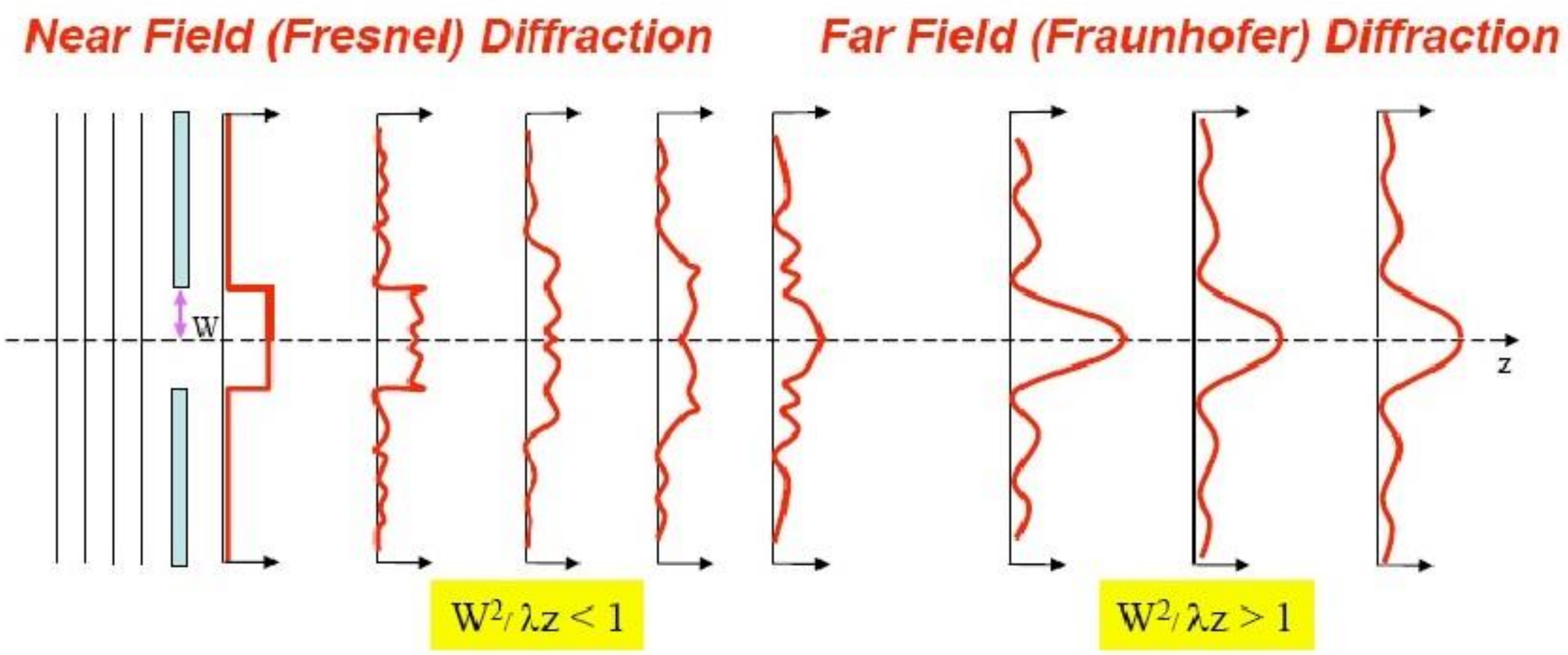
Lecture 5

Chemical Engineering for Micro/Nano Fabrication

Now we have Frauenhofer Diffraction

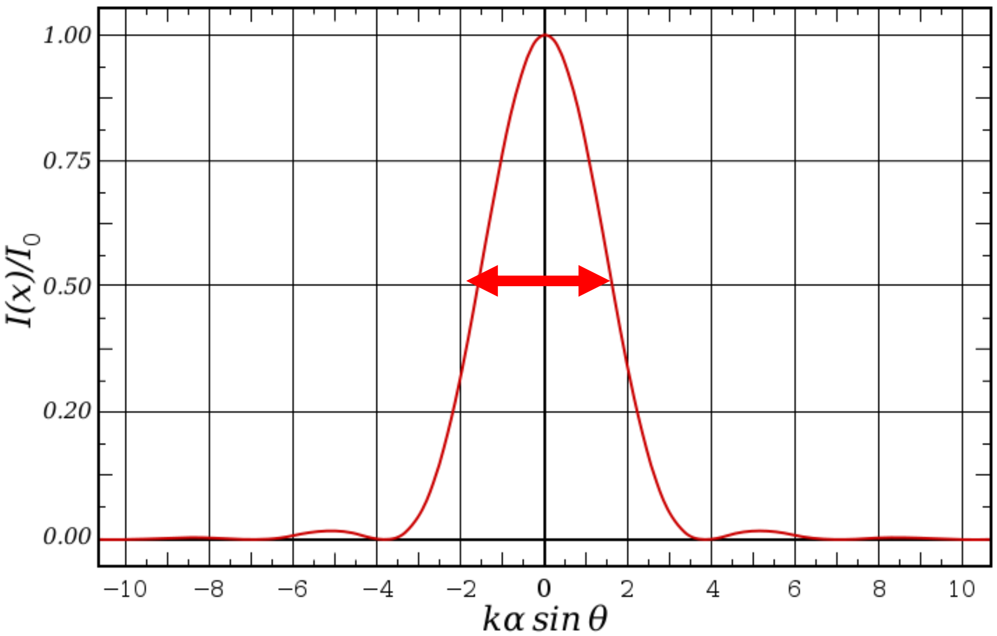
Far Field Diffraction.

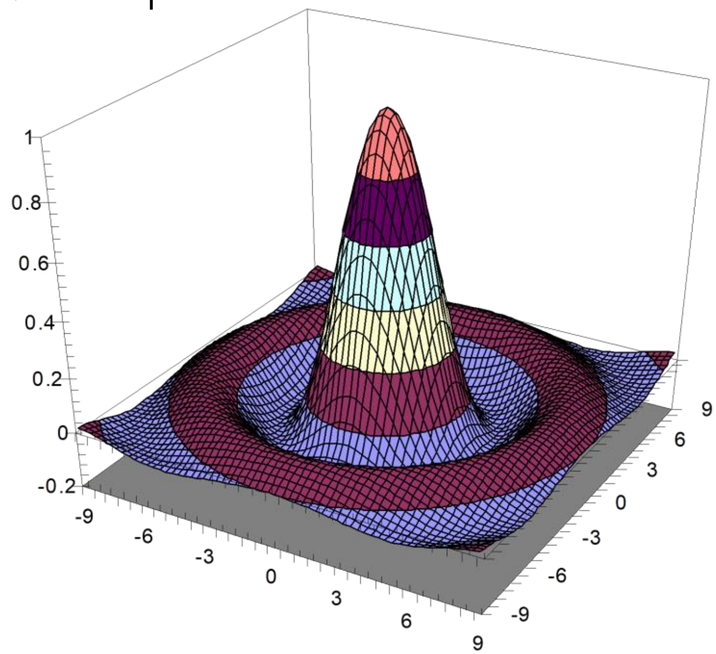


Defining the resolution of an imaging system

- When a single point of light is imaged it becomes the point spread function (PSF) of the lens system.
  - For an ideal, circular imaging system, the PSF is called the Airy disk:
  - The FWHM of the Airy disk is **0.5 λ/NA**, which defines the smallest image of a point source

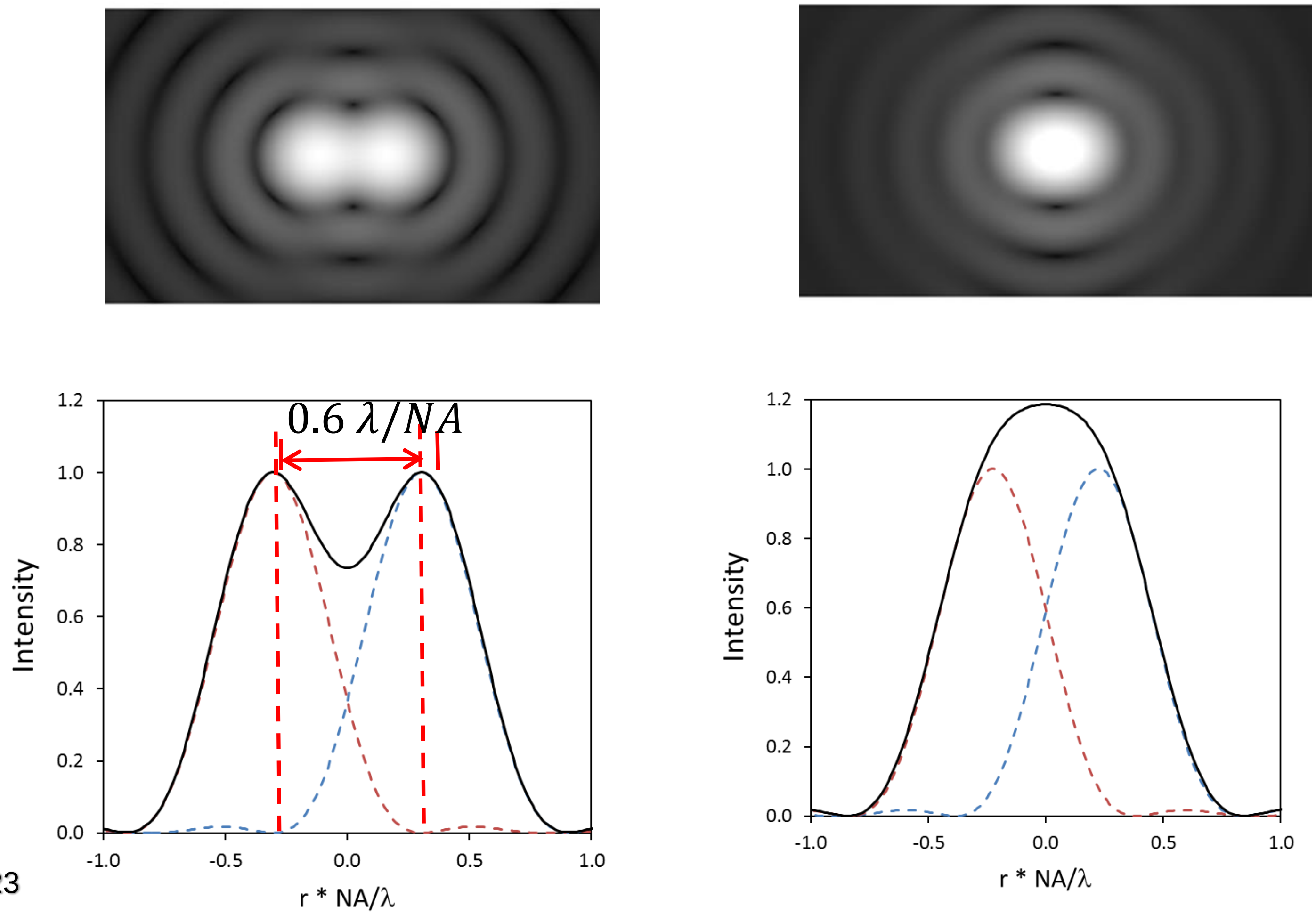
$$PSF = \left| J_1(2\pi r NA/\lambda)/\pi r \right|^2$$



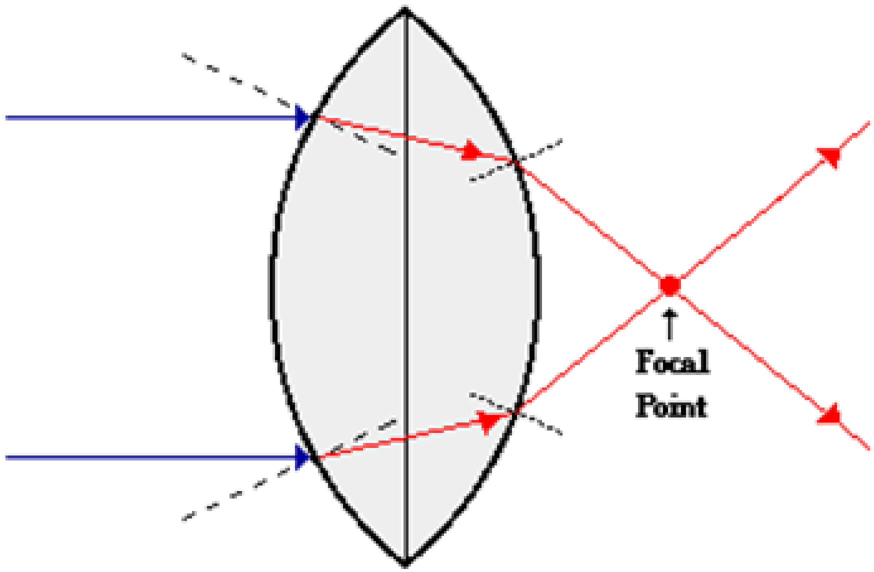


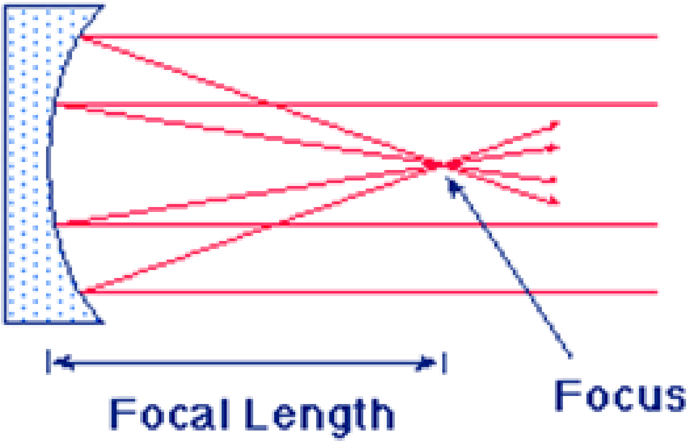
Rayleigh's Rule for Resolution

Lord Rayleigh defined this criterion: when the first minimum of one Airy disk coincides with the maximum of another -> $0.6\,\lambda/NA$



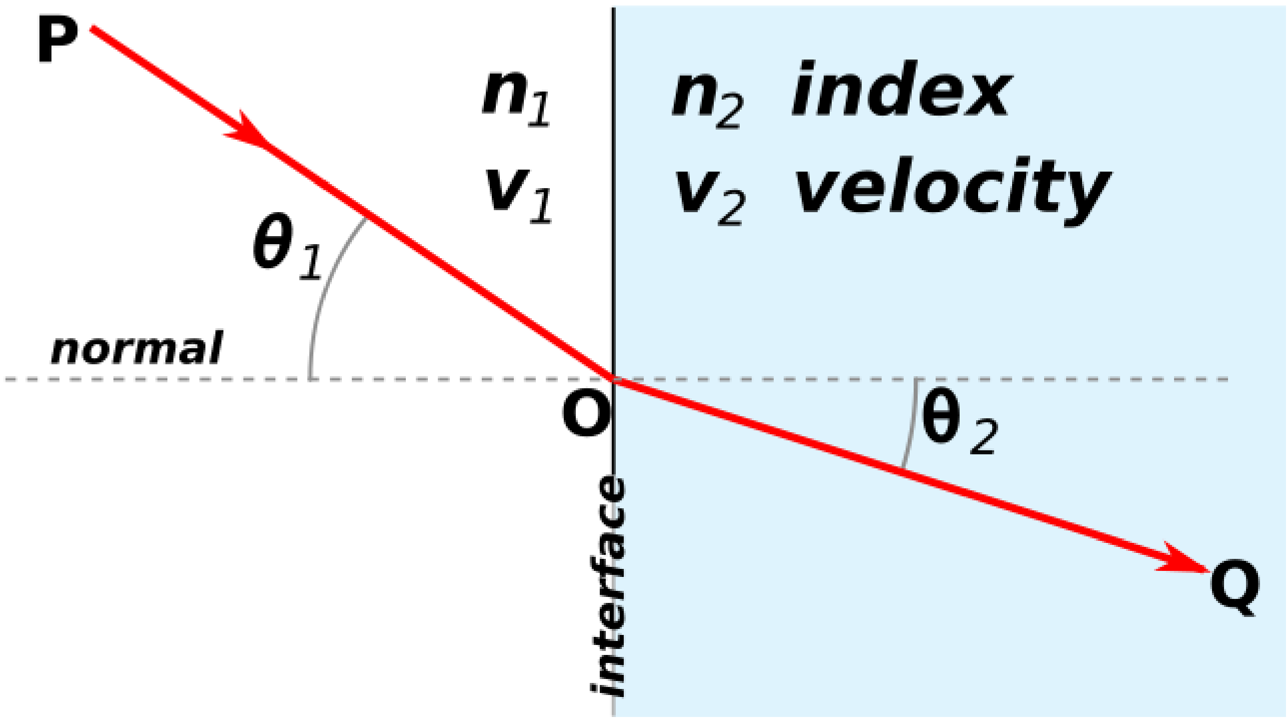
Focusing Light





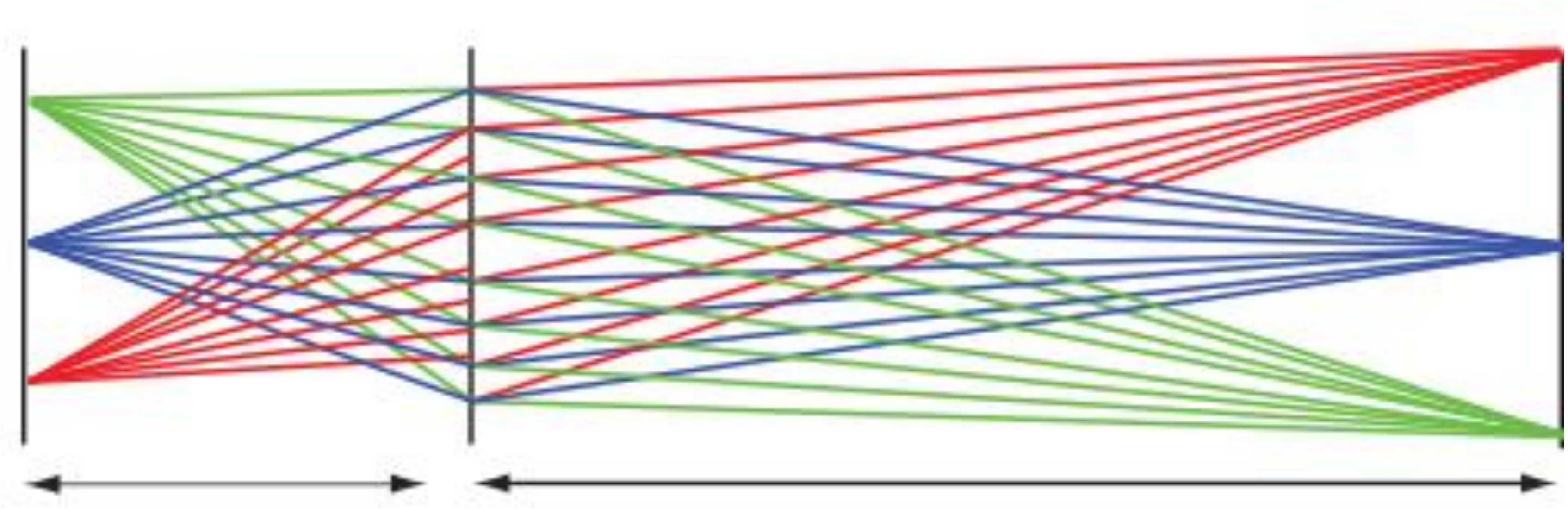
Snell's Law

Snell's Law $$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$



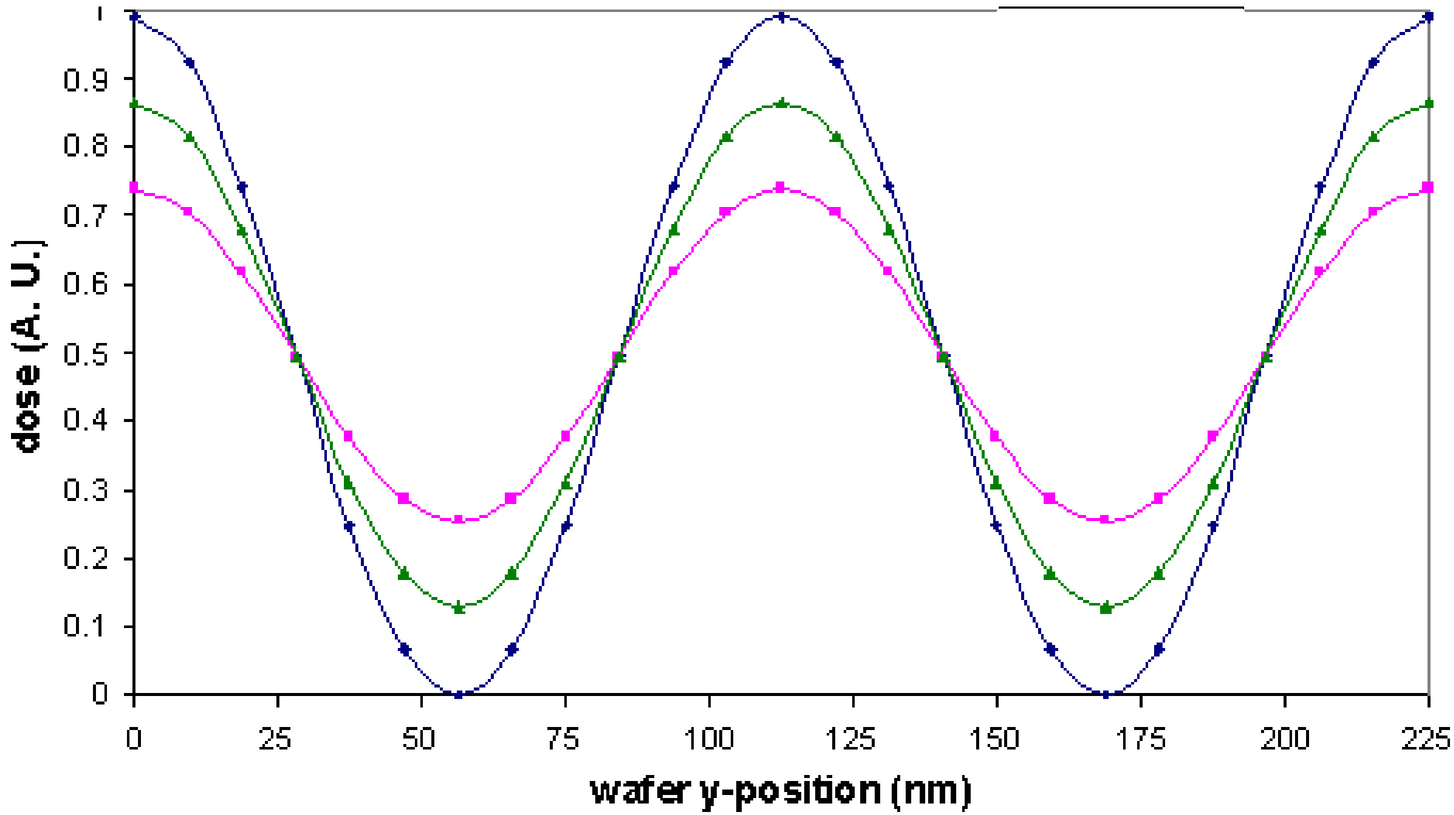
Off Axis Imaging

Imaging more than one spot or slit

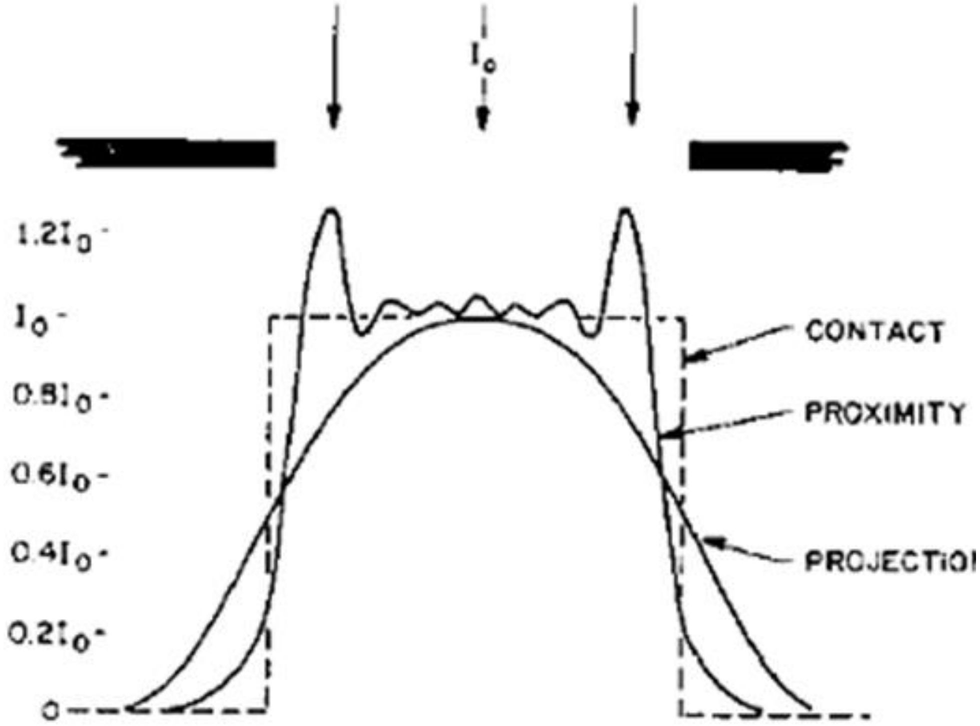


https://www.youtube.com/watch?v=37H5jJmHh2Y

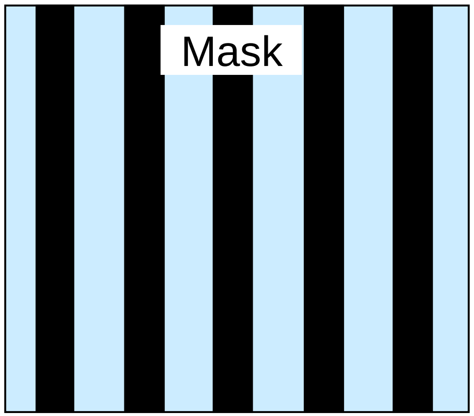
Aerial Image of a 56 nm grating

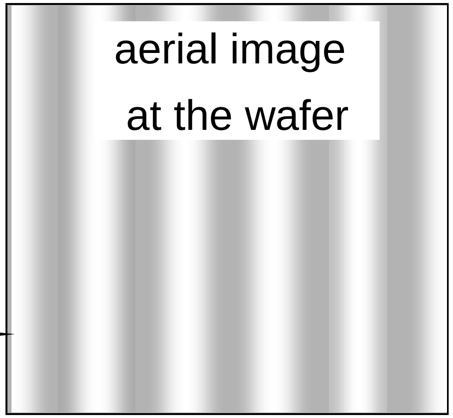


Aerial Image for the Aligner Designs



Chemist’s view of how things really work





$$$$$$$$$$$$$

Amazing Chemistry!!

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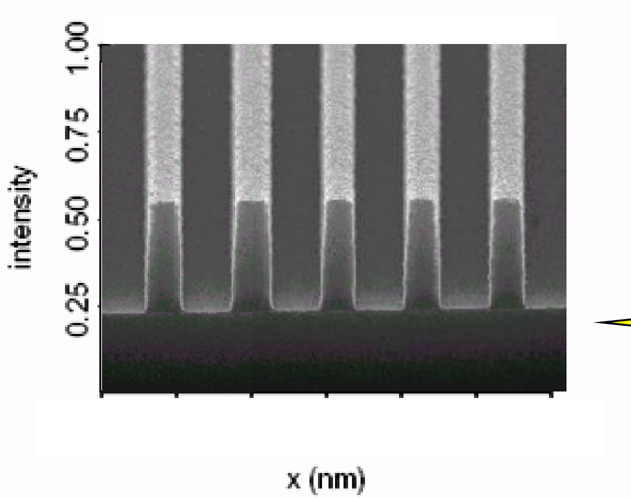
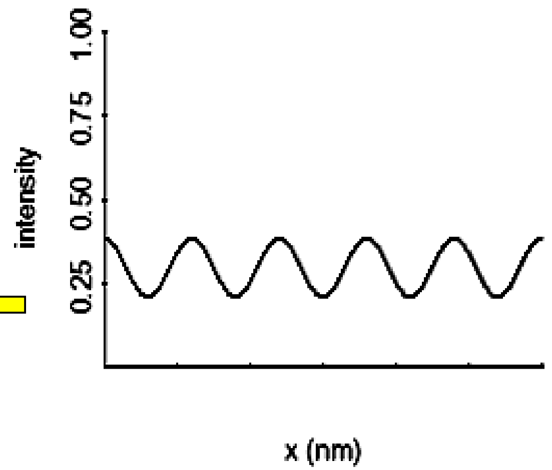
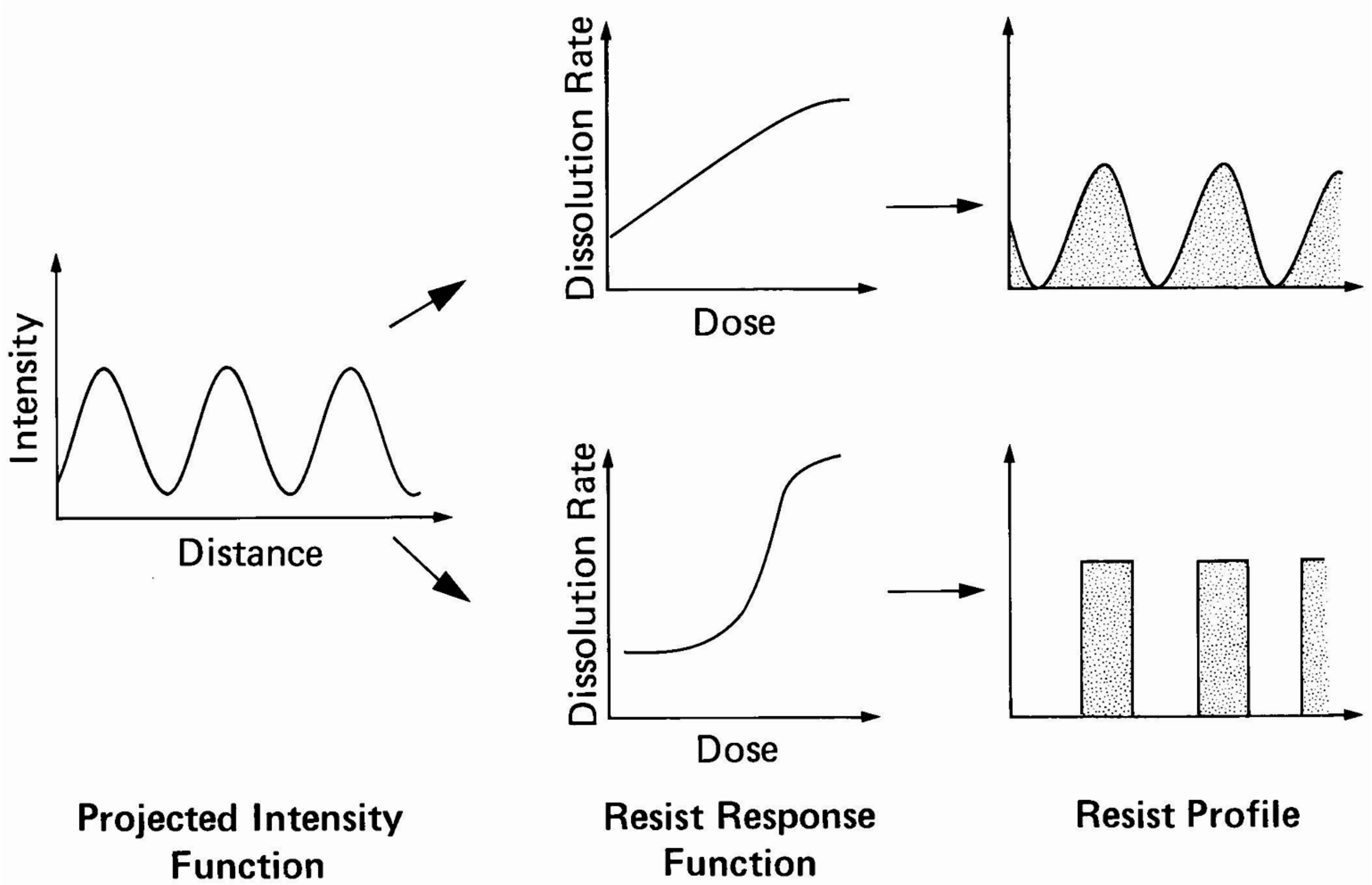


resist image

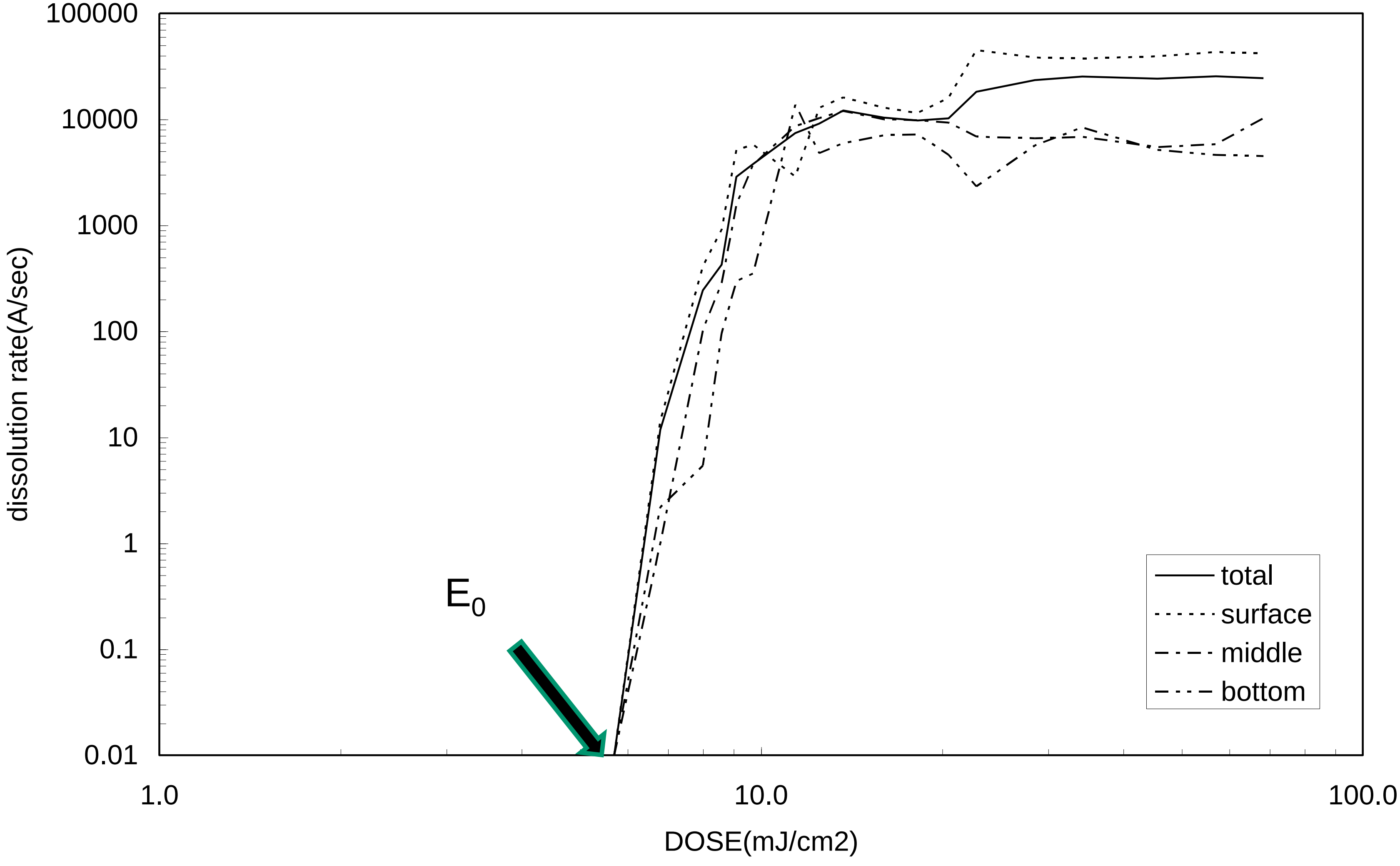


aerial image

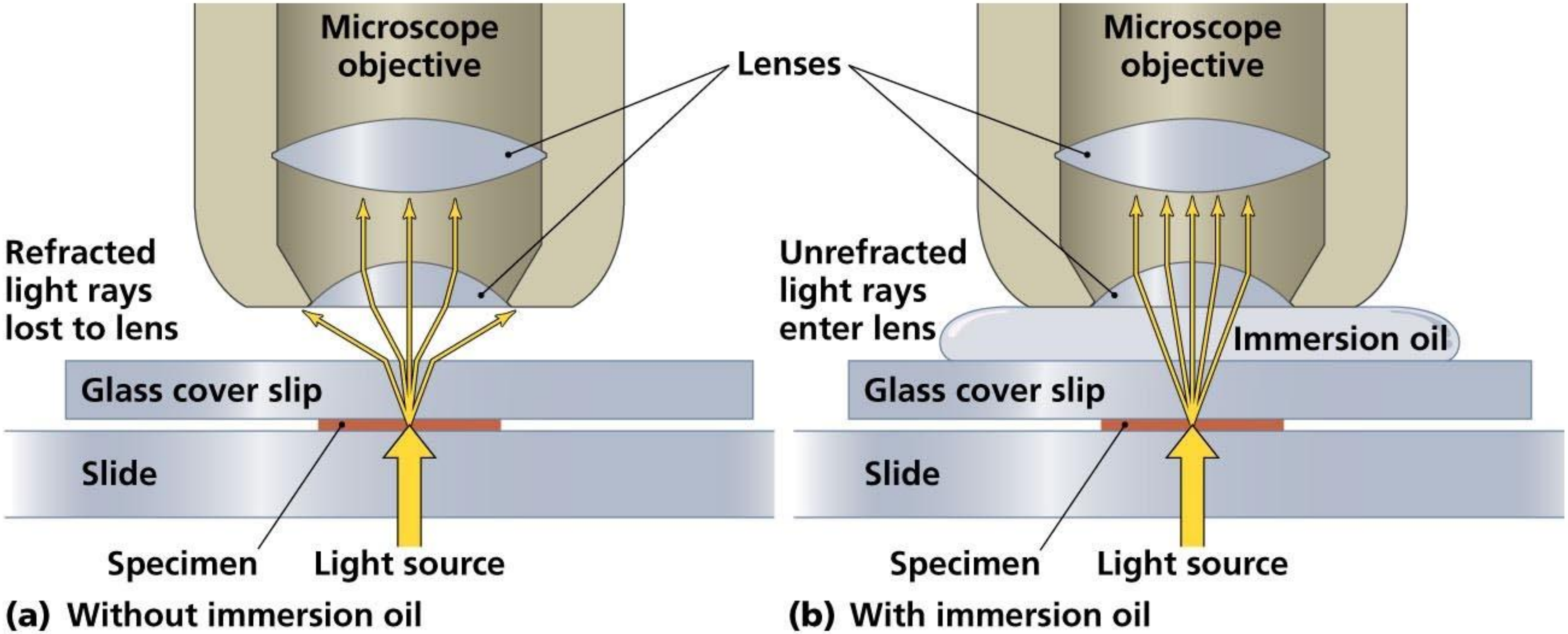
Non-linear dissolution rate response



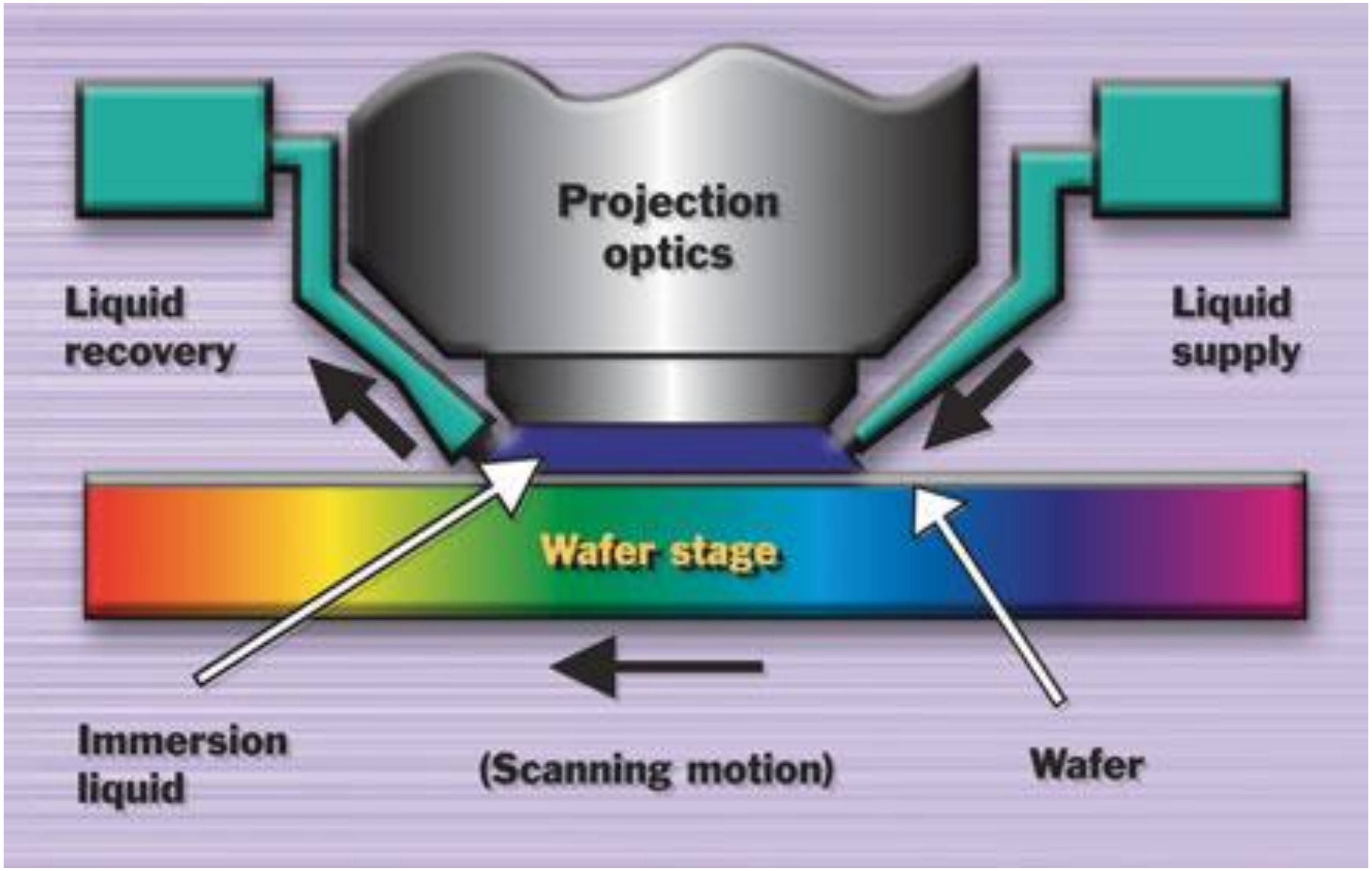
Threshold like Response of ArF Resist



Oil Immersion Microscopy

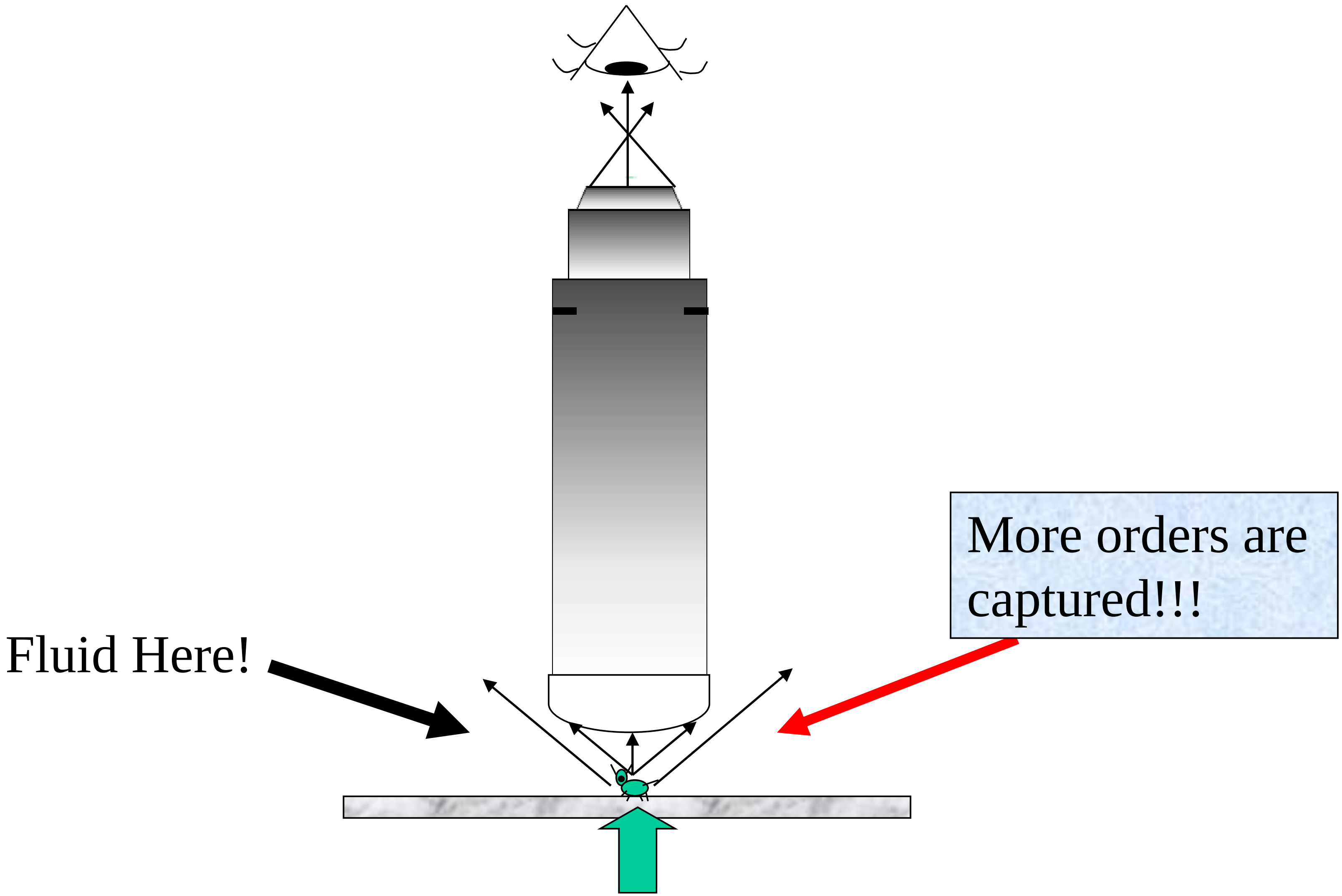


Liquid Immersion Lithography

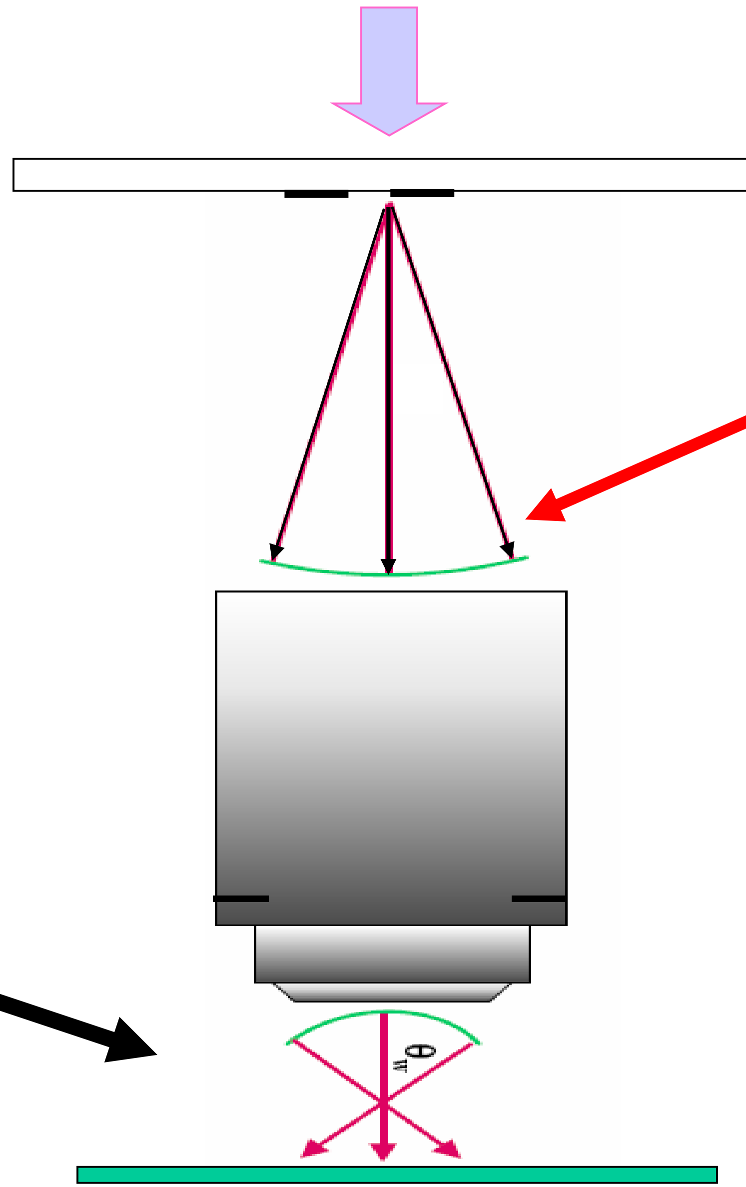


Source: Nikon

Immersion Microscopy



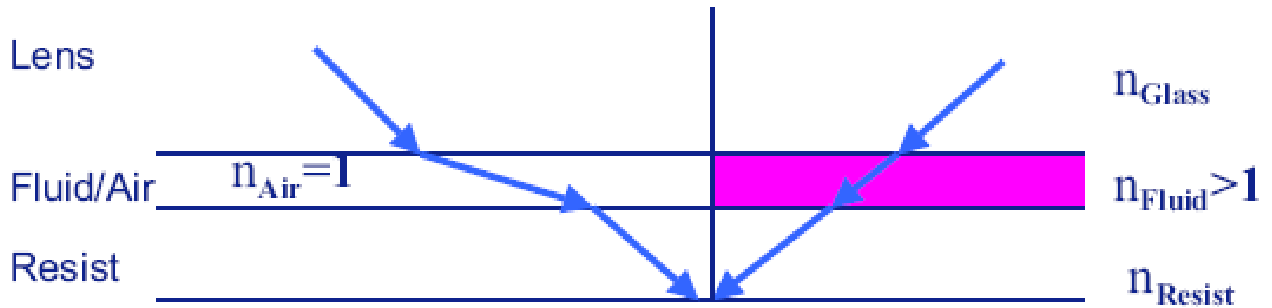
Immersion Lithography



<u>No</u> new rays are captured!!!

Fluid is here!?

Basic Theory of Immersion Resolution



- $NA = n_{Air}\sin(\theta_{Air}) = n_{Fluid}\sin(\theta_{Fluid})$
- For maximum resolution $\sin(\theta) = 1.0$
- For air ($n_A = 1$), max NA = 1
- For fluid ($n_F > 1$), max NA = n_F (water = 1.43 @193nm)
- **Maximum resolution for a system is determined by the lowest refractive index in the glass/fluid/resist stack.**

$$\text{Resolution (L/S)} = \frac{k_1\lambda}{n_{Fluid}\sin(\theta_{Fluid})}$$

$$\text{Depth of Focus (L/S)} = \frac{\lambda}{2n_{Fluid}\left(1 - \sqrt{1 - (NA/n_{Fluid})^2}\right)}$$

Brewer Science ARC Symposium, Albany, Oct 28, 2004

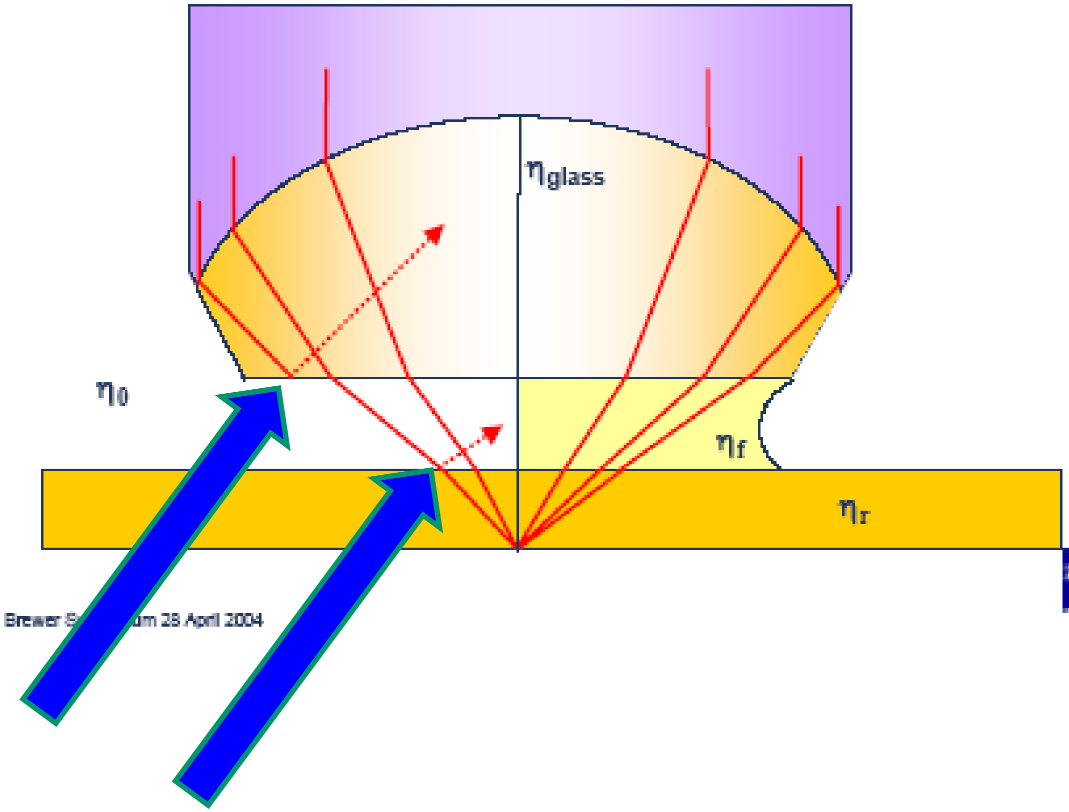
ASML

Immersion Lithography

Improvements in resolution

- Snell's law :

$$NA = \eta_0 \sin\theta_0 = \eta_f \sin\theta_f = \eta_r \sin\theta_r$$



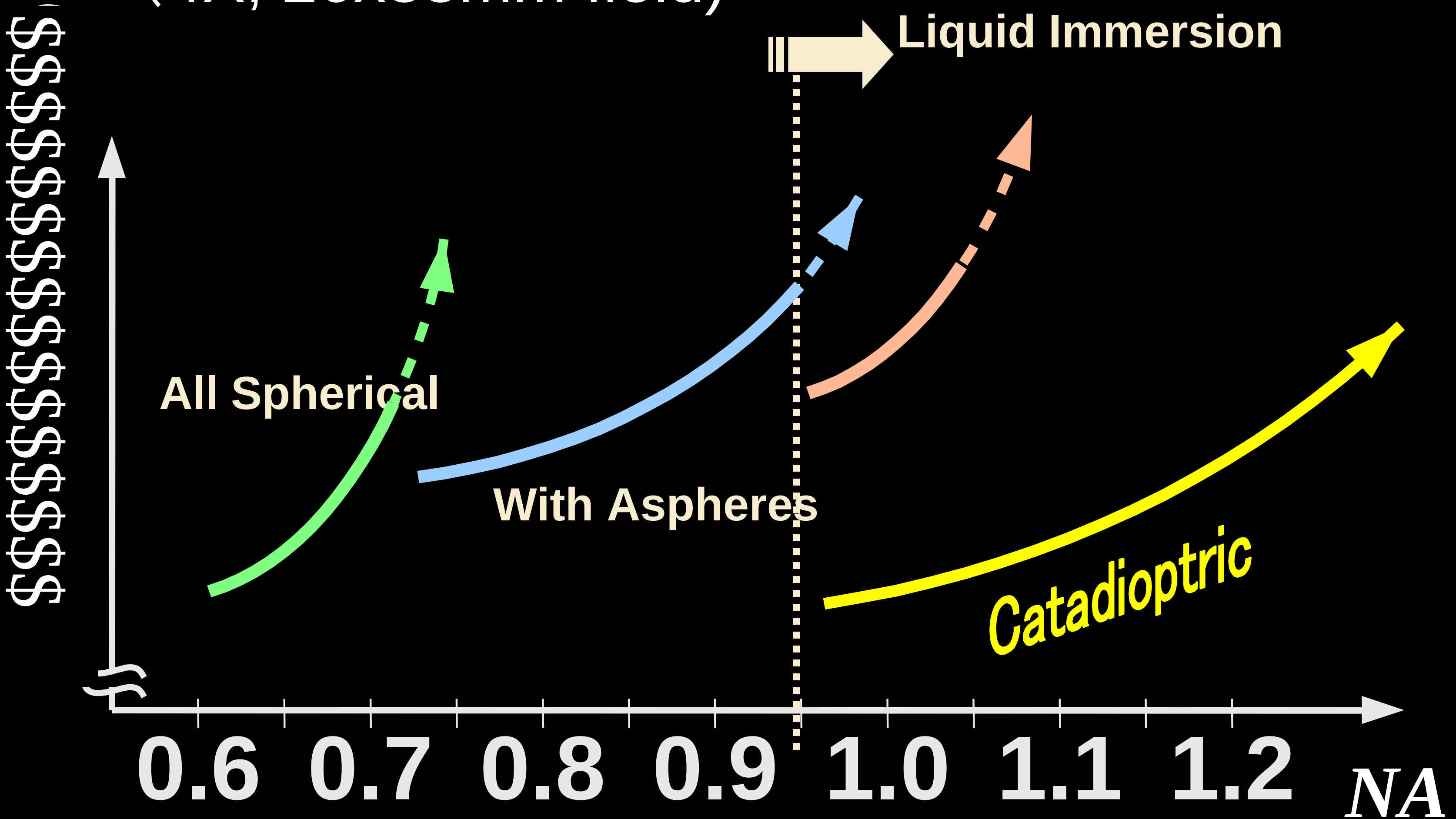
Chemist's View of Immersion

- **Adding water to the space between the final lens and the wafer <u>does not</u> improve resolution.**
- **It <u>does</u> improve depth of focus and therefore process latitude**
- **It <u>does</u> allow design of high NA lenses that would otherwise not work!**

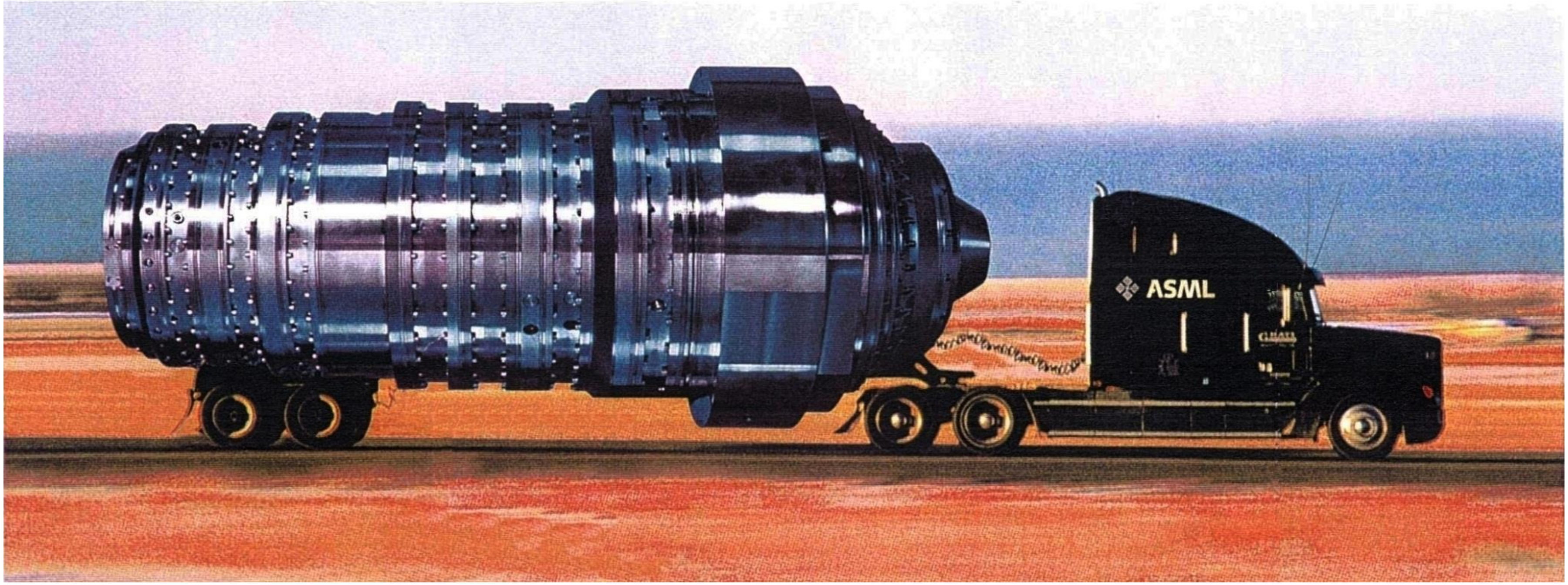
Immersion Lens

Lens diameter vs. NA

(4X, 26x33mm field)



A Prophetic Advertisement??



Size Matters????

Optical Lithography Limits

$$R = k_1 \frac{\lambda}{n \sin\theta}$$

R = feature size, λ = wavelength, n = refractive index, $sin\theta$ = incident angle

n = 1 (Air)

k_1 = 0.3
λ = 193 nm
sinθ = 0.9

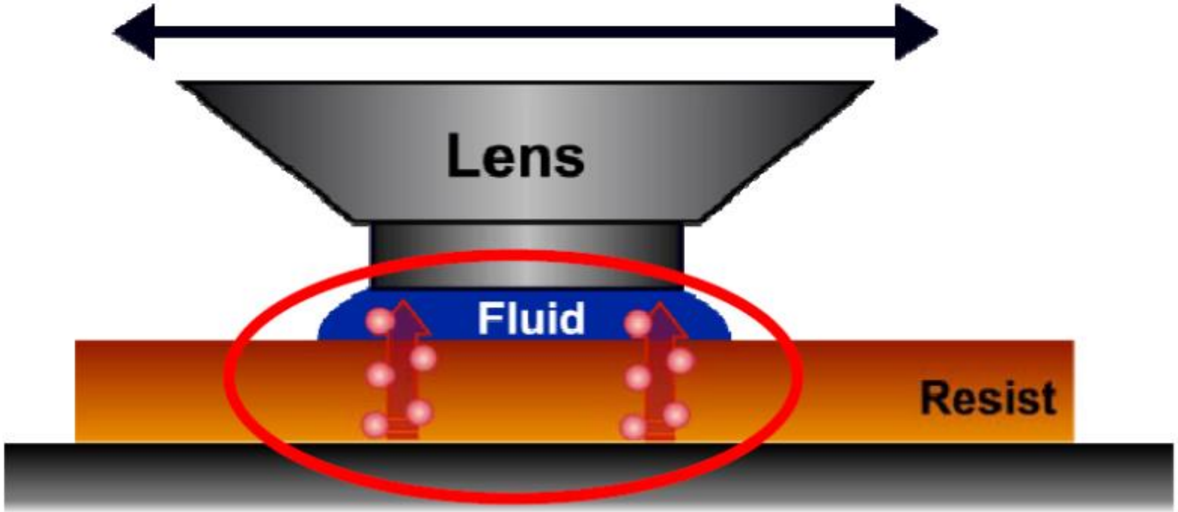
R = 65

n = 1.44 (Water)

k_1 = 0.3
λ = 193 nm
sinθ = 0.9

R = 45 $\neq$ *22 !!*

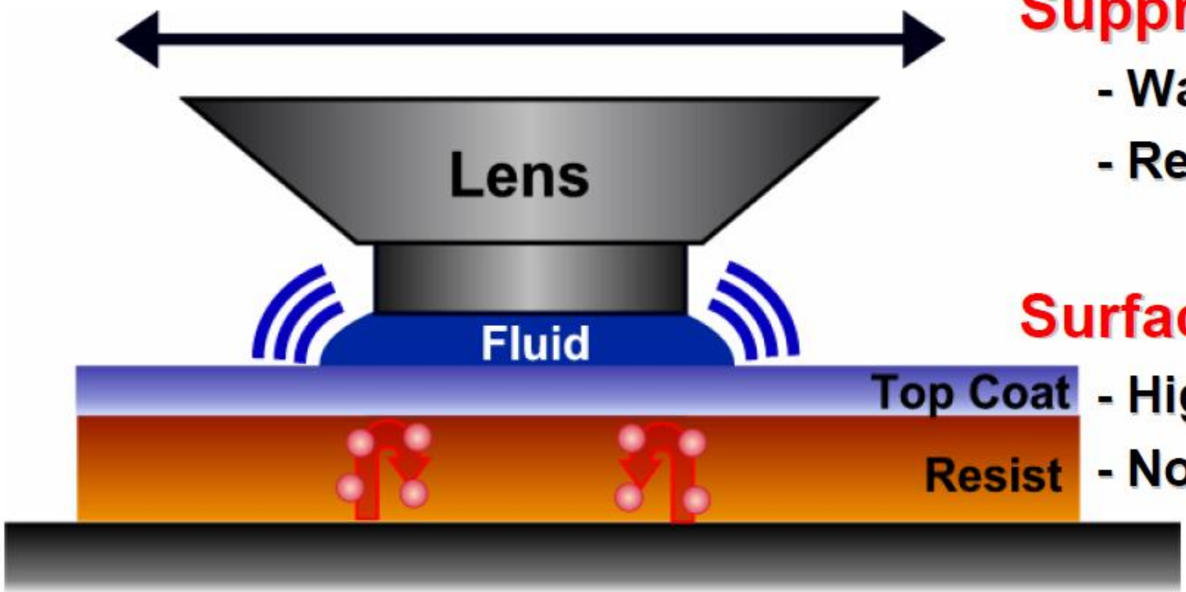
Immersion Specific Issues



Leaching

- Lens damage
- Change resist characteristics

Prospects of Top Coat



Suppression ability
- Water uptake
- Resist component leaching

Surface tension control
- High scan speed durability
- No water droplet

Litho. improvement
- Immersion defect prevention
- No characteristic change

Limitations of water

- Indices of refraction for water immersion.
  - SiO_2: 1.56
  - CaF_2: 1.51
  - Water: 1.435
  - Resists ~ 1.70

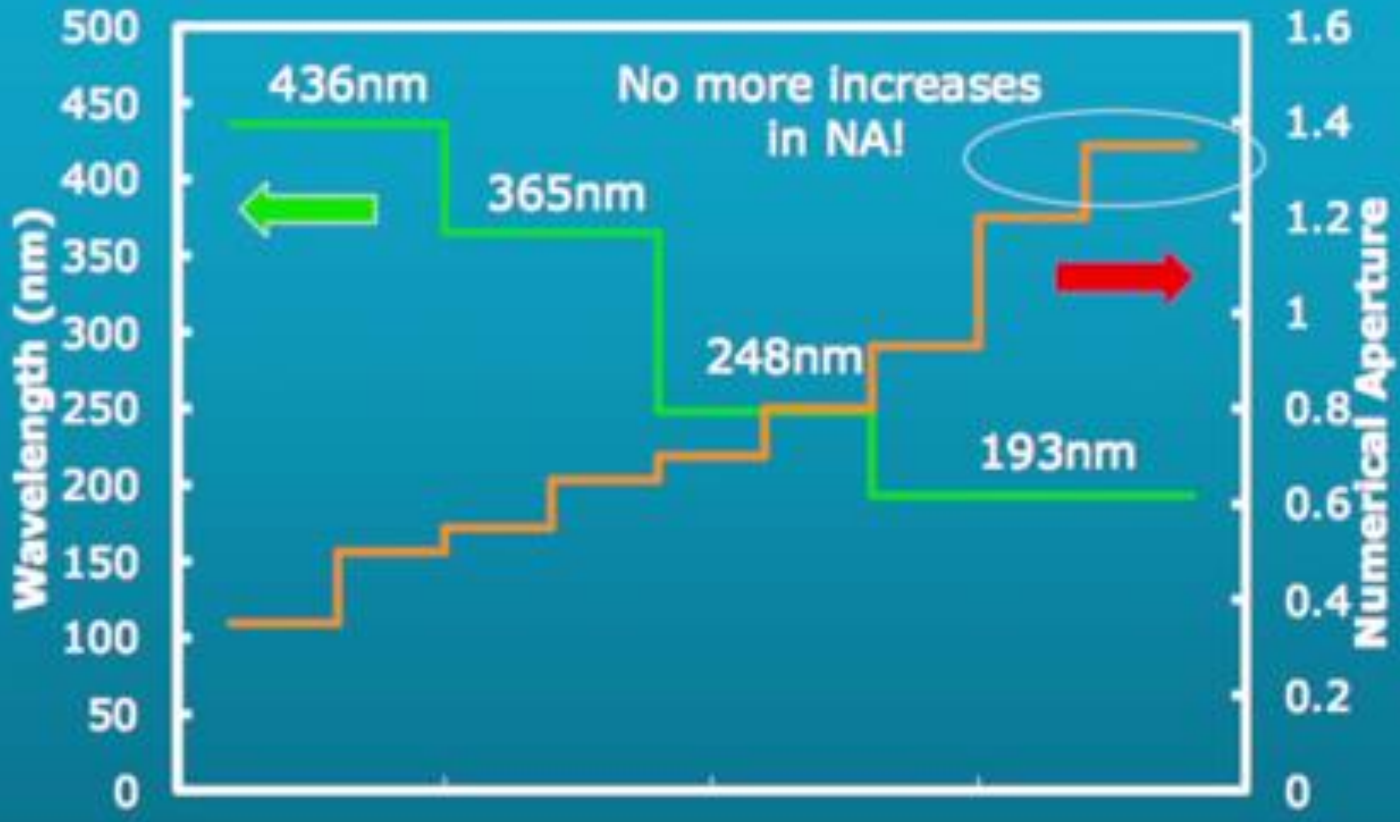
} 0.93*1.435 = 1.33

$$n\sin\theta \leq 0.93 * \min(n\text{glass}, n\text{fluid}, n\text{resist})$$

$$R = 0.3\left[\frac{193}{(1.435)0.93}\right] = 43nm$$

If k=0.25, R = 36nm

1.35NA is Maximum NA Possible



Sivakumar

intel

Options beyond water

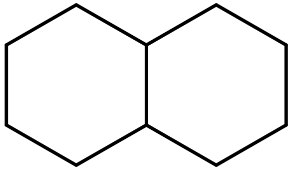
- Options for high index immersion lithography.
  - Glass.
    - $BaLiF_3$: 1.64
    - ($Lu_3Al_5O_{12}$, LuAG): 2.1
    - ($Mg_3Al_2Si_3O_{12}$,Pyrope): 2.0
  - Fluid.
    - Cyclic organics, such as decalin: 1.64-1.65

$$R = 0.3\left[\frac{193}{(1.65)0.93}\right] = 37nm$$

High Index Materials

2nd generation

Fluid n = 1.64



Decalin

R= 37nm

3rd generation

Lens LuAG (n = 2.1)

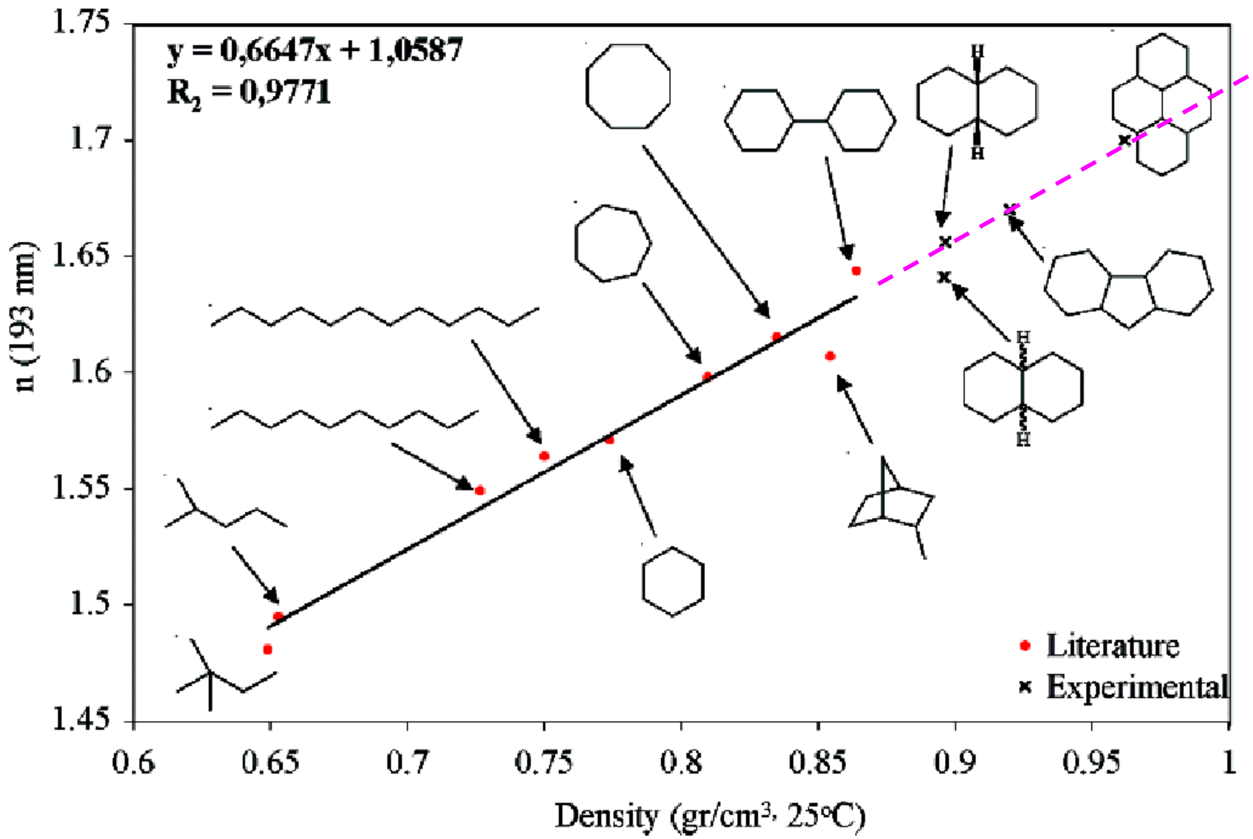
Fluid n = 1.9*

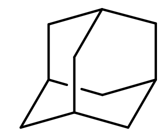
Resist n = 1.8

R= 32nm

No candidate has been identified for high index fluid or high index resist.

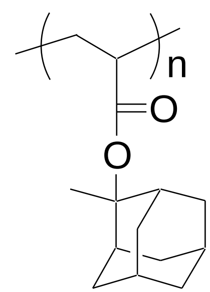
Cycloalkanes





Density 1.07 g/cm^3

Highest RI is expected

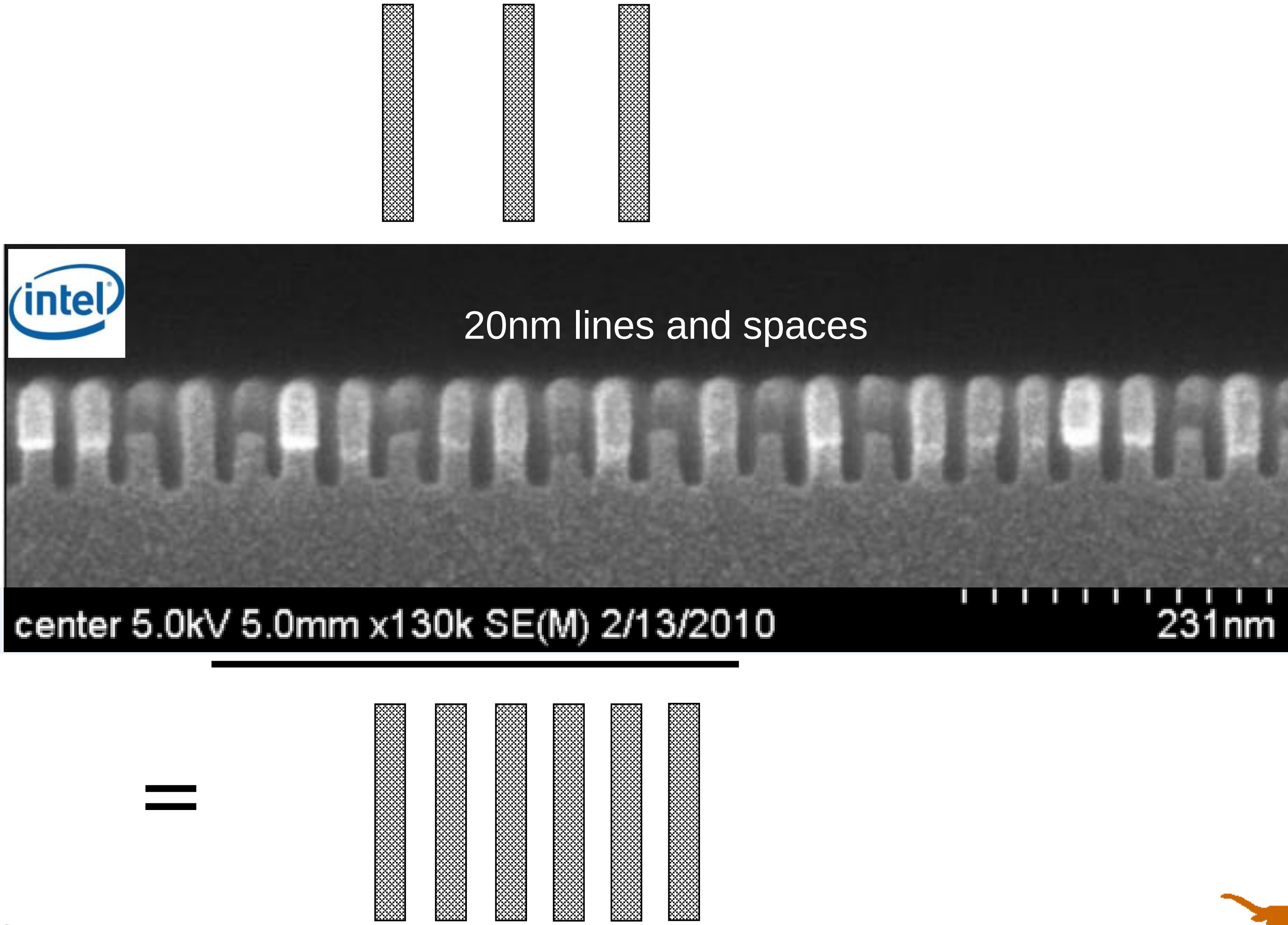


n_{193} = 1.73

Abs_{193} = 0.13

López-Gejo et. al., Chem. Mater.19, 3641-3647 (2007)

Only option is double exposure?



Pitch Division