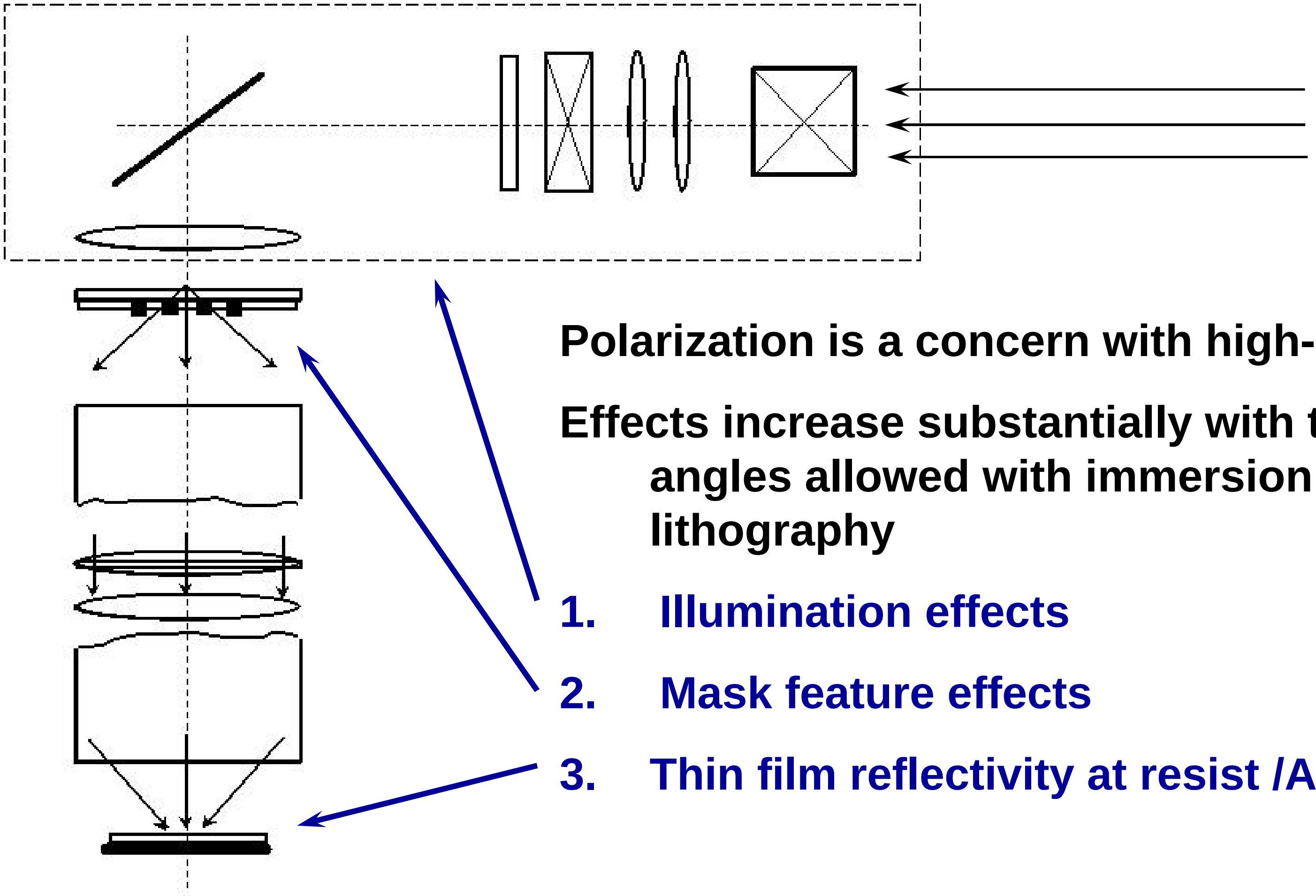
Benefiting from Polarization: Effects at High-NA Imaging

Bruce W. Smith

L. Zavyalova, A. Estroff, Y. Fan, A. Bourov
Rochester Institute of Technology
P. Zimmerman
International SEMATECH and Intel
J. Cashmore
Exitech

Polarization Issues and High-NA



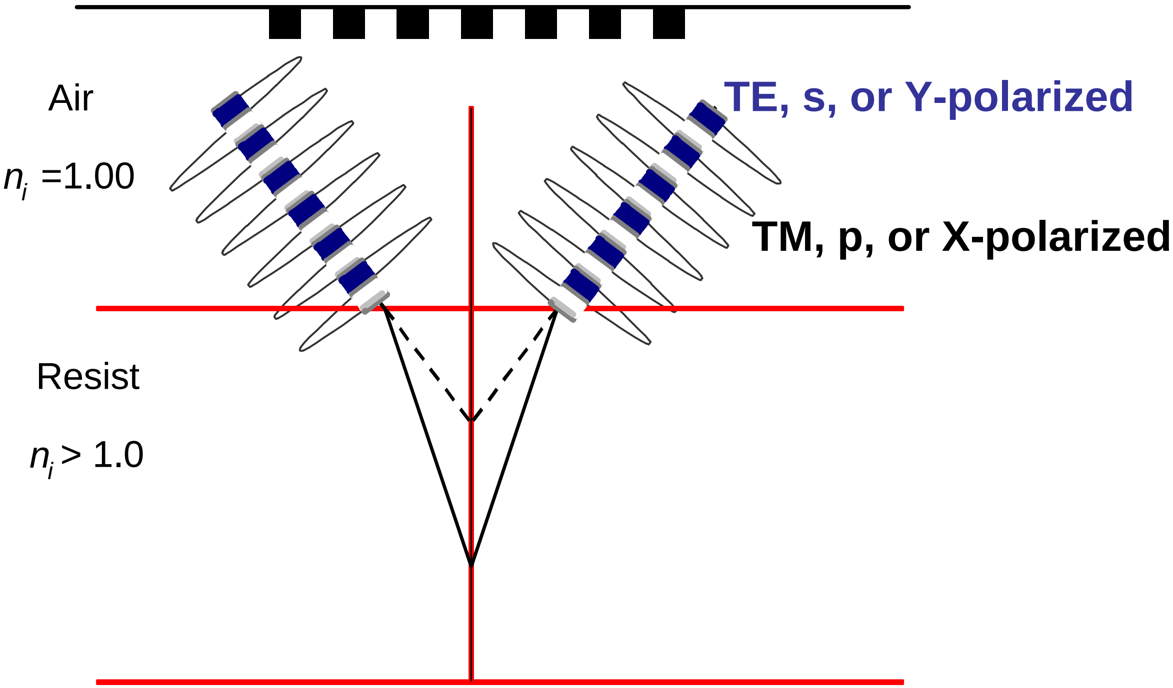
Polarization is a concern with high-NA

Effects increase substantially with the large angles allowed with immersion lithography

1. Illumination effects
2. Mask feature effects
3. Thin film reflectivity at resist /AR

Illumination Effects

Oblique Angles from High NA



Air

n_i =1.00

TE, s, or Y-polarized

TM, p, or X-polarized

Resist

$n_i > 1.0$

- Polarization effects scale with cosine of angle.
- TM state will interfere exactly at normal incidence only.
- Image is the sum of TE and TM.
- Aerial image metrics no longer useful.

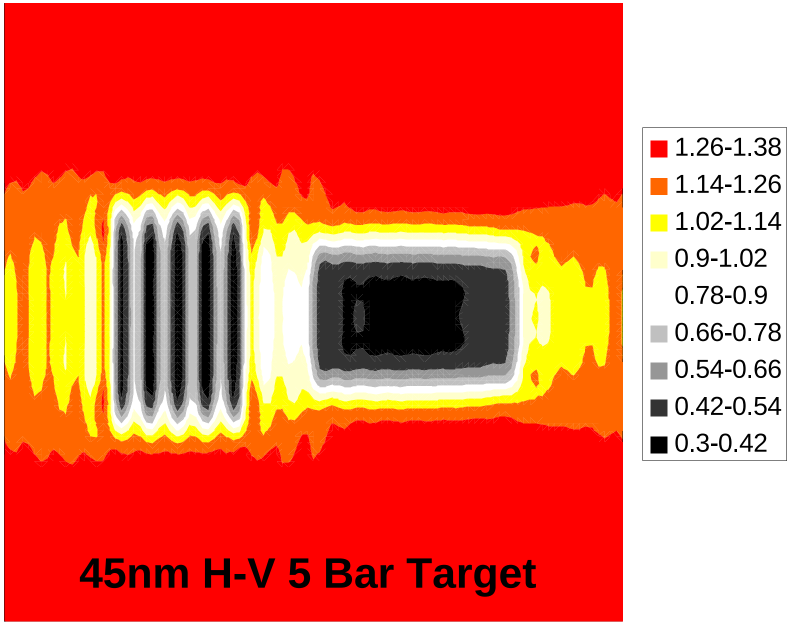
Images in Resist

Dipole and Cross Quad Illumination

Unpolarized Dipole

s_c=1.0, s_r=0.25

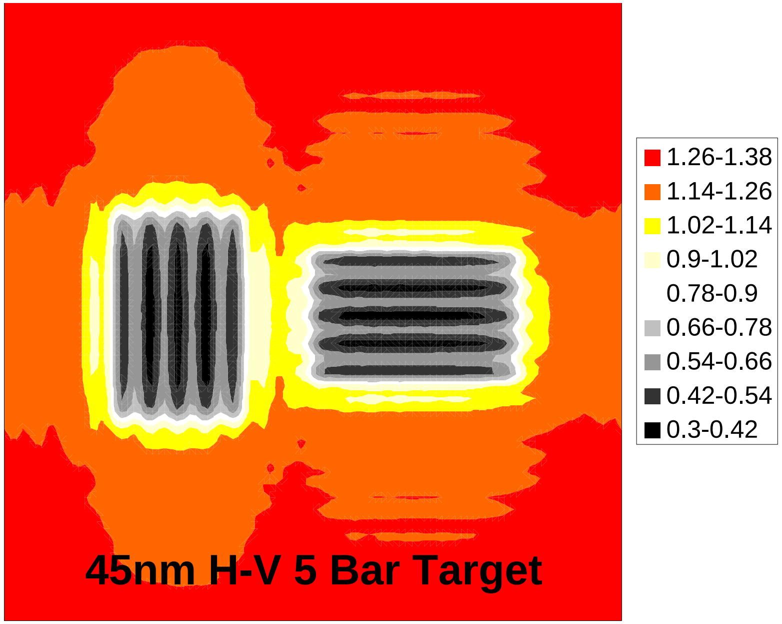
Contrast = 0.42

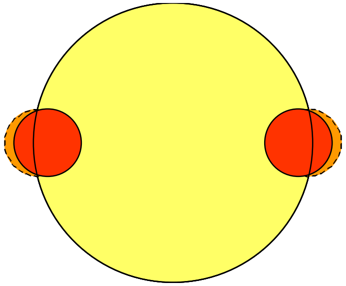


Unpolarized Cross - Quadrupole

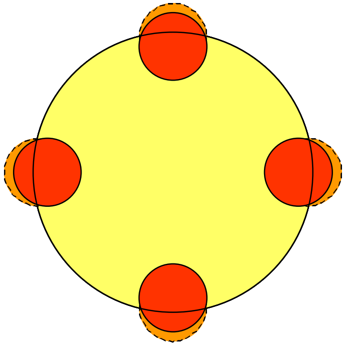
s_c=1.0, s_r=0.25

Contrast = 0.23





Diffraction Energy in Pupil



Prolith/8

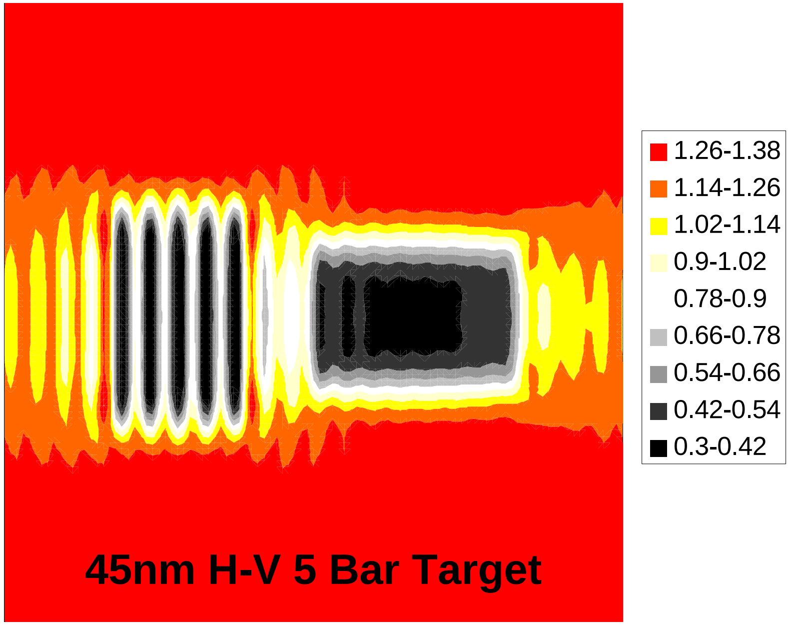
Images in Resist

Polarized Dipole Illumination

X-Orient / Y-Polarization

Dipole s_c=1.0, s_r=0.25

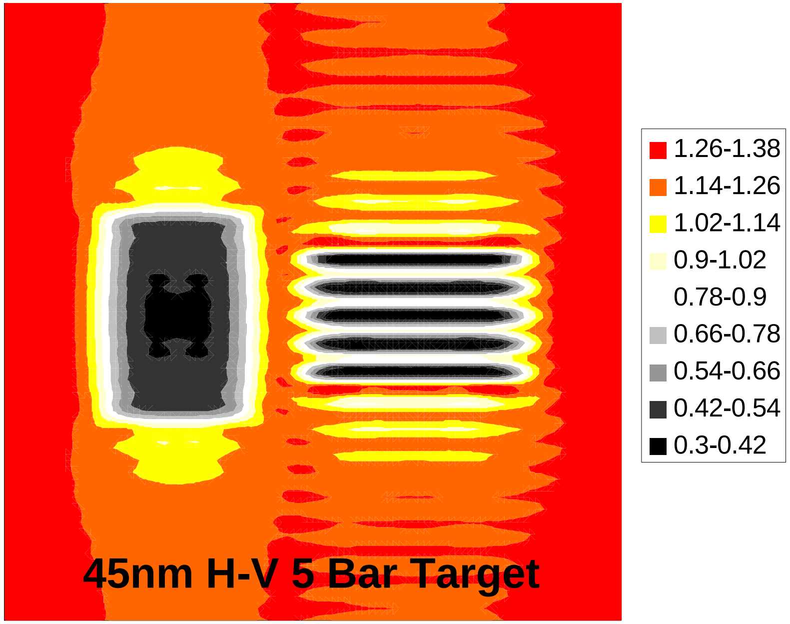
Contrast = 0.69

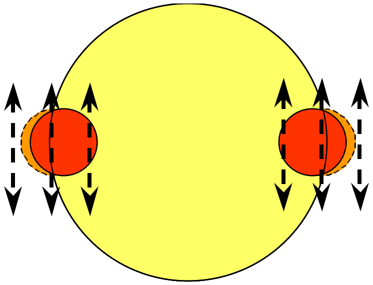


Y-Orient / X-Polarization

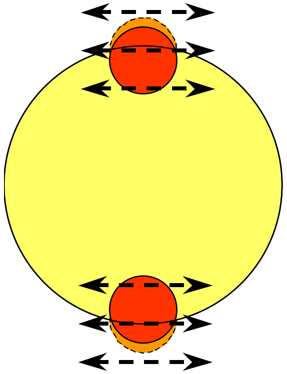
Dipole s_c=1.0, s_r=0.25

Contrast = 0.0





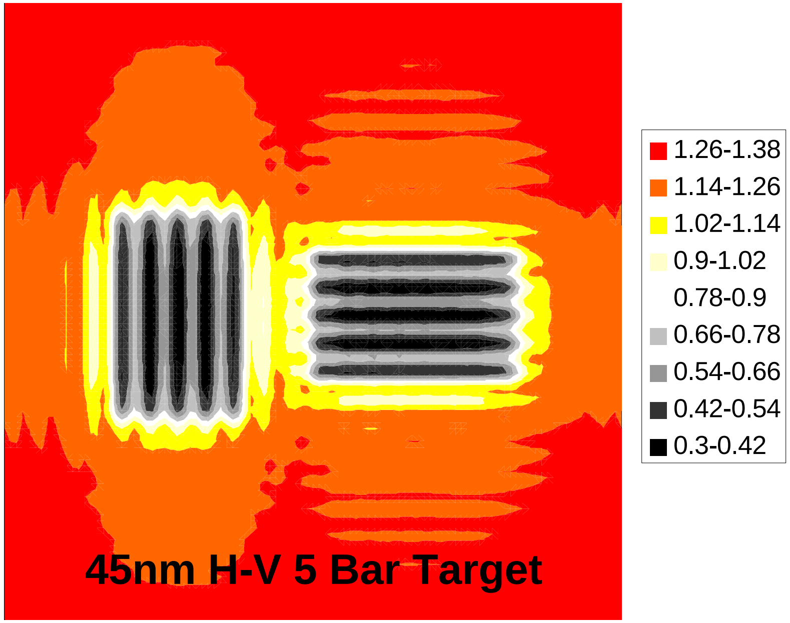
Diffraction Energy in Pupil

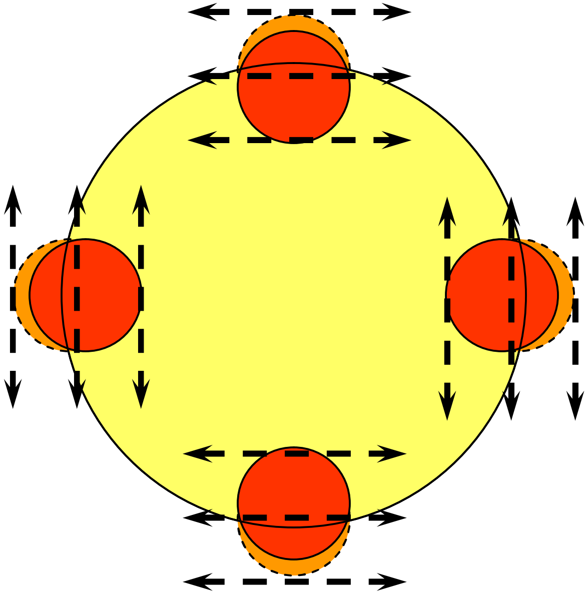


Images in Resist

Polarized Cross Quad Illumination

TE Polarized Cross Quad
Dipole s_c=1.0, s_r=0.25
Contrast = 0.38



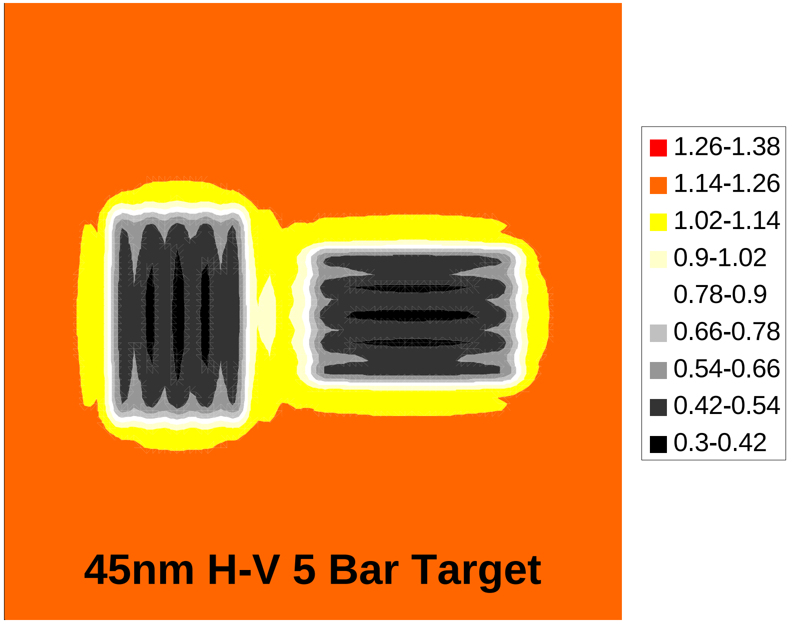


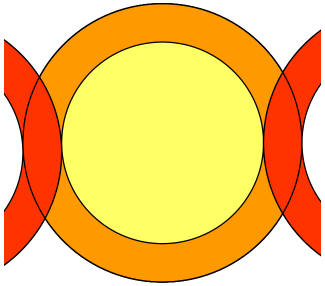
Diffraction Energy in Pupil

Images in Resist

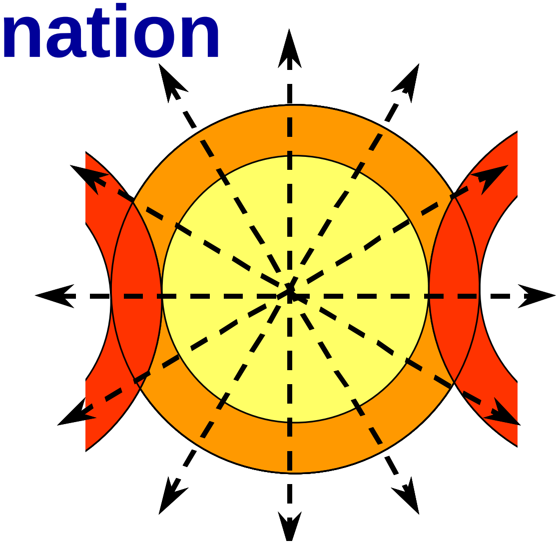
Annular Illumination

Unpolarized Annular
Dipole s_o=1.0, s_i=0.80
Contrast = 0.12

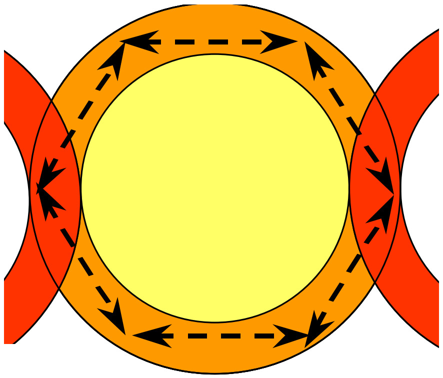




Diffraction Energy in Pupil



TM polarized (Radial) Annulus



TE polarized (Azimuthal) Annulus

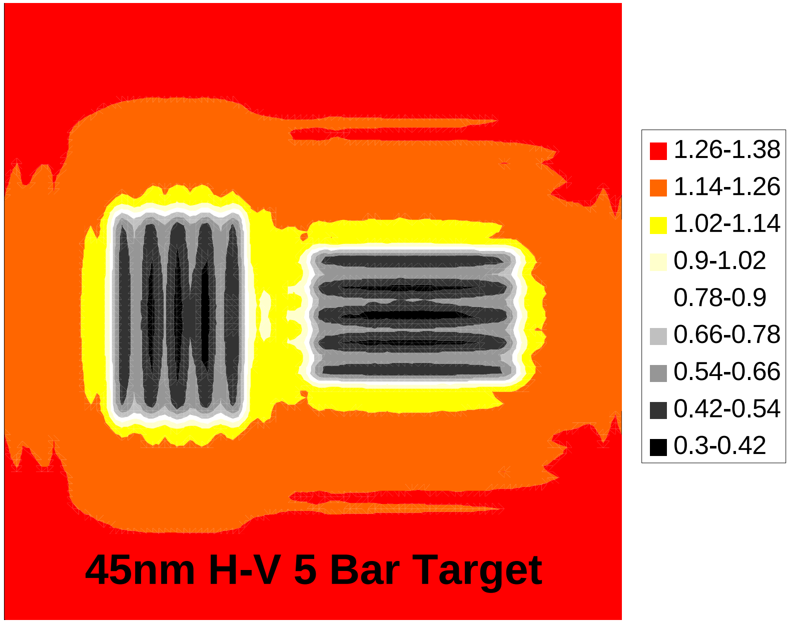
Images in Resist

Radial and Azimuthal Annular

Azimuthal Polarized Annular

Dipole s_c=1.0, s_r=0.25

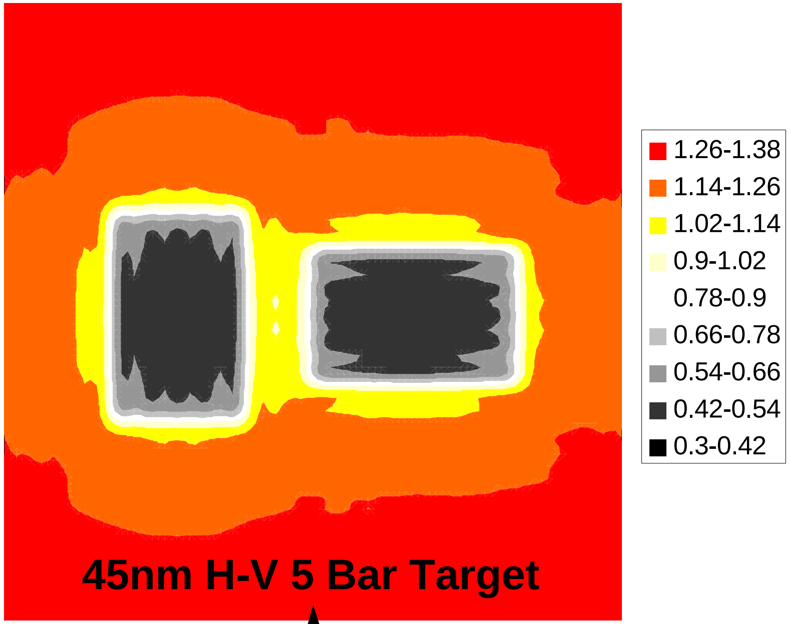
Contrast = 0.23

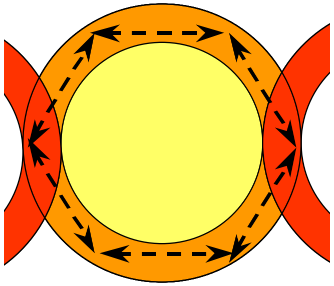


Radial Polarized Annular

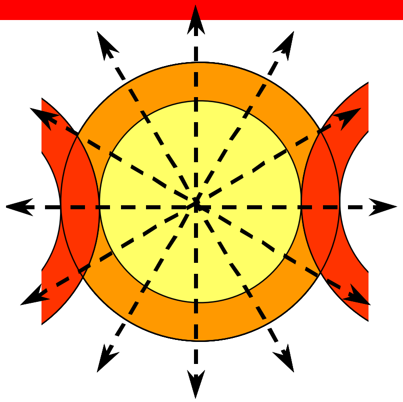
Dipole s_c=1.0, s_r=0.25

Contrast = 0.02





Diffraction Energy in Pupil



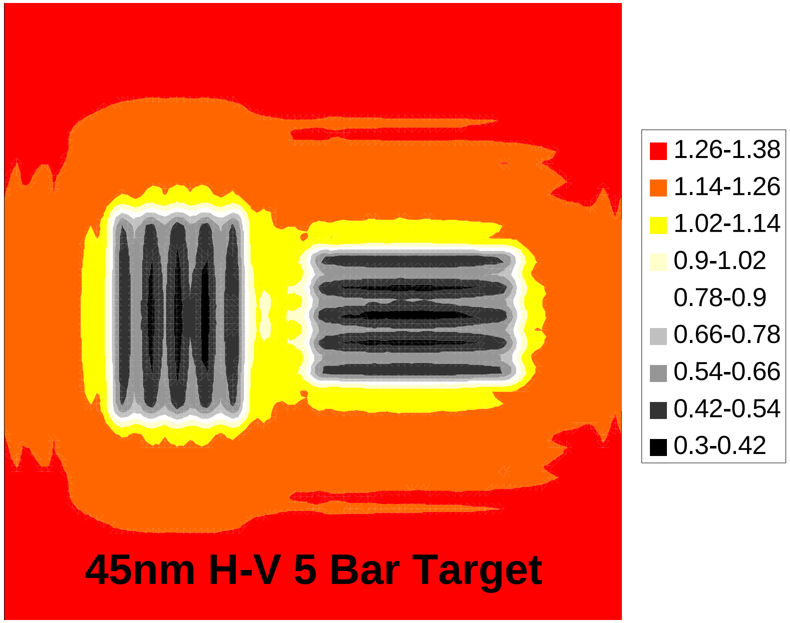
Images in Resist

Polarized Annular vs. C-Quad

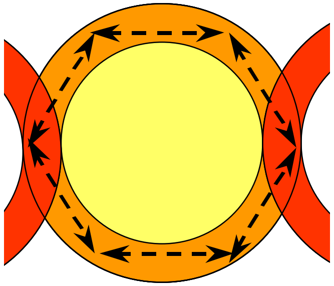
Azimuthal Polarized Annular

Dipole s_c=1.0, s_r=0.25

Contrast = 0.23



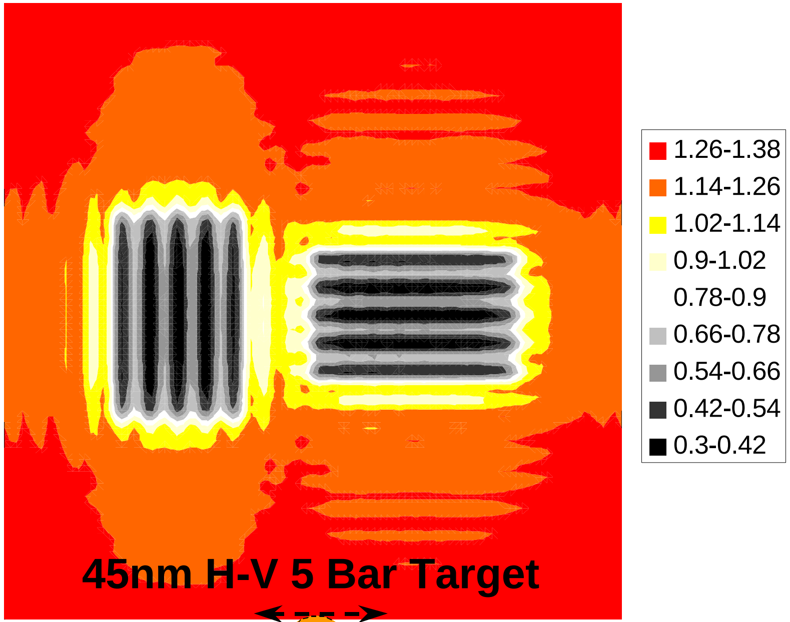
45nm H-V 5 Bar Target



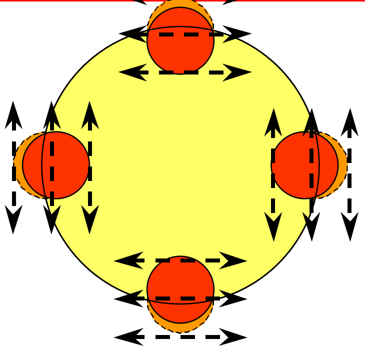
TE Polarized C-Quad

Dipole s_c=1.0, s_r=0.25

Contrast = 0.38



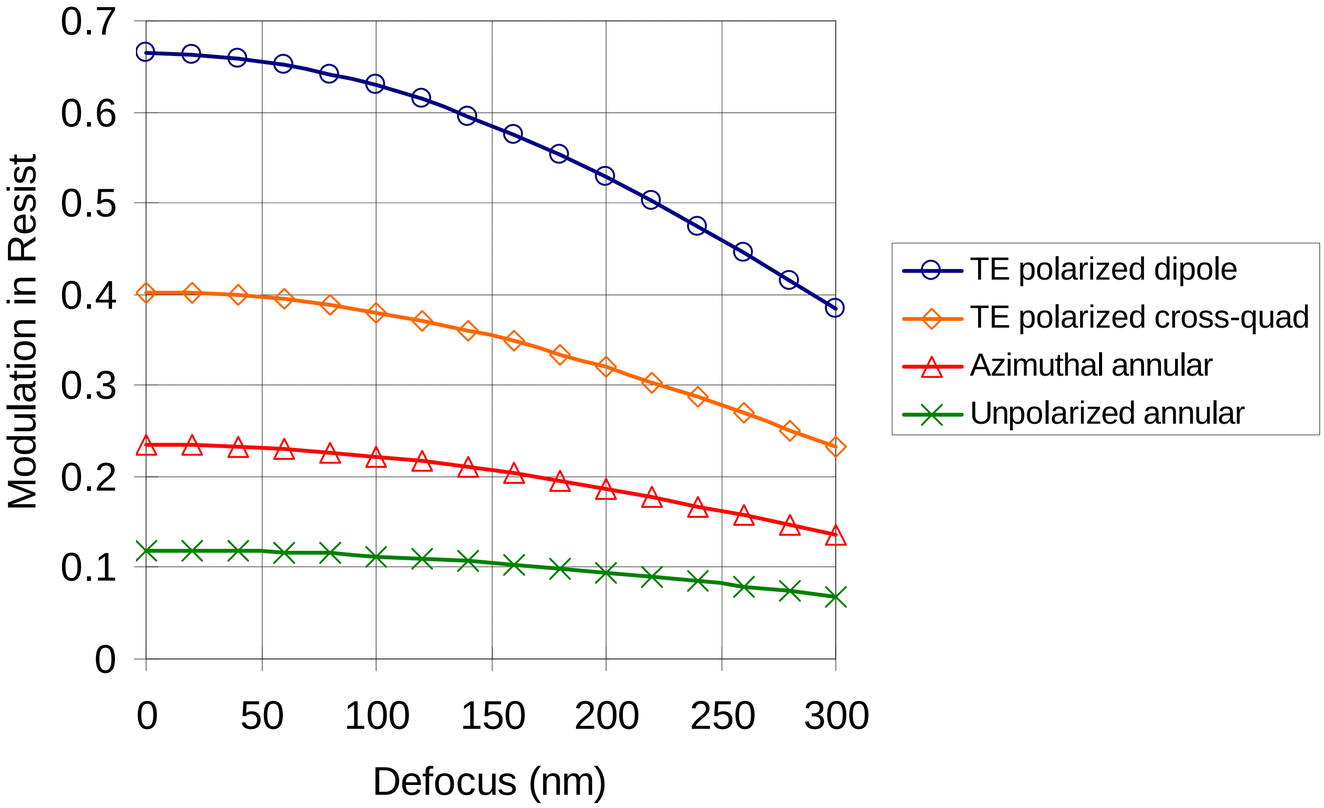
45nm H-V 5 Bar Target



Diffraction Energy in Pupil

Images in Resist through Focus

Radial vs. TE-Dipole



- Annular illumination will be used in dipole mode at low k_1
- TE polarized cross quadrupole may be superior to TE annular

Implementing Polarization

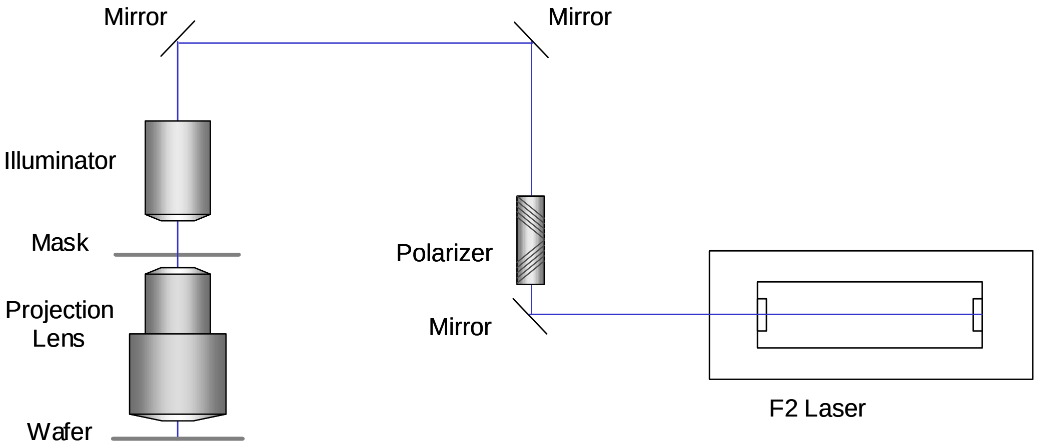
ISMT / Exitech 0.85NA 157nm

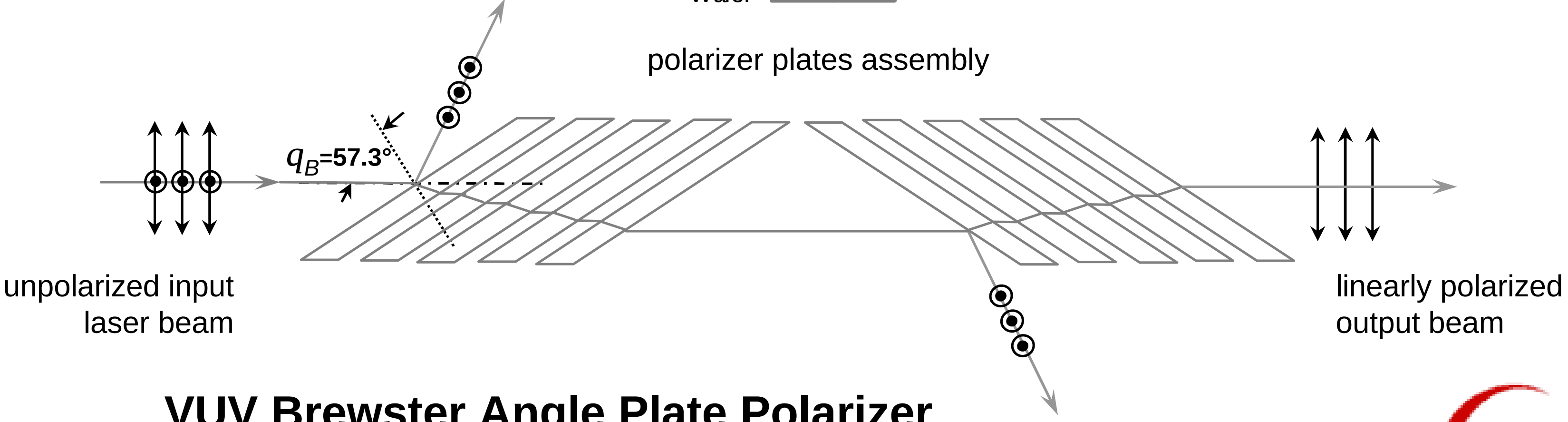
Polarization methods:

Birefringence (Glan-Taylor)

Selective absorption (Dichroic)

Selective reflection (Wollaston)





VUV Brewster Angle Plate Polarizer

CaF_2 Brewster angle of 57.3º

VUV Polarizer Performance

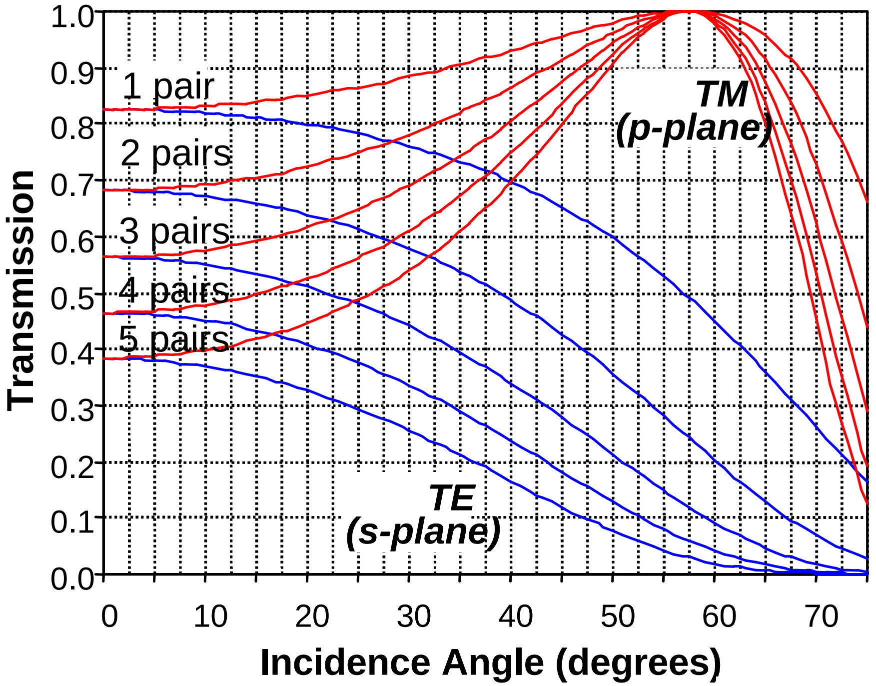
Performance specifications

Principal (TM) Transmittance: >96%T

Extinction Ratio: ~0.03

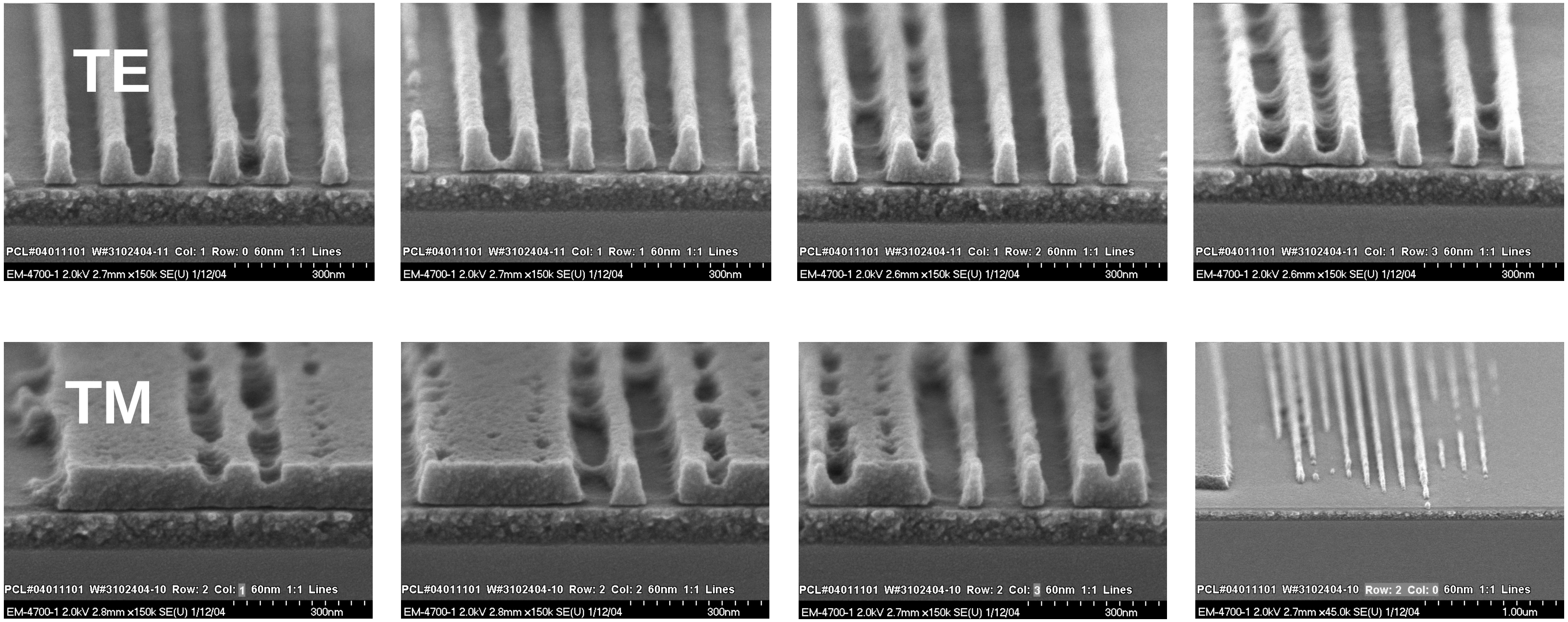
Transmission: 51.5%

	Efficiency 1-T(s)/T(p)	Extinction T(s)T(p)	Transmission [T(p)+T(s)]/2
1 pair	0.500	0.500	0.750
2 pairs	0.750	0.250	0.625
3 pairs	0.875	0.125	0.562
4 pairs	0.938	0.062	0.531
5 pairs	0.969	0.031	0.515



Binary 60nm 1:1, Polarized Imaging

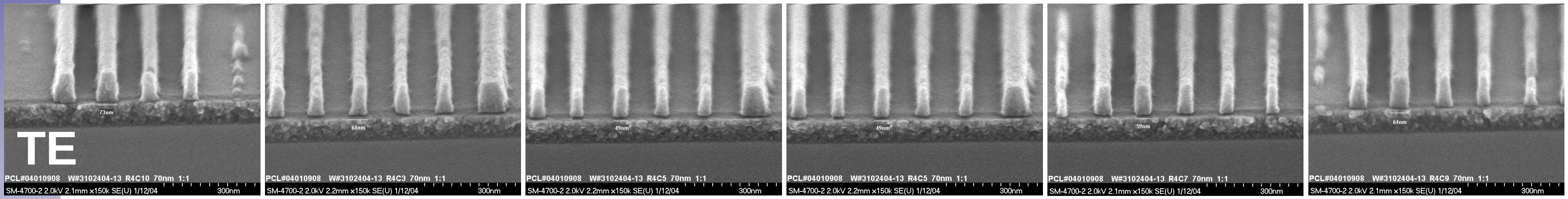
Focus (positive direction) ⟶ **(0.05 µm steps)**



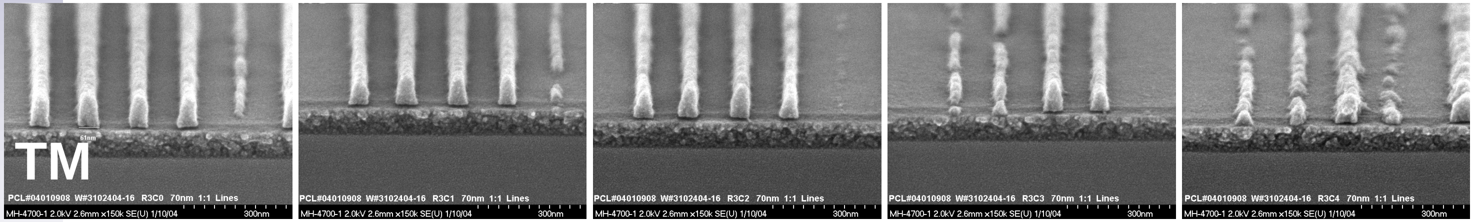
60nm 1:1, Binary mask
DIPOLE illum 0.77σ_c/0.1σ_p

AltPSM 70nm 1:1 0.3σ, Polarized

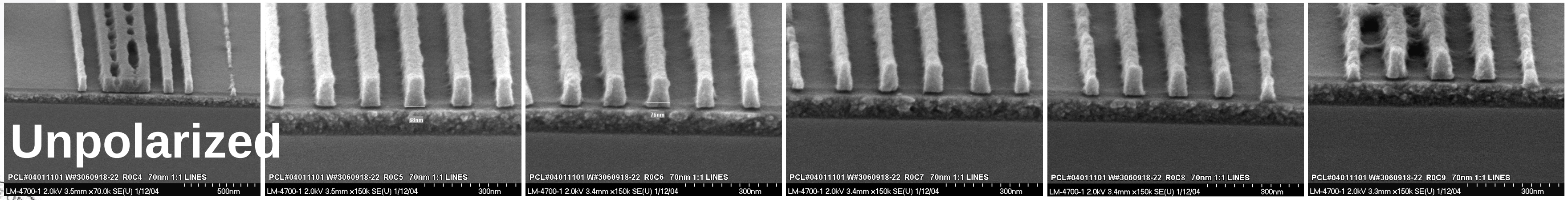
Focus (positive direction) → **(0.10 µm steps)**



Focus (positive direction) → **(0.05 µm steps)**



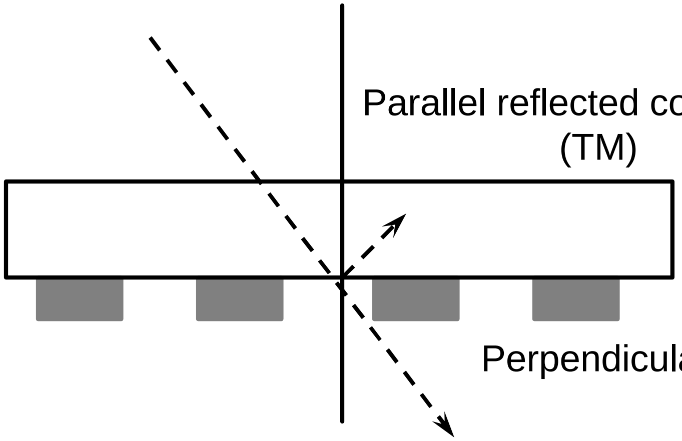
Focus (positive direction) → **(0.05 µm steps)**



Mask Feature Effects

Mask-induced Polarization

“Wire Grid Polarizers”



Sub-wavelength
Zero-Order Grating

Parallel reflected component
(TM)

Perpendicular transmitted component
(TE)

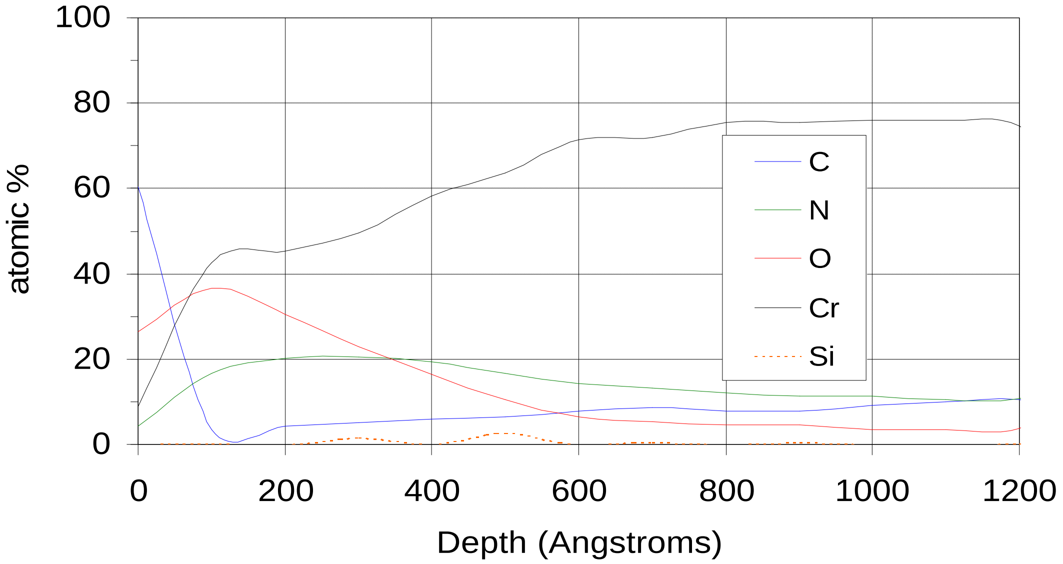
Polarizing wires (Wood, Philosophical Magazine, 1902).

Resonant high orders (Rayleigh, Philosophical Magazine, 1907).

$$l = \frac{\boldsymbol{p}}{\boldsymbol{k}}(\boldsymbol{n} \pm \sin q)$$

Mask Polarization

Graded $Cr_xO_yN_z$ over Cr_xN_y



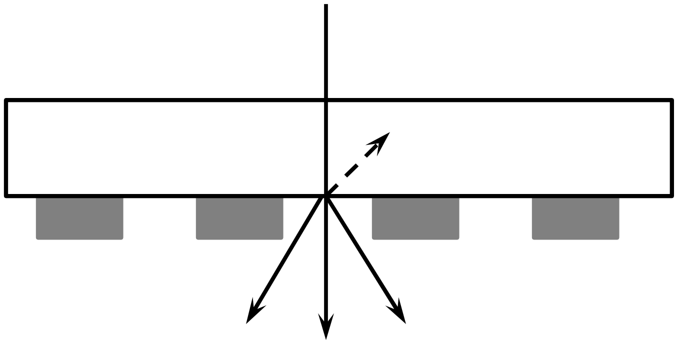
"Mask induced polarization effects at low k_1," A. Estroff et al 5377-220

	Cr-O-N Stack Composition			
	Layer 1	**Layer 2**	**Layer 3**	**Layer 4**
Cr	90.00%	18.90%	9.45%	0.00%
CrN	10.00%	2.10%	1.05%	0.00%
CrOx	0.00%	79.00%	89.50%	100.00%

	Data for Cr-O-N Stack (Layer 1 is closest to substrate, Layer 4 is furthest)							
	Layer 1		**Layer 2**		**Layer 3**		**Layer 4**	
	193nm	**248nm**	**193nm**	**248nm**	**193nm**	**248nm**	**193nm**	**248nm**
n	0.8209	0.8863	1.5649	1.8142	1.6740	1.9734	1.7782	2.1260
k	1.1825	1.8700	0.4121	0.7391	0.3597	0.6584	0.3148	0.5918
Thickness (A)	900	900	133	133	133	133	133	133

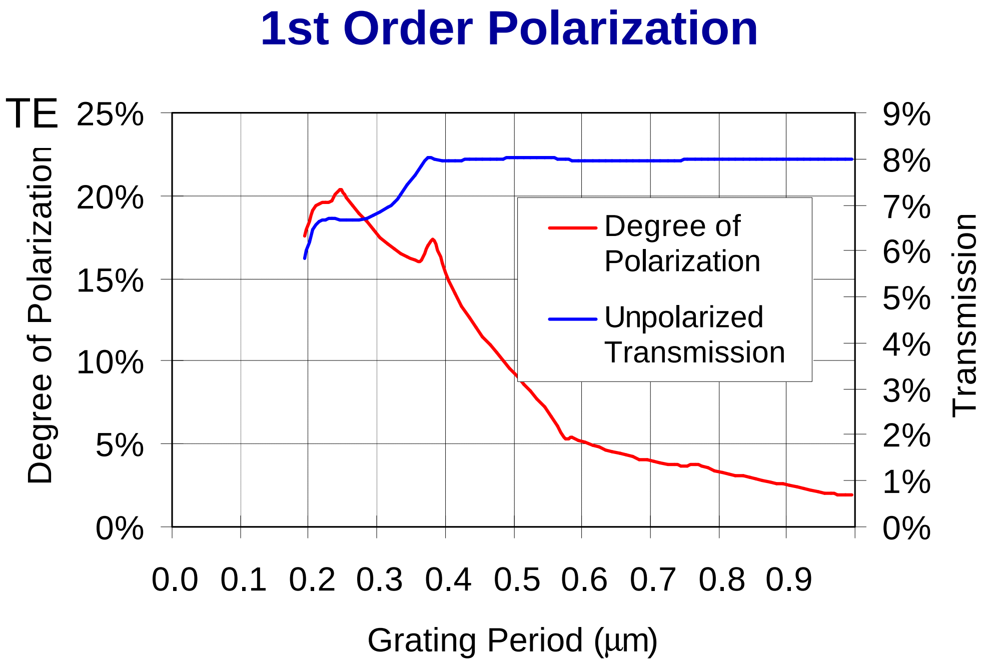
Cr-O-N 193nm Binary Mask Polarization

Normal incidence

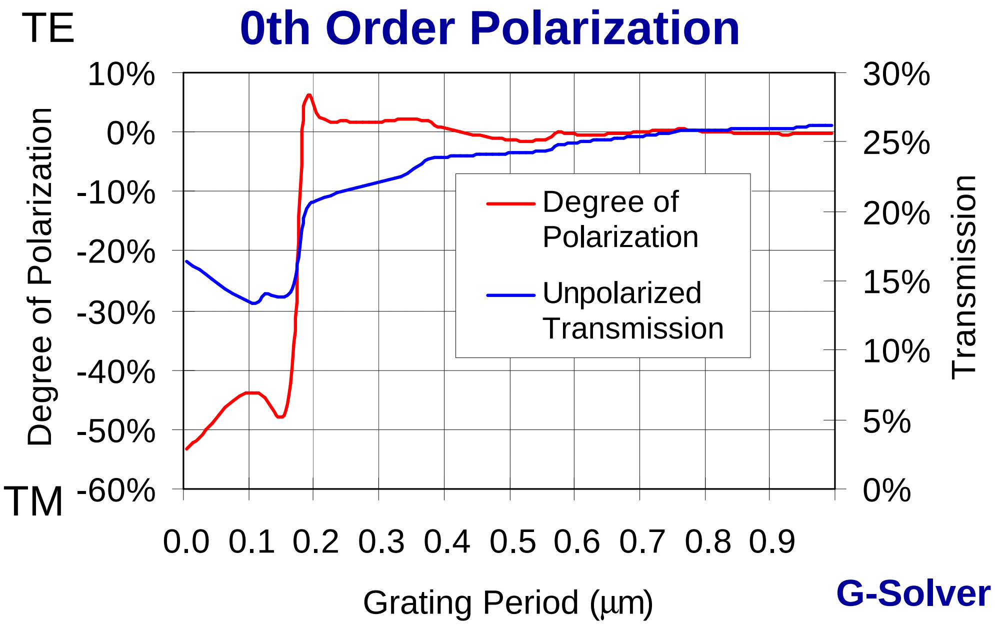


RCWA of mask structures

Degree of Polarization = (TE-TM)/(TE+TM)



1st Order Polarization



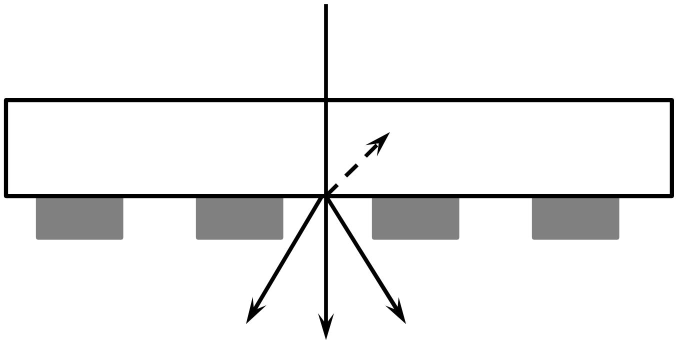
0th Order Polarization

G-Solver

"Mask induced polarization effects at low k_1," A. Estroff et al 5377-220

193nm Attenuated PSM Polarization

Normal incidence

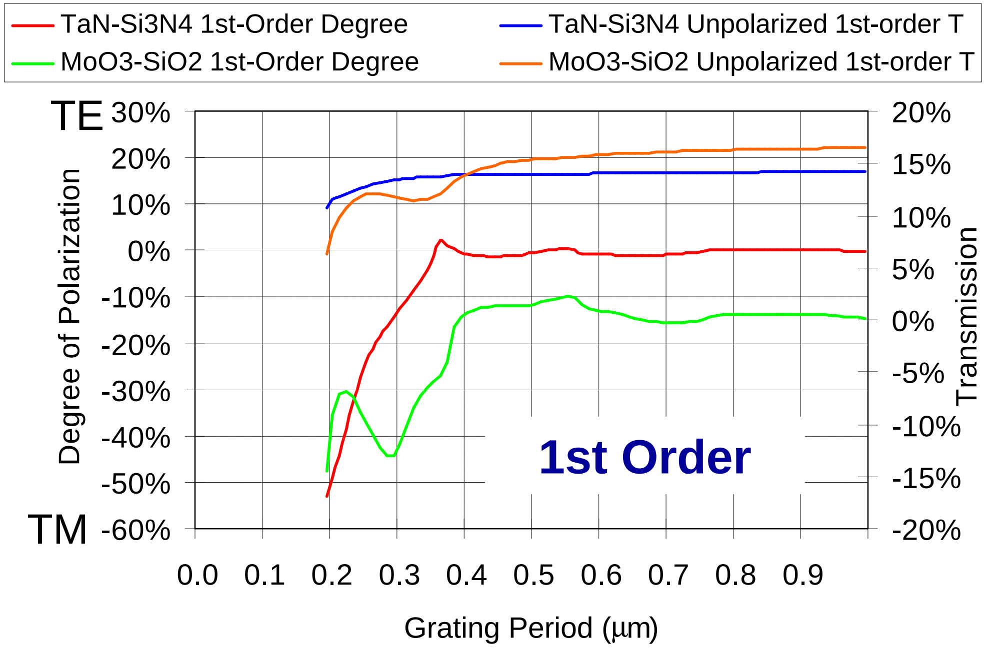


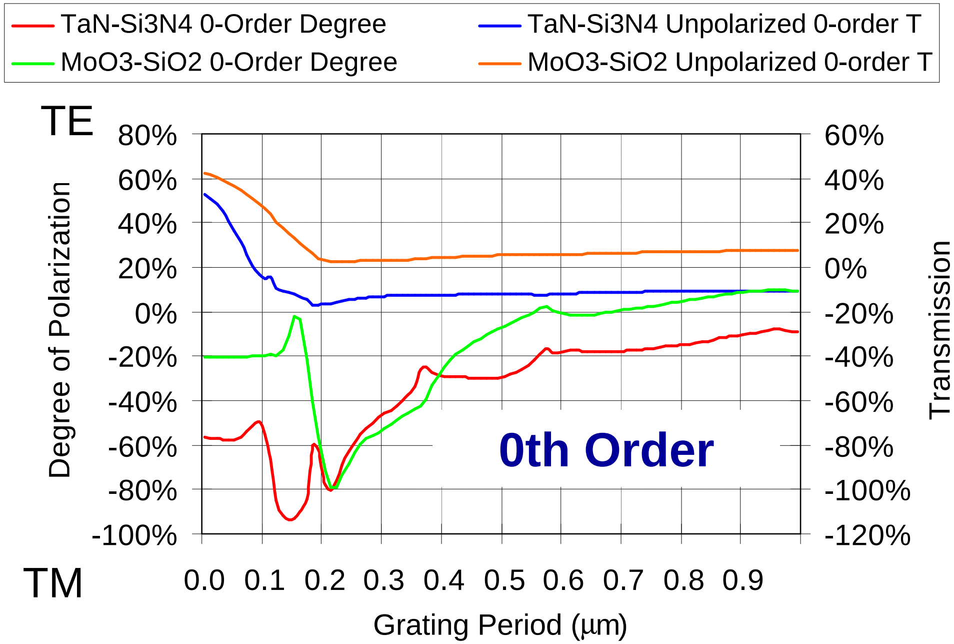
10% Transmitting Attenuated PSM Materials

TaN - Si_3N_4

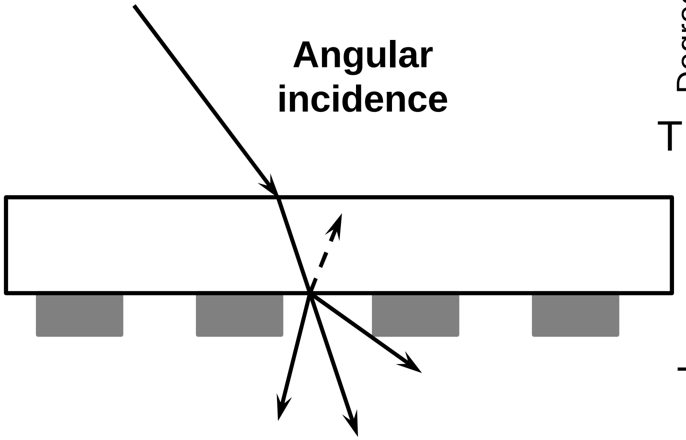
MoO_3 – SiO_2

"Mask induced polarization effects at low k_{1}," A. Estroff et al 5377-220





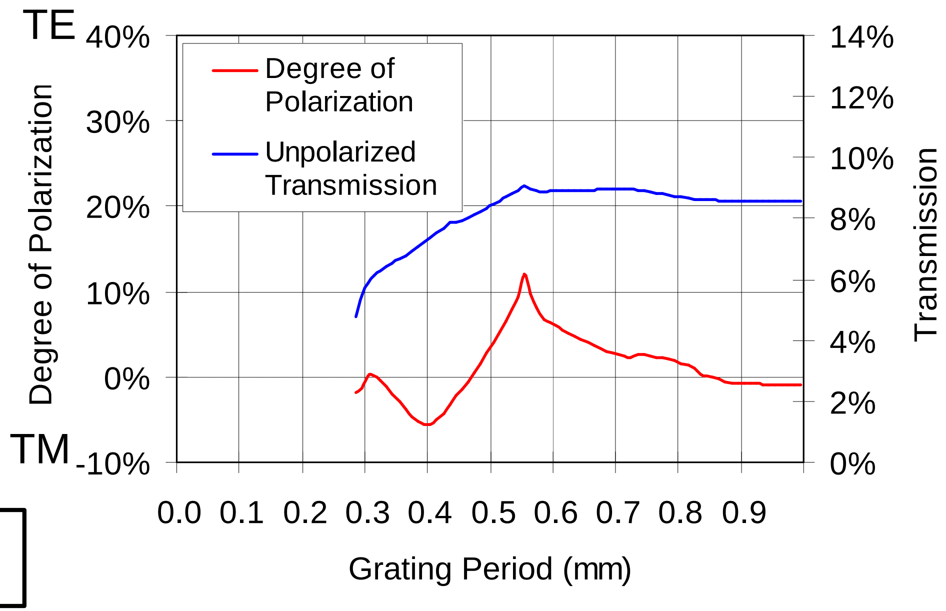
Asymmetrical Order Polarization



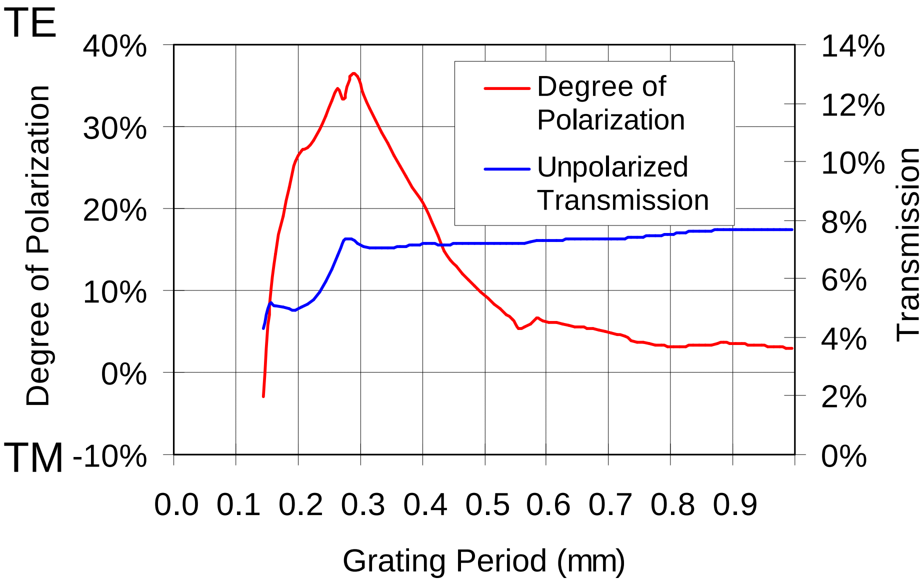
1.2NA 4X Imaging System

17.45° in air, 11.5° in glass

+1st Order Polarization



-1st Order Polarization



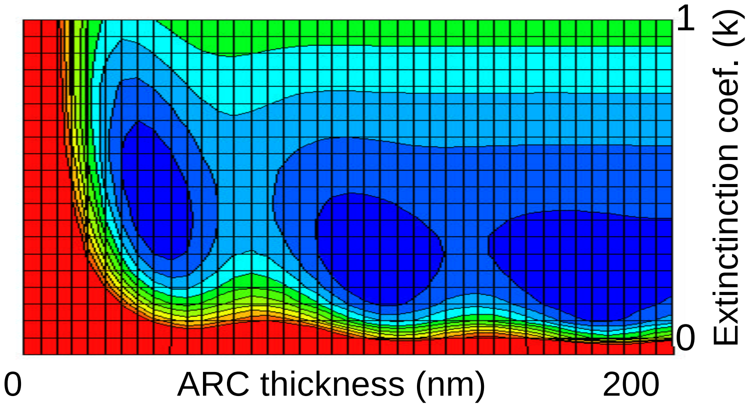
"Mask induced polarization effects at low k_1," A. Estroff et al 5377-220

Thin Film Reflection Effects

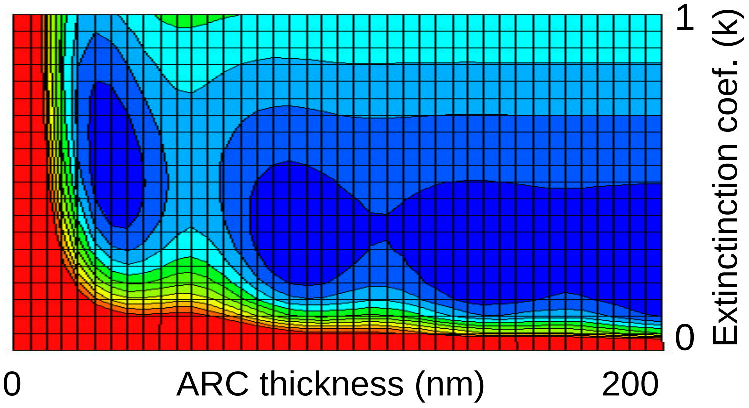
ARC Reflectivity at Normal Incidence

193nm in Resist (1.70, 0.005), 2% reflectivity contours

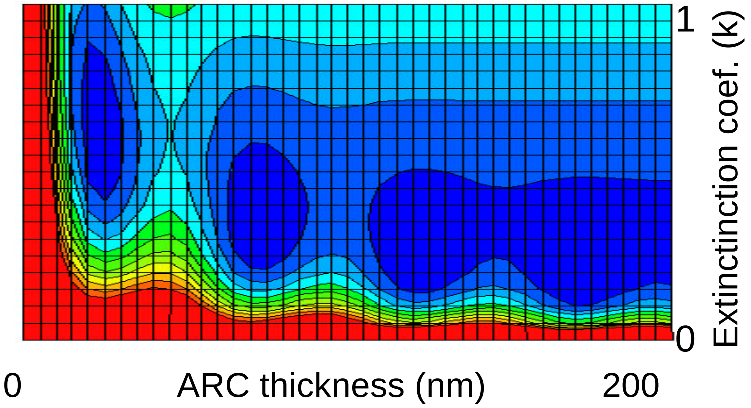
n(ARC) = 1.5



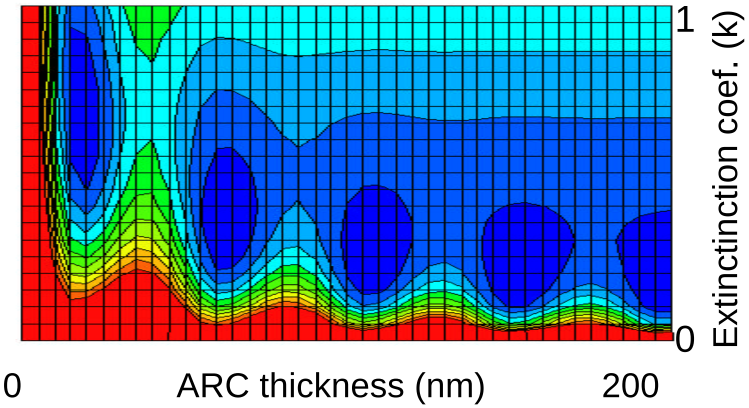
n(ARC) = 1.7



n(ARC) = 1.9

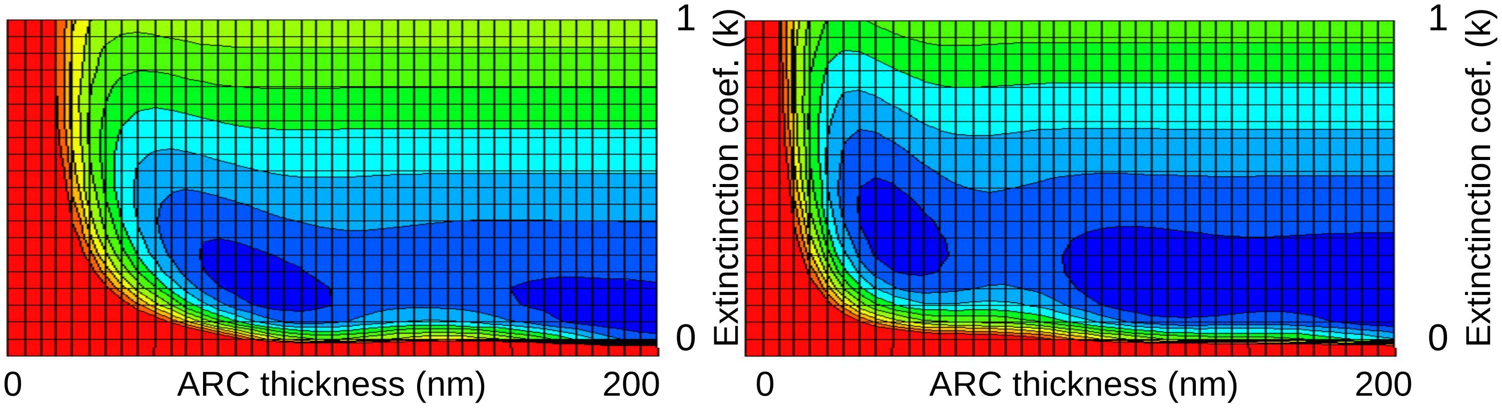


n(ARC) = 2.1



ARC Reflectivity at 45° Incidence

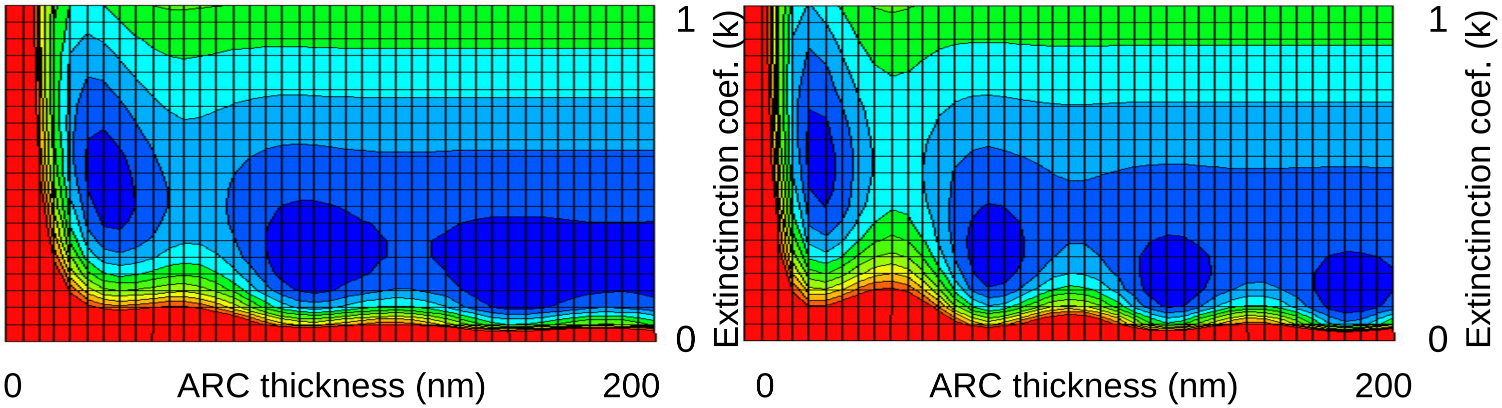
Unpolarized radiation, 2% reflectivity contours


n(ARC) = 1.5

n(ARC) = 1.7

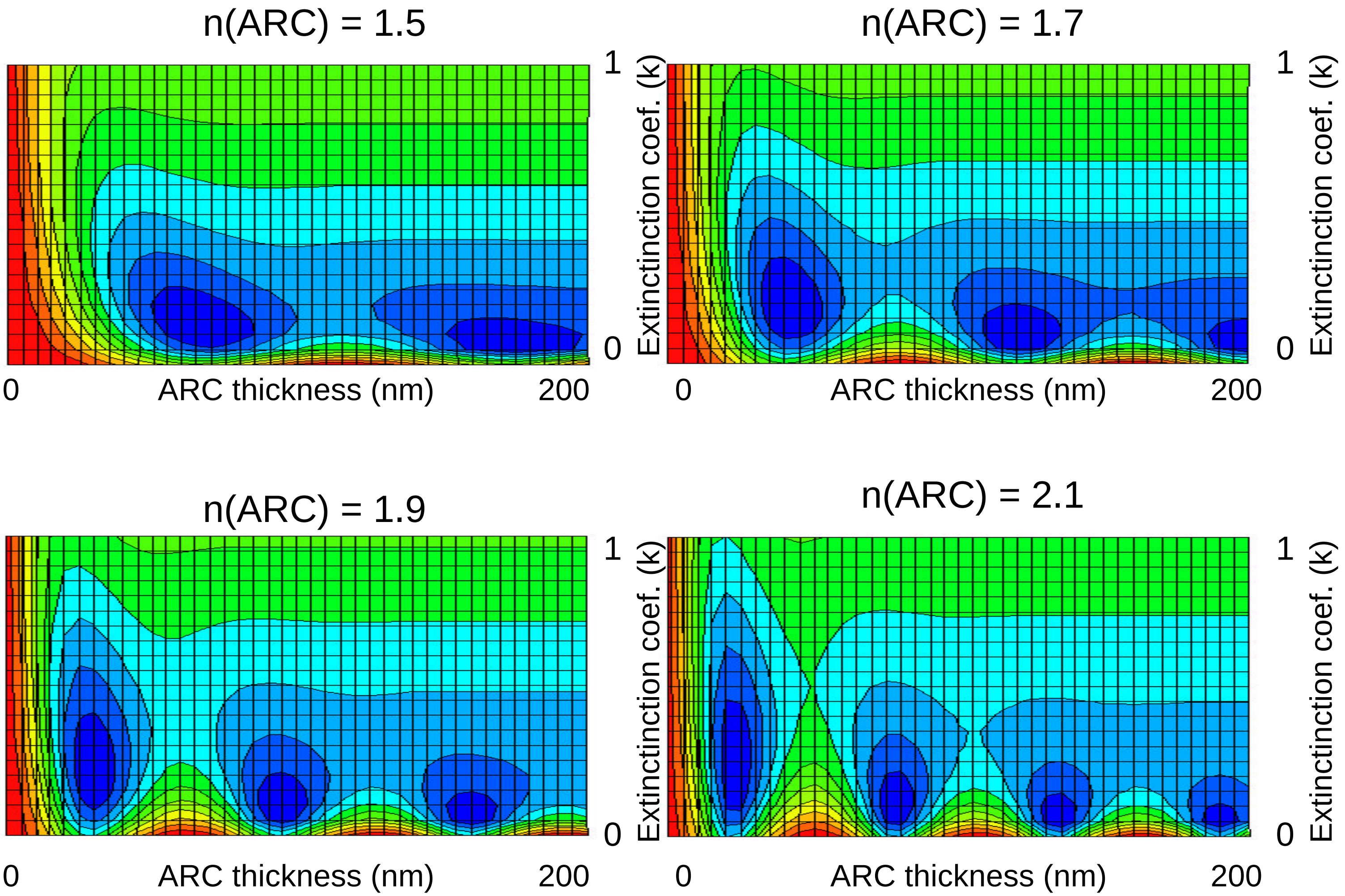
n(ARC) = 1.9

n(ARC) = 2.1



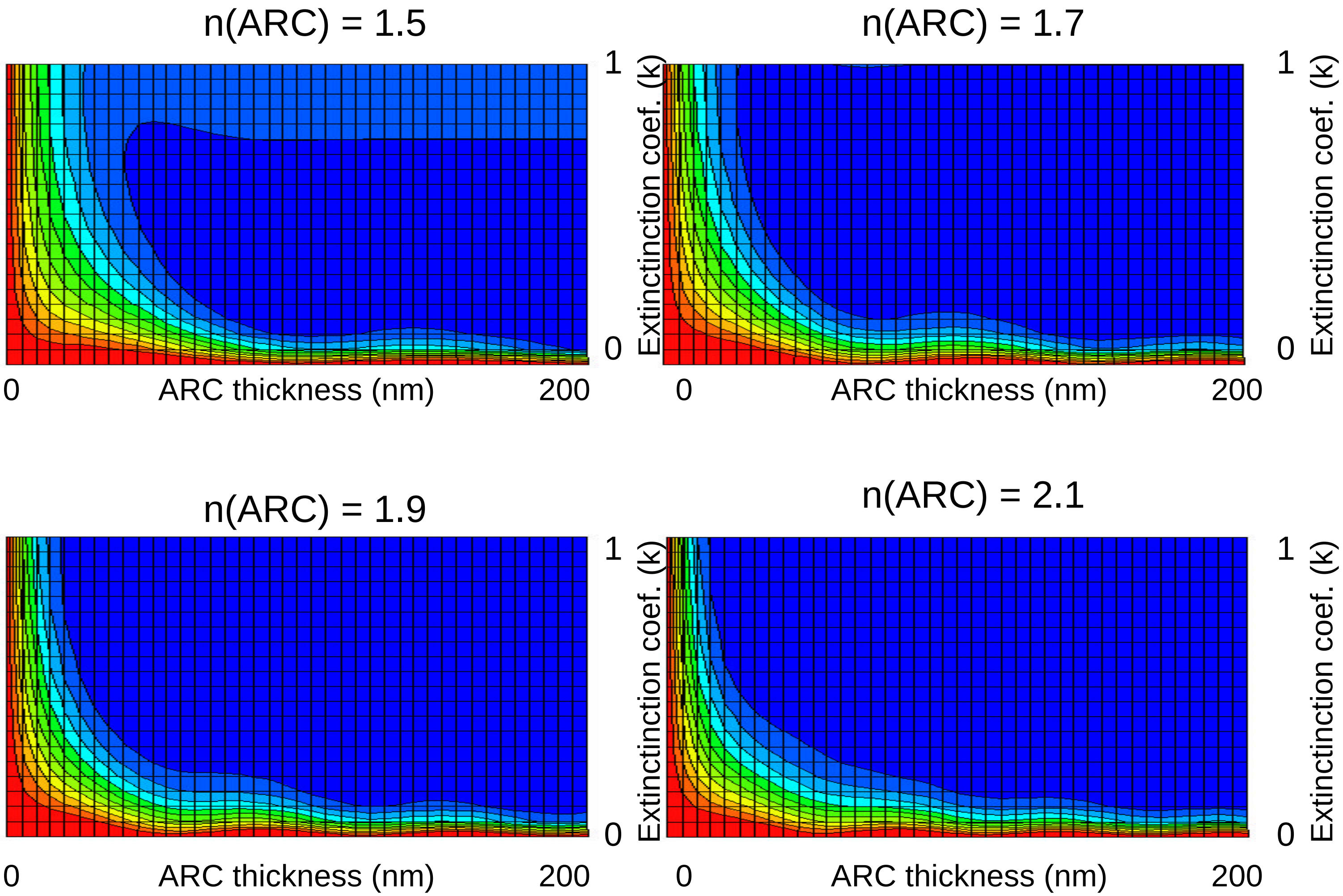
ARC Reflectivity at 45° Incidence

TE Polarization, 2% reflectivity contours



ARC Reflectivity at 45° Incidence

TM Polarization, 2% reflectivity contours



n(ARC) = 1.5

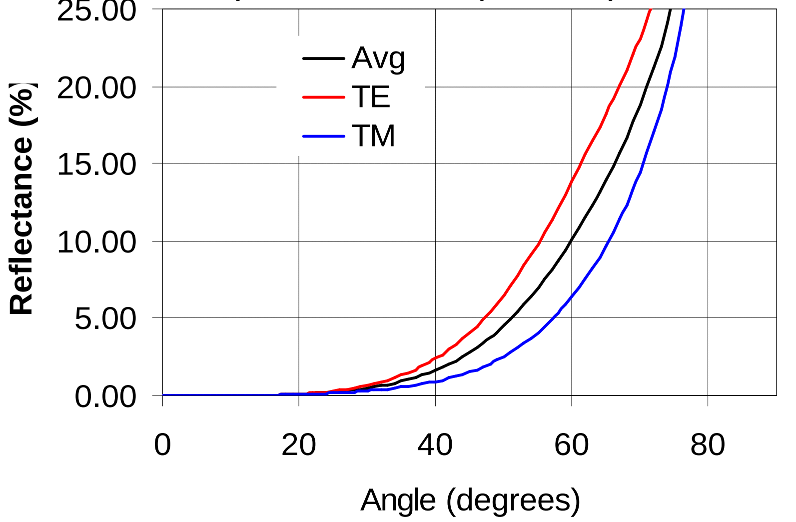
n(ARC) = 1.7

n(ARC) = 1.9

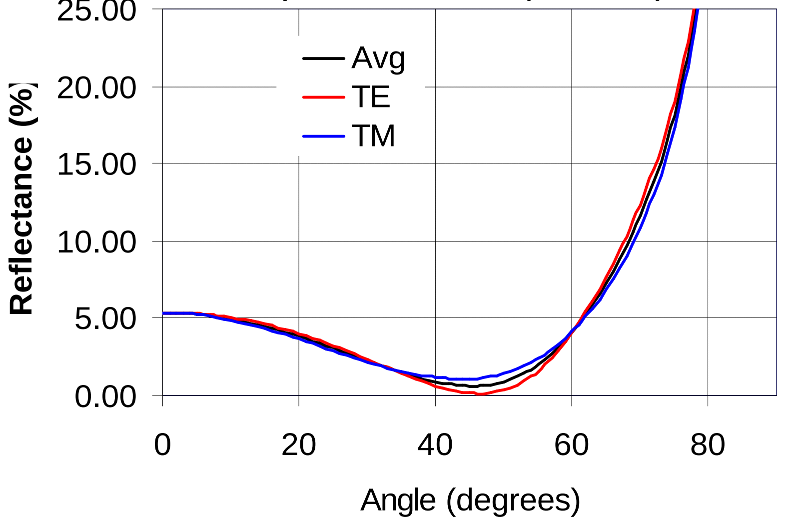
n(ARC) = 2.1

Single Layer ARC Optimization for 1.2NA

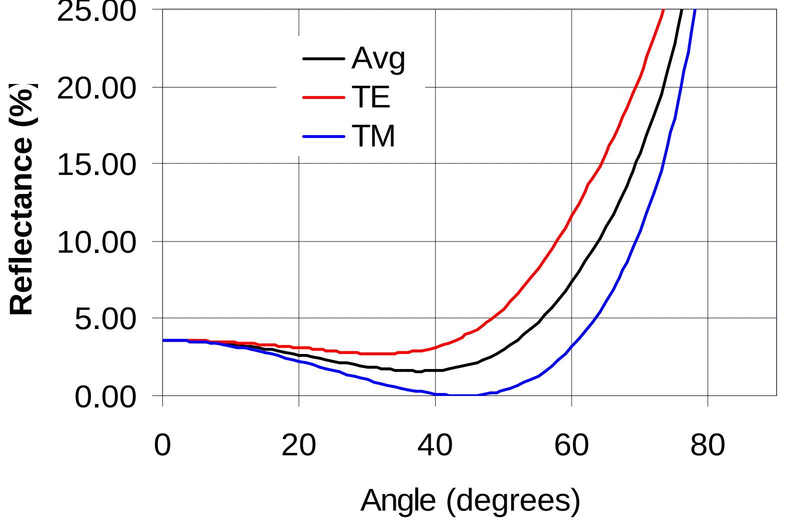
0° optimized, ARC(1.7, 0.5), 35nm



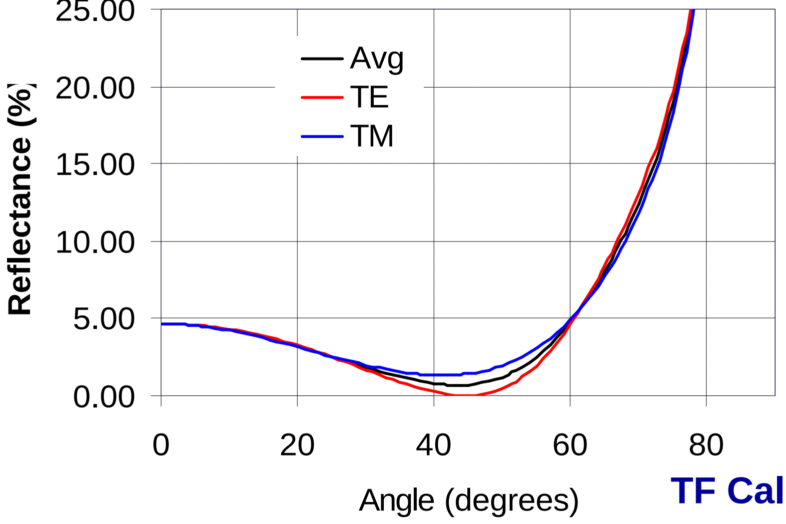
45 ° optimized, ARC(1.7, 0.3), 52nm



45 ° TM optimized, ARC(1.7, 0.5), 52nm



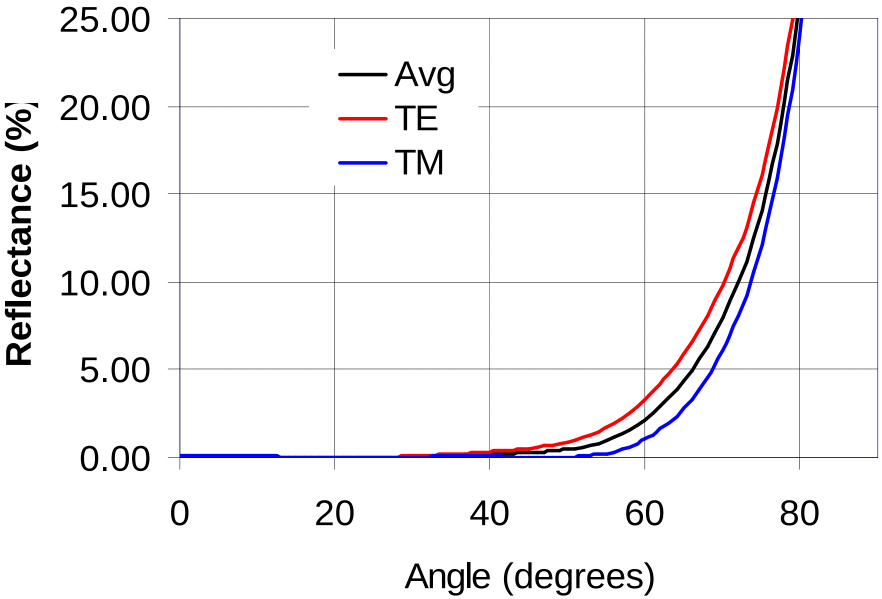
45 ° TE optimized, ARC(1.7, 0.3), 48nm

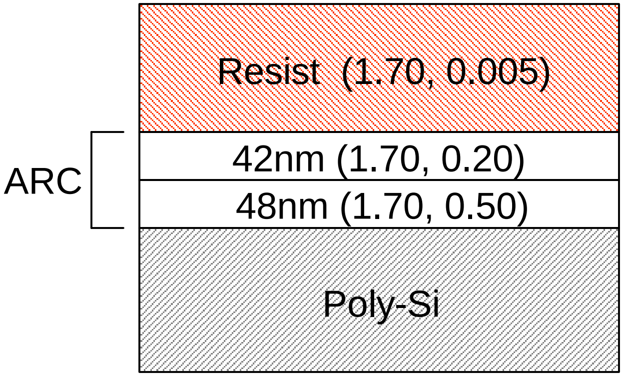


TF Calc

ARC for 0-45° TE/TM Polarization

Multilayer Designs


Full angular optimization 0-45° (1.2NA)

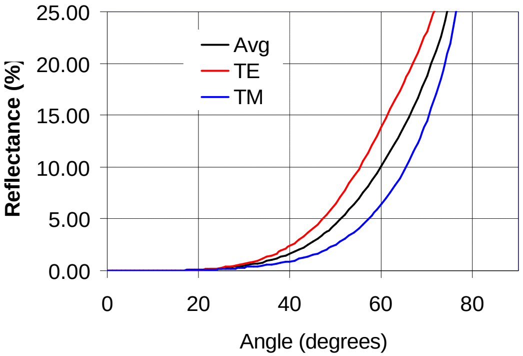

Resist (1.70, 0.005)

ARC

42nm (1.70, 0.20)

48nm (1.70, 0.50)

Poly-Si



Normal incidence optimized ARC(1.7, 0.5) 35nm

Conclusions

- TE polarized illumination can provide resolution enhancement, TE C-Quad may be useful

- Early results at 157nm confirm TE polarized imaging

- Mask induce polarization effects exist, the impact is to be seen (e.g. Mag).

- Resist stacks require full angle / polarization optimization