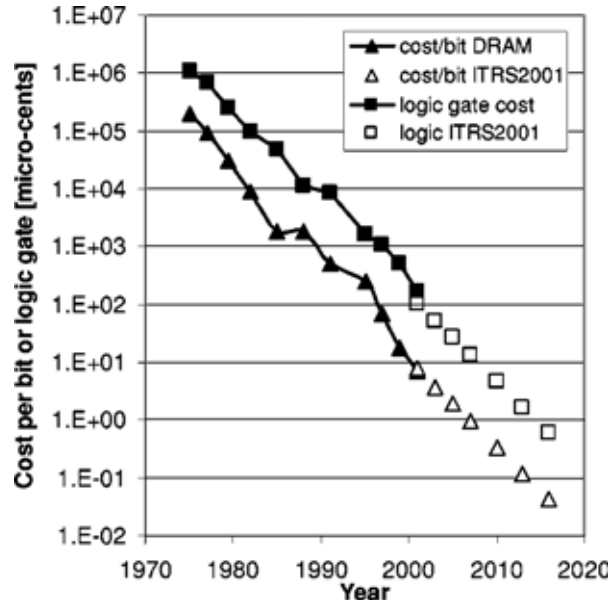


## Modern Optical Lithography



### Optical Lithography:

$$W_{\min} = k_1 \times \frac{\lambda}{\text{NA}},$$

where  $W_{\min}$  is the minimum linewidth of the printed feature,  $\lambda$  is the exposure wavelength, NA is the numerical aperture ( $\text{NA} = n \sin\theta$ ) of the projection optics, and  $k_1$  is a dimensionless scaling parameter.

$$\text{DOF} = \pm k_2 \lambda / \sin^2 \theta$$

$$\text{DOF} = k_3 \times \frac{\lambda}{4 \sin^2(\theta/2)} = k_3 \times \frac{\lambda}{2(1 - \sqrt{1 - \text{NA}^2})},$$

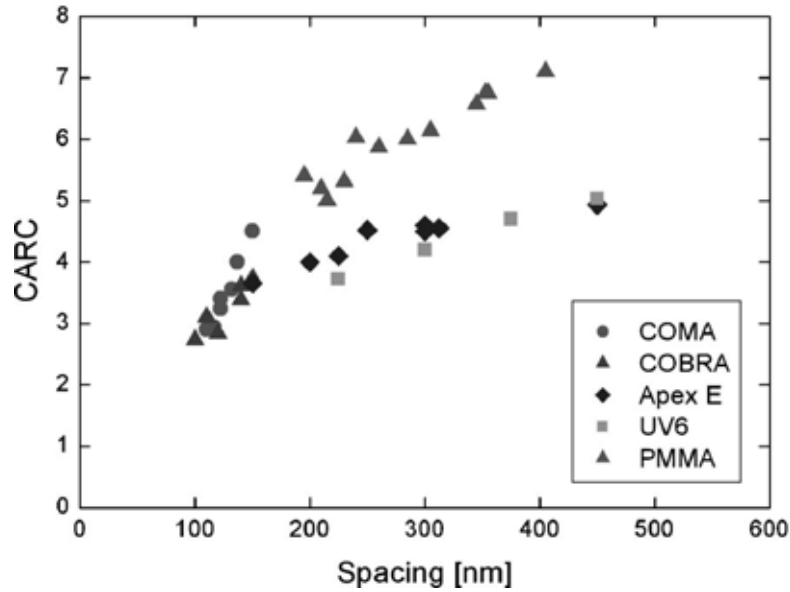
where  $\lambda_i = \lambda_0/n$  is the wavelength in the imaging media rather than vacuum [3].

TABLE I. Wavelengths for optical lithography. Resolution  $W_{\min}$  uses  $k_1 = 0.3$  and DOF uses  $k_3 = 1$ , assuming  $\text{NA} = 0.9$  for all wavelengths except EUV, which assumed  $\text{NA} = 0.25$ .

	$\lambda$ (nm)	$\Delta\lambda/\lambda$ (%)	$W_{\min}$ (nm)	DOF (nm)
G line		-		
Hg	436		145	386
I line Hg	365	16	122	324
KrF	248.3	32	83	220
ArF	193.4	22	64	171
F <sub>2</sub>	157.6	19	53	140
EUV	13.5	91	16	213

**Interesting nanomechanical issue: Aspect-ratio limitation**

**Benchmarking the Collapse Behavior of Different Resist Platforms**



Collapse behavior of various resist platforms. The critical aspect ratio for collapse (CARC) is defined to be the ratio of the resist thickness to the linewidth where collapse would begin. CARC was found to decrease for smaller feature sizes for all resist platforms studied by Cao *et al.* at the University of Wisconsin ~Ref. (9).

## Immersion Lithography:

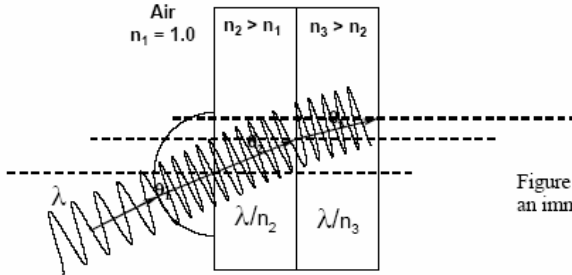
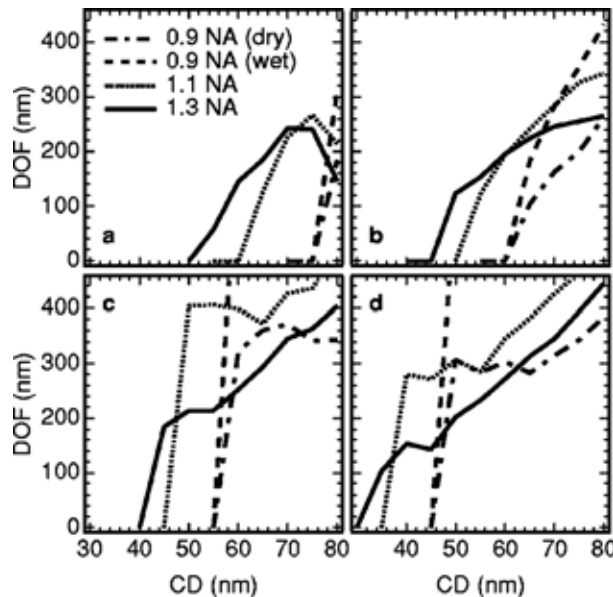


Figure 2. Refractive effects reducing the effective wavelength in an immersion media..

$$NA' = nNA = 1.44NA \text{ for water !!!}$$

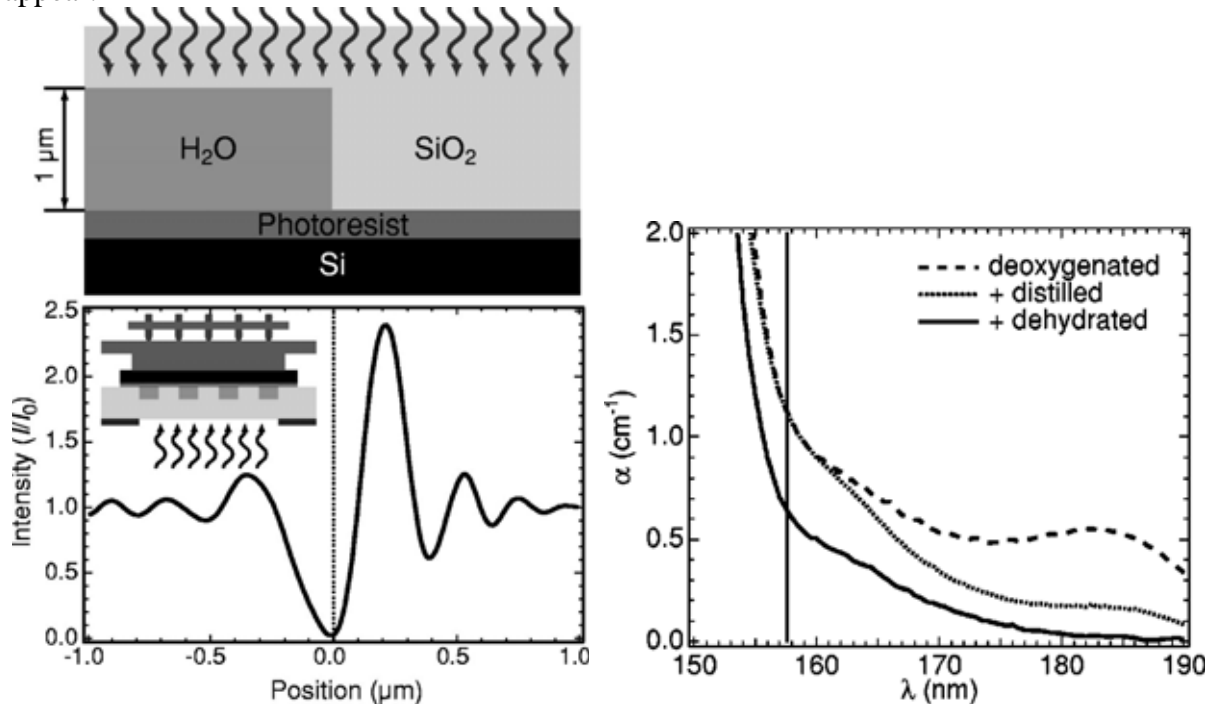
There are a number of open issues with regard to chip production with immersion lithography including:

- moderate to severe loss of image contrast for the TM polarization;
- fast, clean fluid dispensing onto wafer;
- bubble formation and other optical distortion during wafer scanning;
- resist process interactions with fluid; and
- lens contamination issues.



Numerical simulations of printing dense line and space patterns for NAs of 0.9, immersion and dry, 1.1, and 1.3. The depth of focus at 10% exposure latitude is shown as a function of the feature size. (a) Binary mask at 193 nm with annular illumination  $\sim s=0.4-0.6$ . (b) Binary mask at 157 nm with annular illumination. (c) Alternating phase shift mask at 193 nm with conventional illumination  $\sim s=0.3$ . (d) Alternating phase shift mask at 157 nm.

For all of these reasons, water is a very attractive candidate liquid at 193 nm. It has low absorbance, below  $0.05 \text{ cm}^{-1}$  and a relatively high index,  $n=1.44$ , along with low viscosity and familiarity in the semiconductor manufacturing process. Water for 193nm  $\rightarrow n=1.44$ , 2010 to appear.

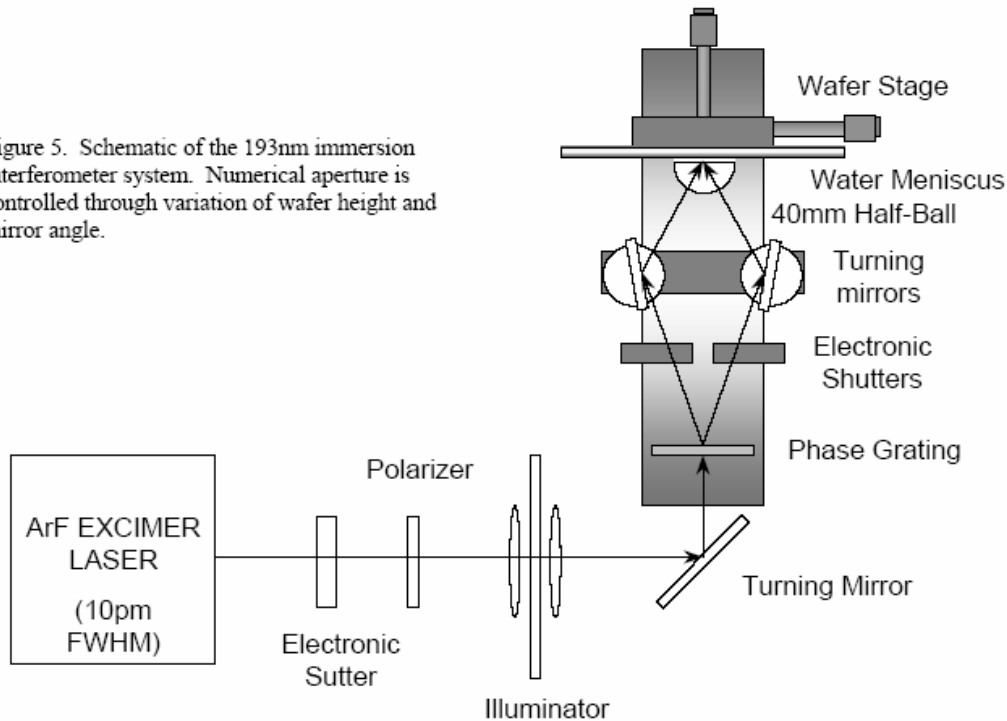


Left : Schematic of the immersion phase-edge contact printing process. The relief in the phase mask is filled with water. Bottom: Simulated aerial image at the phase edge. Inset: Schematic of the simple jig used to achieve optical contact between the wafer and the mask. An array of fine pitched screws apply pressure, while the fringes are observed through the mask from below. Perfluorinated polyethers ~PFPEs for 157 nm,  $n=1.4$ , 2013 to appear The lowest absorbance material measured to date is perfluorotriglyme ~PFTG,  $\text{CF}_3[\text{OCF}_2\text{CF}_2]_3\text{OCF}_3$ .

Right: Absorbance of perfluorotriglyme after de-oxygenation ~dashed line, distillation followed by de-oxygenation ~dotted line, and distillation followed by de-oxygenation and dehydration.

## Water immersion interferometric lithography:

Figure 5. Schematic of the 193nm immersion interferometer system. Numerical aperture is controlled through variation of wafer height and mirror angle.



NA=0.9 is achieved through interferometric lithography.  
 NA=1.3 is achieved by interferometric immersion lithography.

Example: 100 Hz 4W commercial compact excimer laser (GAM EX10) to operate to the following specifications:

- Energy Control Range mJ 4-12
- Repetition Rate 100 Hz
- Pulse Length 15 ns
- Beam Size 8 X 3-5 mm, Divergence 1 X 2 mRad
- Stability <2% Standard Deviation
- Temporal coherence 0.5mm (optional to 1 –2 mm)
- Spatial Coherence >0.5mm
- Beam Uniformity +/-5%

By expanding the beam to 10 cm, we allow for the following operation:

- Pulse energy 5mJ
- Dose per pulse ~0.1mj/cm<sup>2</sup>
- Spatial coherence region 5mm
- Field uniformity 1% in 2mm

The effect of the spatial coherence and spectral width can be correlated to the useful field size for an imaging IL system based on this 193nm source, with the following parameters:

- Critical path length control ~ 0.35mm
- Beam misalignment requirement 0.8mm
- Usable field size for 90% contrast 2mm

