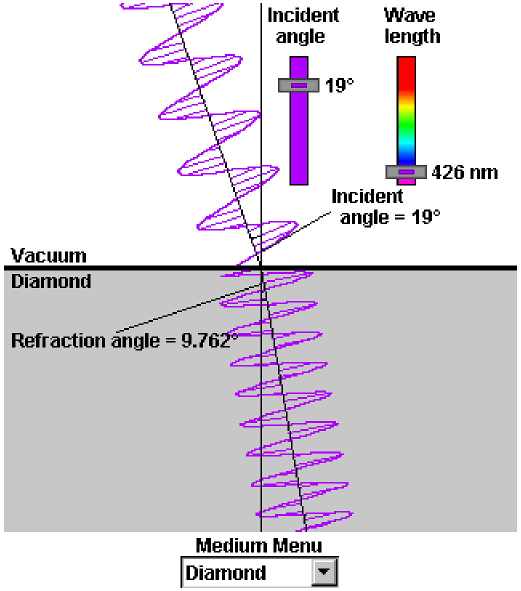
60°

426 nm

Incident angle = 60°

Refraction angle = 26.81°

Medium Menu: Diamond



19°

426 nm

Incident angle = 19°

Refraction angle = 9.762°

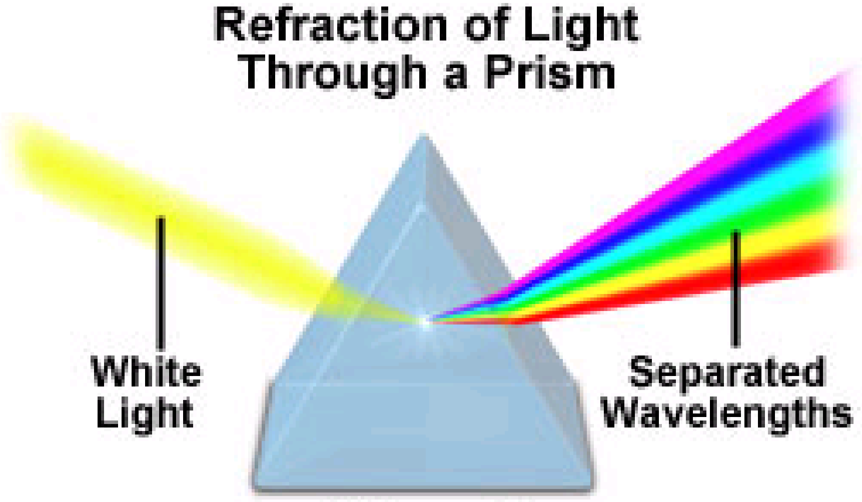
Medium Menu: Diamond

Change refractive index effect.

Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

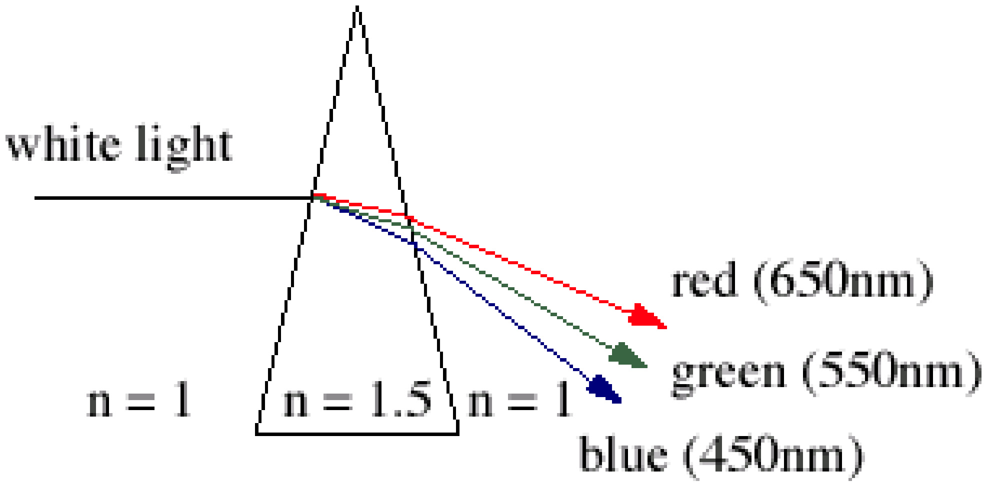
- Dispersion: refractive index is wavelength dependent: short wavelengths have higher refractive index and thus have a higher refraction angle. That’s why blue light is closer to the prism than red light.



Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

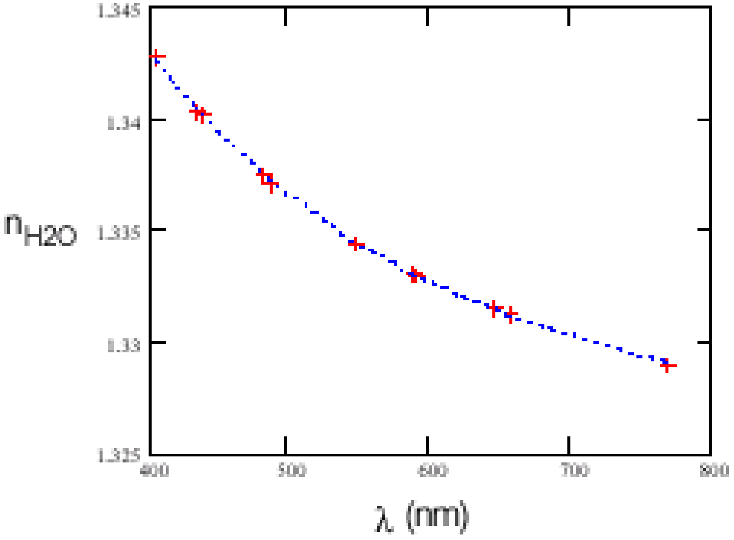
- Dispersion: refractive index is wavelength dependent: short wavelengths have higher refractive index and thus have a higher refraction angle. That's why blue light is closer to the prism than red light. This dispersion explains chromatic aberration and why the excimer lasers need tight bandwidths!



Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

- Dispersion: refractive index is wavelength dependent:



The Abbé Refractometer

Fig.1: Index of refraction for H_2O at 20°C as a function of the wavelength • . The data are from ref.[LB], p.5-566, and the curve is Cauchy's equation with the coefficients

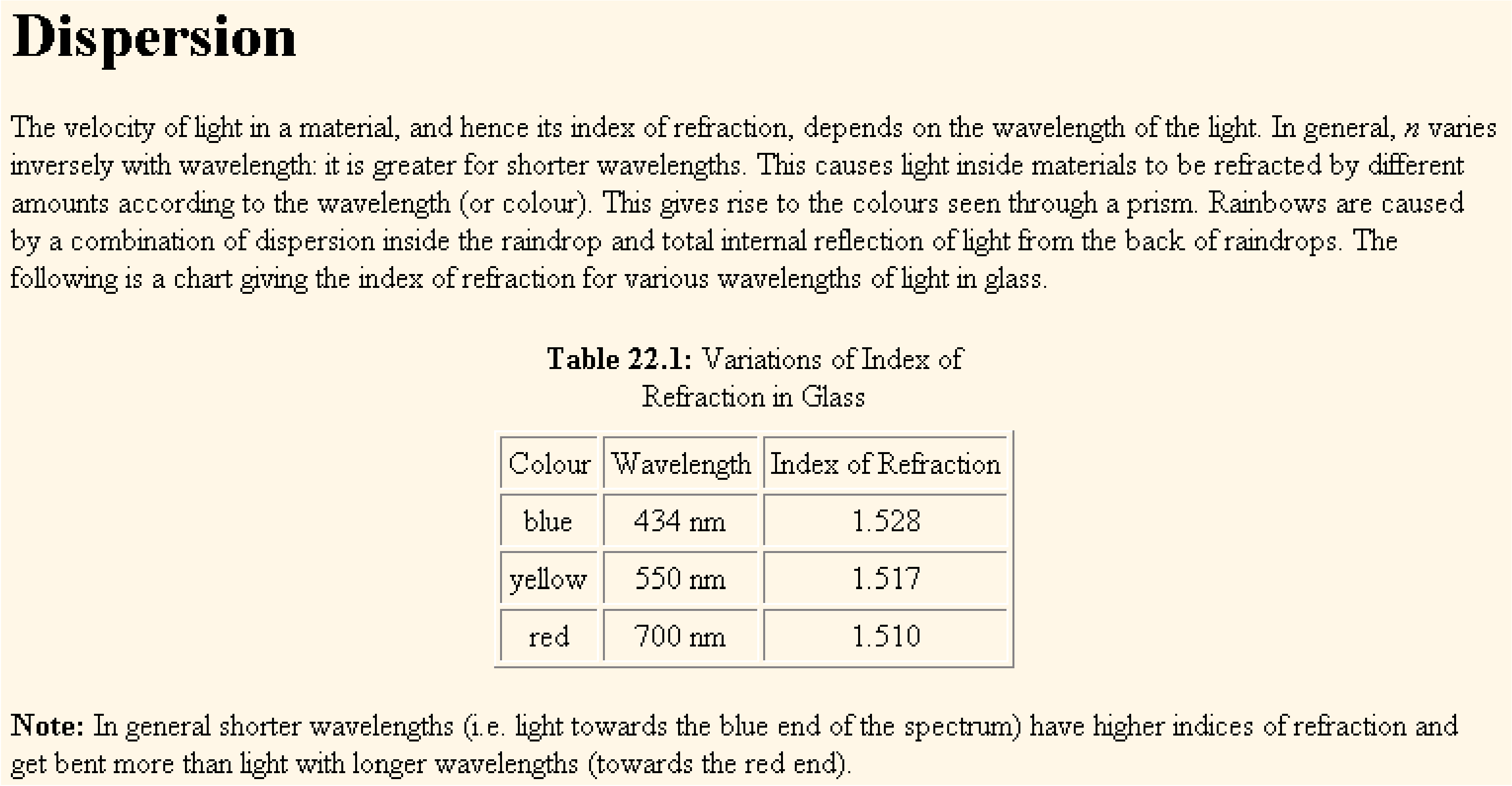
$A = 1.323$, $B = 3.62 \cdot 10^3\ \mathrm{nm}^2$ and

$C = -6.74 \cdot 10^7\ \mathrm{nm}^4$

Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

- Dispersion: refractive index is wavelength dependent



Dispersion

The velocity of light in a material, and hence its index of refraction, depends on the wavelength of the light. In general, n varies inversely with wavelength: it is greater for shorter wavelengths. This causes light inside materials to be refracted by different amounts according to the wavelength (or colour). This gives rise to the colours seen through a prism. Rainbows are caused by a combination of dispersion inside the raindrop and total internal reflection of light from the back of raindrops. The following is a chart giving the index of refraction for various wavelengths of light in glass.

Table 22.1: Variations of Index of Refraction in Glass

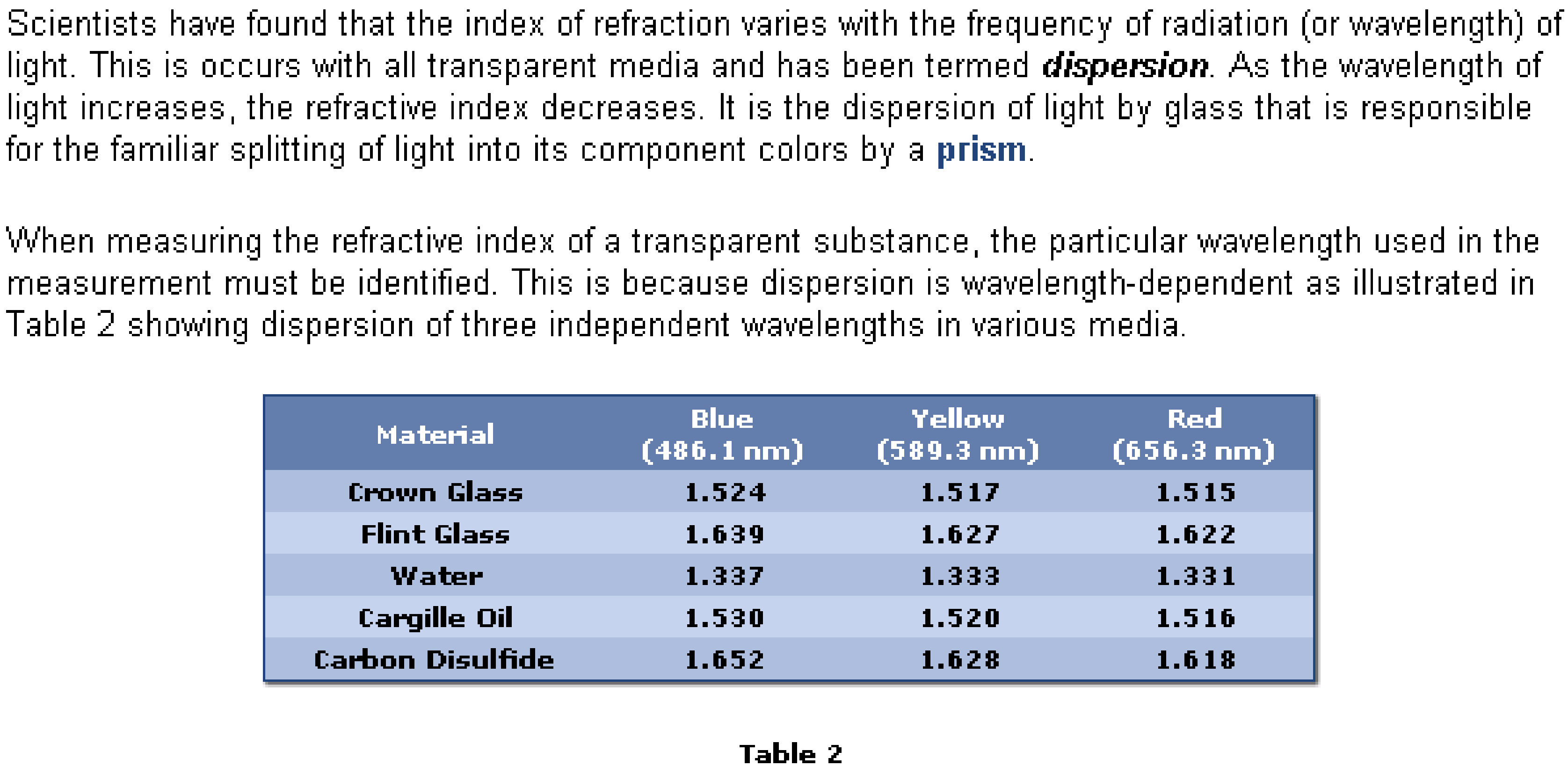
Colour	Wavelength	Index of Refraction
blue	434 nm	1.528
yellow	550 nm	1.517
red	700 nm	1.510

Note: In general shorter wavelengths (i.e. light towards the blue end of the spectrum) have higher indices of refraction and get bent more than light with longer wavelengths (towards the red end).

Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html



Scientists have found that the index of refraction varies with the frequency of radiation (or wavelength) of light. This is occurs with all transparent media and has been termed ***dispersion***. As the wavelength of light increases, the refractive index decreases. It is the dispersion of light by glass that is responsible for the familiar splitting of light into its component colors by a **prism**.

When measuring the refractive index of a transparent substance, the particular wavelength used in the measurement must be identified. This is because dispersion is wavelength-dependent as illustrated in Table 2 showing dispersion of three independent wavelengths in various media.

Material	Blue (486.1 nm)	Yellow (589.3 nm)	Red (656.3 nm)
Crown Glass	1.524	1.517	1.515
Flint Glass	1.639	1.627	1.622
Water	1.337	1.333	1.331
Cargille Oil	1.530	1.520	1.516
Carbon Disulfide	1.652	1.628	1.618

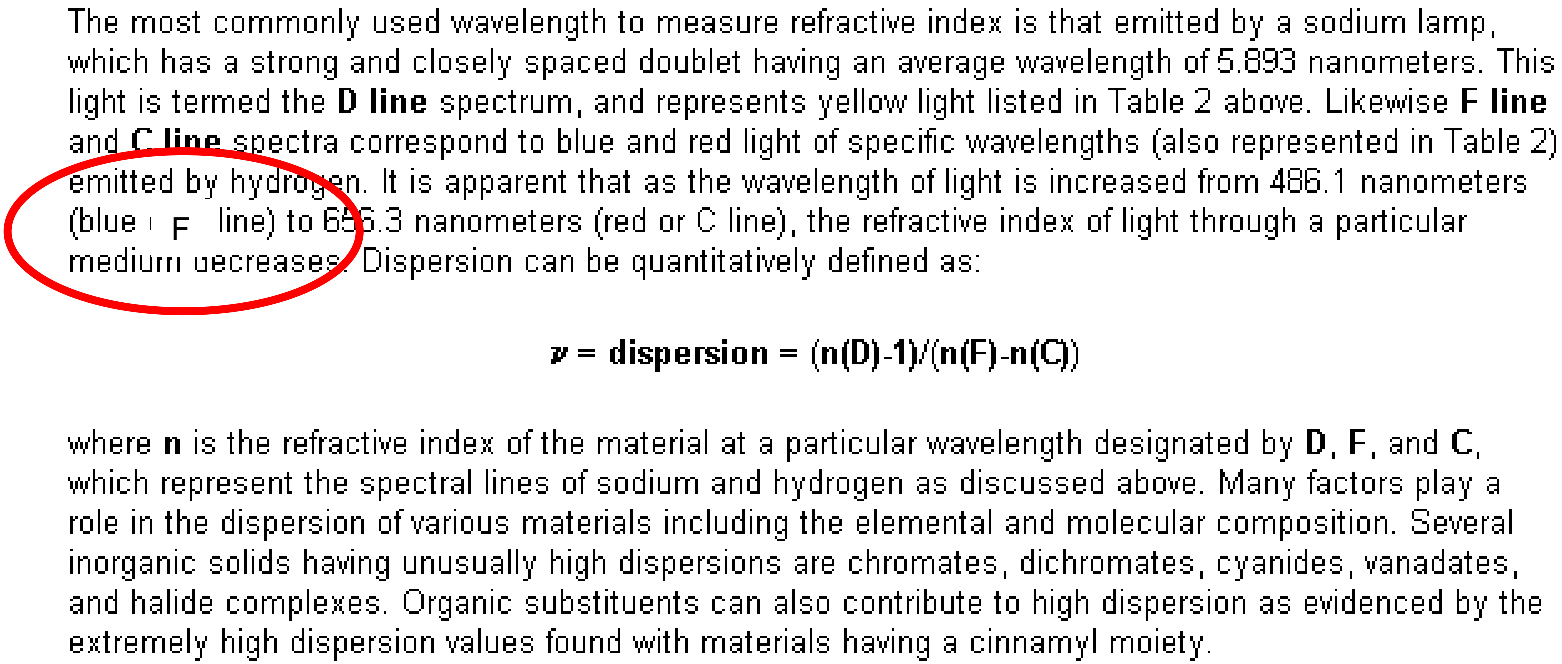
Table 2

Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

- **Dispersion: refractive index is wavelength dependent: quantified with the Abbe numbers (dispersive index and V-numbers)**



The most commonly used wavelength to measure refractive index is that emitted by a sodium lamp, which has a strong and closely spaced doublet having an average wavelength of 5.893 nanometers. This light is termed the **D line** spectrum, and represents yellow light listed in Table 2 above. Likewise **F line** and **C line** spectra correspond to blue and red light of specific wavelengths (also represented in Table 2) emitted by hydrogen. It is apparent that as the wavelength of light is increased from 486.1 nanometers (blue F line) to 656.3 nanometers (red or C line), the refractive index of light through a particular medium decreases. Dispersion can be quantitatively defined as:

$$\nu = \textbf{dispersion} = (n(D)-1)/(n(F)-n(C))$$

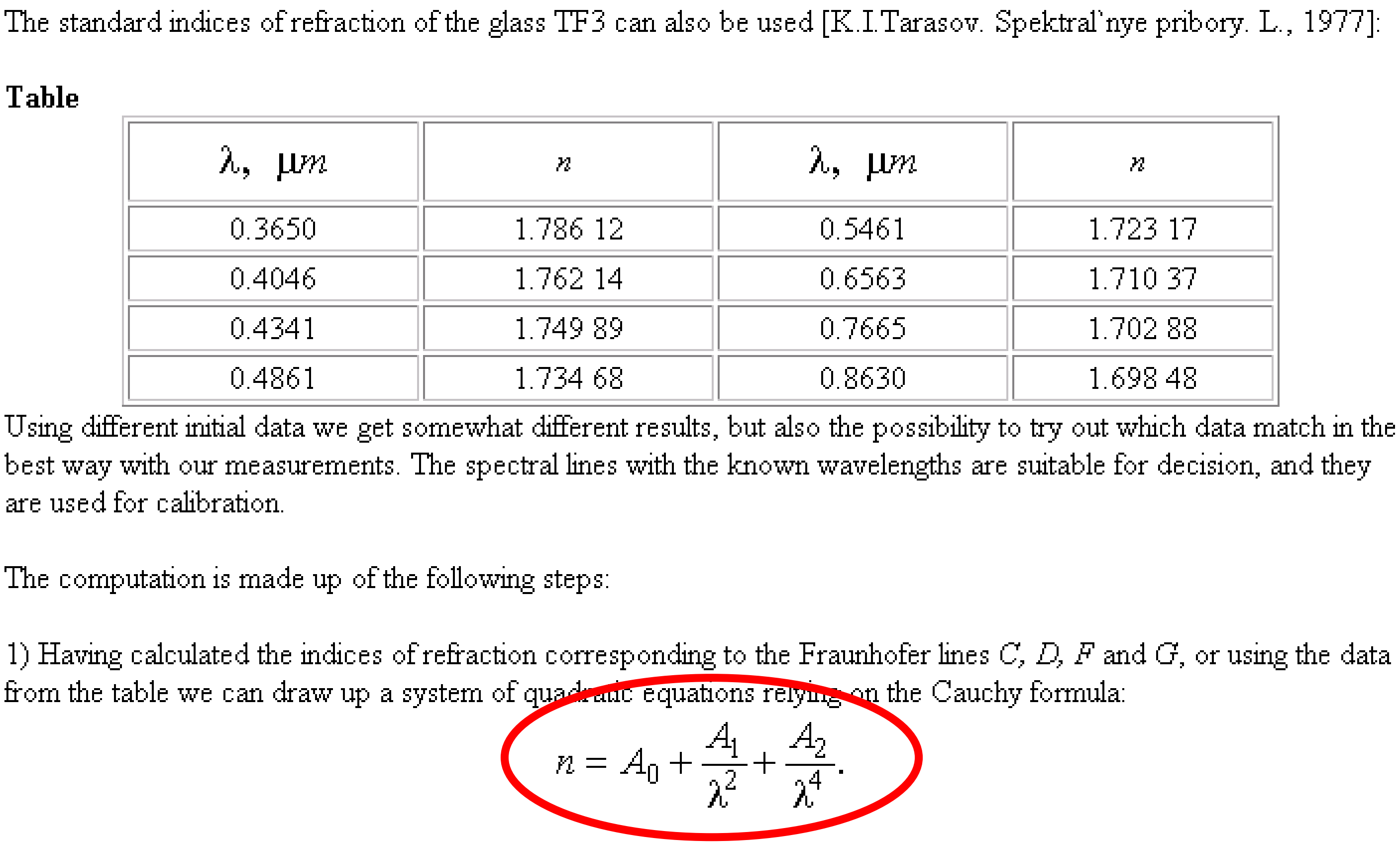
where **n** is the refractive index of the material at a particular wavelength designated by **D**, **F**, and **C**, which represent the spectral lines of sodium and hydrogen as discussed above. Many factors play a role in the dispersion of various materials including the elemental and molecular composition. Several inorganic solids having unusually high dispersions are chromates, dichromates, cyanides, vanadates, and halide complexes. Organic substituents can also contribute to high dispersion as evidenced by the extremely high dispersion values found with materials having a cinnamyl moiety.

Basic Optics : Microlithography

2. Refractive Index and refraction Dispersion

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

- Dispersion: refractive index is wavelength dependent



The standard indices of refraction of the glass TF3 can also be used [K.I.Tarasov. Spektral'nye pribory. L., 1977]:

Table

λ, μm	n	λ, μm	n
0.3650	1.786 12	0.5461	1.723 17
0.4046	1.762 14	0.6563	1.710 37
0.4341	1.749 89	0.7665	1.702 88
0.4861	1.734 68	0.8630	1.698 48

Using different initial data we get somewhat different results, but also the possibility to try out which data match in the best way with our measurements. The spectral lines with the known wavelengths are suitable for decision, and they are used for calibration.

The computation is made up of the following steps:

1) Having calculated the indices of refraction corresponding to the Fraunhofer lines *C*, *D*, *F* and *G*, or using the data from the table we can draw up a system of quadratic equations relying on the Cauchy formula:

$$n = A_0 + \frac{A_1}{\lambda^2} + \frac{A_2}{\lambda^4}.$$

Basic Optics : Microlithography

2. Refractive Index and refraction

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

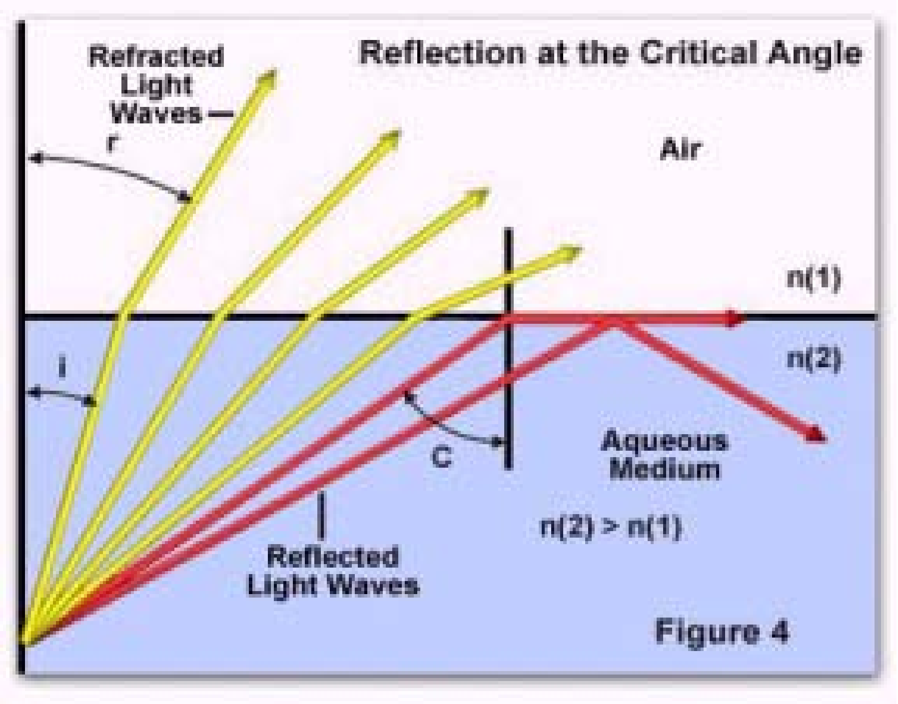
Total internal reflection when angle refraction = 90^o

Critical Angle: Defined as that angle where light is no longer refracted but reflected when light propagates from dense to rare mediums.

Snells law : nsinΦ = n’sinΦ’

Let Φ = 90o then critical angle is

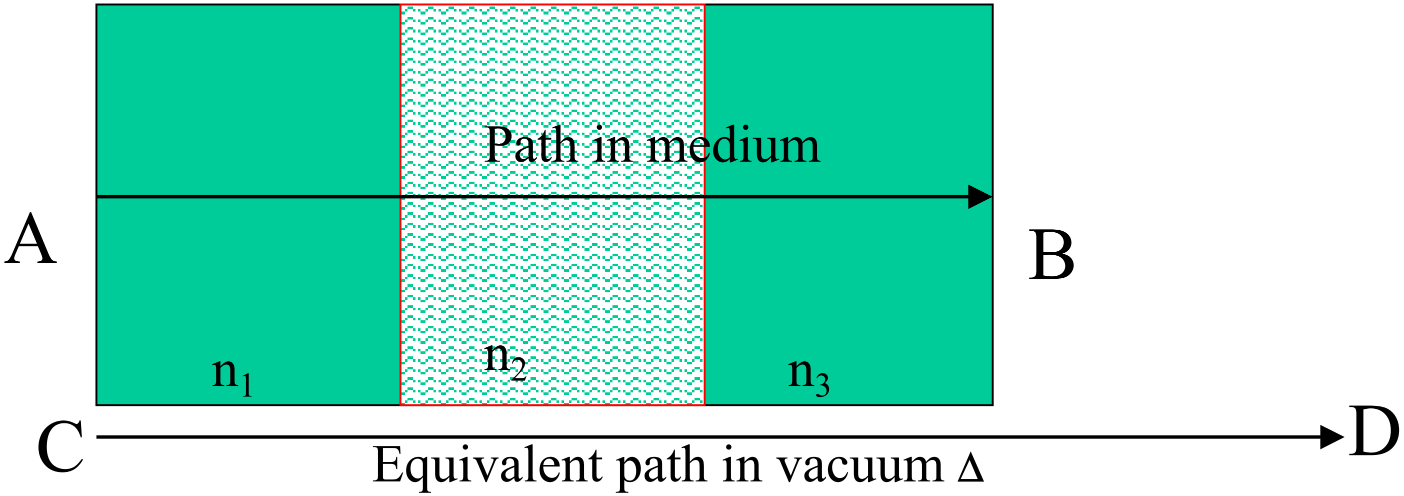
sinΦ’ $\sin\Phi_c$=n’/n



Basic Optics : Microlithography

3. Optical Path length: Key Concept!

- **Optical path length OPL:** Defined as the distance light would travel in a vacuum in the same time it takes to travel through a medium of thickness d with refractive index n:
  - **OPL** $\Delta = nd = \lambda/\lambda_m\, d$

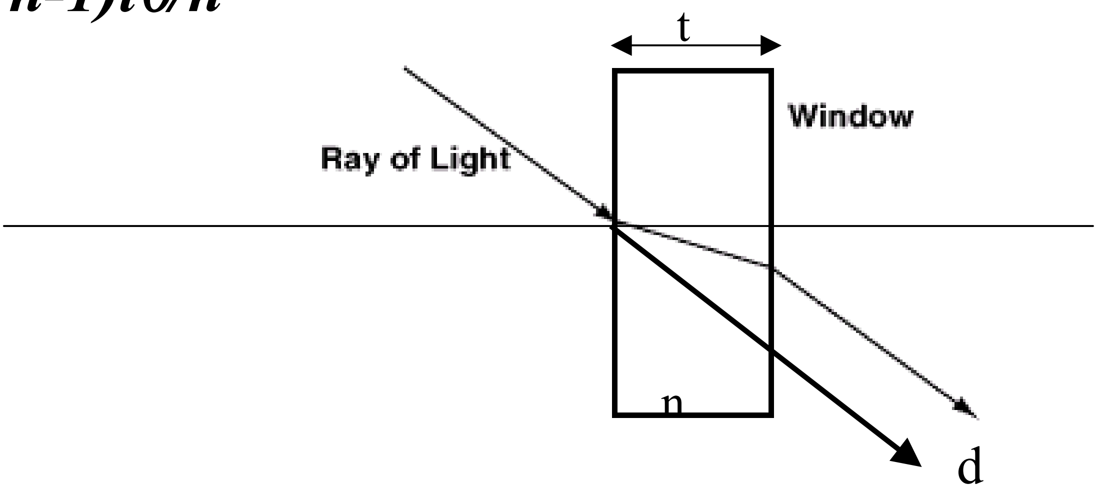


- **OPL** $\Delta = nd + n'd' + n''d''$

Basic Optics : Microlithography

3. Optical path length

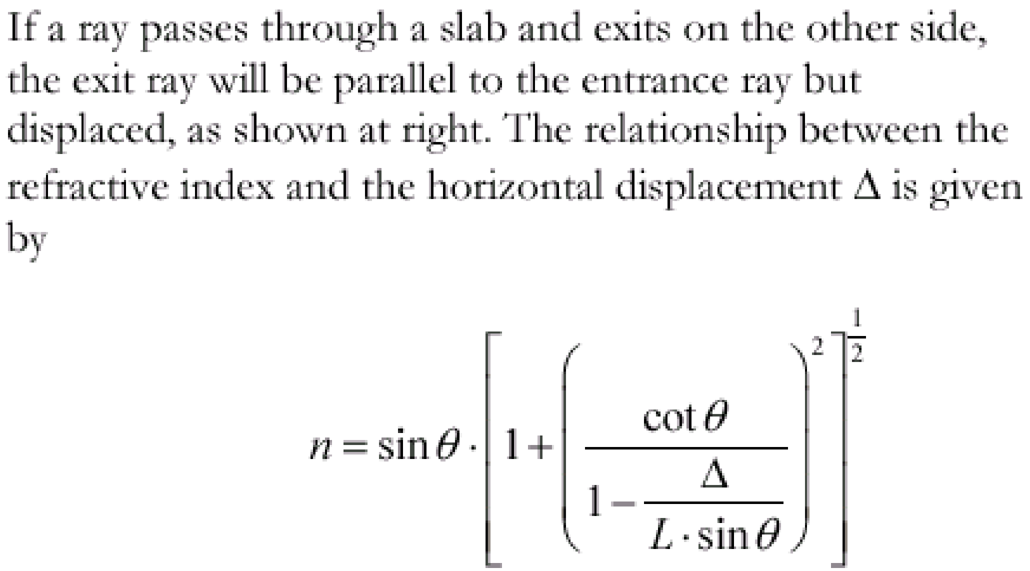
- **Refraction and beam shifts relationships:**
- **Very important idea for image displacements with pellicle or parallel plates (focus offset system) in optical path.**
- $d=(n-1)t\theta/n$



Basic Optics : Microlithography

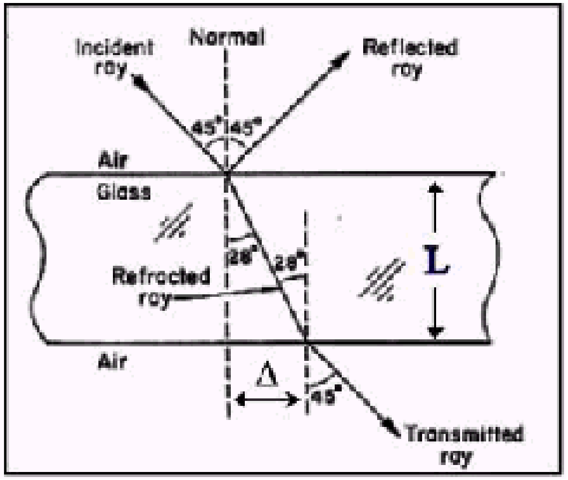
3. Optical path length

- **Refraction and parallel plate beam displacement :**
-



If a ray passes through a slab and exits on the other side, the exit ray will be parallel to the entrance ray but displaced, as shown at right. The relationship between the refractive index and the horizontal displacement Δ is given by

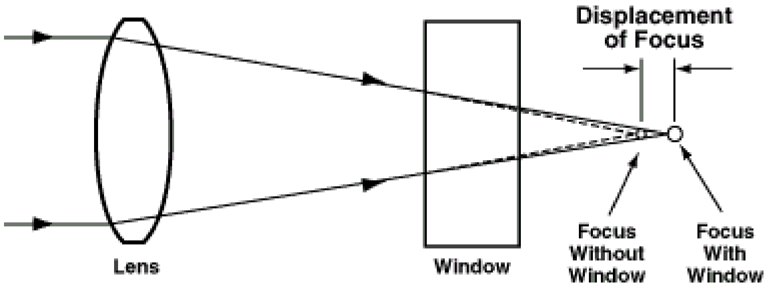
$$n = \sin\theta \cdot \left[1 + \left(\frac{\cot\theta}{1 - \frac{\Delta}{L \cdot \sin\theta}} \right)^2 \right]^{\frac{1}{2}}$$



Basic Optics : Microlithography

3. Optical path length

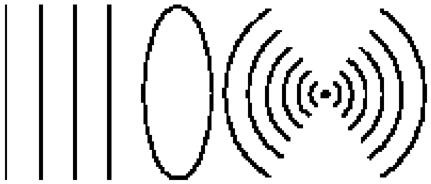
- **Refraction and beam shifts relationships:**
- **Very important idea for image displacements with pellicle or parallel plates (focus offset system) in optical path.**
  - ***Displacement d=(n-1)t/n***

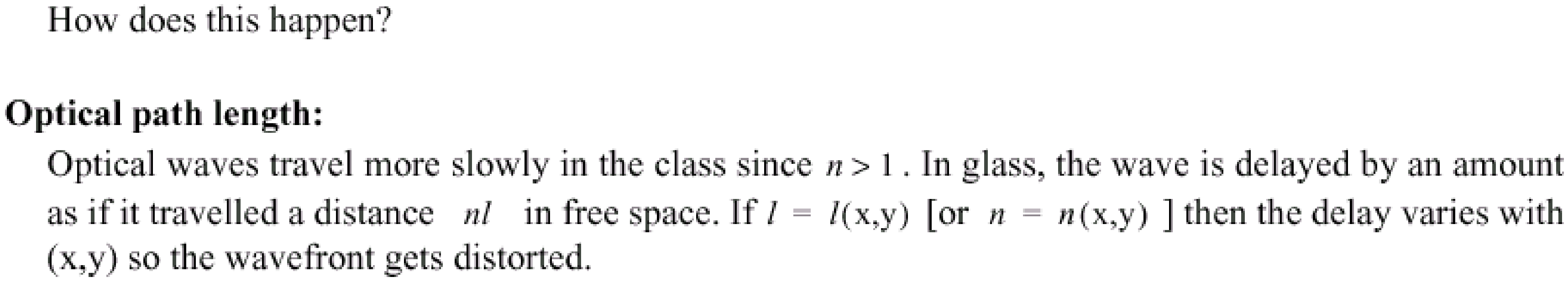


Basic Optics : Microlithography

3. Optical path length

- **Refraction: A lens modifies a wavefront For example from planar to spherical. The idea is critical to understanding lens aberrations!**





How does this happen?

Optical path length:

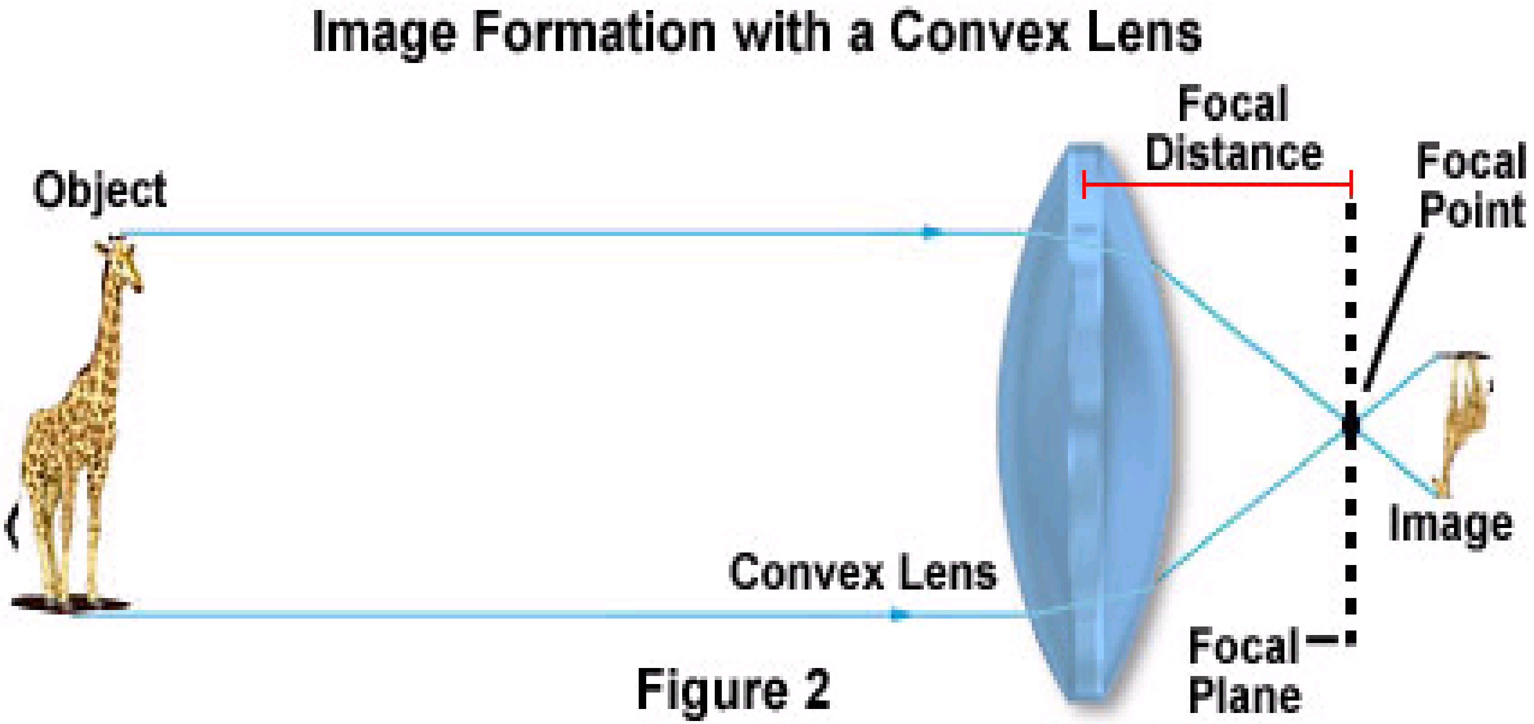
Optical waves travel more slowly in the class since $n > 1$. In glass, the wave is delayed by an amount as if it travelled a distance nl in free space. If $l = l(x,y)$ [or $n = n(x,y)$] then the delay varies with (x,y) so the wavefront gets distorted.

Basic Optics : Microlithography

4. Focal Length

http://micro.magnet.fsu.edu/primer/lightandcolor/refraction.html

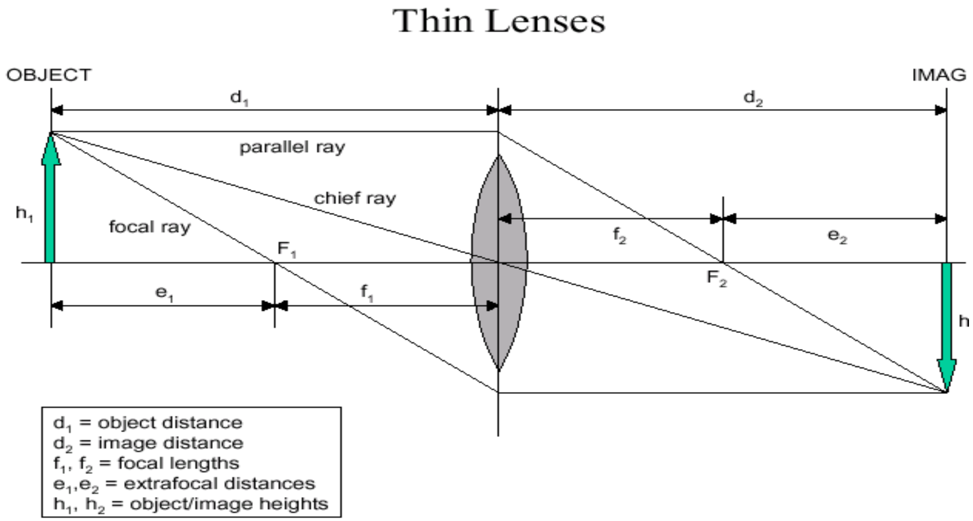
Image formation with a simple lens



Basic Optics : Microlithography

5. Geometrical Optics

- Geometrical Optics: Use rays to locate image plane
- ***<u>RAYS:</u>***
- **<u>Focal ray:</u>** Ray emitted from off-axis point passing through front focal plane of the optical system, Focal ray emerges parallel to optical axis
- **<u>Parallel ray:</u>** Ray emitted from off-axis point traveling parallel to the optical axis. Parallel ray passes through the back focal plane.


Thin Lenses

Basic Optics : Microlithography

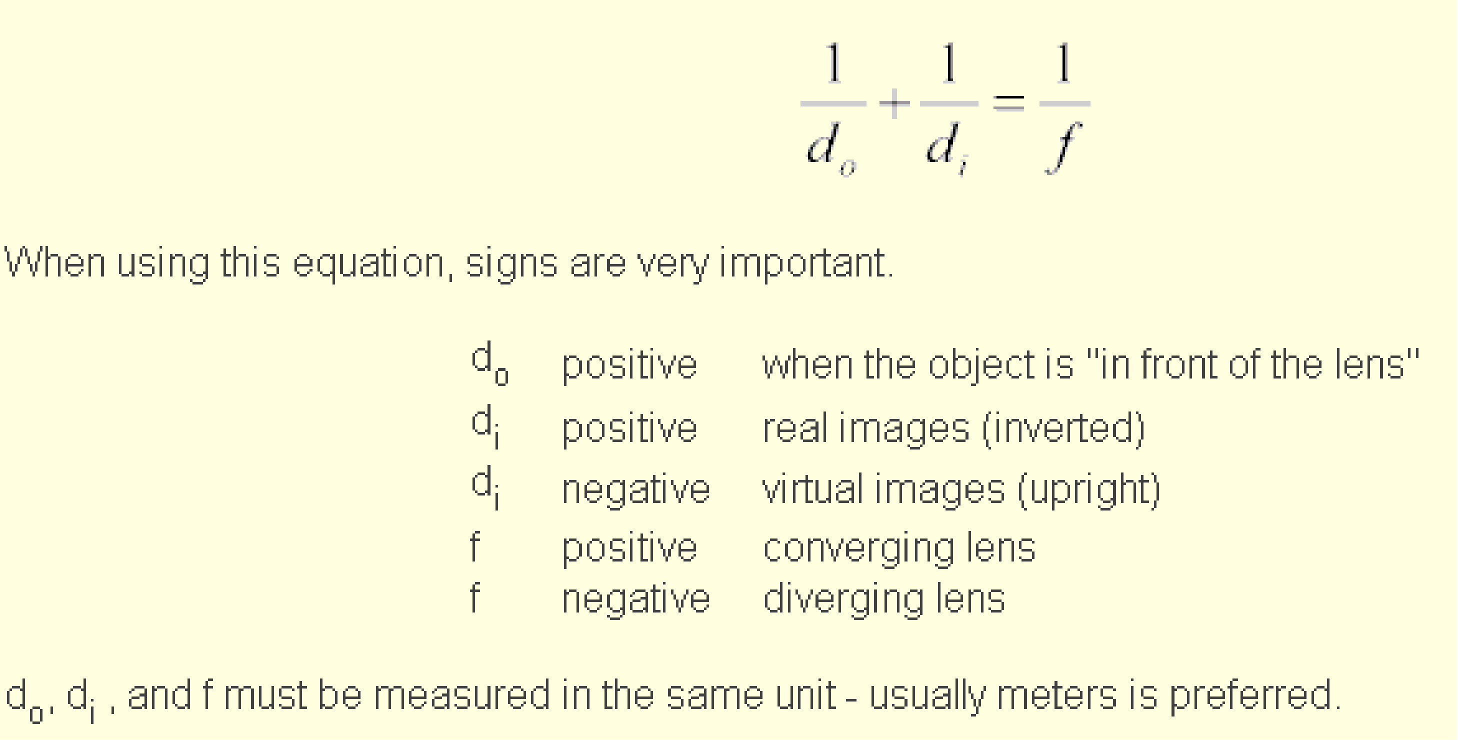
5. Geometrical Optics

- **Geometrical Optics:** Use rays to locate image Plane. Apply Snells law at each interface
- ***RAYS:***
- **Optical Axis:** Line through center of optical system
- **Paraxial ray**: Rays close to optical axis
- **Marginal ray:** Ray emitted from off-axis point passing through edge of entrance pupil. It defines the numerical. Intersection of marginal ray and optical axis define image plane.
- **Chief ray:** Ray emitted from off-axis point passing through center of optical system (center of entrance pupil).Image height is determined by distance of chief ray from the optical axis at the image plane.

Basic Optics : Microlithography

4. Focal Length

- Gauss Thin Lens Equation



$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

When using this equation, signs are very important.

d_o	positive	when the object is "in front of the lens"
d_i	positive	real images (inverted)
d_i	negative	virtual images (upright)
f	positive	converging lens
f	negative	diverging lens

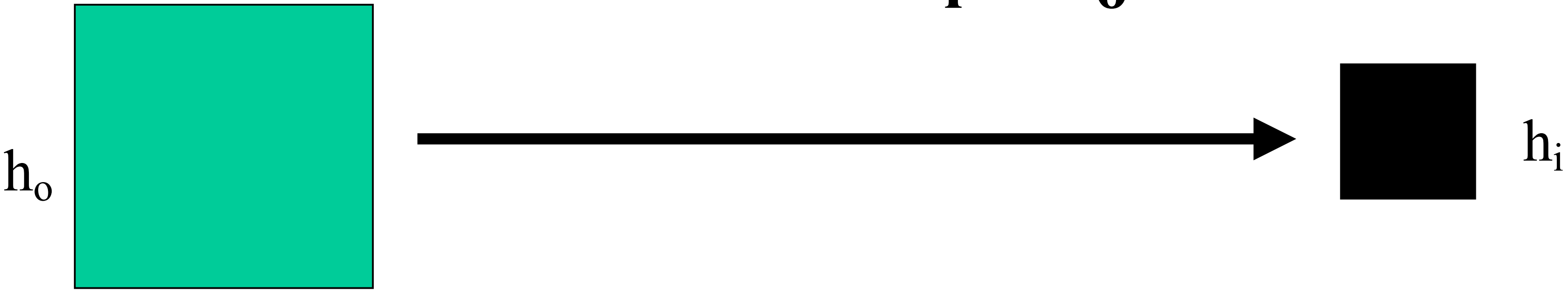
d_o, d_i , and f must be measured in the same unit - usually meters is preferred.

Basic Optics : Microlithography

4. Focal Length

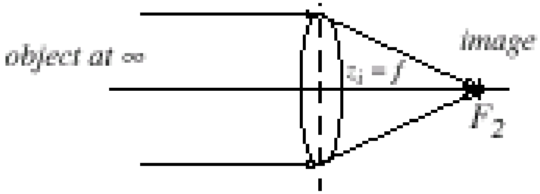
- Gauss Thin Lens Equation Magnification
- i = image side distance from lens
- o = object distance to lens
- h_i = height of image
- h_o = height of object

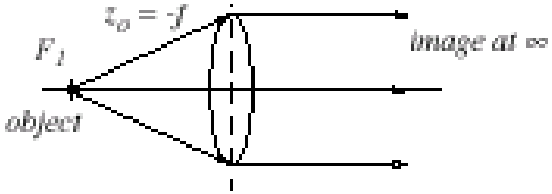
- $\mathbf{m = i/o = h_i / h_o}$



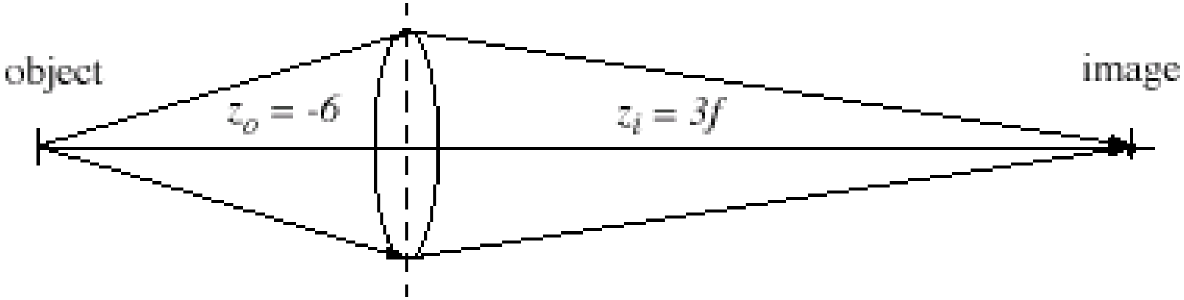
Basic Optics : Microlithography

4. Focal Length examples





- ***Ex*: find focal length of a converging (+) lens, given:**



$$\frac{1}{3f} = \frac{-1}{6} + \frac{1}{f} \quad \Rightarrow \quad f = 4$$

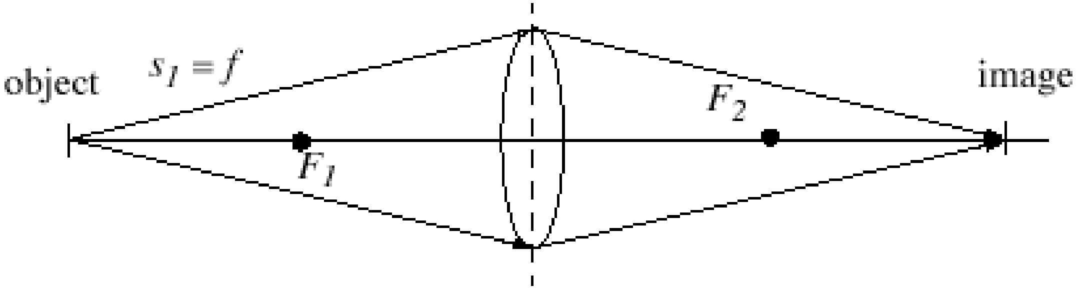
Basic Optics : Microlithography

4. Focal Length examples

- ***Newtonian Formula:*** $s_1 s_2 = f^2$

  where s_1 is distance of object from F_1 (+ to left), s_2 is distance of image from F_2 (+ to right)

- ***Ex**: object 2f to left of + lens; find image location*



$$s_2 = \frac{f^2}{s_1} = f$$

- *Therefore, image is 2f to right of lens (symmetric to object)*

Basic Optics : Microlithography

5. Geometrical Optics

- **LaGrange Invariant:** Relates marginal ray to chief rays:
- obj = object side
- img = image side
- H = object or image height
- n = refractive index of medium on object side
- u = angle ray subtends with optical axis from edge of entrance pupil
- NA = nu

- $\mathbf{NA_{obj} * h_{obj} = NA_{img} * h_{img}}$
- This is a measure of how much information can be transmitted by the optical system.
- $\mathbf{NA_{img} * h_{img}}$ is also refered to as the ***Etendue***

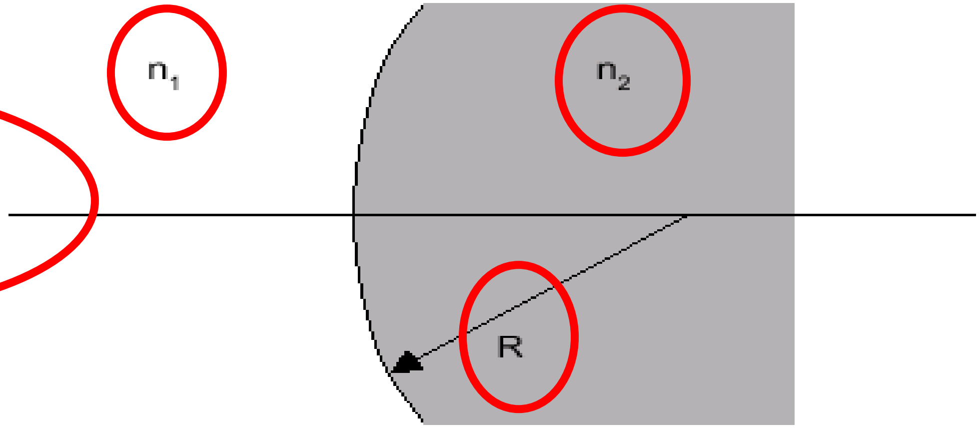
Basic Optics : Microlithography

5. Geometrical Optics

Refractive Power of a Surface

- The refractive power P is measured in diopters when the radius is expressed in meters.
- n_1 and n_2 are the refractive indices of the two media.

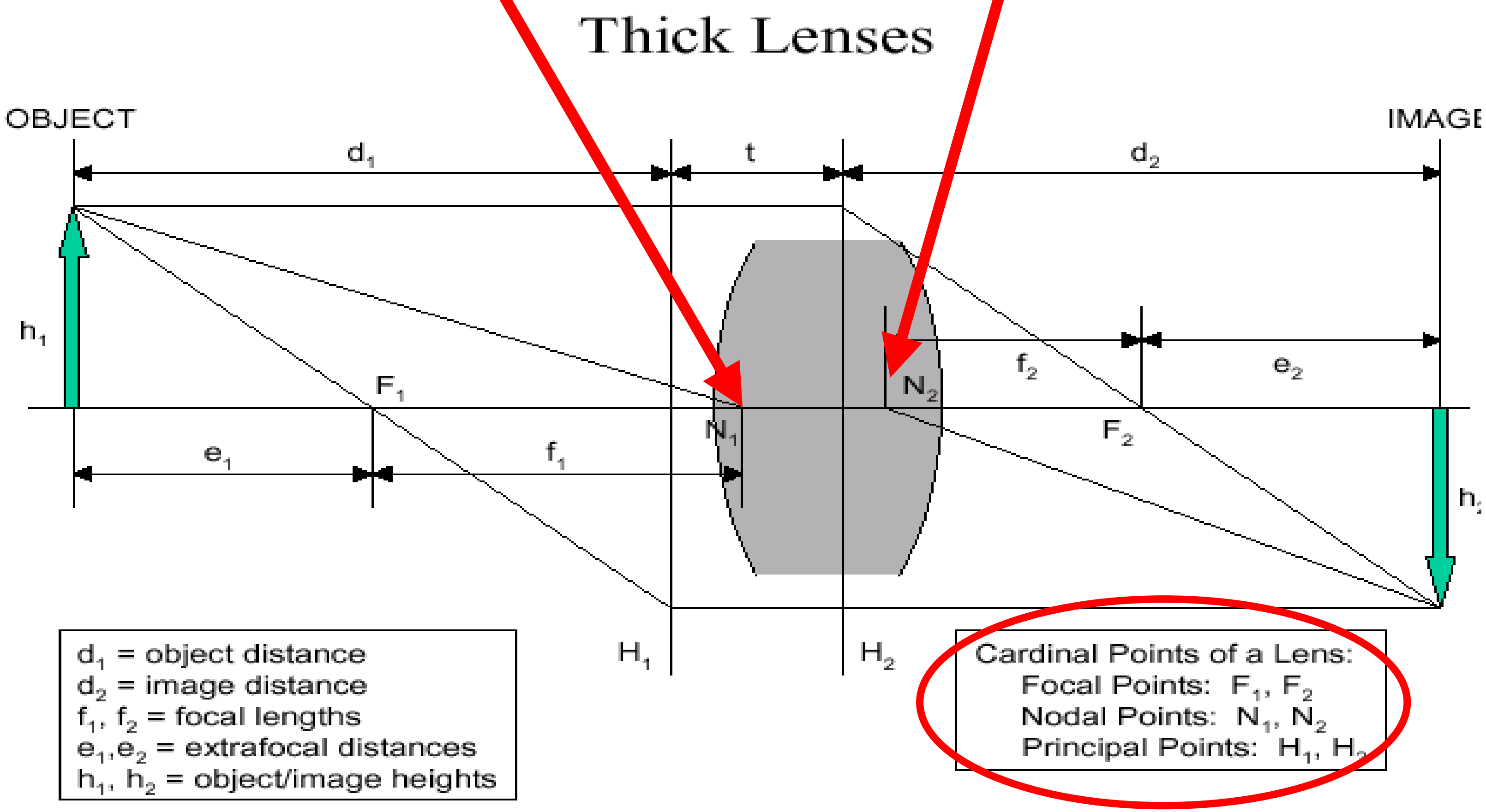
$$P = \frac{n_2 - n_1}{R}$$



Basic Optics : Microlithography

5. Geometrical Optics Lens Basics thick lens

Principle points: Where refraction occurs.



Thick Lenses

d_1 = object distance
d_2 = image distance
f_1, f_2 = focal lengths
e_1,e_2 = extrafocal distances
h_1, h_2 = object/image heights

Cardinal Points of a Lens:
Focal Points: F_1, F_2
Nodal Points: N_1, N_2
Principal Points: H_1, H_2

Basic Optics : Microlithography

5. Geometrical Optics Lens Basics

Lens-Maker's Formula

$$\frac{n_1}{d_1} + \frac{n_2}{d_2} = \frac{n - n_1}{R_1} + \frac{n - n_2}{R_2}$$

If $n_1 = n_2 = 1$, then

$$\frac{1}{d_1} + \frac{1}{d_2} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \boxed{P = \frac{1}{f}}$$

This can also be expressed as: $(d_1 - f)(d_2 - f) = f^2$

or: $e_1 e_2 = f^2$

Basic Optics : Microlithography

5. Geometrical Optics Lens Basics: Thick Lens in air

1. The lensmaker equation:

$$\frac{1}{f}=(n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right] \qquad (3)$$

2. The thick lens formula:

$$\frac{1}{f}=(n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]-\frac{(n-1)}{R_1}\frac{(1-n)}{R_2}\frac{\boxed{t}}{n}$$

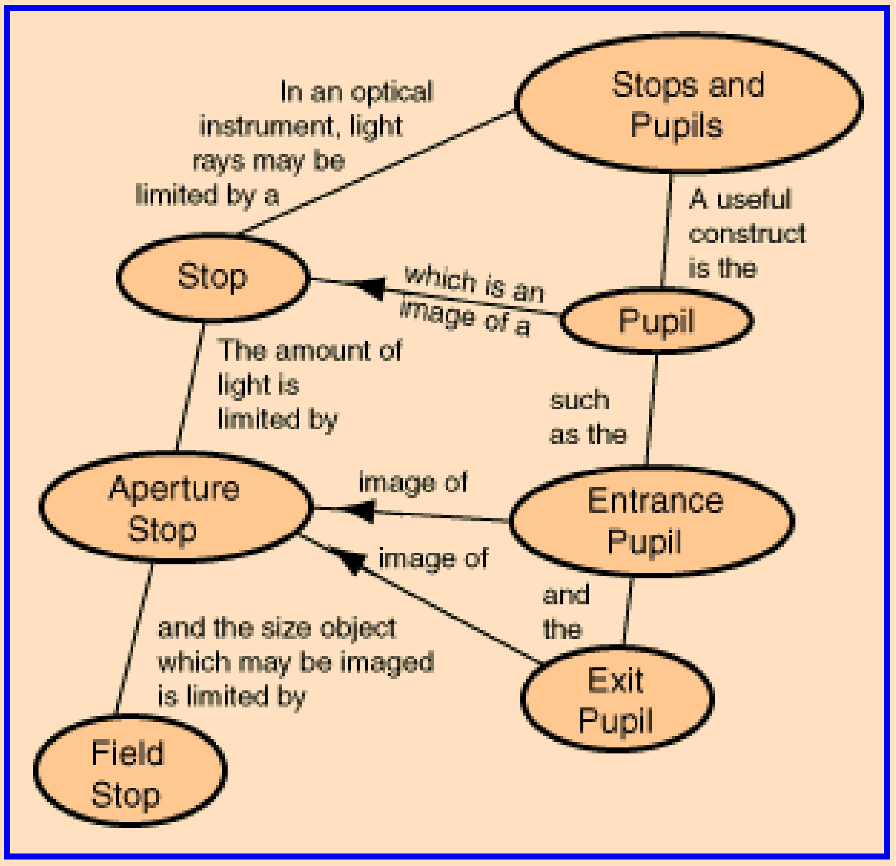
where t is the thickness of the lens.

[REMEMBER SIGN CONVENTIONS FOR R_1, R_2]

Basic Optics : Microlithography

5. Geometrical Optics Pupils

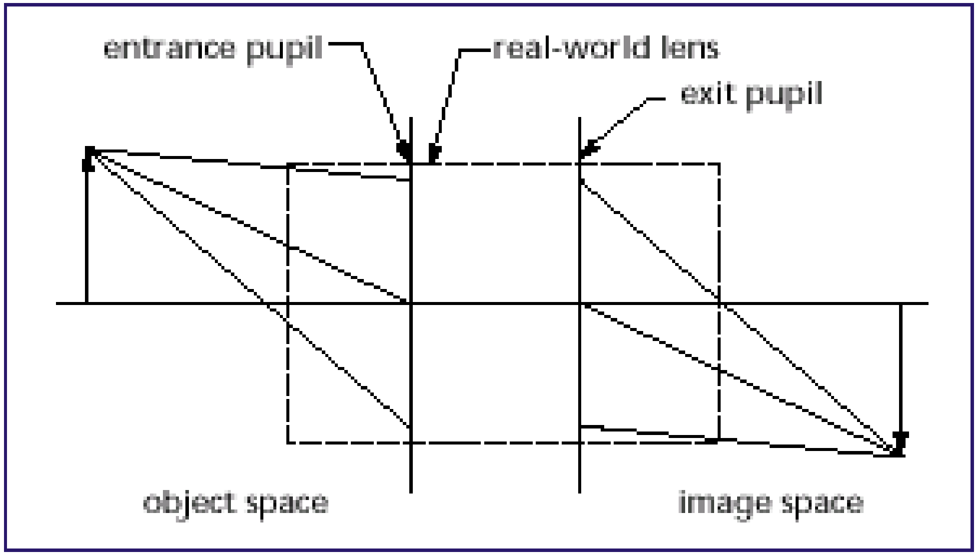
- Pupils and stops: Typically circular obstructions in optical system that limit rays.
- Define numerical aperture, image height, and image quality (limit aberrations).



Basic Optics : Microlithography

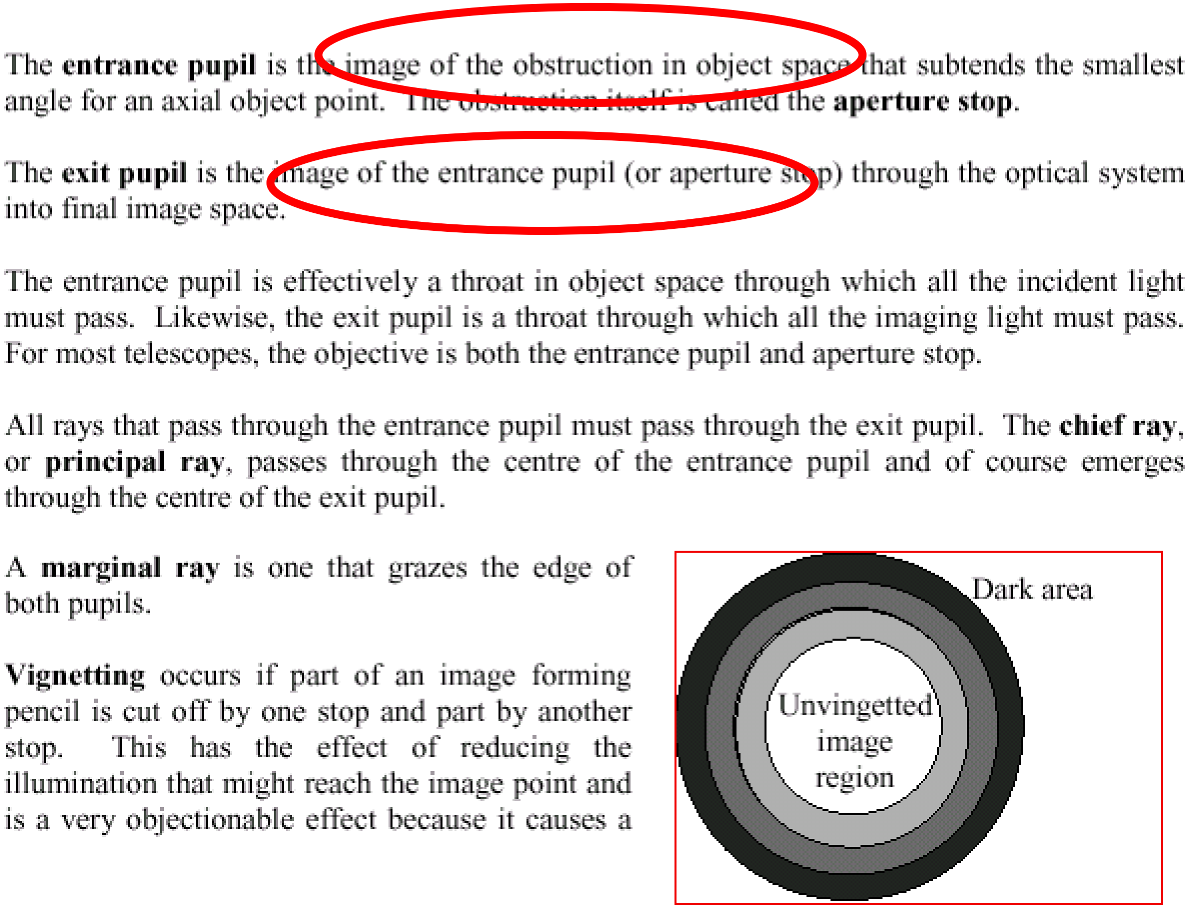
5. Geometrical Optics Pupils

- Pupils and stops:



Basic Optics : Microlithography

5. Geometrical Optics Pupils: Important in optical design



The **entrance pupil** is the image of the obstruction in object space that subtends the smallest angle for an axial object point. The obstruction itself is called the **aperture stop**.

The **exit pupil** is the image of the entrance pupil (or aperture stop) through the optical system into final image space.

The entrance pupil is effectively a throat in object space through which all the incident light must pass. Likewise, the exit pupil is a throat through which all the imaging light must pass. For most telescopes, the objective is both the entrance pupil and aperture stop.

All rays that pass through the entrance pupil must pass through the exit pupil. The **chief ray**, or **principal ray**, passes through the centre of the entrance pupil and of course emerges through the centre of the exit pupil.

A **marginal ray** is one that grazes the edge of both pupils.

Vignetting occurs if part of an image forming pencil is cut off by one stop and part by another stop. This has the effect of reducing the illumination that might reach the image point and is a very objectionable effect because it causes a

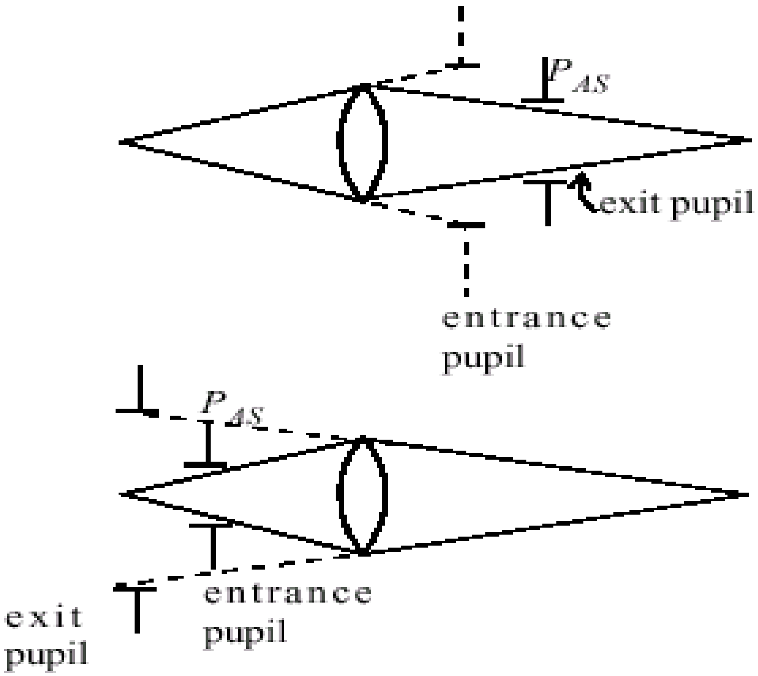
Basic Optics : Microlithography **5.**

Geometrical Optics Pupils

In a complex lens system, how can we account for diffraction? We must find the *most severely limiting aperture*. This is referred to as the aperture stop, P_{AS} .

Entrance pupil: The image of the P_A, viewed from object space

Exit pupil: The image of the P_A, viewed from image space



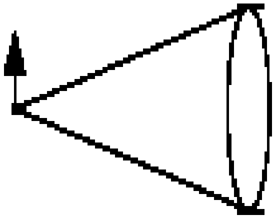
Basic Optics : Microlithography

5. Geometrical Optics Pupils

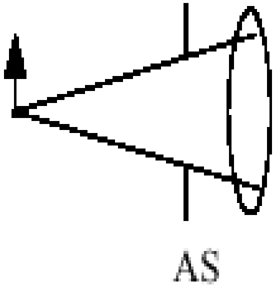
Aperture Stop

Every optical system has same component that limits the light cone that is accepted from an axial object.

Simple case - single lens



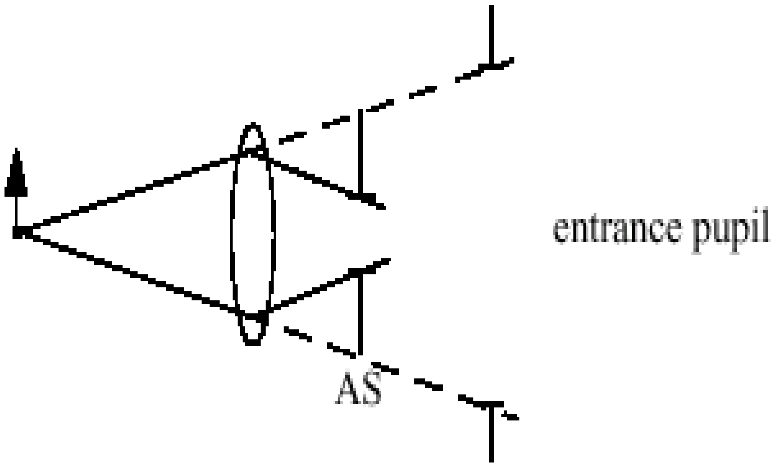
could be the diameter "clear aperture" of the lens.



could be a physical aperture placed somewhere in the optical path.

Basic Optics : Microlithography

5. Geometrical Optics Entrance Pupil defines NA



- Entrance pupil:

  Image of the aperture stop as seen from the object side. Defines the cone of light accepted by the optic.

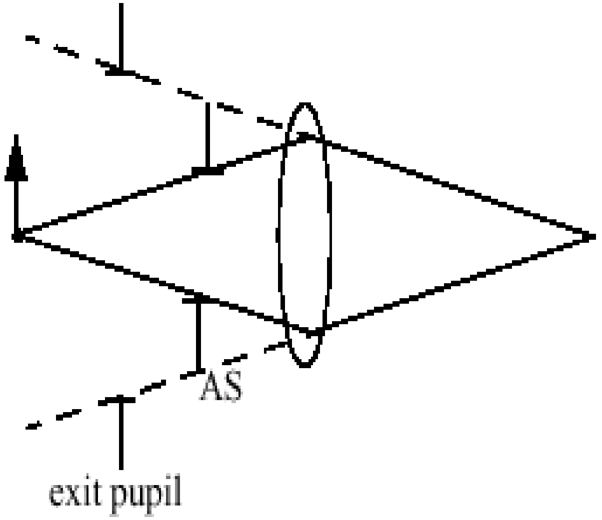
  The importance of the entrance pupil is that the brightness of the image depends on this cone angle. The larger the acceptance angle, the more light that is collected from each object point, and hence the brighter the image.

Basic Optics : Microlithography

5. Geometrical Optics Exit Pupil

Exit Pupil

Image of the aperture stop, as seen from the image side of the optic.



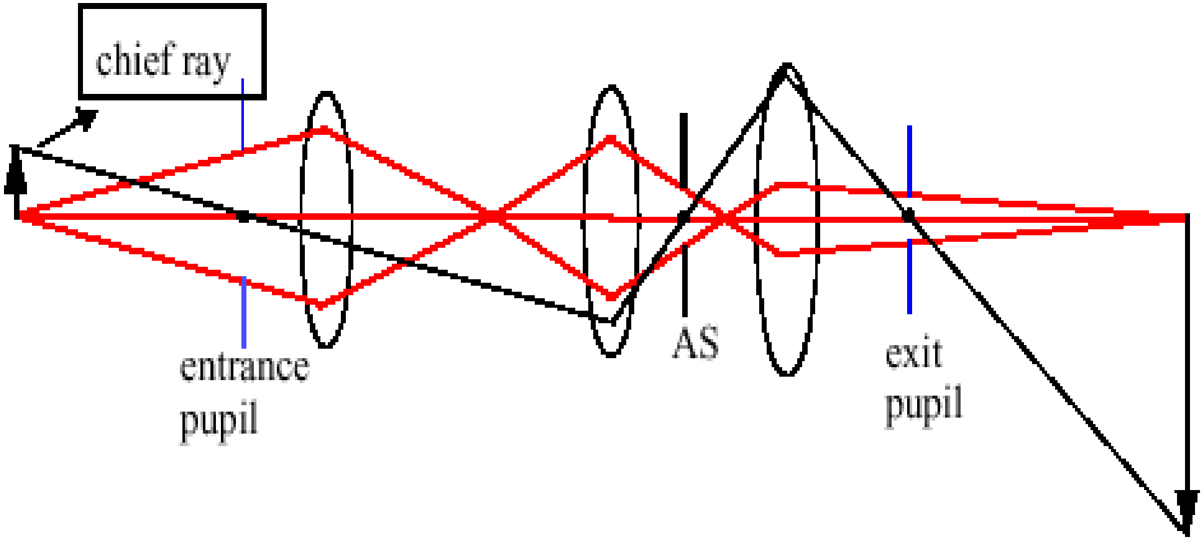
The exit pupil defines the cone angle of light converging to the image point. Later, we will see that this is important in determining the image resolution that is set by diffraction.

Basic Optics : Microlithography

5. Geometrical Optics Entrance and Exit Pupils

Entrance and Exit Pupils are Images of each other

The entrance pupil is the image of the stop. The exit pupil is also an image of the stop. So the entrance and exit pupils must also be images of each other. The pupils define the amount of light accepted by and emitted from the optical system.



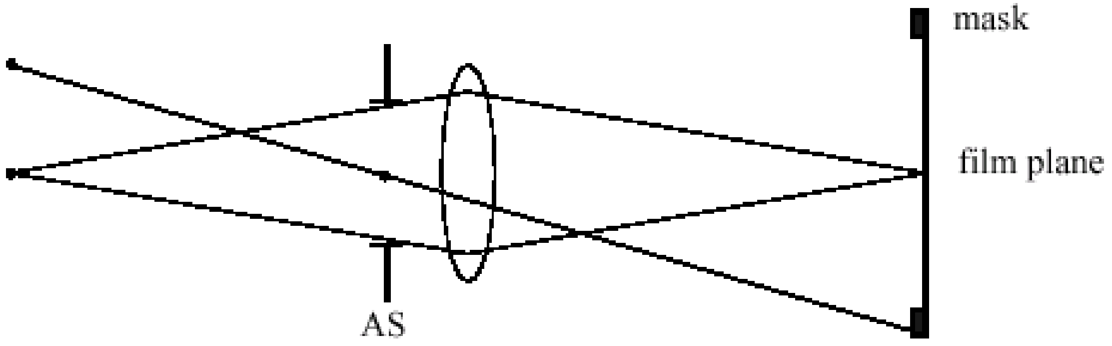
Basic Optics : Microlithography

5. Geometrical Optics Pupils and stops

Field Stop

Another stop in the system limits the extent of the object/image sizes. The <u>chief ray</u> from an object point is blocked by the field stop.

Simple case: a mask at the object or image plane.



The field stop might also be set by a diaphragm somewhere in the optical path.

- <u>Entrance window</u>: Image of the field stop at the object plane.
- <u>Exit window</u>: Image of the field stop at the image plane.