Approaching the NA of Water: Immersion Lithography at 193nm

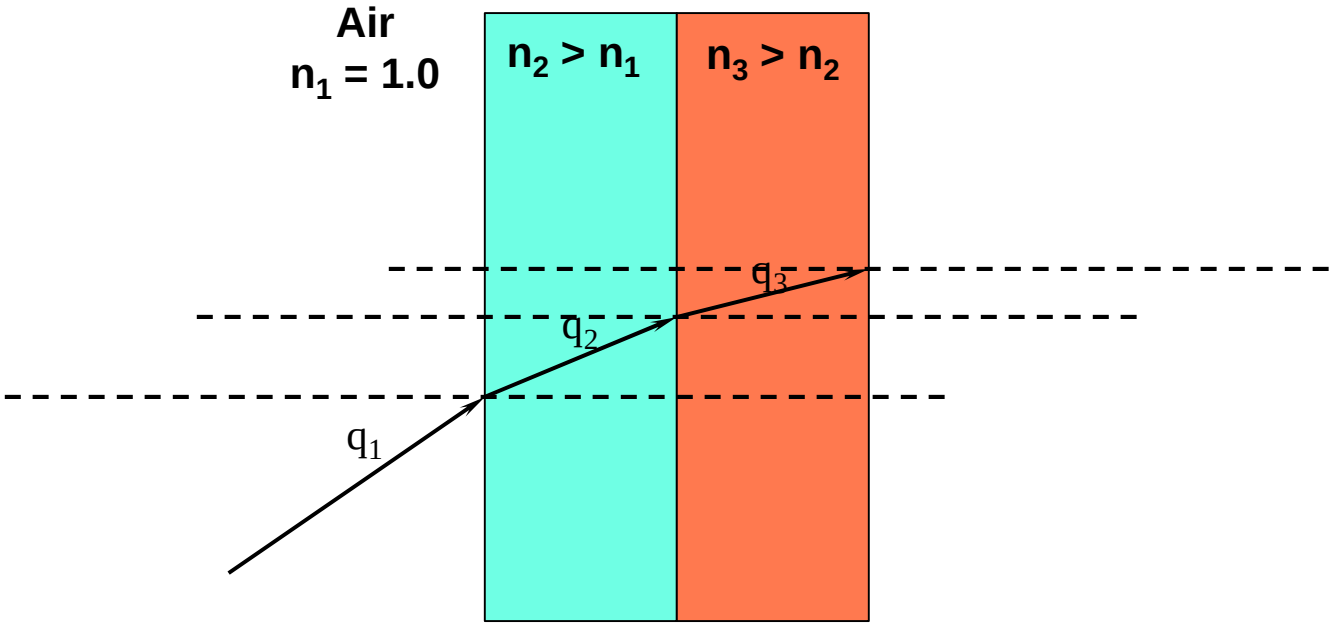
Bruce Smith

Y. Fan, A. Bourov, L. Zavyalova, J. Zhou, F. Cropanese, N. Lafferty
Rochester Institute of Technology
M. Gower, D. Ashworth
Exitech Inc.
J. Webb
Corning Tropel

Outline

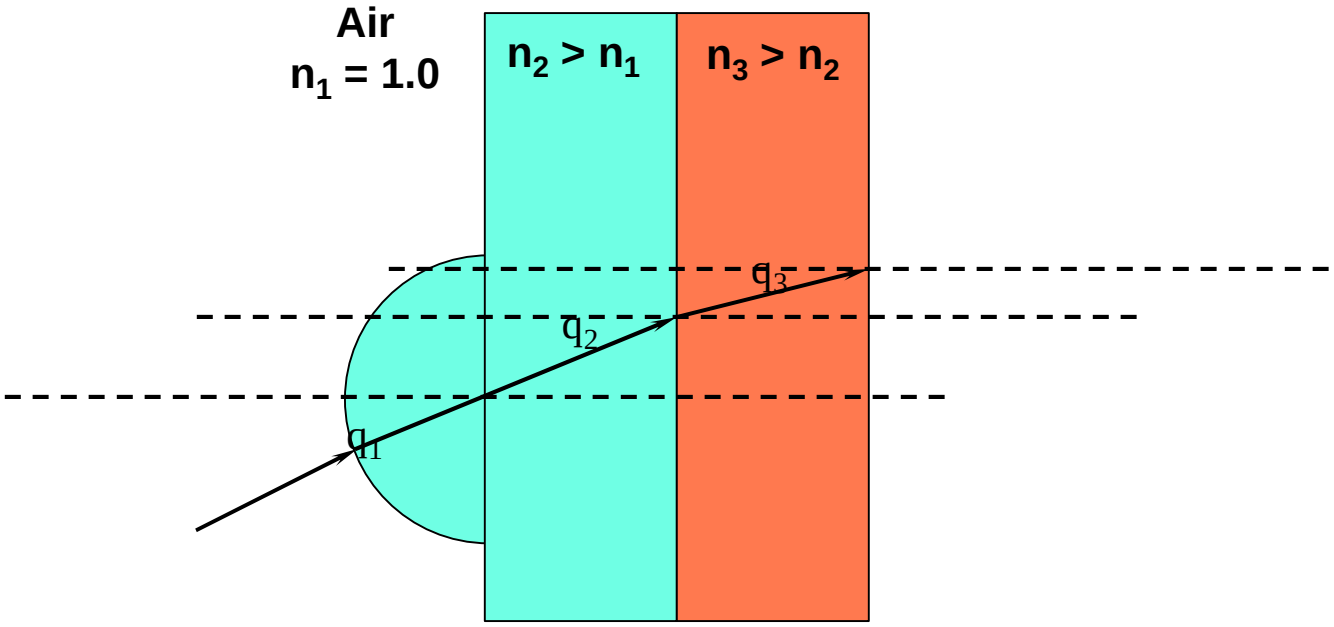
- 193nm immersion lithography to 38nm p/2
- Interferometric vs. projection lithography
- 1.05NA projection microstepper
- Homogeneous immersion and increasing refractive index

Increasing NA with Immersion



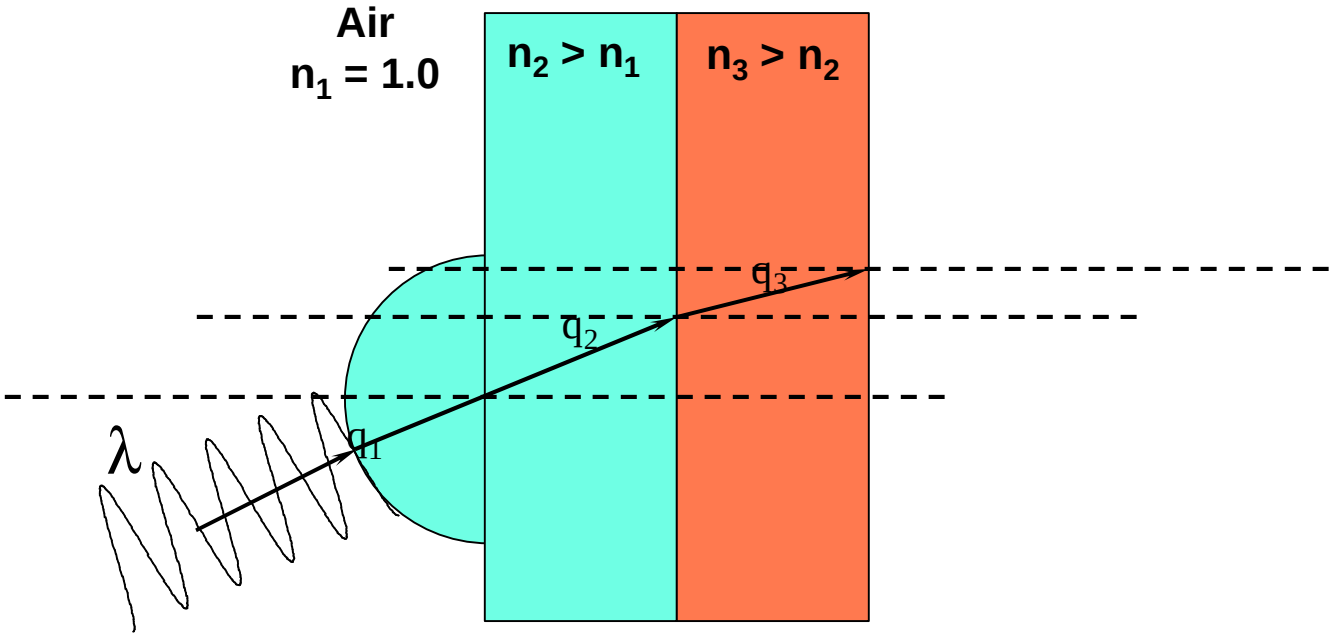
$$NA = n_1 \sin(q_1) = n_2 \sin(q_2) = n_3 \sin(q_3)$$

Increasing NA with Immersion



NA = n_1 sin (q_1) =n_2 sin (q_2)= n_3 sin (q_3)

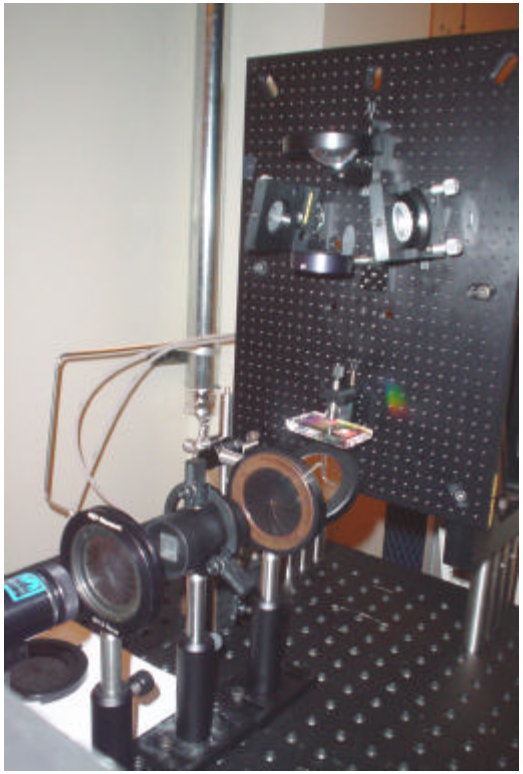
Increasing NA with Immersion
193nm or 134nm



Scaling of NA or wavelength?

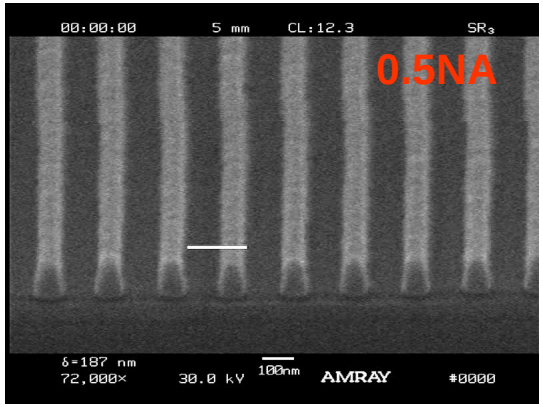
ArF Immersion Talbot Lithography
Breadboard "Half-ball" system

- +/- 1 Order Talbot interferometer preserves spatial coherence
- Unstable excimer resonator for 0.5mm coherence length
- Beam expansion increases length to 2mm (field size)
- Dual etalons provide 6pm FWHM
- Half ball interface allows NA to 1.35

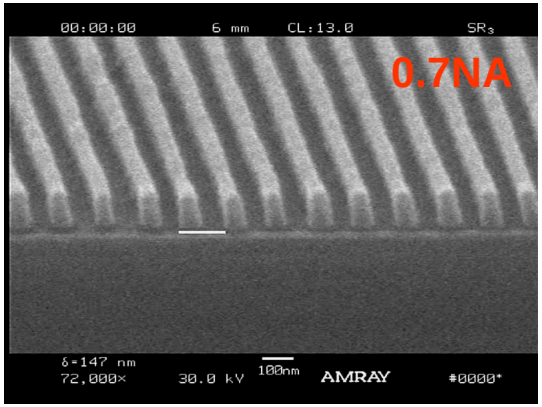


193i Resist Images 55-80nm Resolution

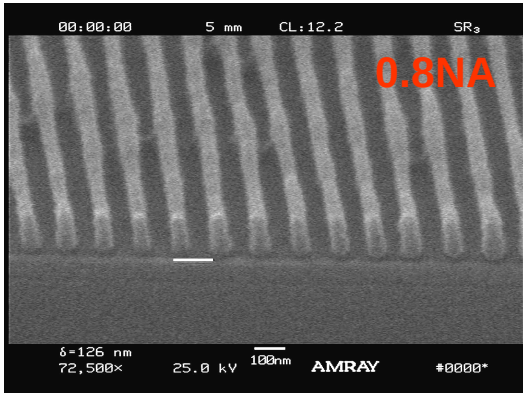
Shipley XP1020 over AR, 50-100nm film thickness, TOK topcoat, TE polarization



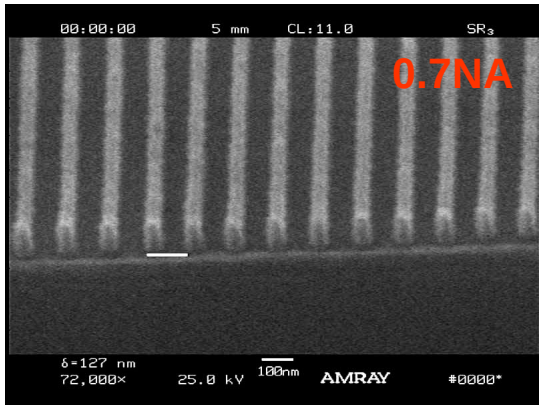
80nm 1:1.5



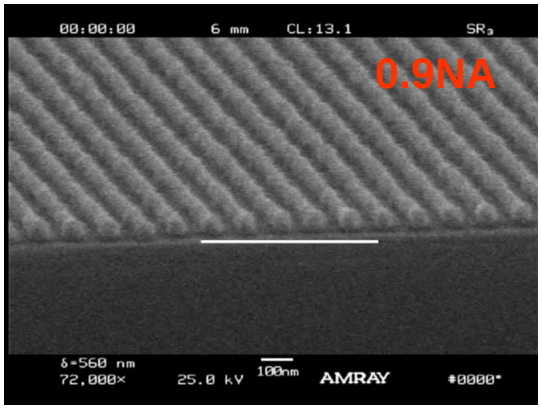
65nm 1:1



60nm 1:1



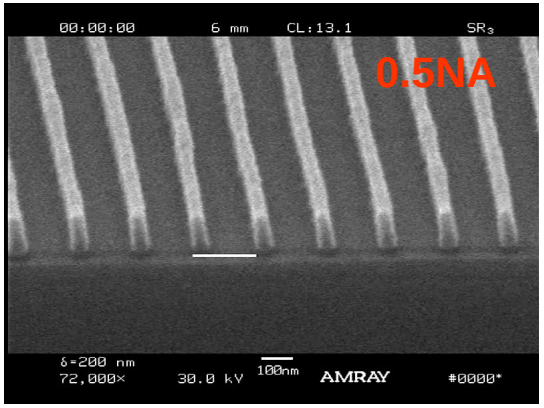
55nm 1:1.5



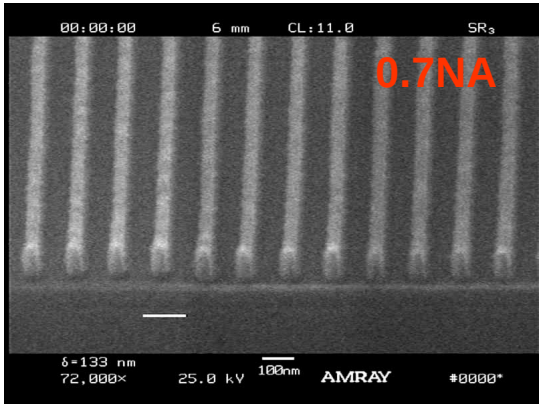
55nm 1:1

193i Resist Images 45-50nm Resolution

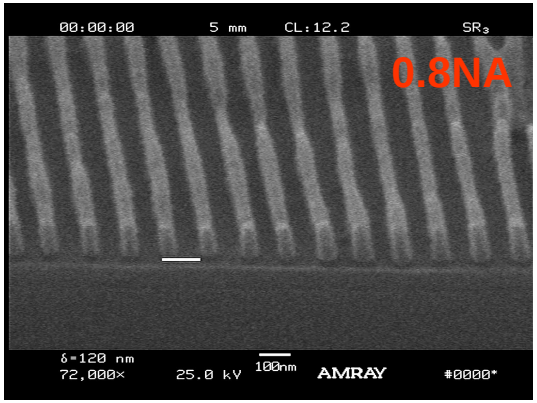
Shipley XP1020 over AR, 50-100nm film thickness, TOK topcoat, TE polarization



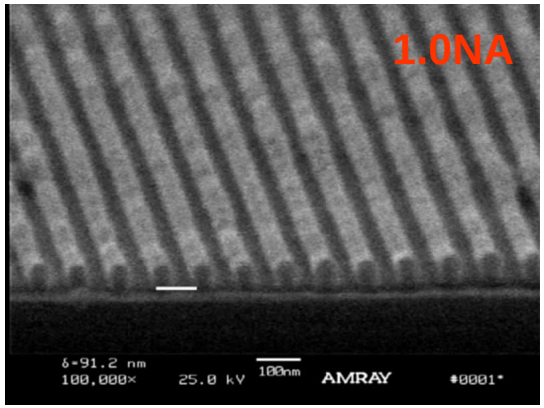
50nm 1:3



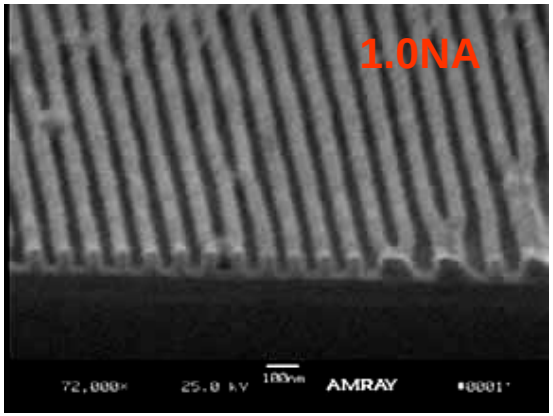
45nm 1:2



45nm 1:1.5



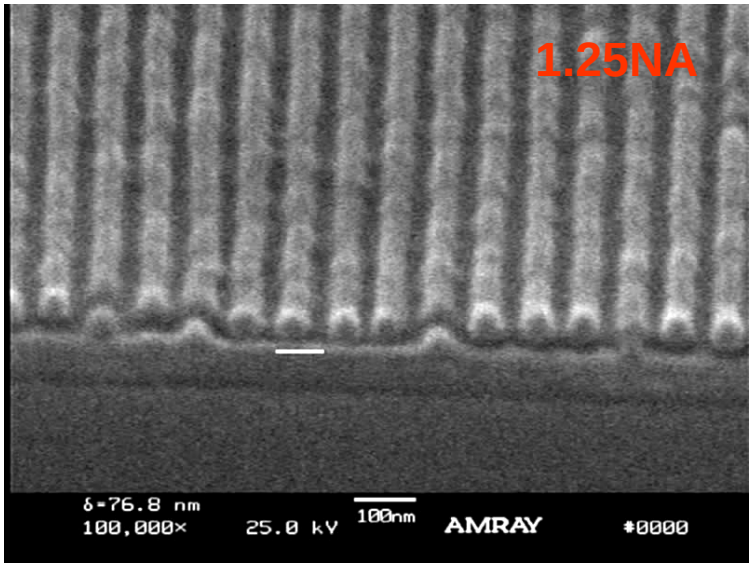
45nm 1:1 70nm
Shipley XP1020

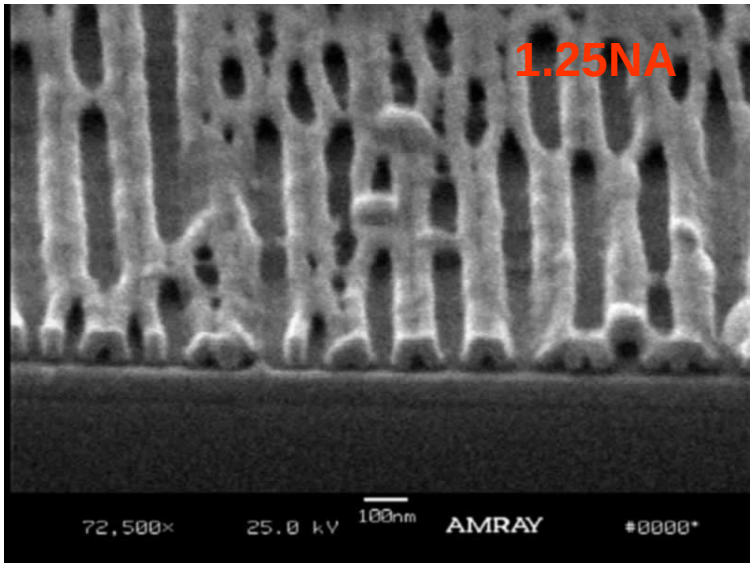


45nm 1:1 80nm
TOK ILP012

193i Resist Images 38nm Resolution

1.25NA Interference Lens, TE polarization

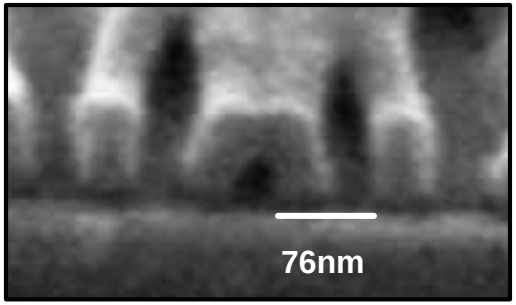




38nm p/2

50nm XP1020

Early results show good optical contrast and resist potential



38nm 1:1

70nm XP1020

Compact Talbot Lens

Entire 193nm Talbot system incorporated into compact lens

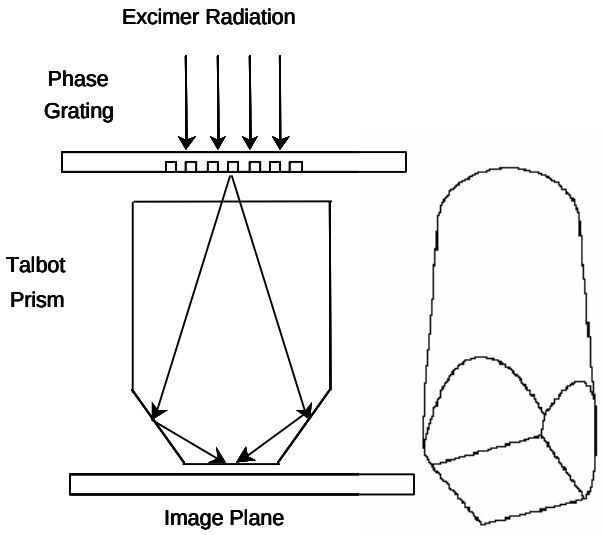
600nm phase grating produces +/-1st diffraction orders at 18.8°

Talbot lens angle increases NA up to 1.35

Line/space and contact patterns are possible

2/4 beam interference allow for large tolerances

Combined with beam expander and MgF_2 polarizer



193 Prism Lens Designs

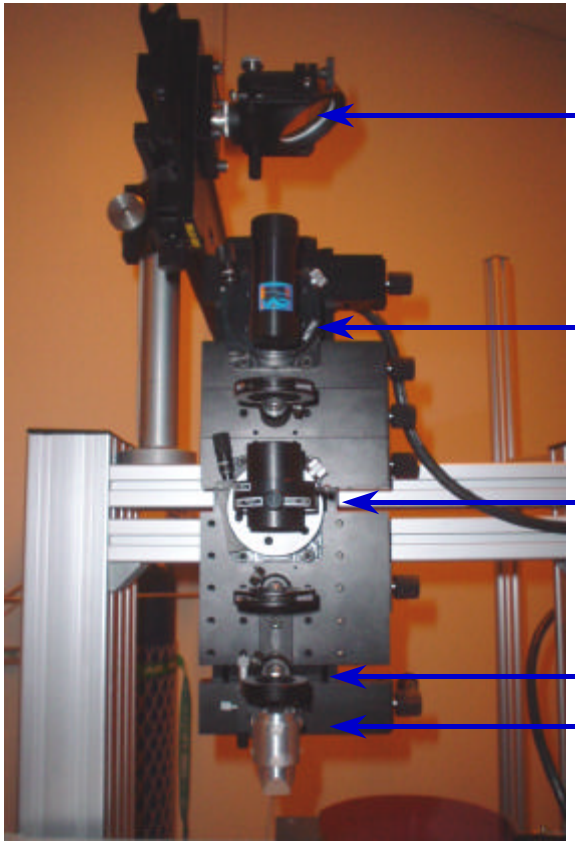
NA	*half-pitch*
0.8	*60nm*
1.05	*45nm*
1.20	*40nm*
1.35	*36nm*

Talbot Immersion Research Tool

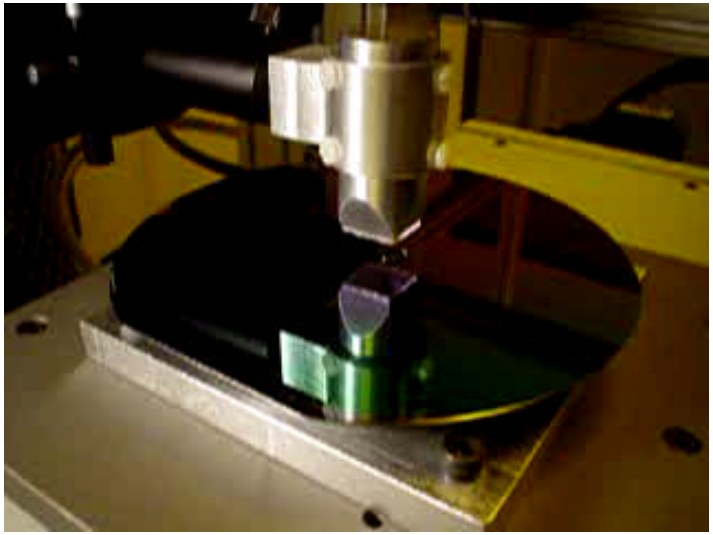
Workstation

- Linear guide bearing stage
- 200mm X-Y stage travel
- 6-8” robotic wafer handling
- Compact GAM ArF excimer
  - 5 mJ pulse energy
  - 6pm linewidth (FWHM)
  - 200 Hz rep. rate

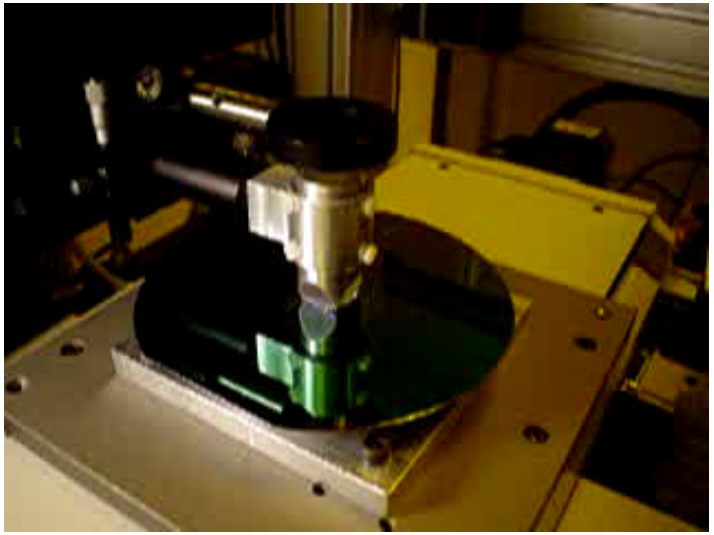
Optical Column



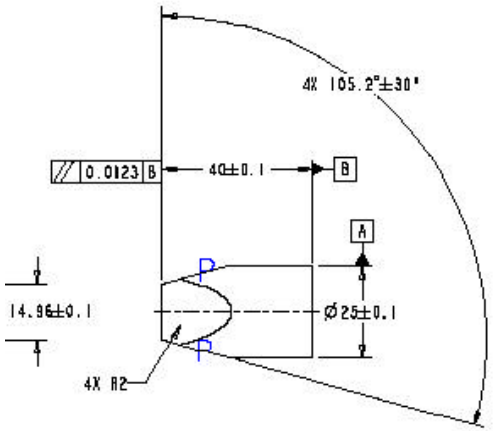
Water Handling at the Wafer Plane

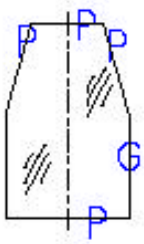


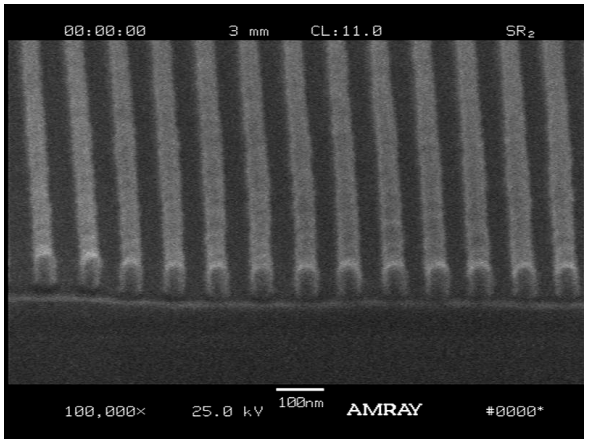
Contact with water



Stepping with water







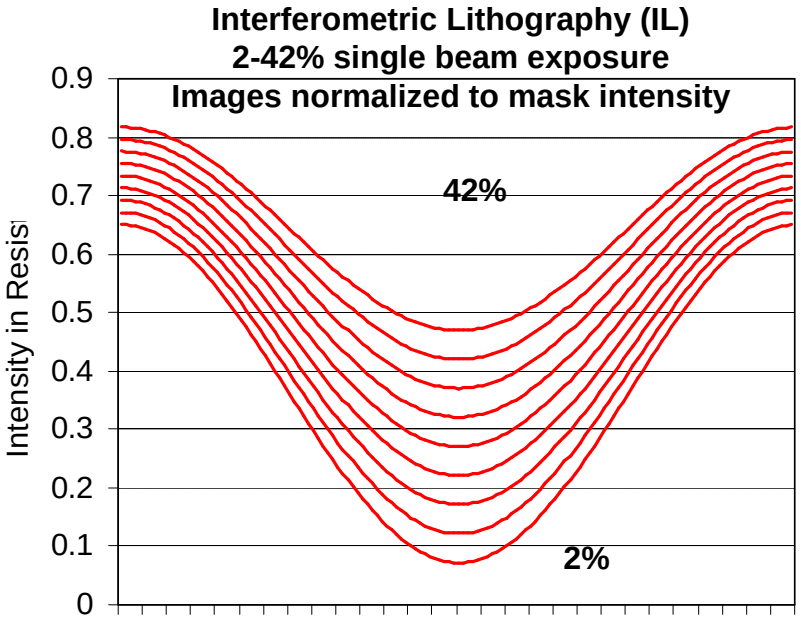
45nm p/2 at 1.05NA

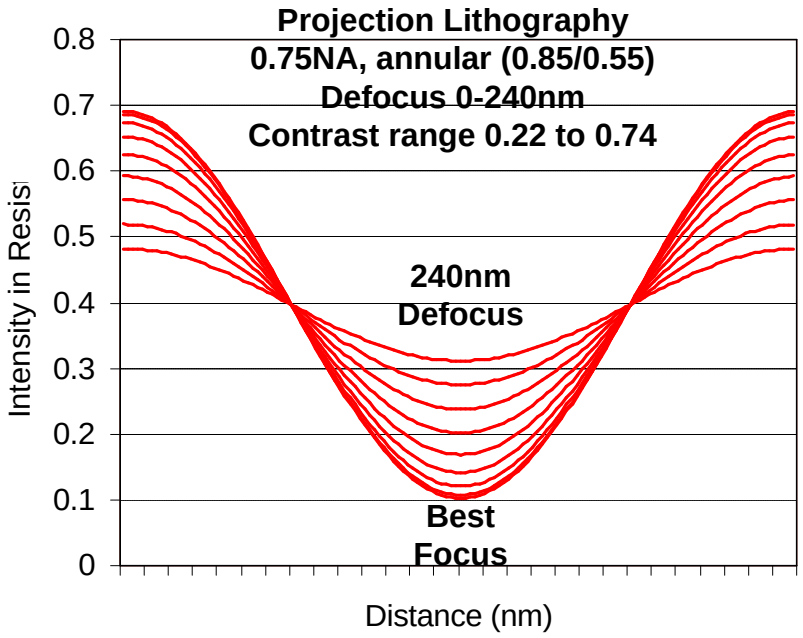
Interferometric Immersion vs. Projection Immersion Lithography

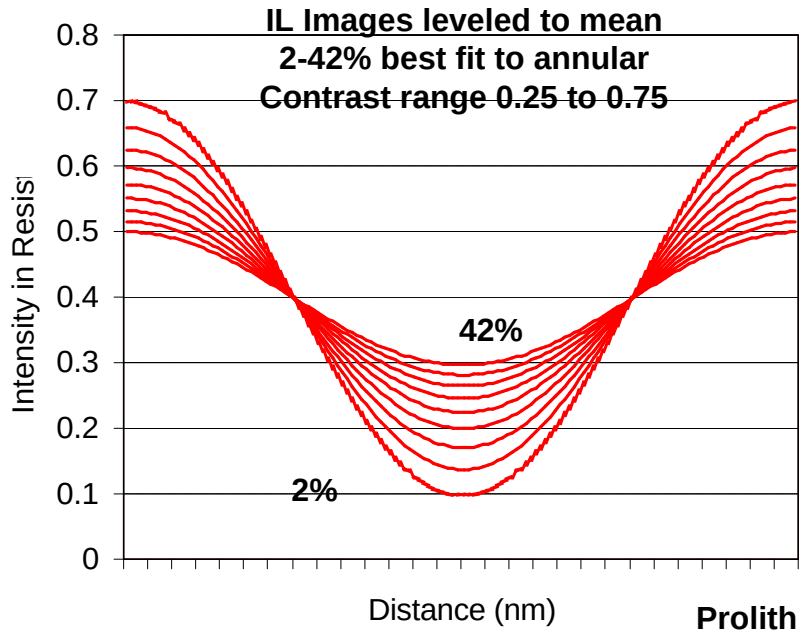
How well can 2-beam interference lithography predict projection lithography?

Resist Image Intensity Comparisons

Projection vs. Interferometric Lithography of 100nm 1:1 lines Resist index = 1.7, a=0 Vector Simulation



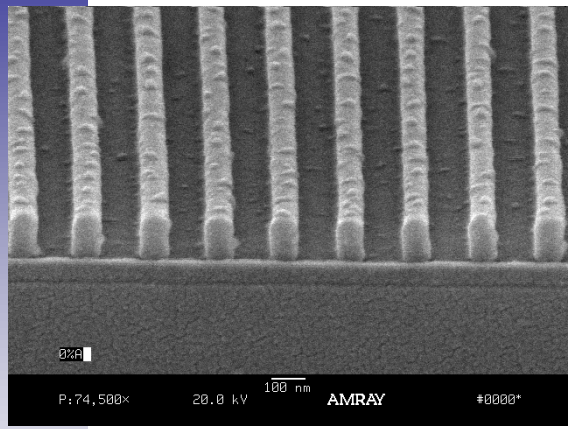


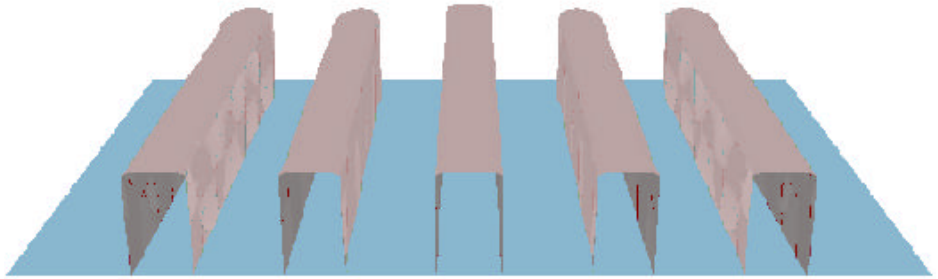


Prolith 8.02

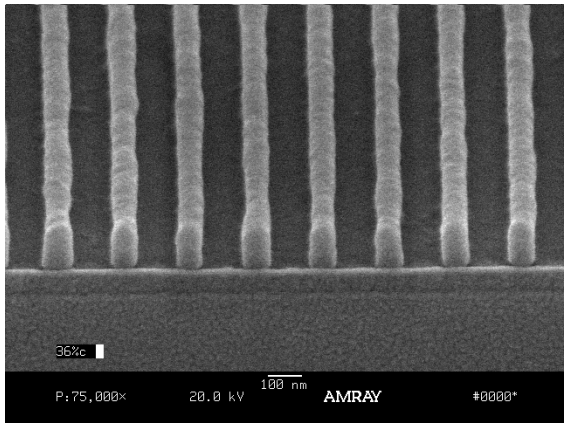
Immersion IL Images with demodulation

Full modulation
(Best Focus)

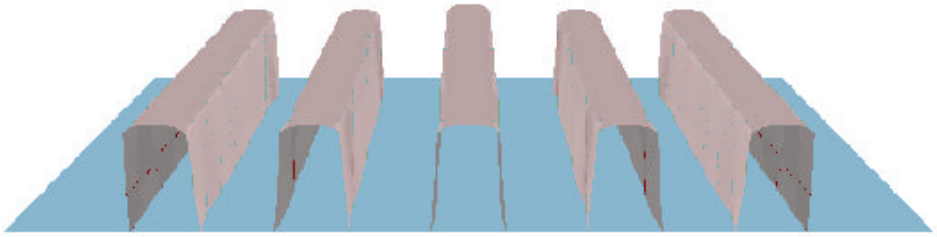




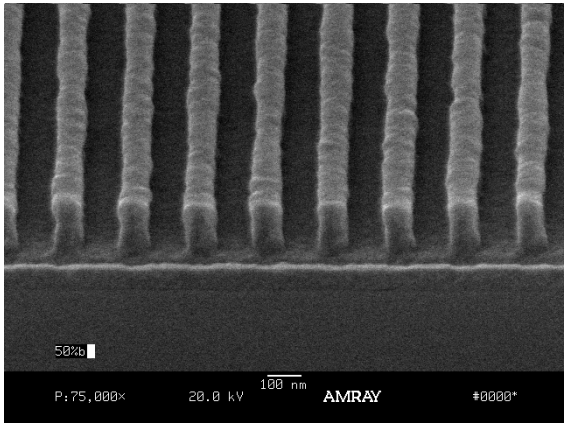
LPM simulation



30% demodulation
(150nm defocus)



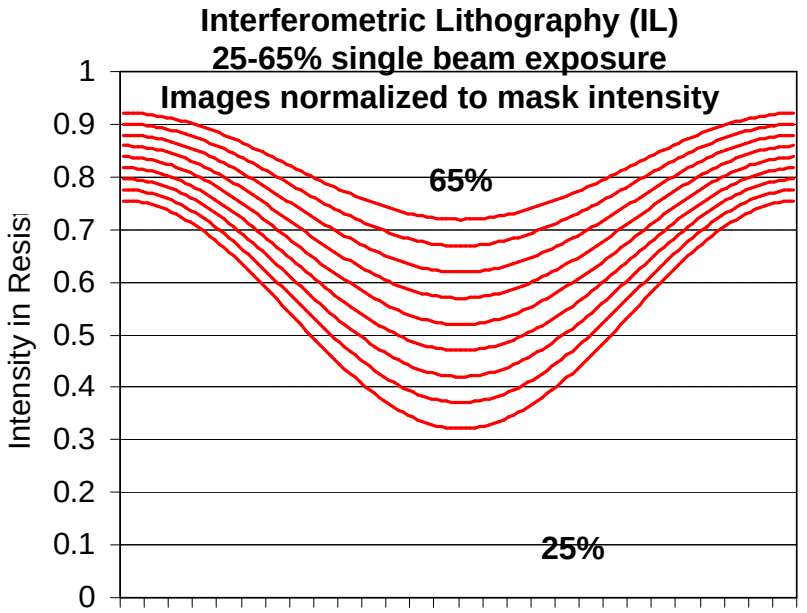
LPM simulation

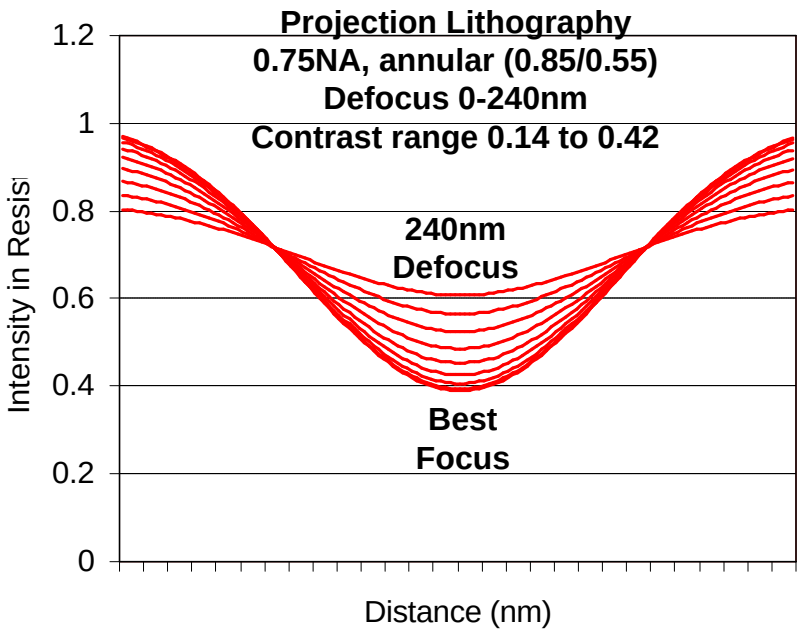


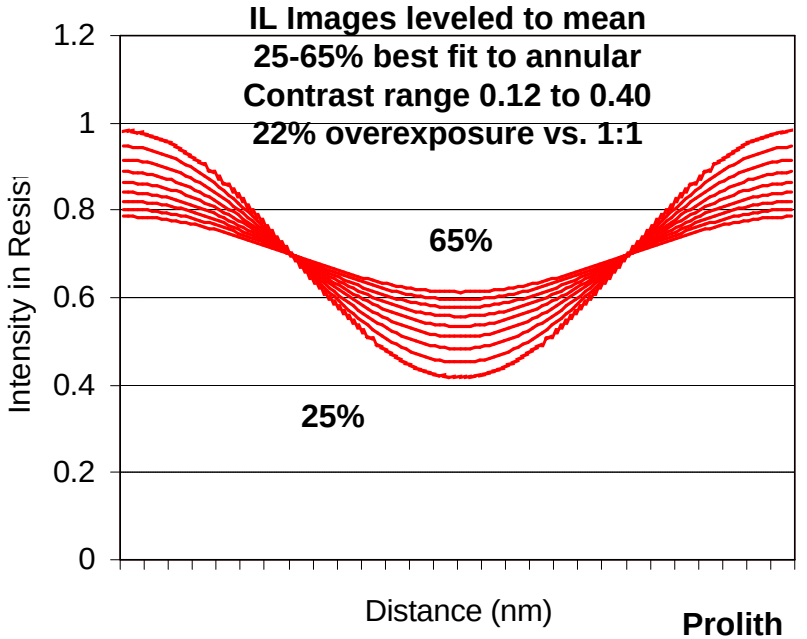
50% demodulation
(220nm defocus)

Resist Image Intensity Comparisons

Projection vs. Interferometric Lithography of 100nm 1:3 lines
Resist index = 1.7, a=0
Vector Simulation



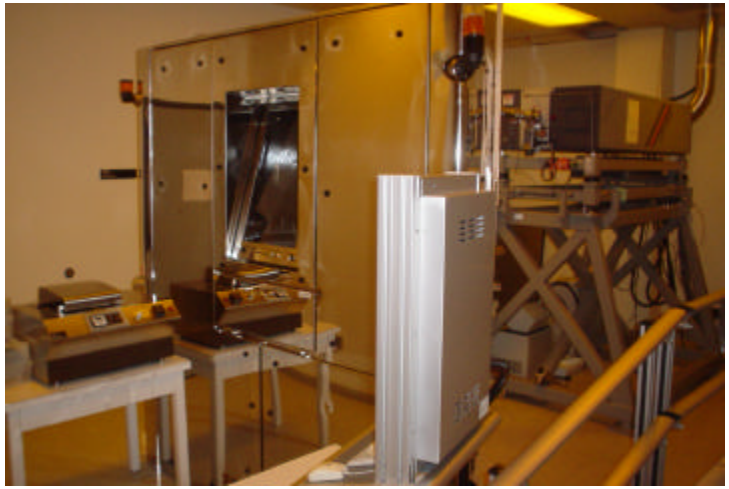


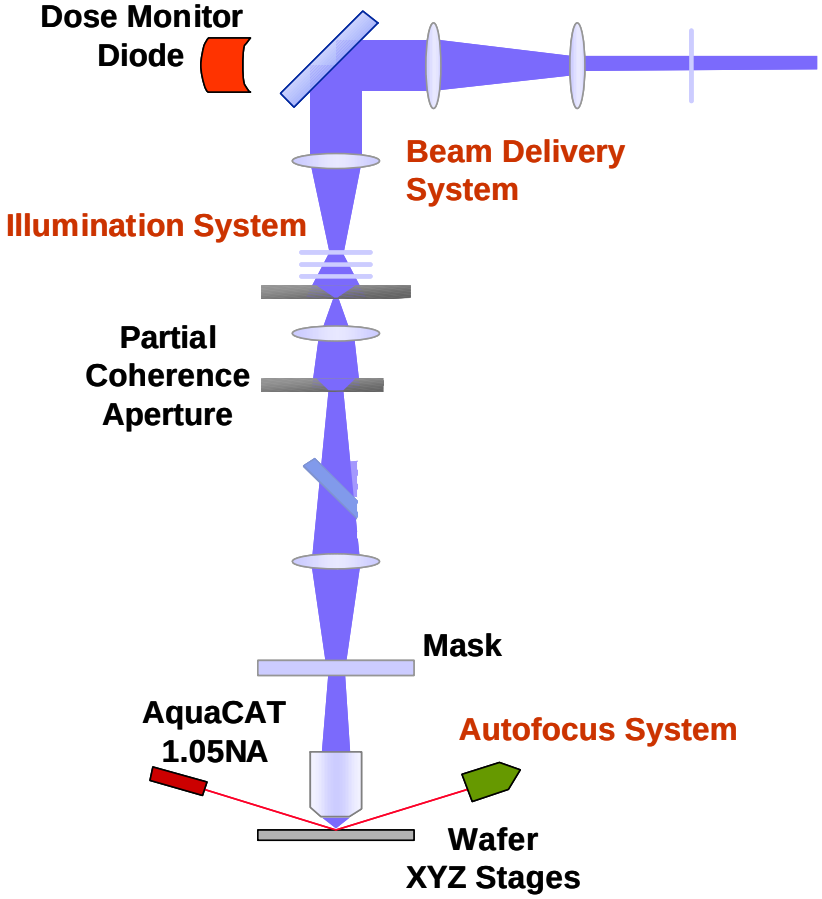


Prolith 8.02

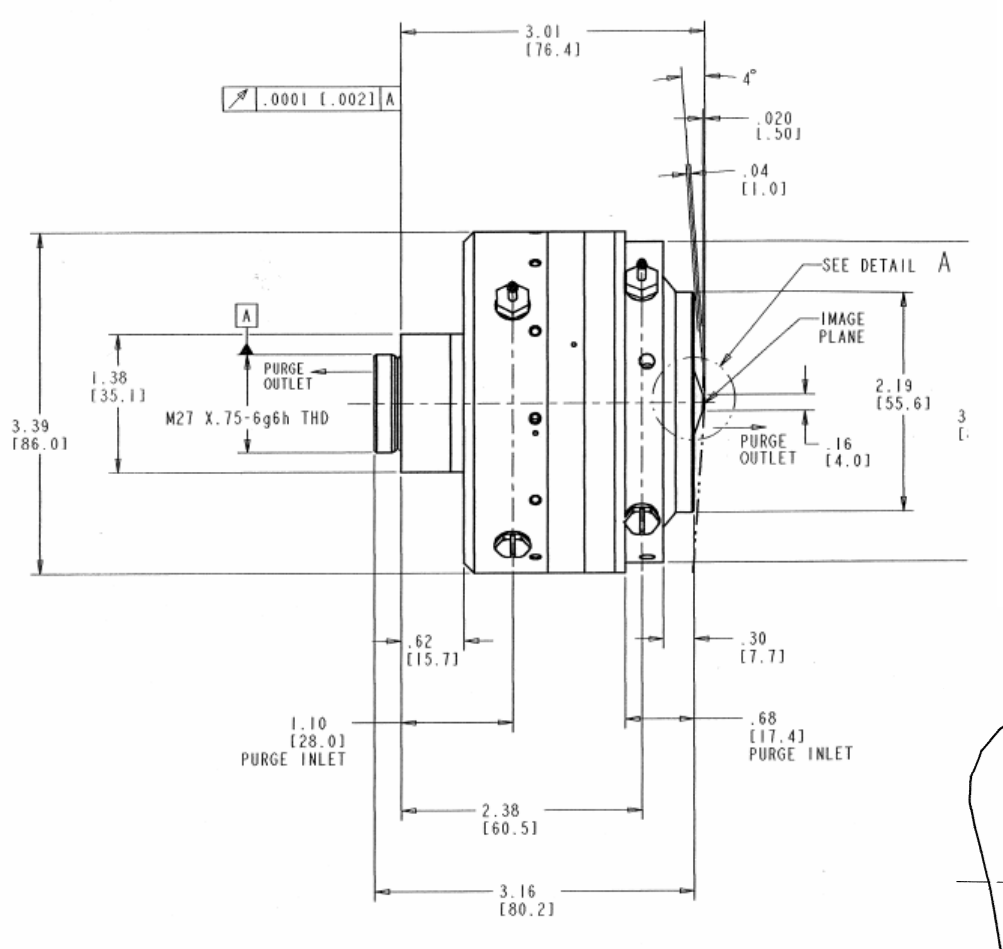
193nm Immersion MicroStepper

Exitech PS3000 / 1.05NA Corning Tropel AquaCAT



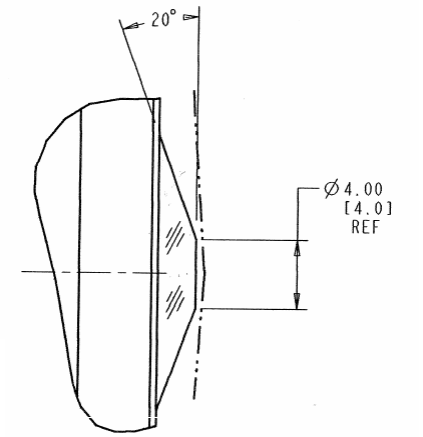


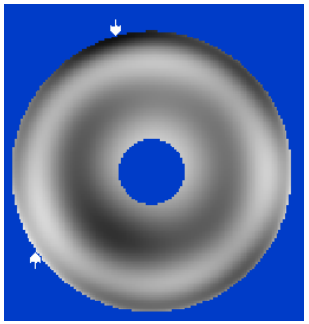
AquaCAT 193i Catadioptric Lens



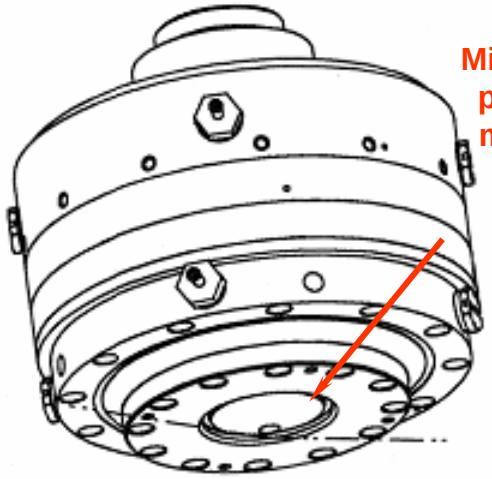
Lens Specifications

NA	**1.05**
Reduction	**90X**
Image field	**0.1 mm**
Wavelength	**193.3 nm**
Bandwidth	**700 pm**
Track length	**210 mm +/- 10 mm**
Entrance Pupil distance	**210 mm +/- 10 mm**
Material	**SiO2**
Immersion fluid	**H2O**
Working distance	**>0.5 mm**
# of elements	**8**
% Obscuration	**<15%**
Measured wavefront	**<0.05 waves rms (SPIE 5377-74)**

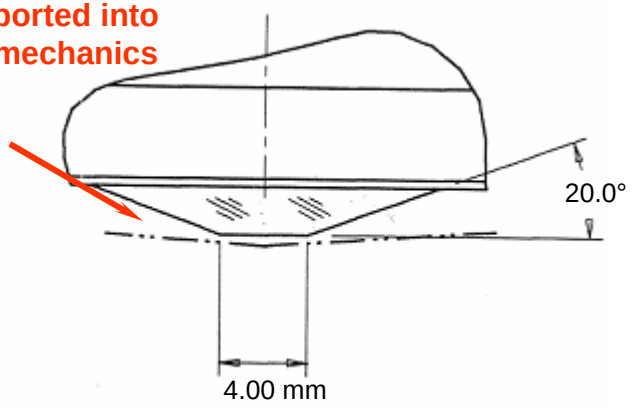




Fluid Injection and Meniscus



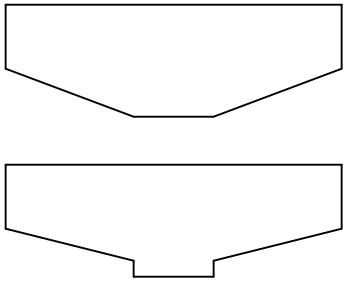
Micro-pipette ported into mechanics



Bottom of assembly

Final glass surface

Meniscus retention testing using final element mock-up
a) 20° surface angle
b) 90° surface angle

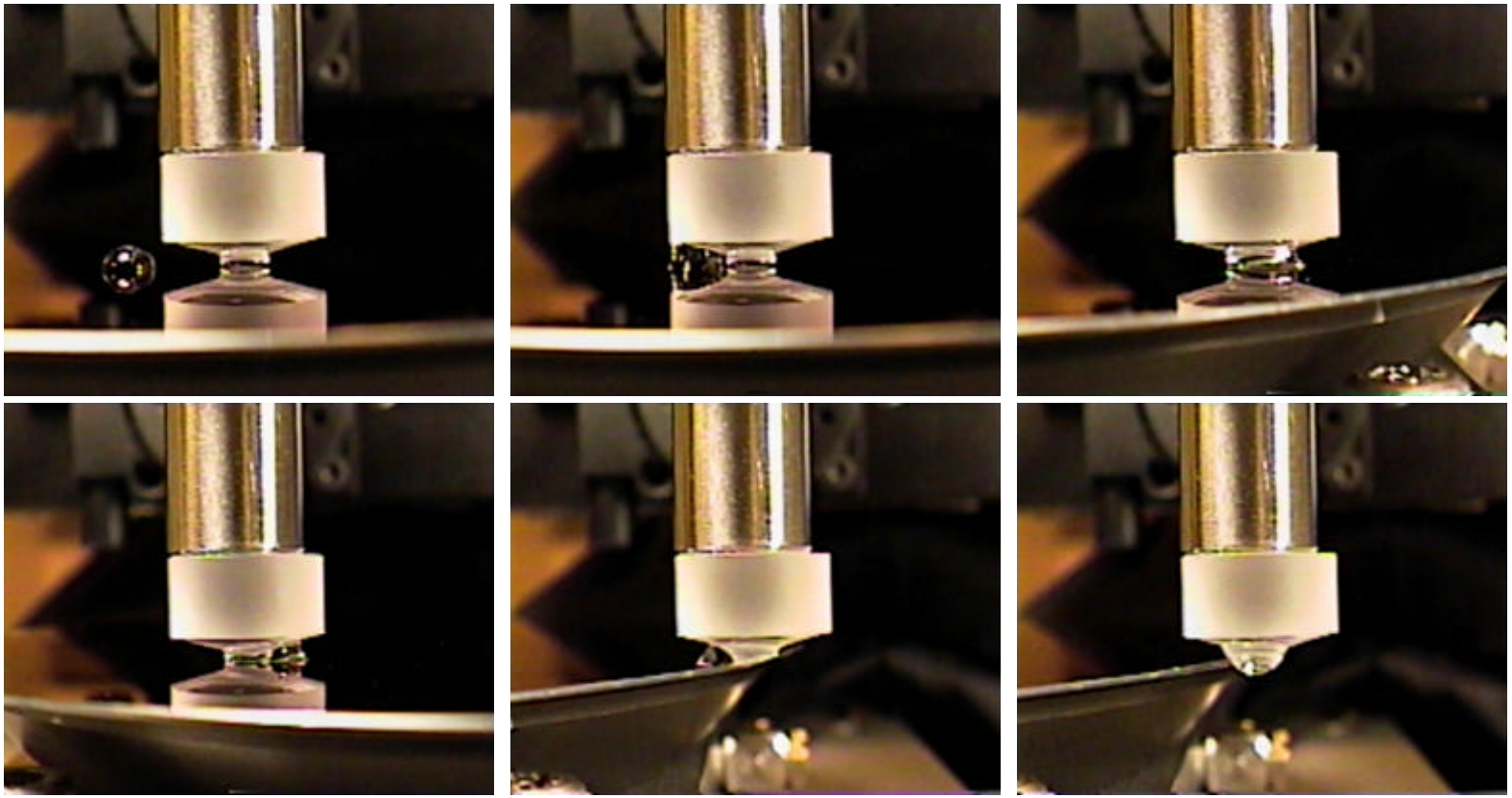


Water Introduction Considerations

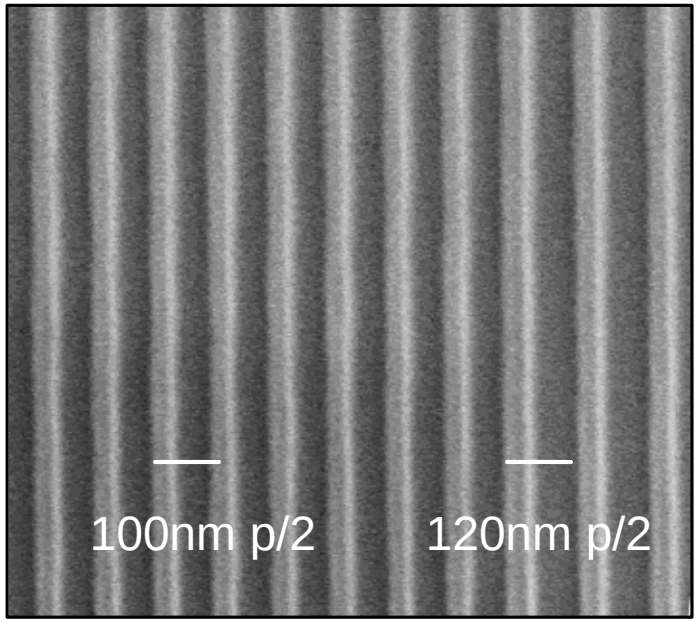
1. Method – micro syringe pipette ~0.01 ml immersion volume in 3.5 sec using 10ml/hr Baxter APII syringe pump
2. Retention – surface tensioning to hold meniscus

Water Meniscus Retention

Experimental Test Approach



Early Image Results



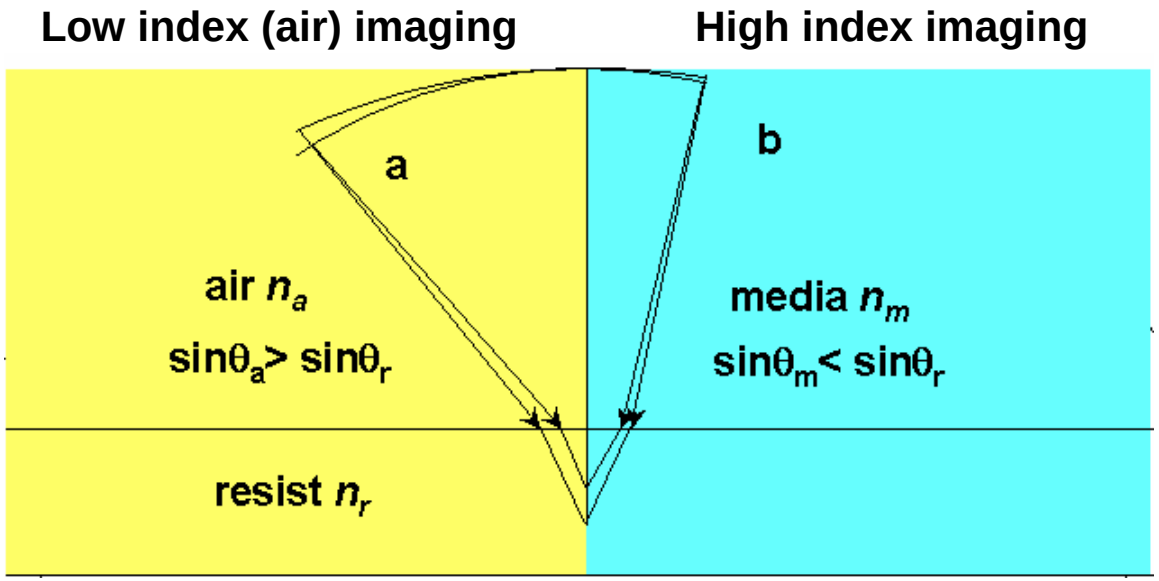
Binary mask 0.70σ
Unpolarized illlumination
200-240nm pitch
TOK ISP topcoat
80nm TOK ILP03 resist
AR29 BARC

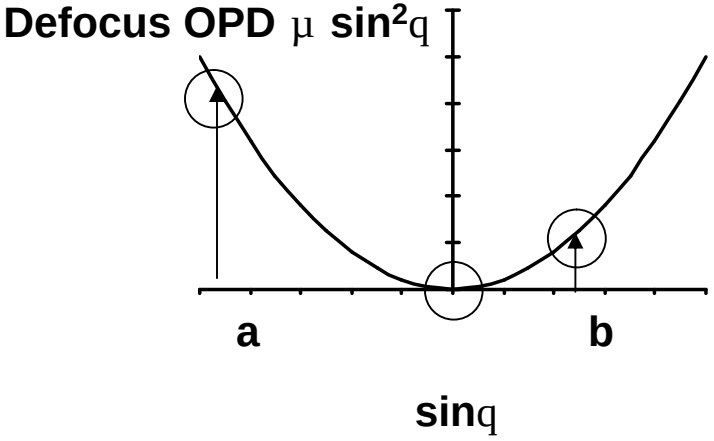
Remaining system action items:

Field stop and sigma apertures, environmental audit, PSM, system qualification, polarization control

Homogeneous Immersion

Increasing refractive indices – the defocus effect





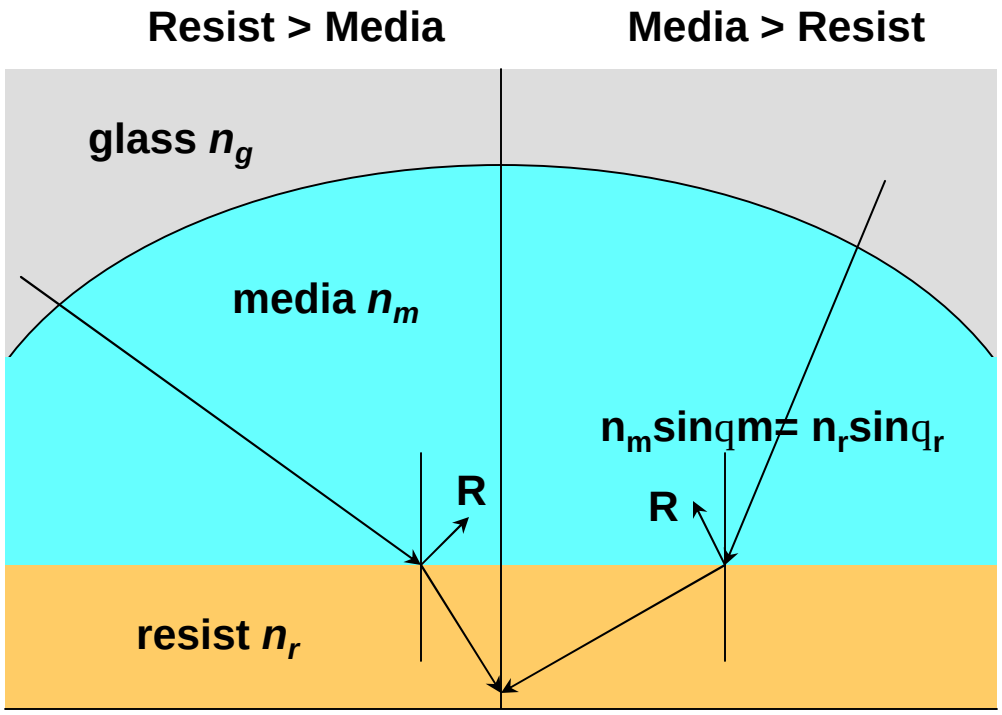
The defocus wave aberration is proportional to $\sin^2 q$

Higher indices reduce defocus OPD at equivalent NA values

Small NA/*n* *is* desirable

Homogeneous Immersion

Increasing refractive indices – the refractive effect



The glass index is not a concern unless surface is planar

The maximum NA is limited to min[n_m,n_r]

Reflectivity is determined by index disparity

Matched indices is desirable

Increasing Water Index in the UV
Inorganic approach

- **UV-vis absorption involves excitation of e^- from ground**
- **Solvents provide "charge-transfer-to-solvent" transitions (CTTS)**
- **CTTS and λ_{max} for halide ions is well documented** [1]

$$F^- < (OH)^- < Cl^- < Br^- < I^-$$

- **Alkalai metal cations can shift λ_{max} lower** [2]

$$Cs^+ < Rb^+ < K^+ < Li^+ < Na^+ < NH_4^+ < H_3^+O$$

- **d λ_{max}/dT is positive (~500ppm/°C), d λ_{max}/dP is negative**
- **Goal to approach "anomolous dispersion" with low absorbance**

[1] E. Rabinowitch, Rev. Mod. Phys., 14, 112 (1942)

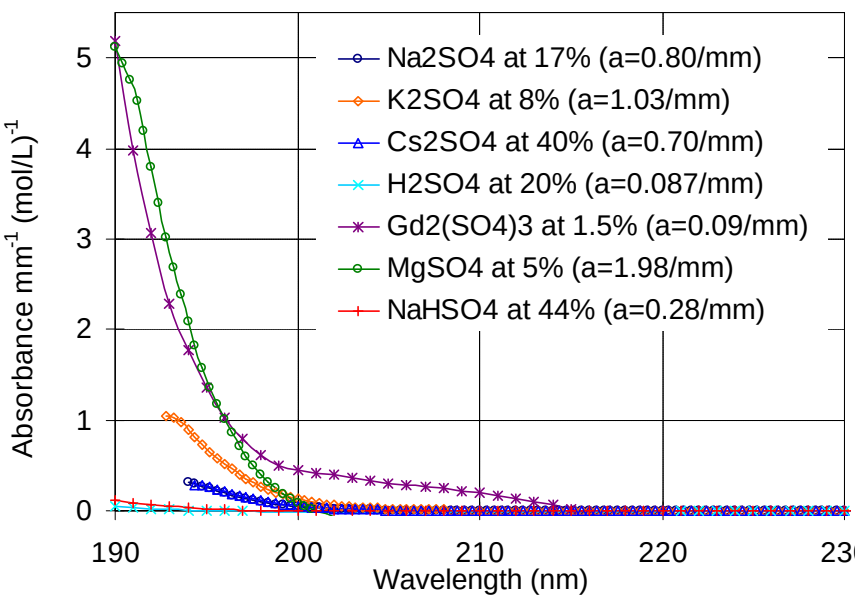
[2] G. Stein and A. Treinen, Trans. Faraday Soc. 56, 1393 (1960)

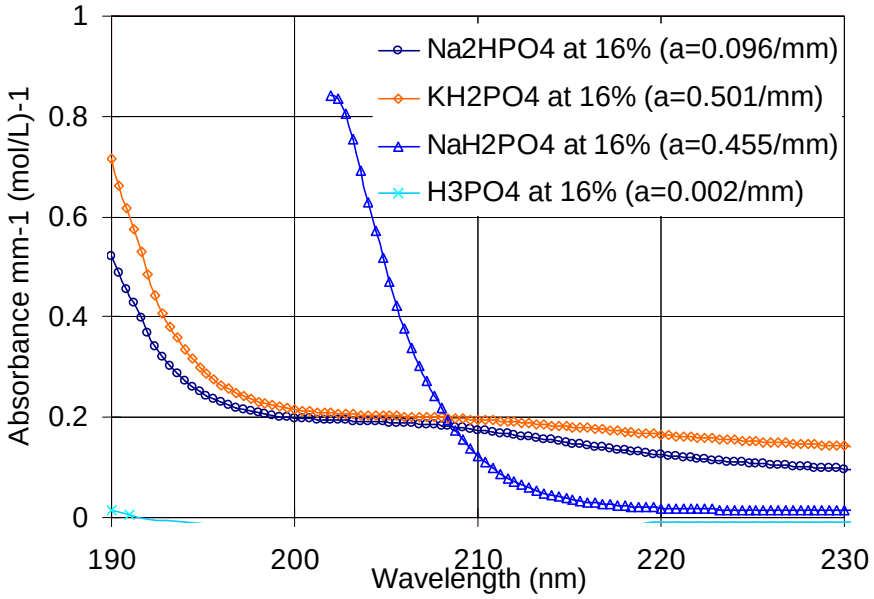
Effect of Anion on Absorption of Water

Anion in water	*Absorption Peak [3]*	
I^-	5.48eV	227nm
Br^-	6.26	198
Cl^-	*6.78*	*183*
ClO_4^{-1}	6.88	180
HPO_4^{2-1}	*6.95*	*179*
SO_4^{2-1}	*7.09*	*175*
$H_2PO_4^-$	*7.31*	*170*
HSO_4^-	*7.44*	*167*

[3] Various including M.J. Blandamer and M.F. Fox, Theory and Applications of Charge-Transfer-To-Solvent Spectra, (1968).

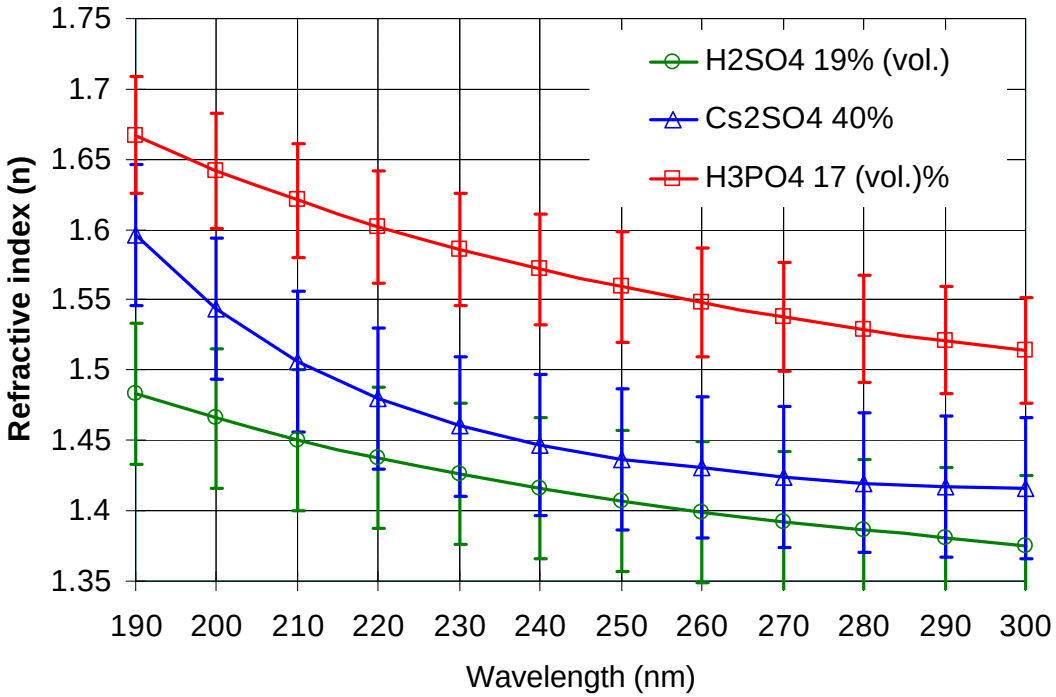
Measured Absorbance Spectra of Sulfates and Phosphates in Water





- Solutions normalized to mole concentration of cation
- Fluids with absorbance < 0.1/mm become interesting
- Mixtures follow EMA behavior

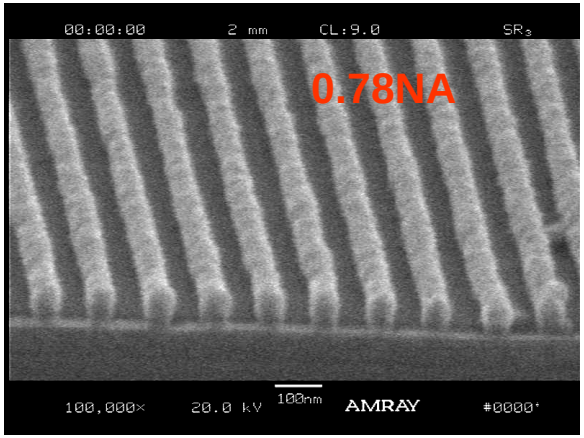
Measured Refractive Index of Select Sulfates and Phosphates in Water



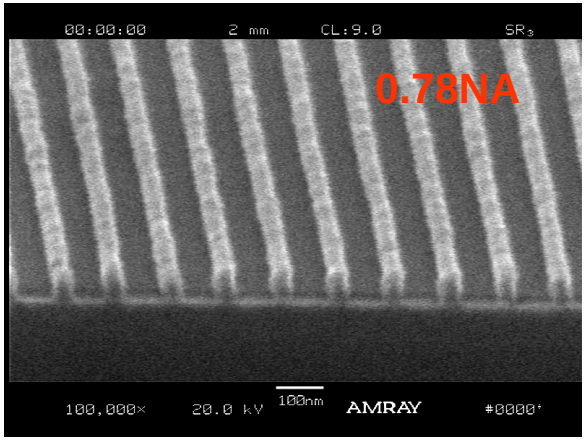
- Spectroscopic ellipsometry screening for Cauchy fit
- Several cations show little impact on index

Pure and Doped Water Comparisons for same angle (31°) in immersion fluids

Water with 40 wt% Cs_2SO_4 ~100㎜ gap 117nm pitch

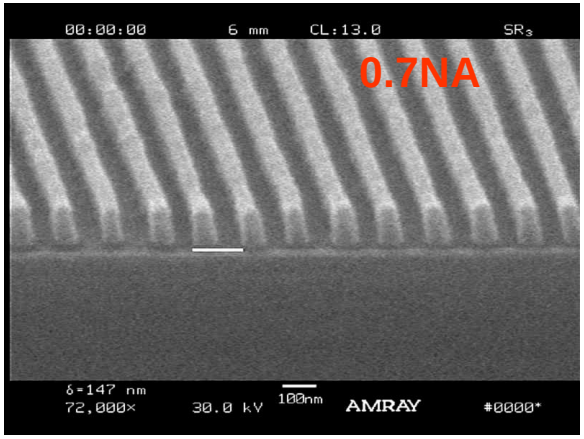


59nm 1:1 (50nm resist)

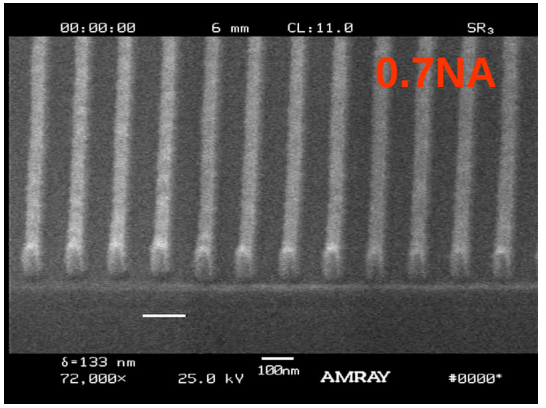


39nm 1:2 (50nm resist)

Water (HPLC grade) ~100㎜ gap 130nm pitch



65nm 1:1 (100nm resist)

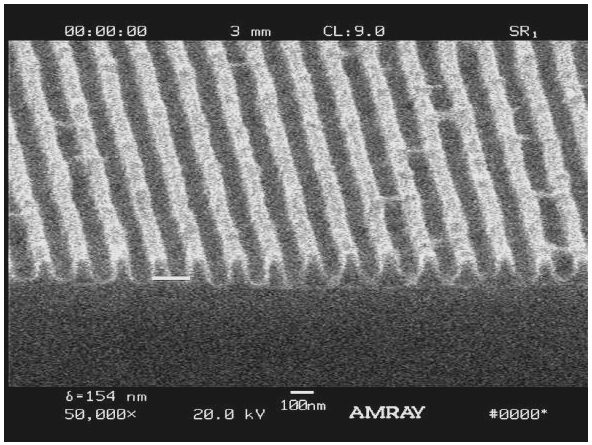


45nm 1:2 (70nm resist)

Summary

- 193nm immersion lithography to 38nm p/2
- Early optical results of water are promising for n ~1.6
- Resolution limit with 1.6n fluid is 30nm p/2

248nm Water Immersion Lithography



75nm half-pitch
0.82NA

Acknowledgements: DARPA / AFRL, International SEMATECH, SRC, IBM, Exitech, Corning Tropel, ASML, Intel, Shipley, TOK, Photronics, Brewer Science, GAM Laser Inc.