Approaching the NA of Water: Immersion Lithography at 193nm

Bruce Smith

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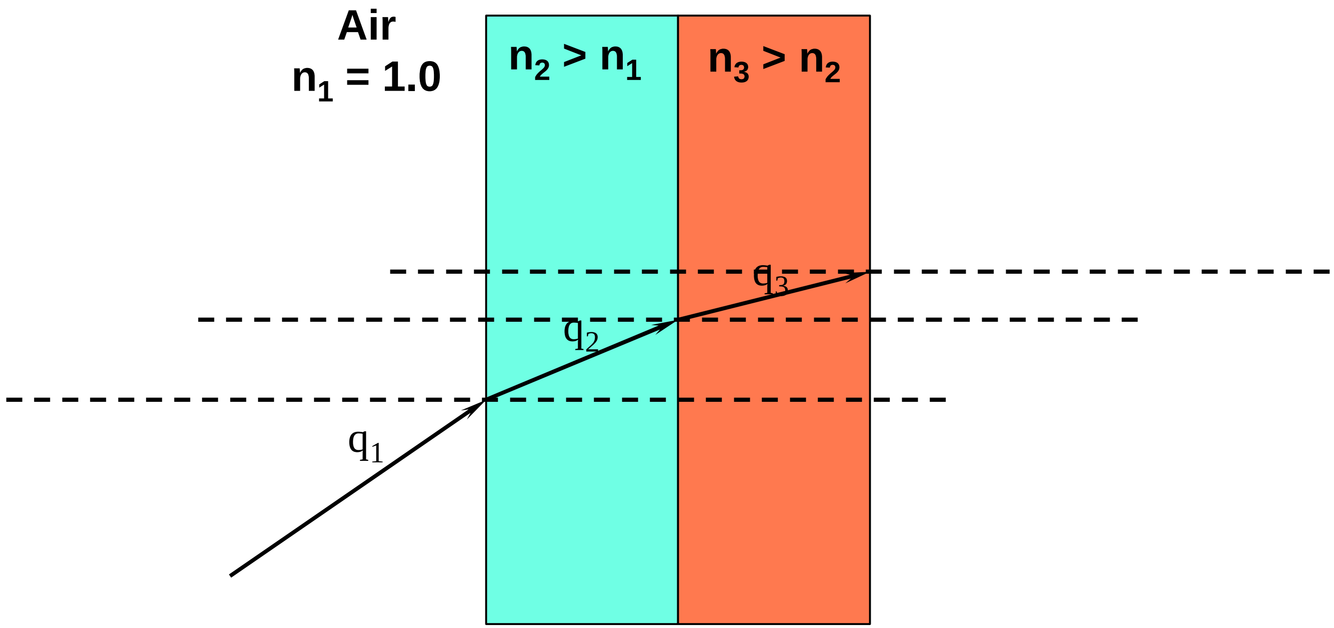
Corning Tropel

Outline

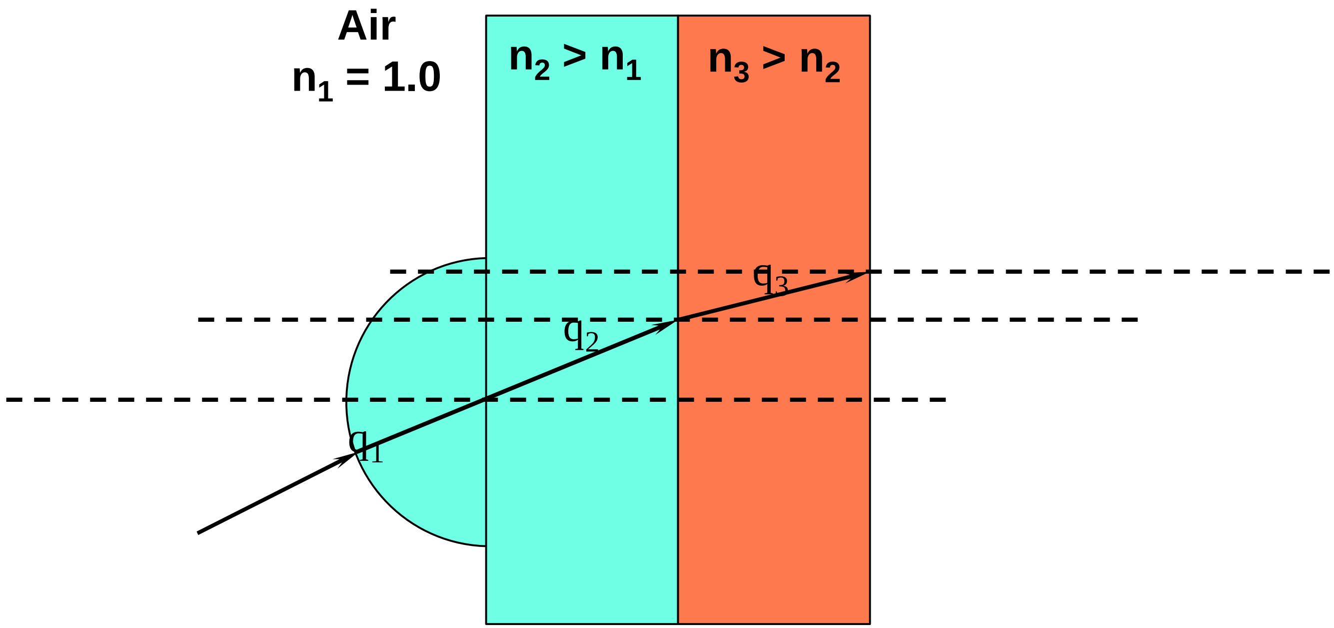
- 193nm immersion lithography to 38nm p/2
- Interferometric vs. projection lithography
- 1.05NA projection microstepper
- Homogeneous immersion and increasing refractive index

Increasing NA with Immersion



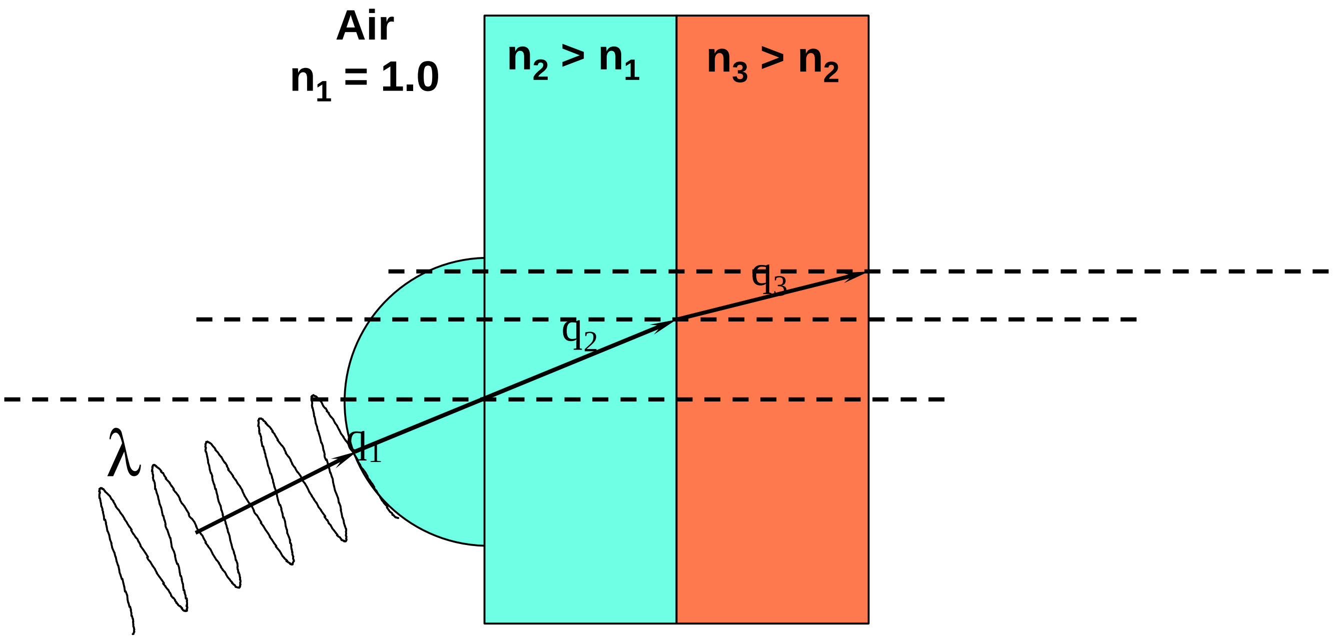
$$NA = n_1 \sin (q_1) = n_2 \sin (q_2) = n_3 \sin (q_3)$$

Increasing NA with Immersion



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

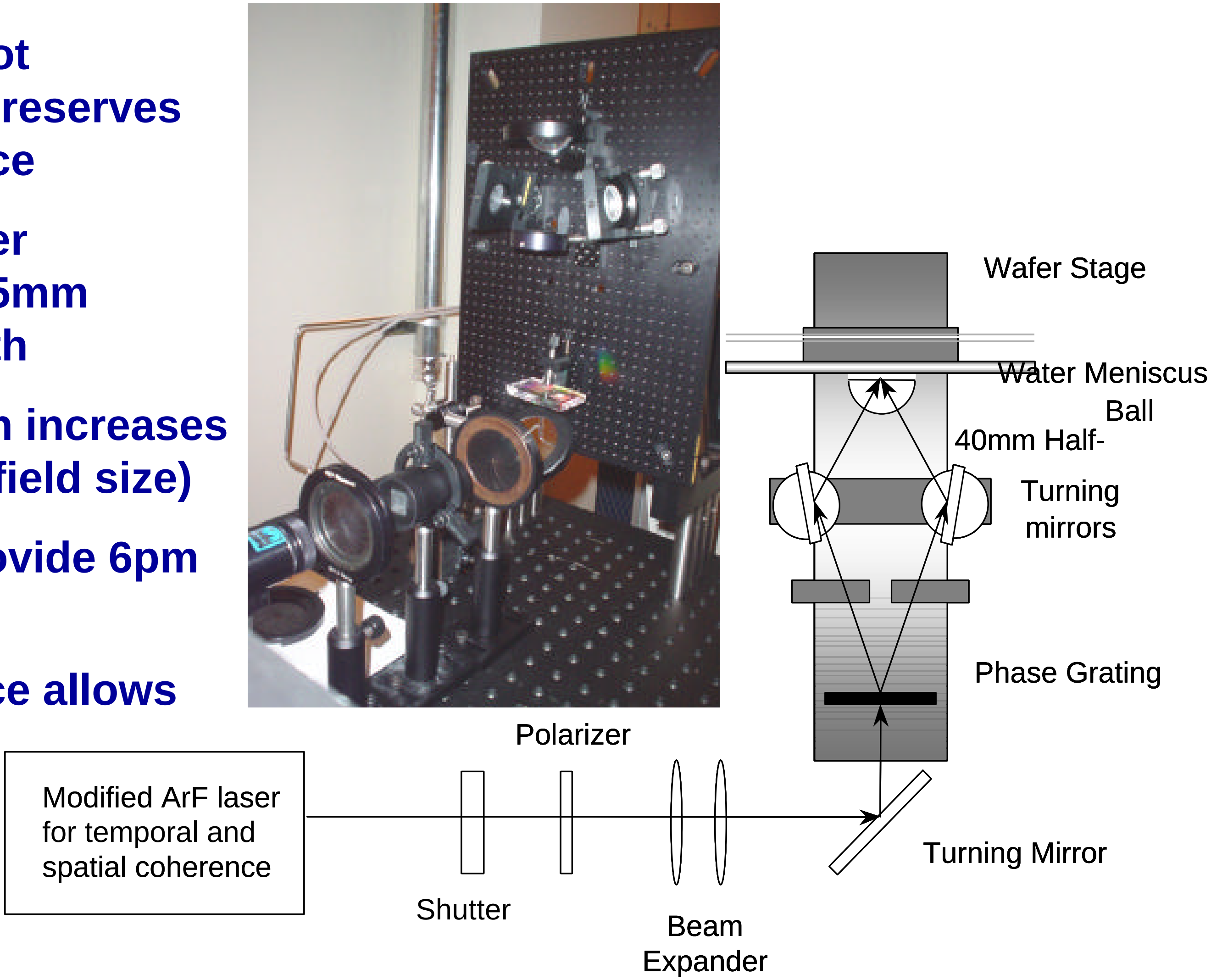
Increasing NA with Immersion
193nm or 134nm



Scaling of NA or wavelength?

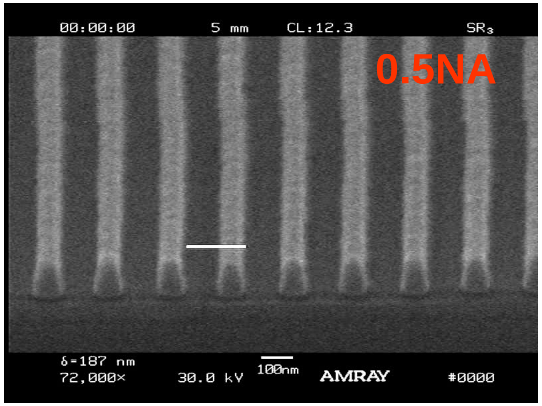
ArF Immersion Talbot Lithography
Breadboard "Half-ball" system

- **+/- 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**

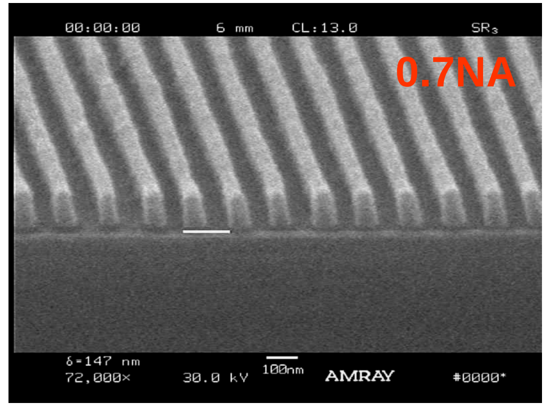


193i Resist Images 55-80nm Resolution

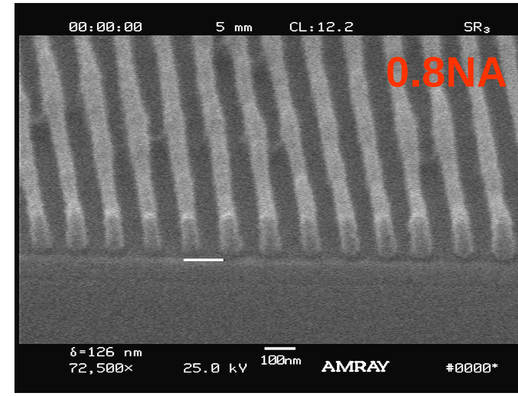
Shipley XP1020 over AR, 50-100nm film thickness, TOK topcoat, TE polarization



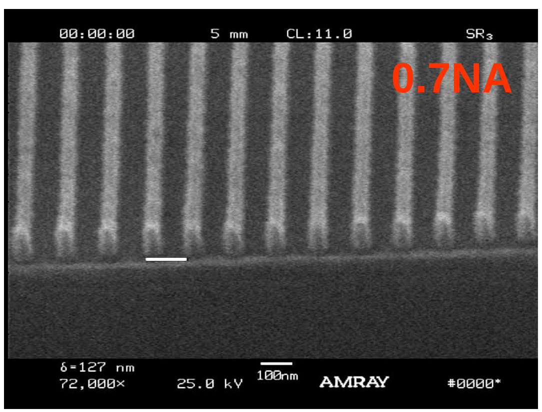
80nm 1:1.5



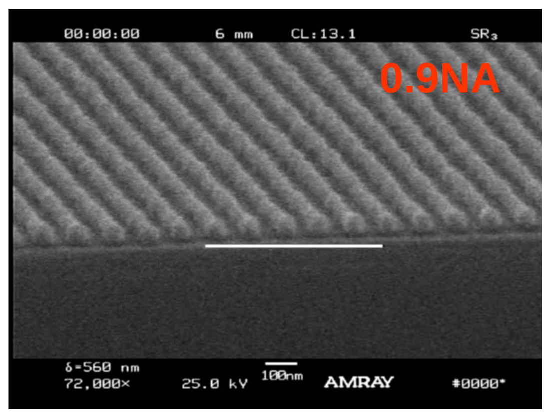
65nm 1:1



60nm 1:1



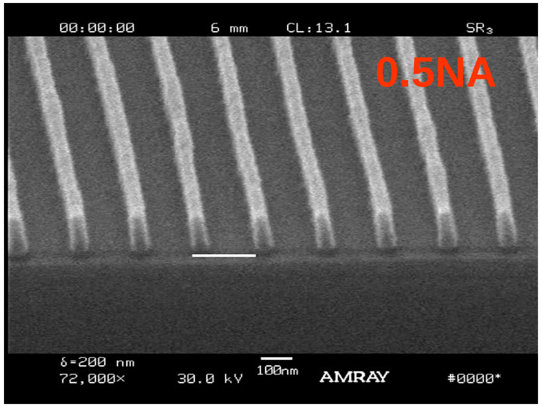
55nm 1:1.5



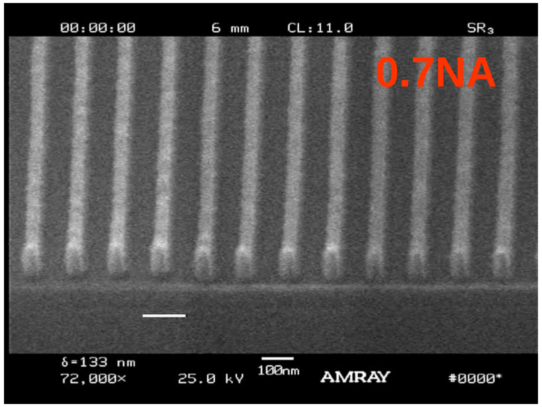
55nm 1:1

193i Resist Images 45-50nm Resolution

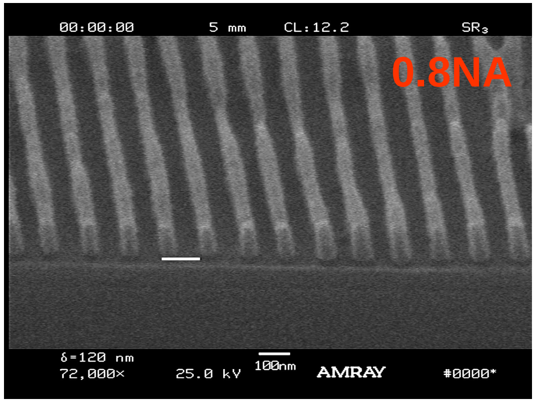
Shipley XP1020 over AR, 50-100nm film thickness, TOK topcoat, TE polarization



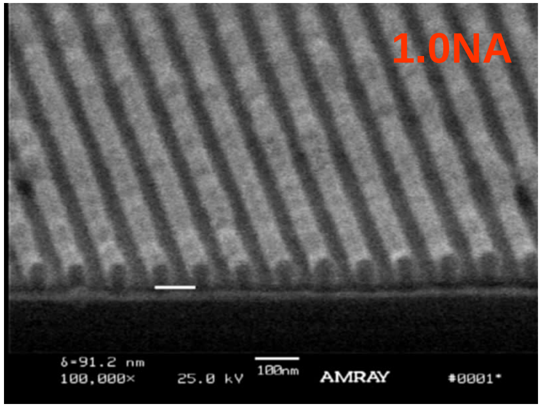
50nm 1:3



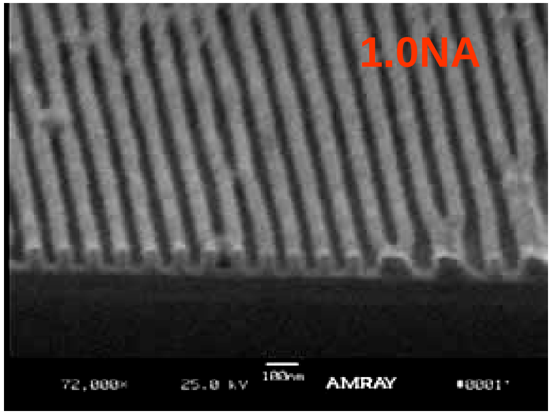
45nm 1:2



45nm 1:1.5



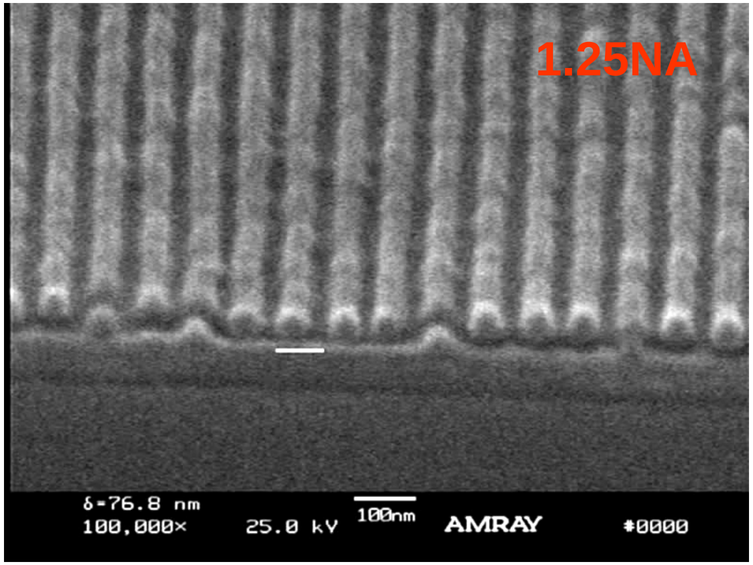
45nm 1:1 70nm
Shipley XP1020

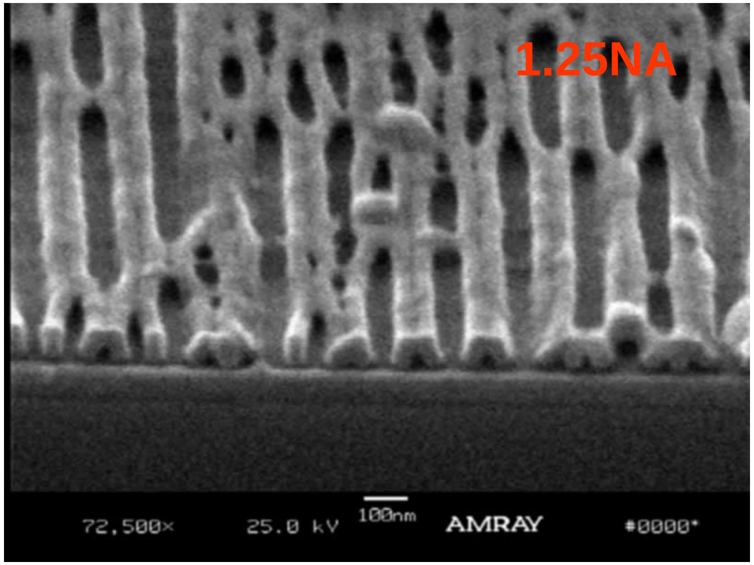


45nm 1:1 80nm
TOK ILP012

193i Resist Images 38nm Resolution

1.25NA Interference Lens, TE polarization

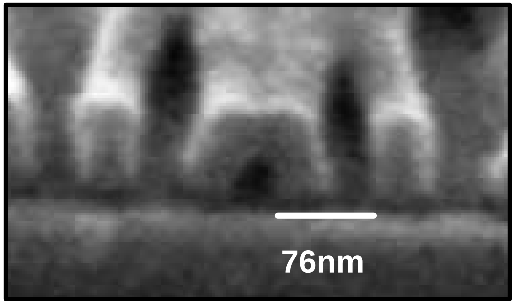




38nm p/2

50nm XP1020

Early results show good optical contrast and resist potential

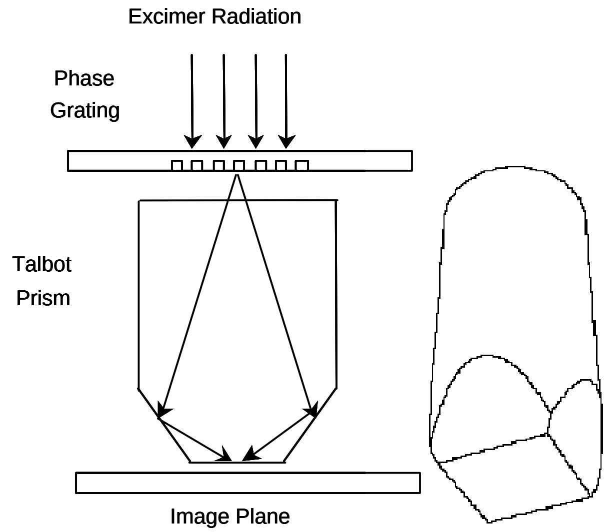


38nm 1:1

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

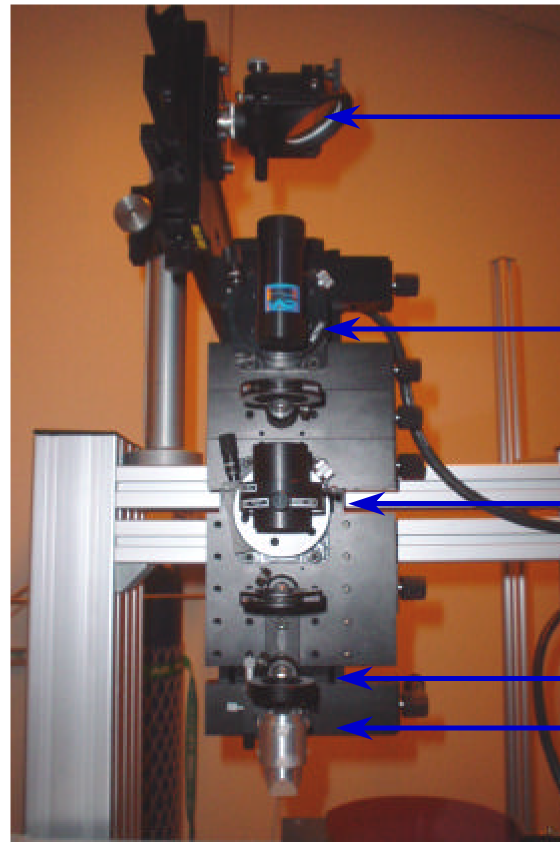
NA	*half-pitch*
0.8	*60nm*
1.05	*45nm*
1.20	*40nm*
1.35	*36nm*

Talbot Immersion Research Tool

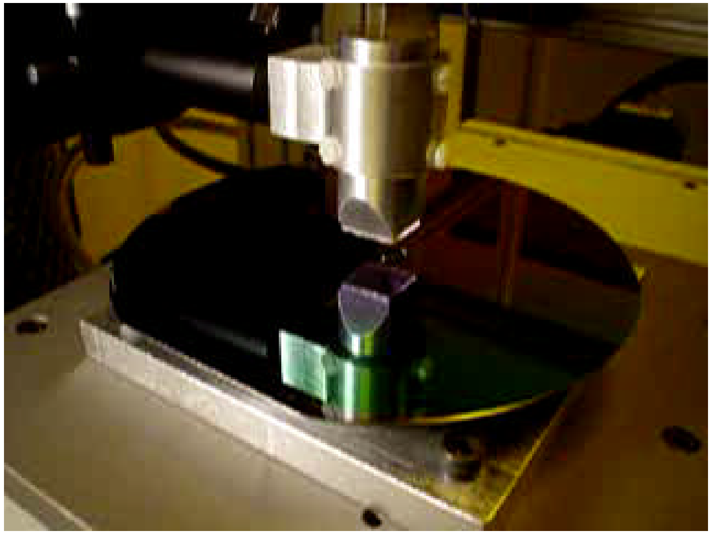
Workstation

- 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

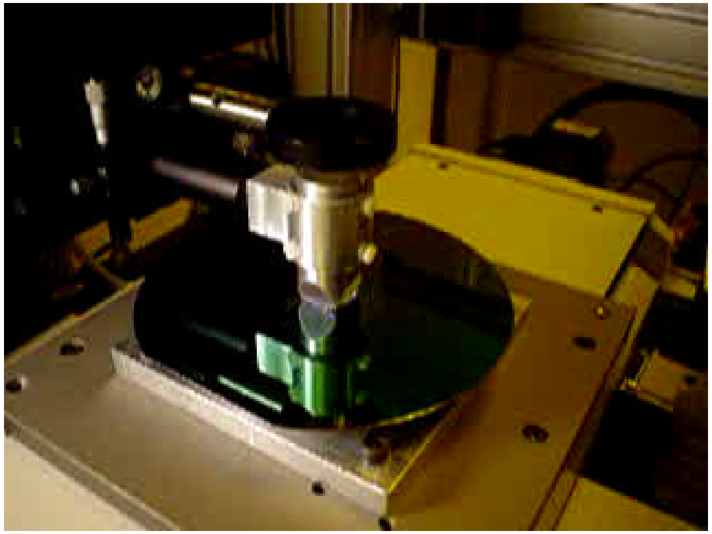
Optical Column



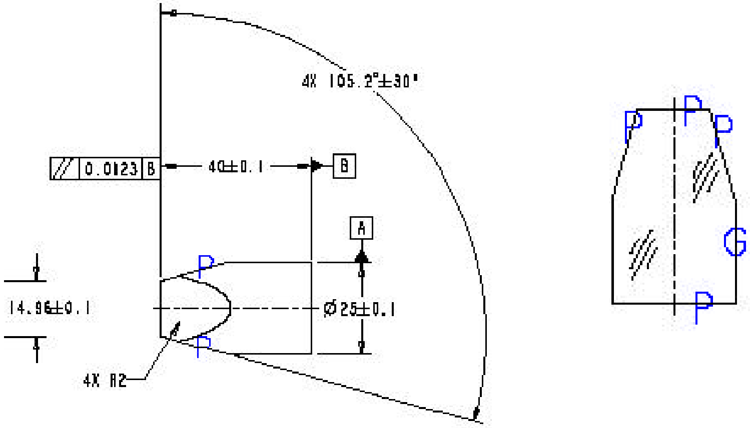
Water Handling at the Wafer Plane

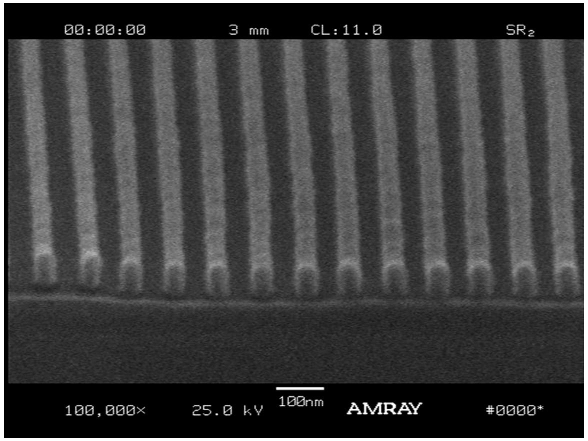


Contact with water



Stepping with water





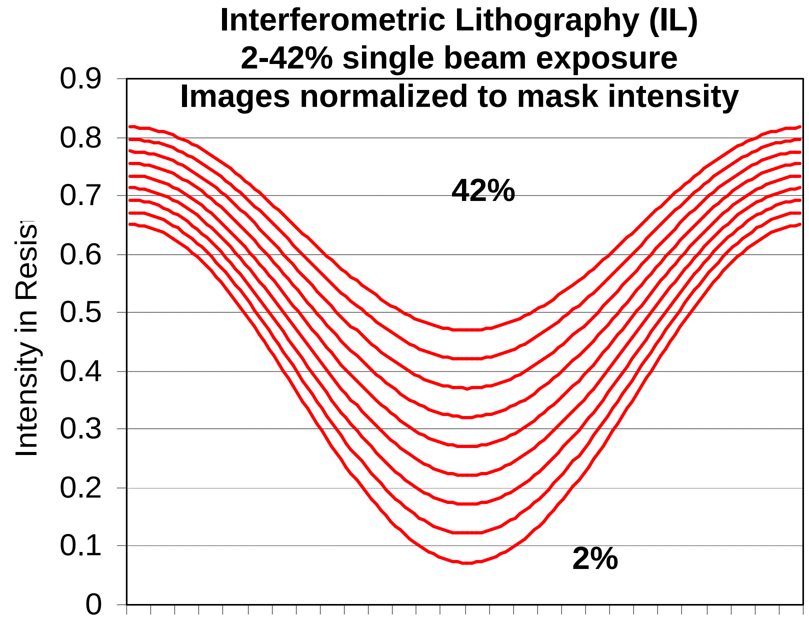
45nm p/2 at 1.05NA

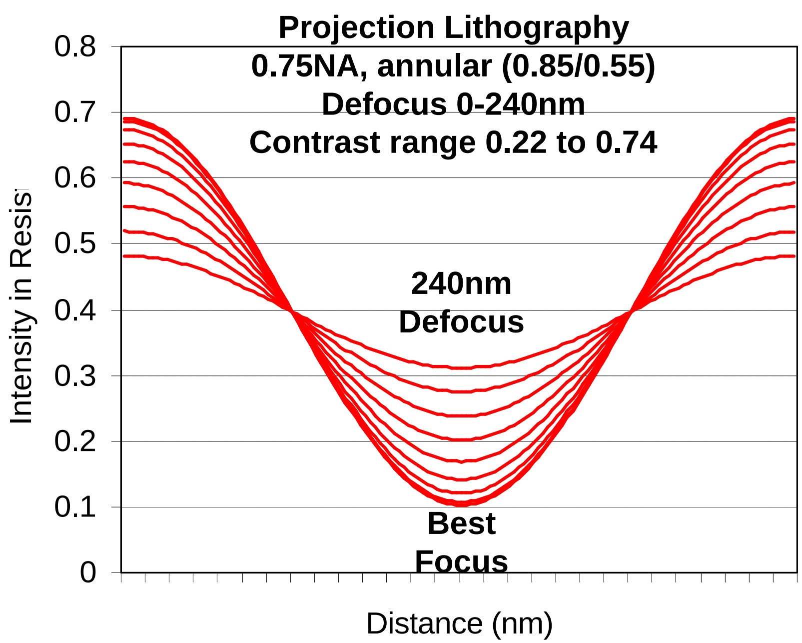
Interferometric Immersion vs. Projection Immersion Lithography

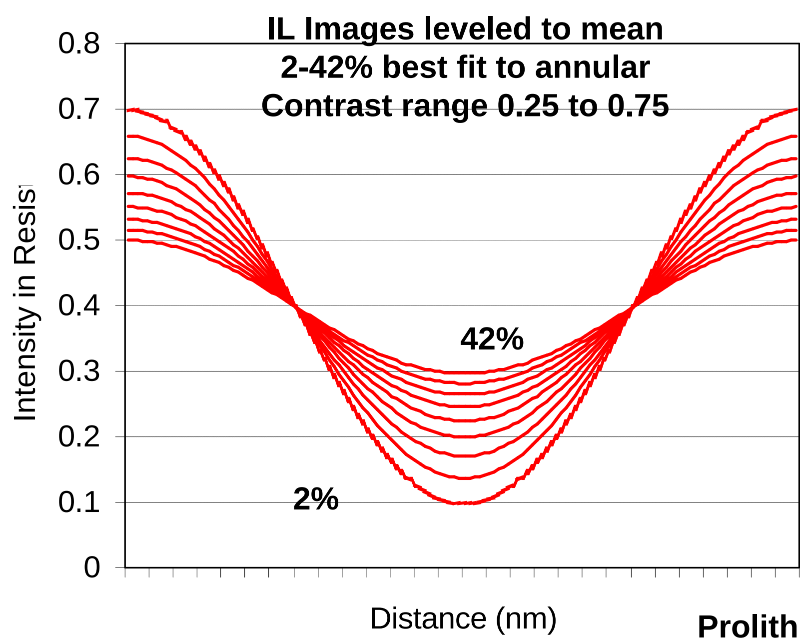
How well can 2-beam interference lithography predict projection lithography?

Resist Image Intensity Comparisons

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



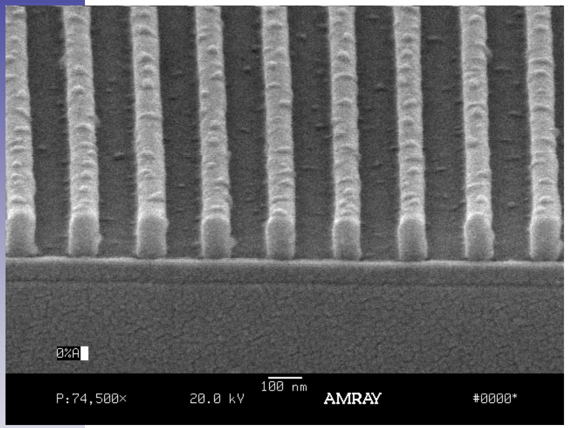


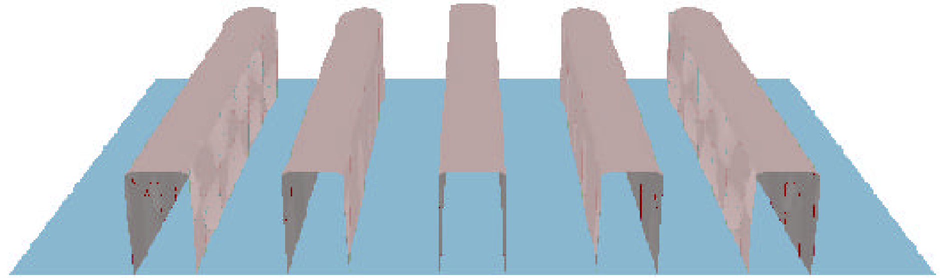


Prolith 8.02

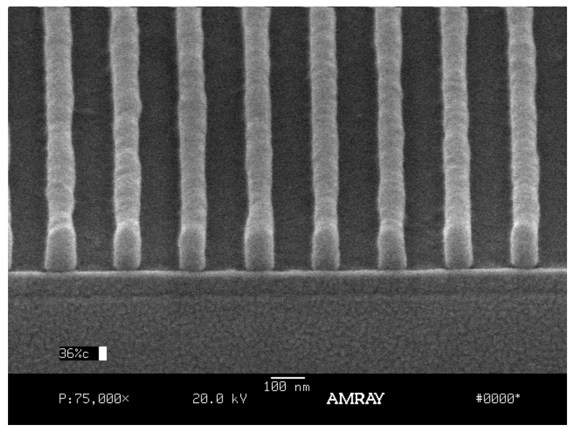
Immersion IL Images with demodulation

Full modulation
(Best Focus)

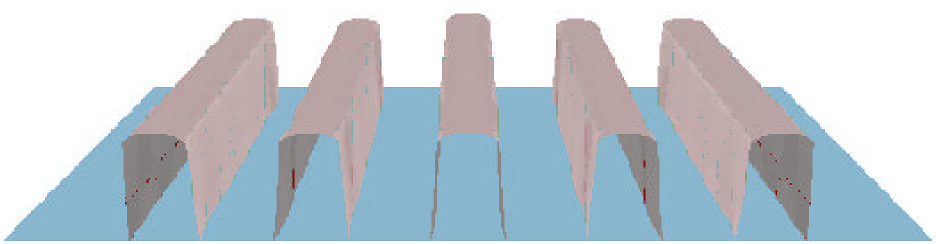




LPM simulation

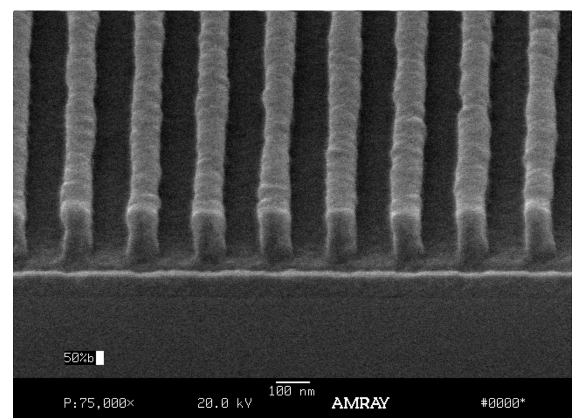


30% demodulation
(150nm defocus)



LPM simulation

50% demodulation
(220nm defocus)



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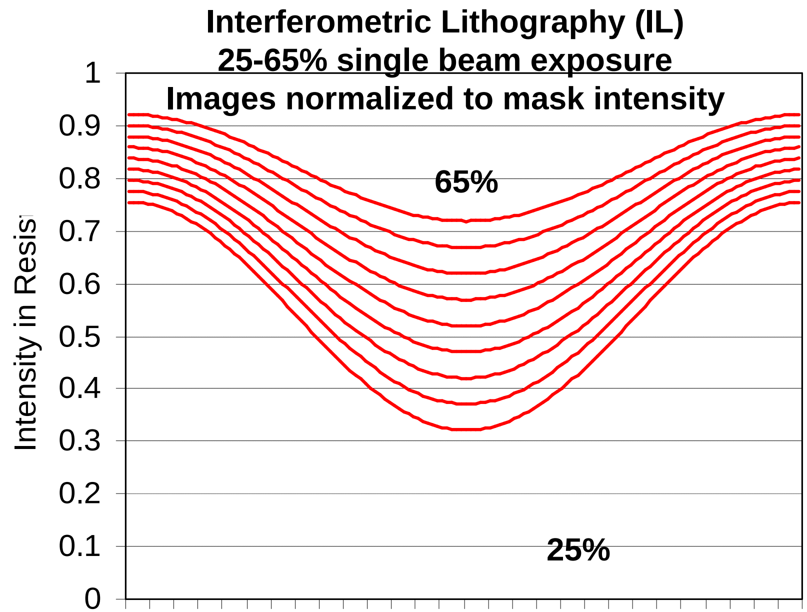
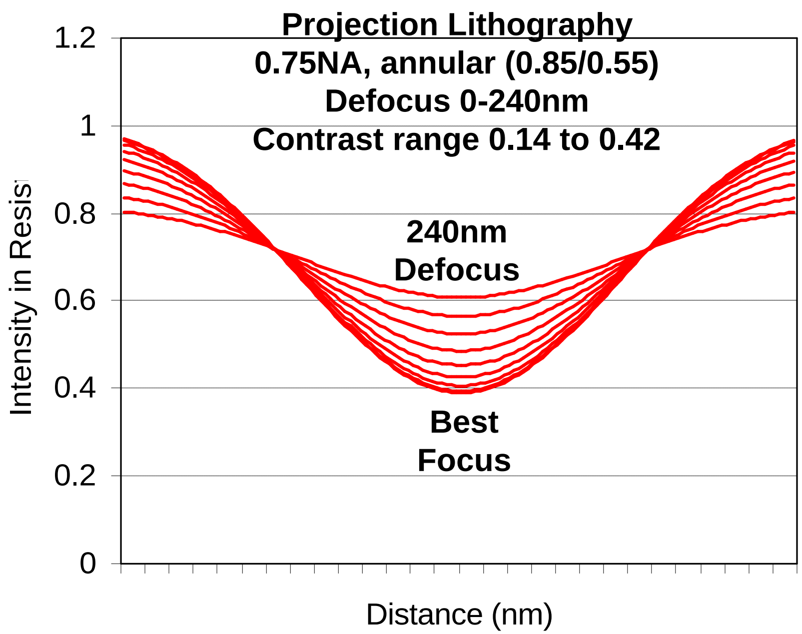
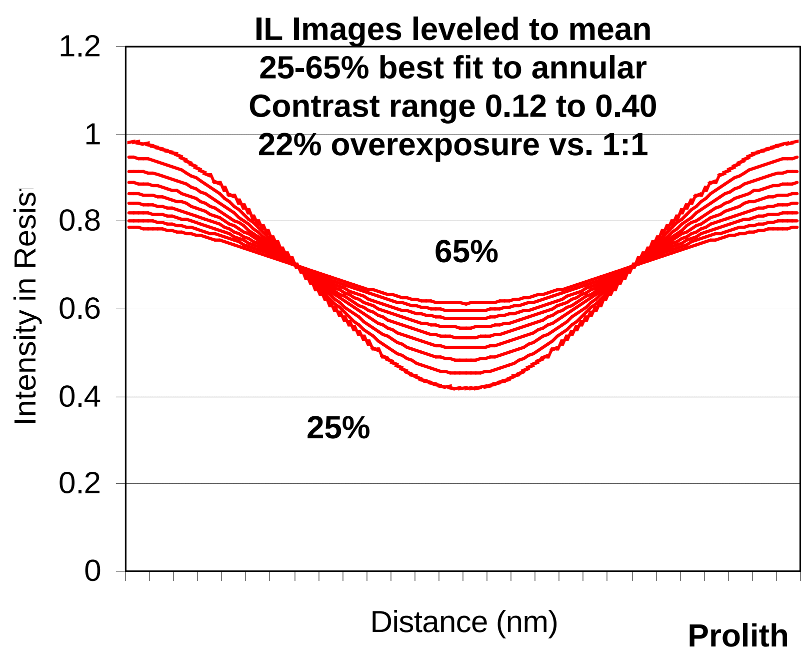


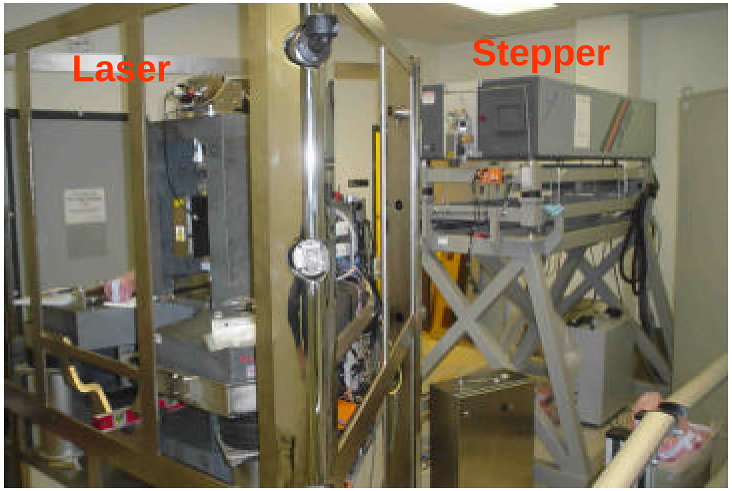


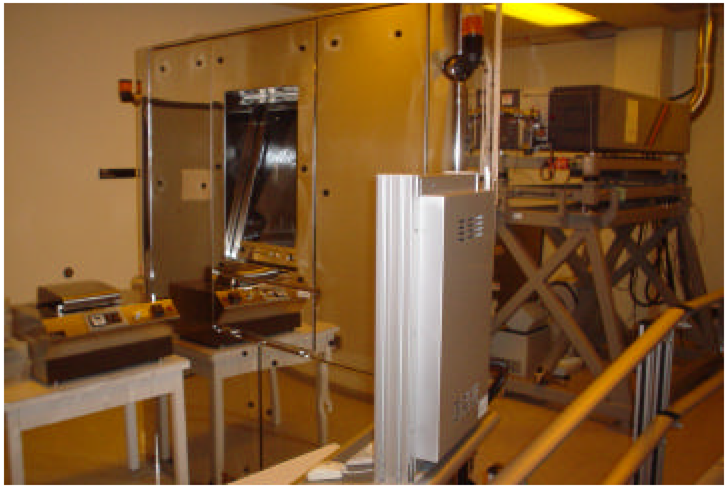


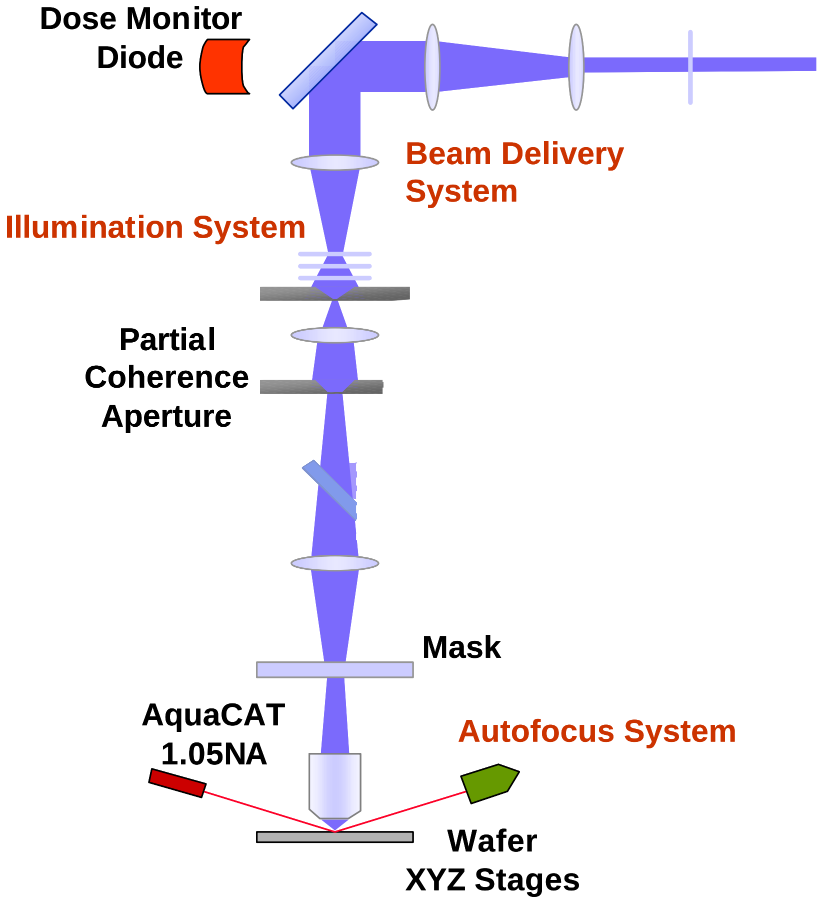
Prolith 8.02

193nm Immersion MicroStepper

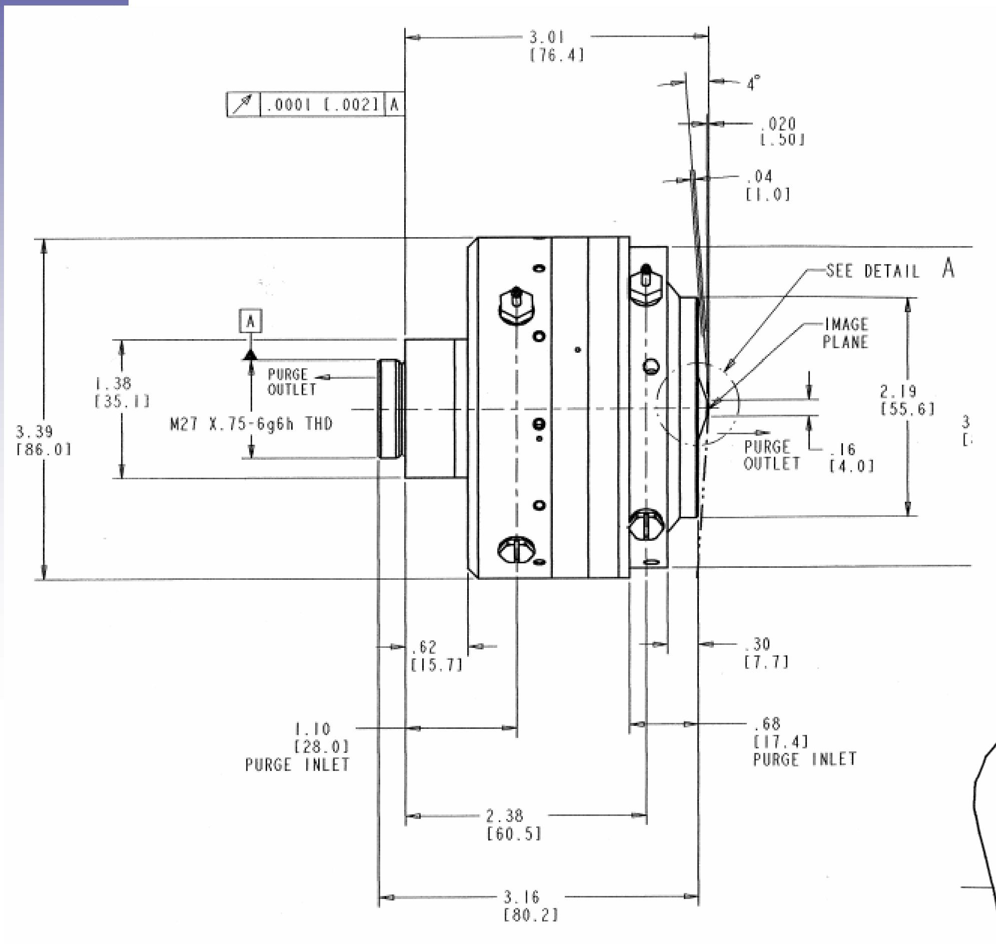
Exitech PS3000 / 1.05NA Corning Tropel AquaCAT



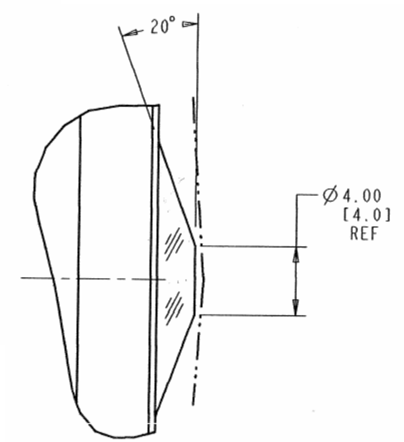


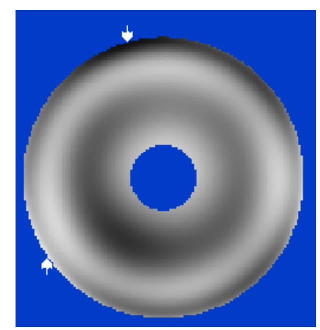


AquaCAT 193i Catadioptric Lens

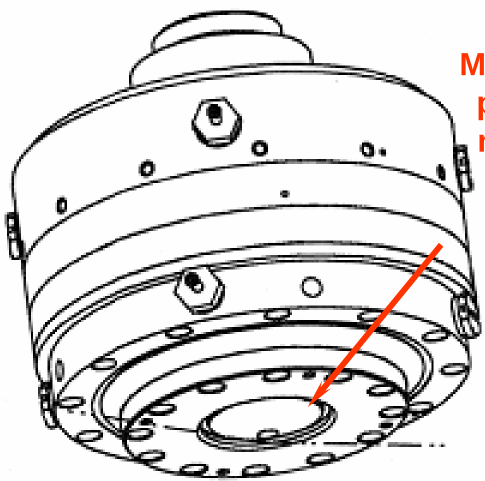


Lens Specifications	
NA	**1.05**
Reduction	**90X**
Image field	**0.1 mm**
Wavelength	**193.3 nm**
Bandwidth	**700 pm**
Track length	**210 mm +/- 10 mm**
Entrance Pupil distance	**210 mm +/- 10 mm**
Material	**SiO2**
Immersion fluid	**H2O**
Working distance	**>0.5 mm**
# of elements	**8**
% Obscuration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

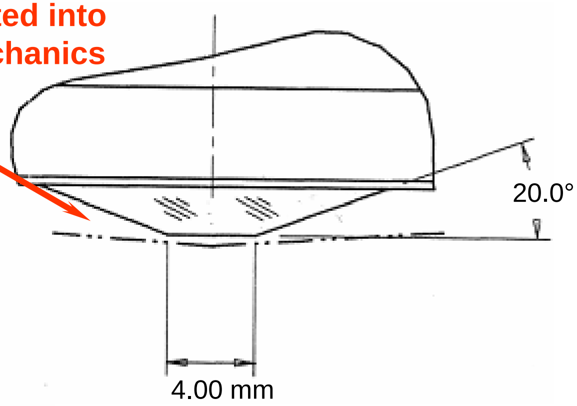




Fluid Injection and Meniscus



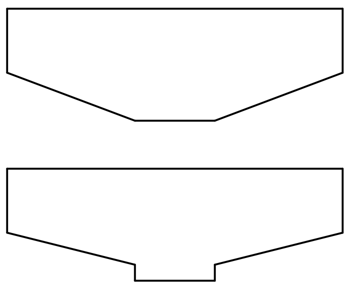
Micro-pipette ported into mechanics



Bottom of assembly

Final glass surface

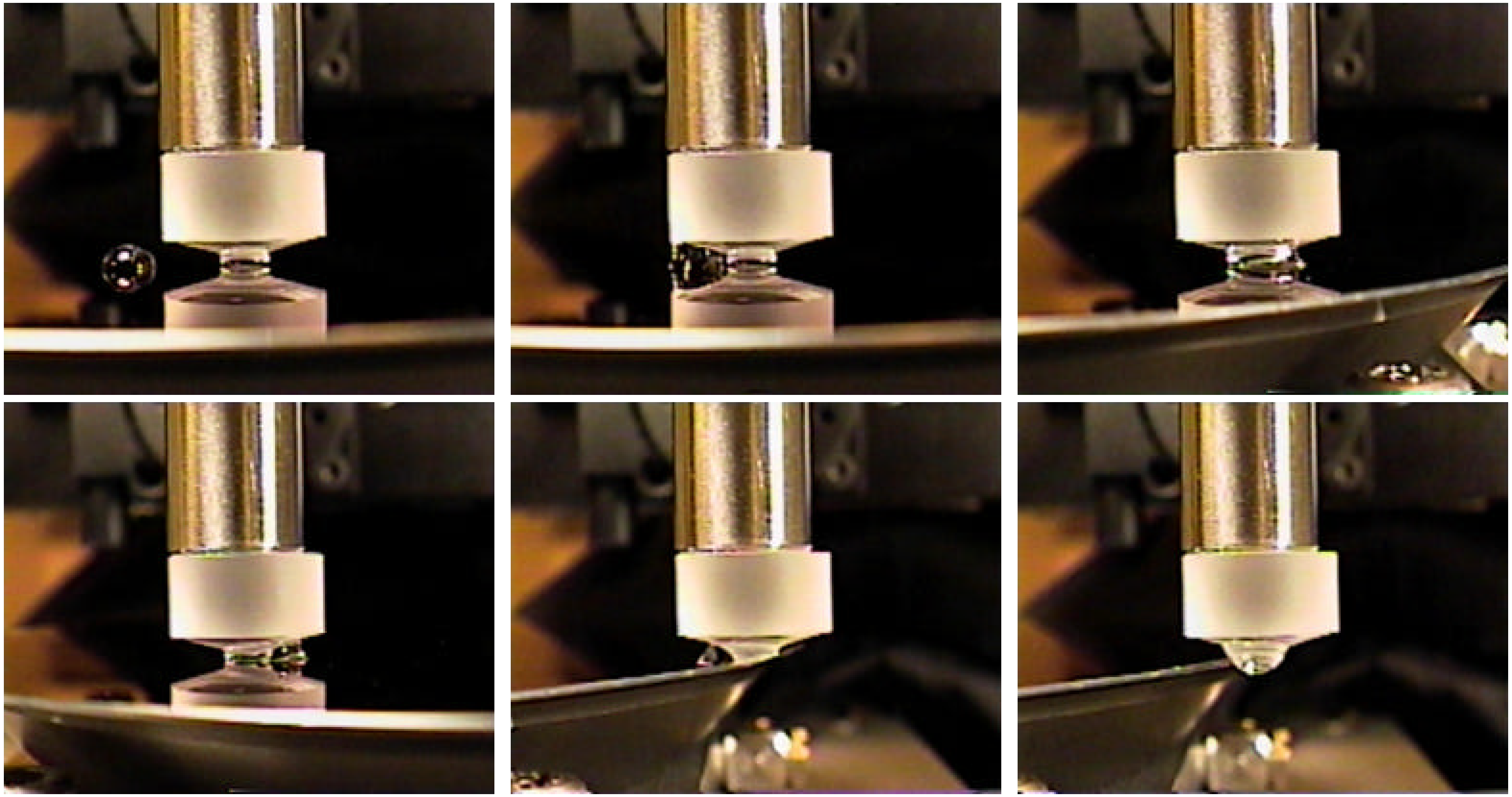
Meniscus retention testing using final element mock-up
a) 20° surface angle
b) 90° surface angle



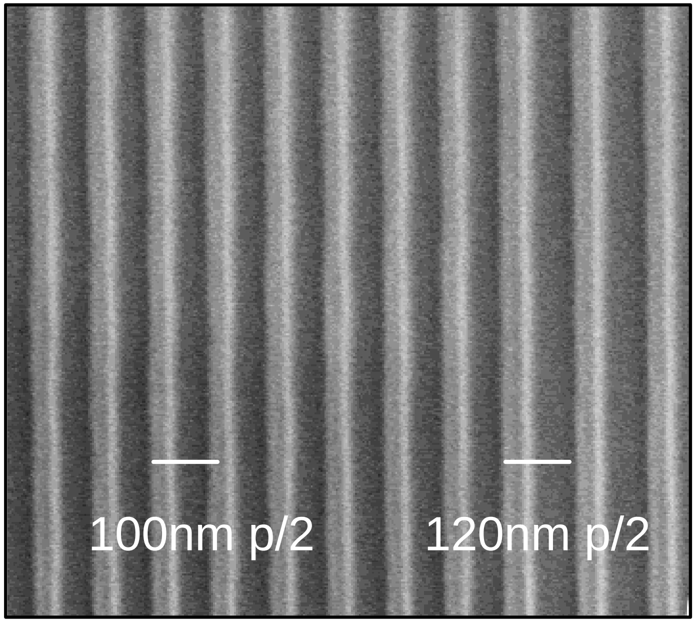
Water Introduction Considerations

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

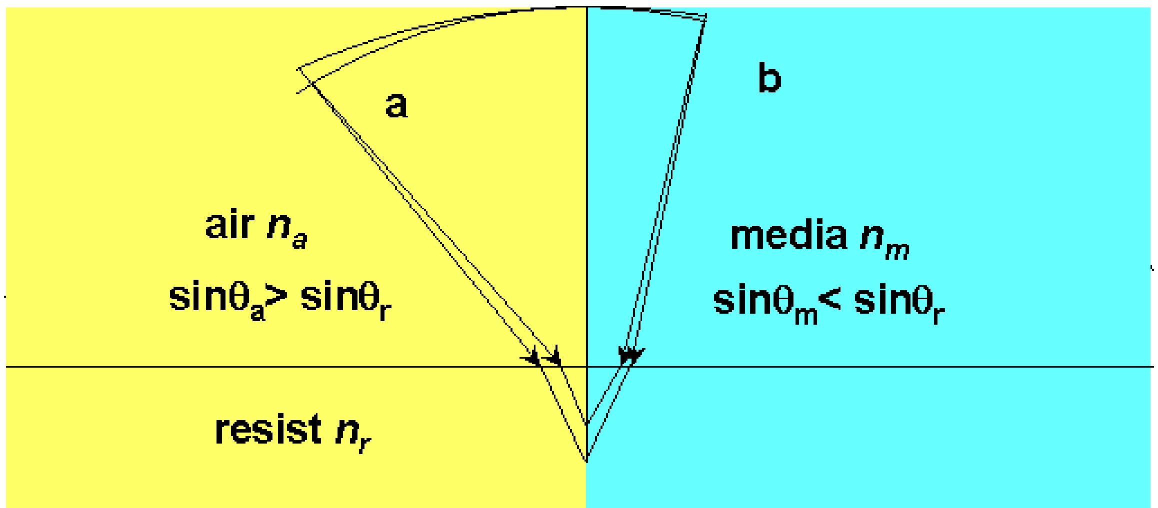
Remaining system action items:

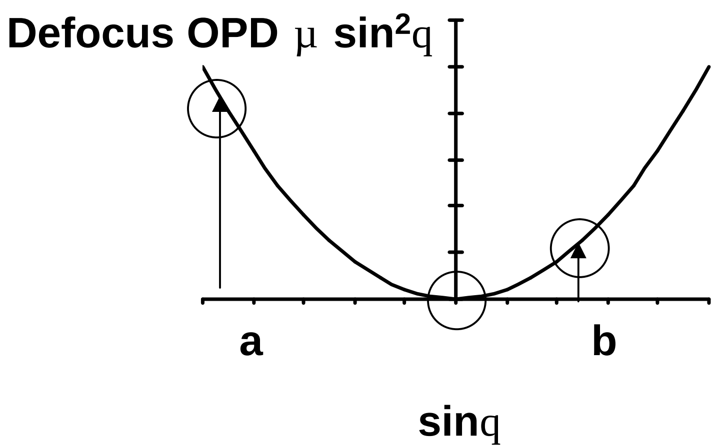
Field stop and sigma apertures, environmental audit, PSM, system qualification, polarization control

Homogeneous Immersion

Increasing refractive indices – the defocus effect

Low index (air) imaging **High index imaging**





The defocus wave aberration is proportional to sin^{2}q

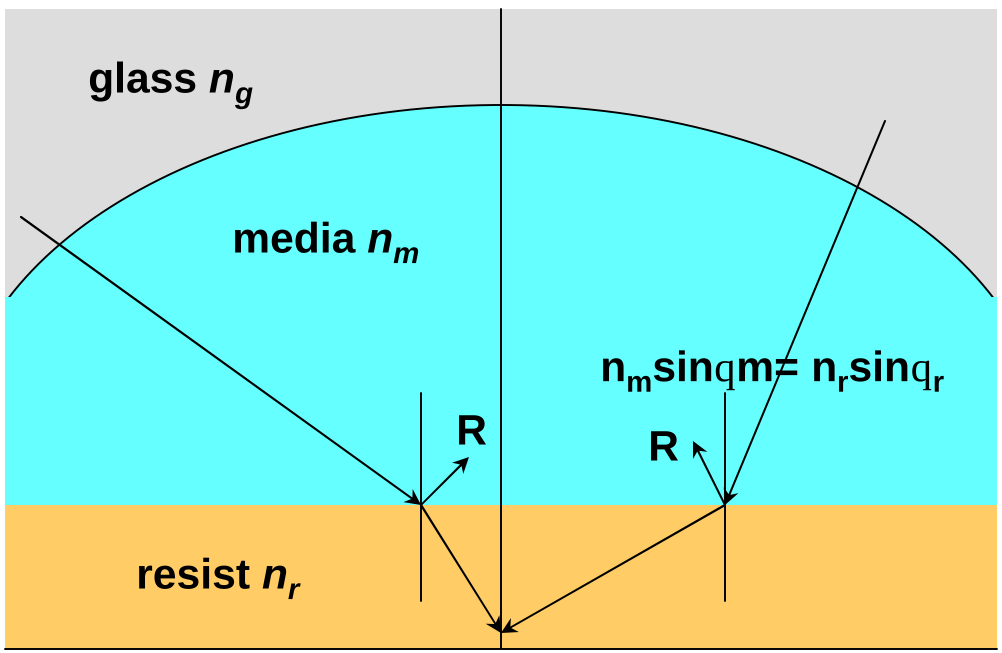
Higher indices reduce defocus OPD at equivalent NA values

Small NA/*n is* desirable

Homogeneous Immersion

Increasing refractive indices – the refractive effect

Resist > Media **Media > Resist**



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 l_{max} for halide ions is well documented** [1]

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

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

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

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

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

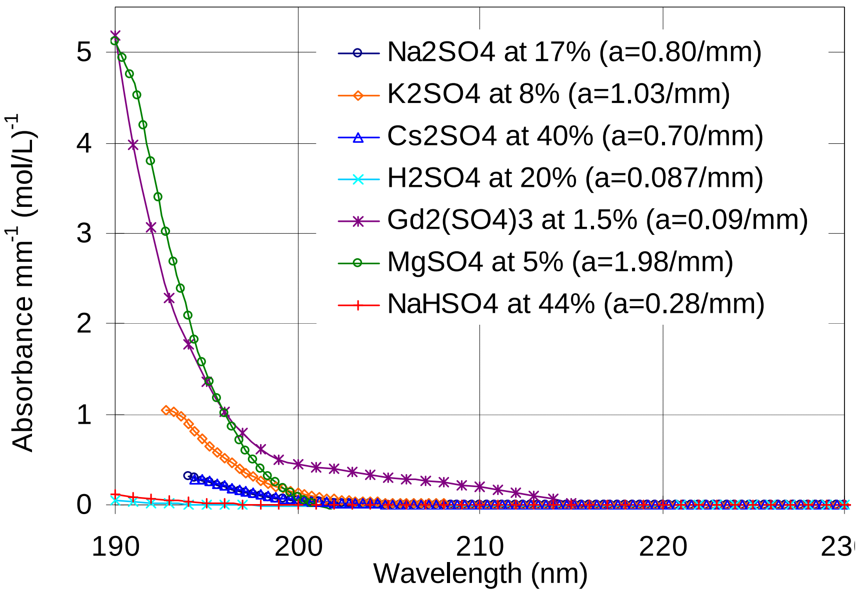
[2] G. Stein and A. Treinen, Trans. Faraday Soc. 56, 1393 (1960)

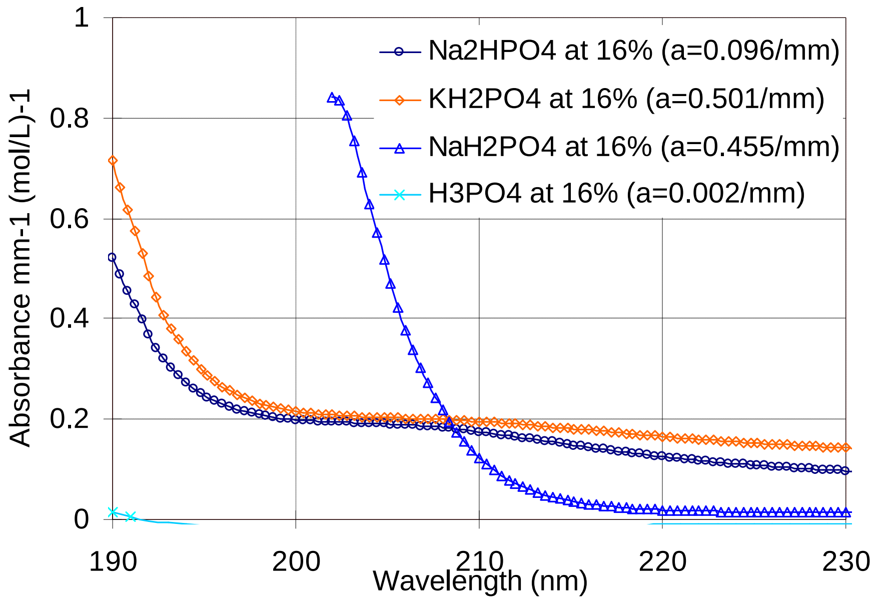
Effect of Anion on Absorption of Water

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

Fluid Refractive Index and Dispersion

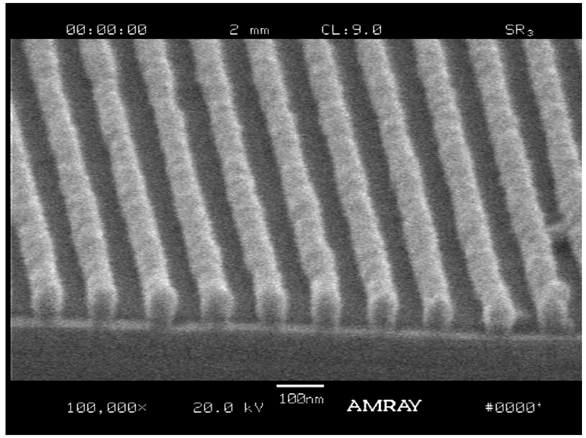
Fluids	Refractive index @ 193nm	Refractive index @ 248nm	Cauchy parameters A	Cauchy parameters B	Cauchy parameters C
HCl@37%	1.583	1.487	1.3997	0.0032	0.000134
CsCl@60%	1.561	1.466	1.3912	0.0020	0.000160
H_2SO_4@20%	1.472	1.418	1.3635	0.0022	0.000068
H_2SO_4@96%	1.516	1.469	1.4151	0.0027	0.000040
$NaHSO_4$@44%	1.473	1.418	1.3643	0.0021	0.000074
Cs_2SO_4@40%	1.481	1.422	1.3685	0.0020	0.000083
Na_2SO_4@30%	1.479	1.423	1.3667	0.0023	0.000069
H_3PO_4@20%	1.452	1.398	1.3486	0.0018	0.000077
H_3PO_4@40%	1.475	1.420	1.3723	0.0015	0.000085
H_3PO_4@85%	1.538	1.488	1.4316	0.0028	0.000042
H_2O (DI)	1.435	1.373	1.3283	0.0021	0.000067

Hydrogen Phosphates

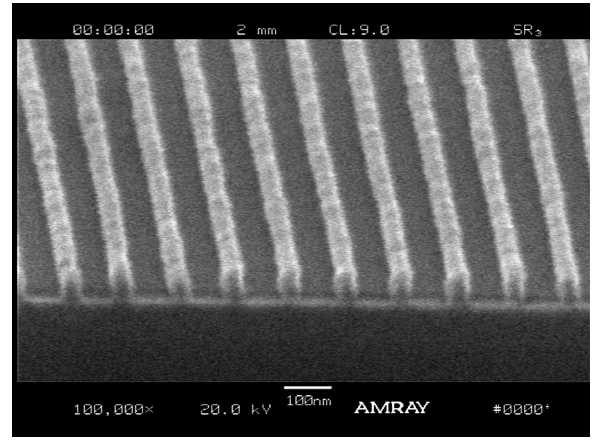
*Data obtained by Cauchy model fit are labeled red. Experimental data are not available due to high absorption

Pure and Doped Water Comparisons

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

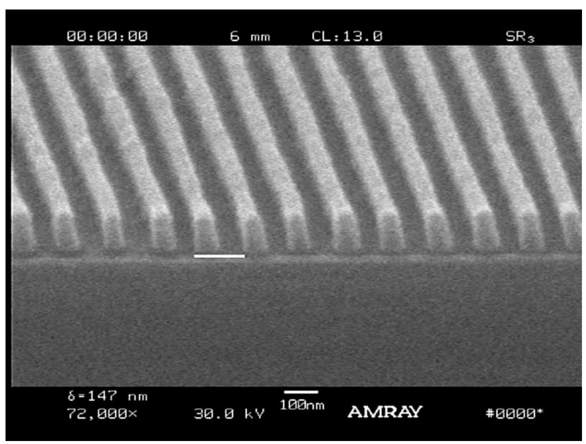


59nm 1:1 (50nm resist)

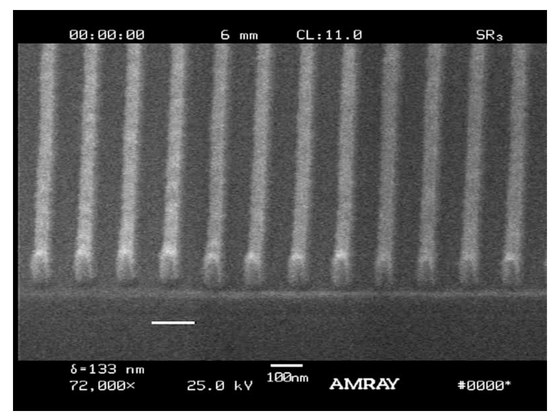


39nm 1:2 (50nm resist)

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



65nm 1:1 (100nm resist)

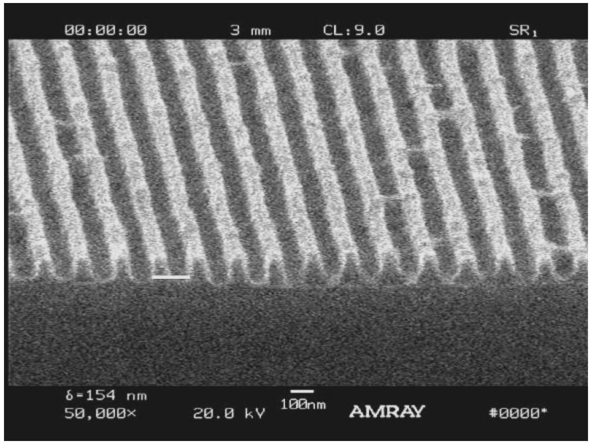


45nm 1:2 (70nm resist)

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

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