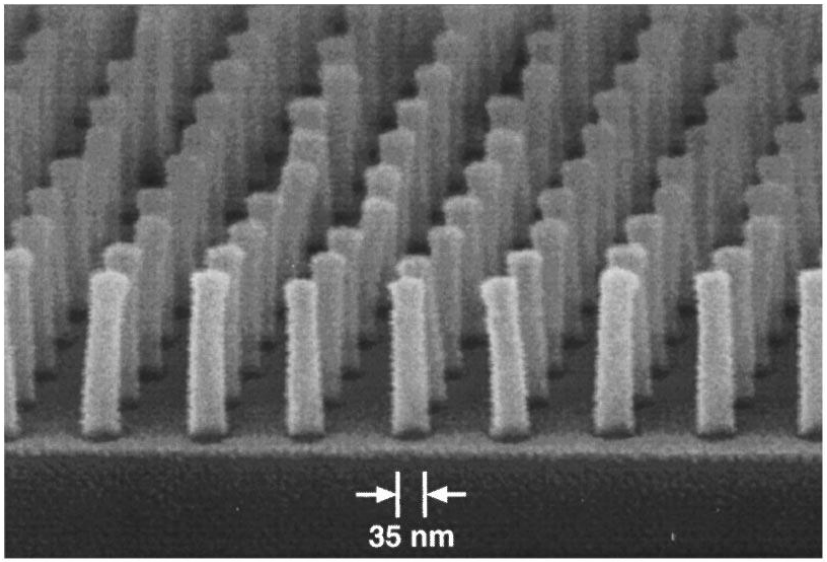
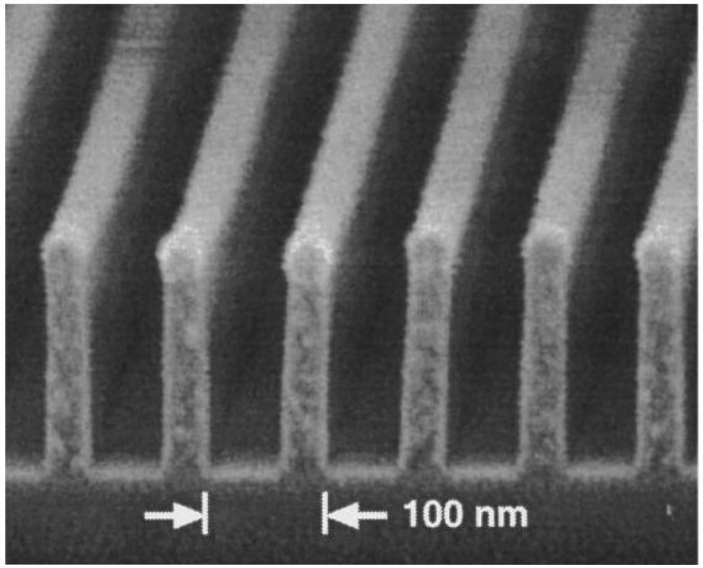
Interferometric Lithography

Jeremy Hicks

Overview

- Interferometric Lithography (also known in the literature as Holographic Lithography) exploits the natural ability of waves to form well-defined standing patterns to selectively expose resist sans mask
- Used to produce simple 1-2D patterns with periodicity higher than what is achievable with a mask using the same wavelength of light
- Uses: Field emitters, diffraction gratings





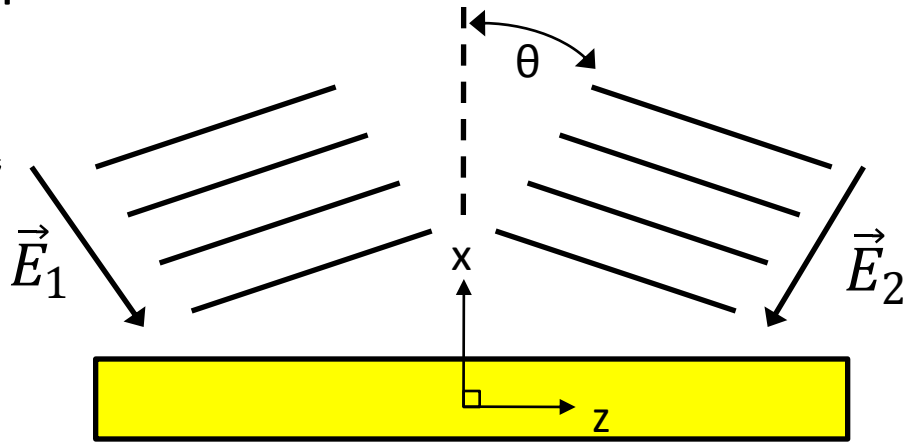
Savas, et al, J. Vac. Sci. Tech. B 14 (1996)

Principle

- Consider two convergent plane waves of wavelength λ and wavenumber $k_0 = 2\pi / \lambda$ incident upon a surface

$$\vec{E}_1(x,z) = E_0 e^{j k_o (\mathrm{z} \sin \theta - \mathrm{x} \cos \theta)} \hat{y}$$

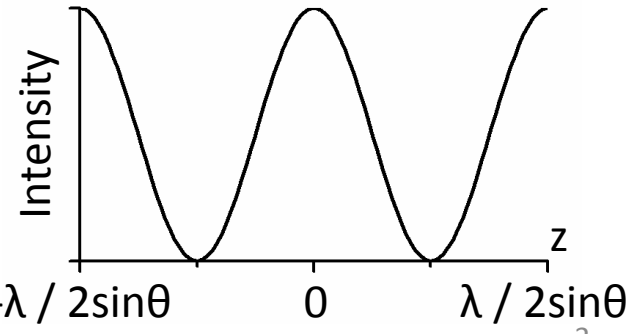
$$\vec{E}_2(x,z) = E_0 e^{j k_o (-\mathrm{z} \sin \theta - \mathrm{x} \cos \theta)} \hat{y}$$



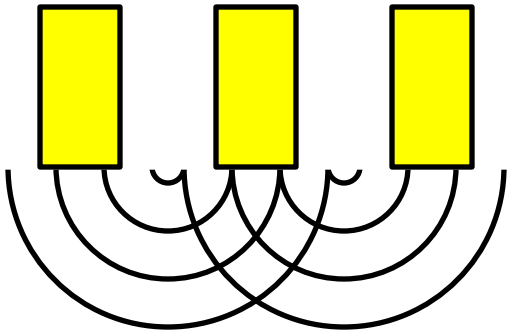
- Interference causes a standing wave intensity of period λ / 2sinθ

$$\vec{E}_1 + \vec{E}_2 = E_0 \Big[\underbrace{e^{j k_0 z \sin \theta} + e^{-j k_0 z \sin \theta}}_{2 \cos\left(\frac{2\pi z \sin\theta}{\lambda}\right)} \Big] e^{-j k_0 x \cos \theta} \hat{y}$$

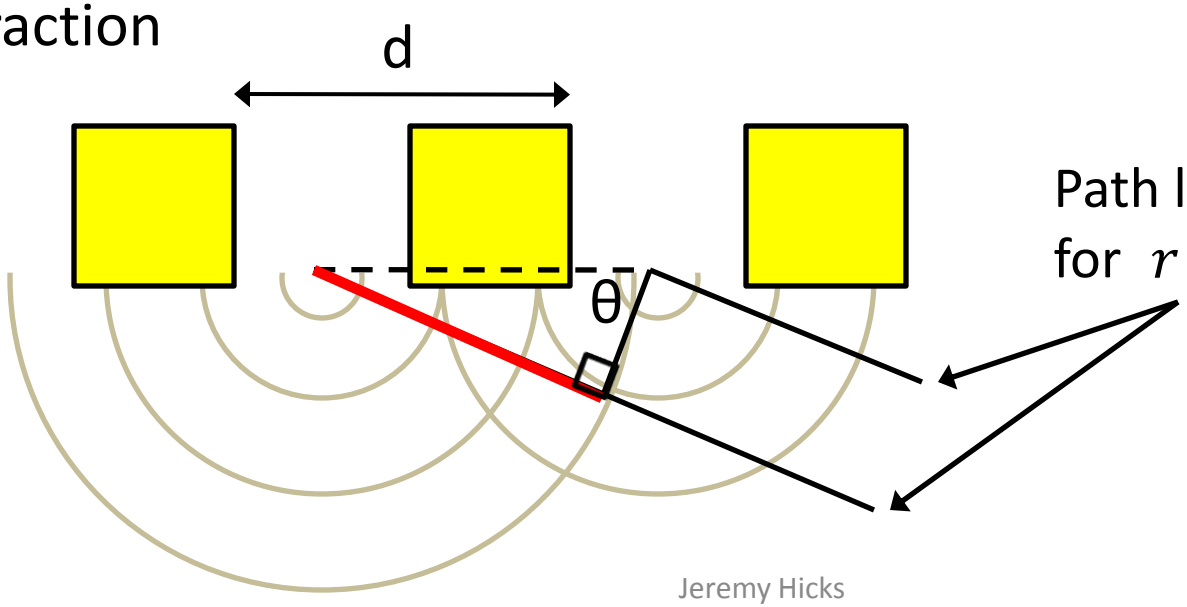
- Result: Possible feature size can be halved when compared to an aperture of width λ



Diffraction Grating Optics



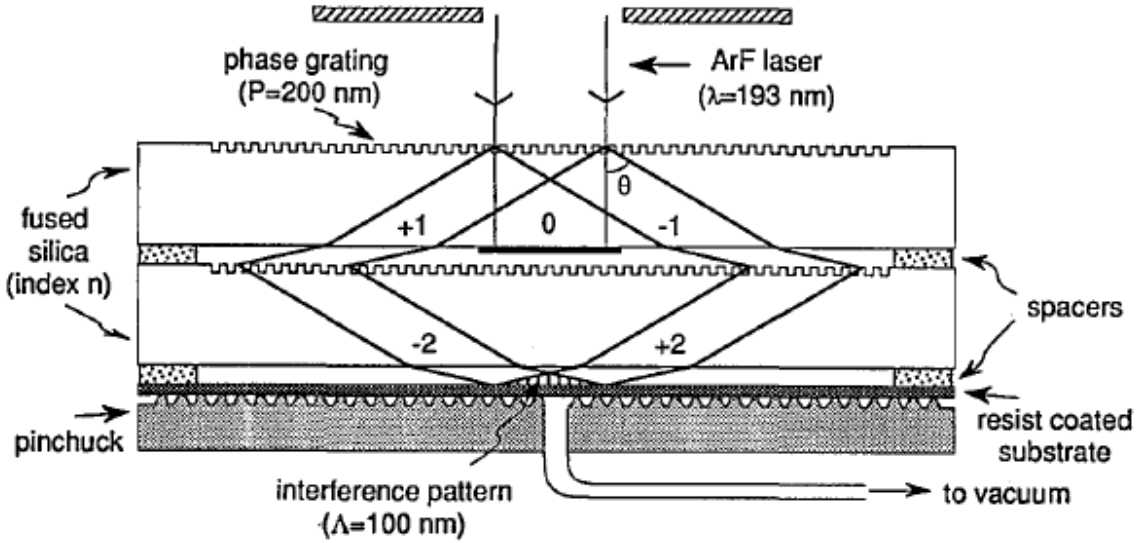
- Diffraction gratings used to predictably alter light
- Light exiting gratings treated as point sources (Huygens' Principle)
- Constructive interference occurs for a select few angles, $d \sin\theta = m\lambda$
- An angle satisfied by an integer m is referred to as m^{th} order diffraction

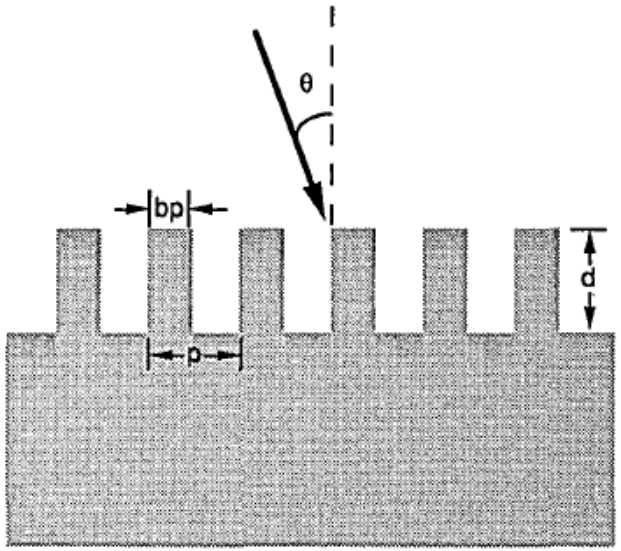


Path lengths differ by mλ for $r \gg d$

The Setup

- ArF laser (λ = 193nm) shone upon a diffraction grating patterned into fused silica
- First grating selectively passes 1st order diffracted light, splitting it
- Second gratings selectively passes 2nd order diffracted light, recombining the split light, interfering at the resist surface

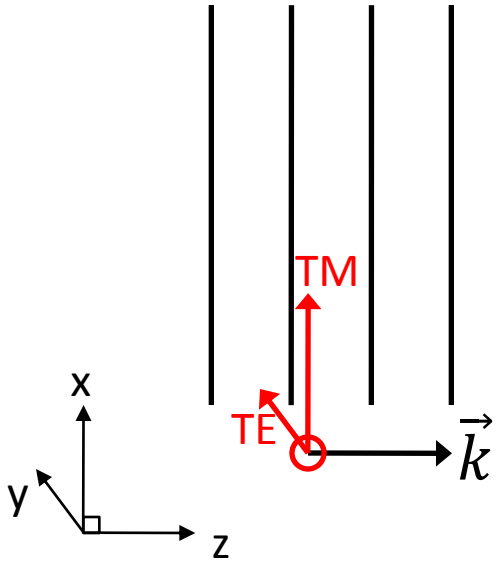


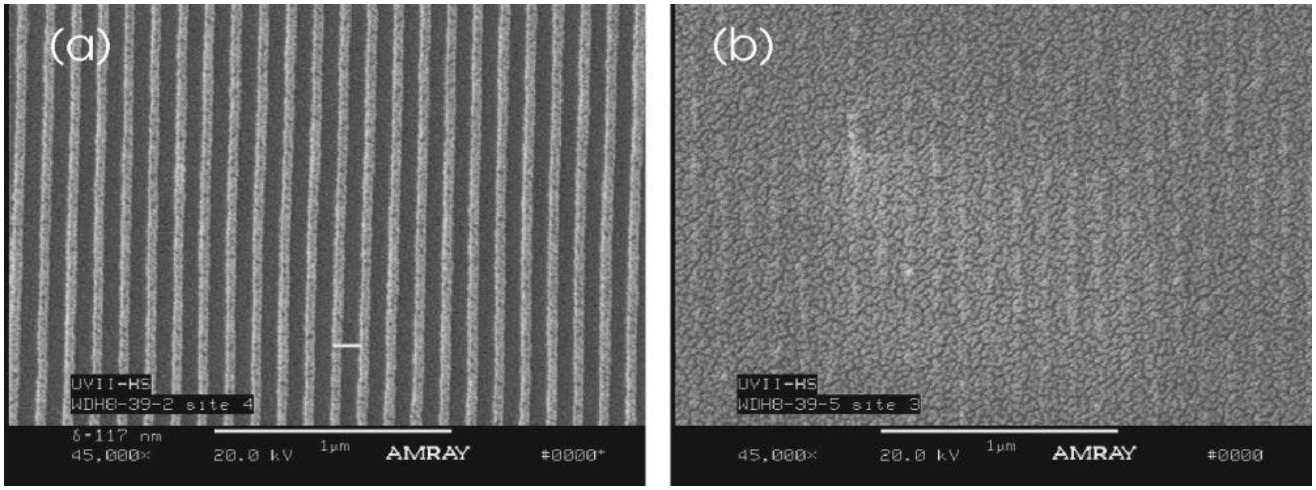


Yen, et al, Applied Optics 31 (1992)

Laser/Grating

- Lasers generate mostly linearly-polarized light, however the direction of polarization is difficult to control perfectly
- Transverse Electric (TE) light is preferable to Transverse Magnetic (TM) light because it provides a higher contrast
- Grating designed to block TM; Some TM is instead used to monitor power levels to ensure a uniform exposure

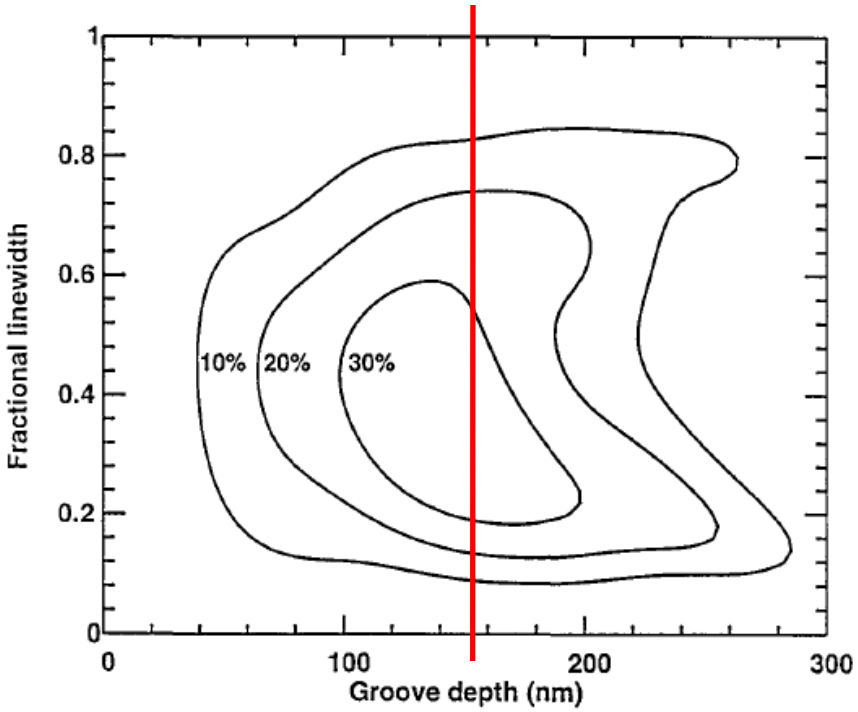


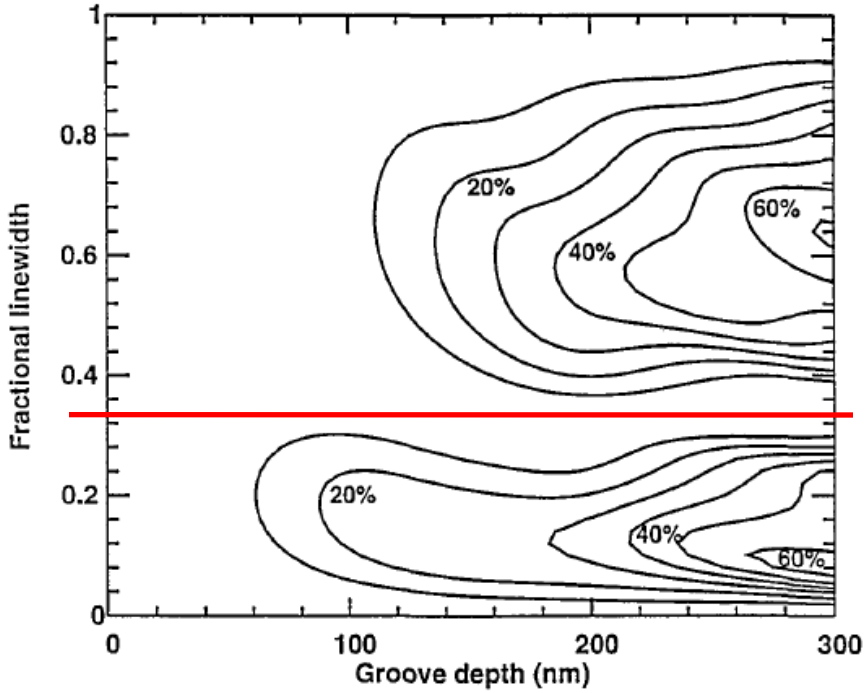


Hoffnagle, et al, J. Vac. Sci. Tech. B 17 (1999)

Grating Design

- Kirchhoff Approximation invalid for grating width d ≈ λ = 193nm, so TE/TM light interact differently
- To pass first order TE diffraction, the ideal grating has a fractional linewidth of around 0.4 and a depth of around 150nm





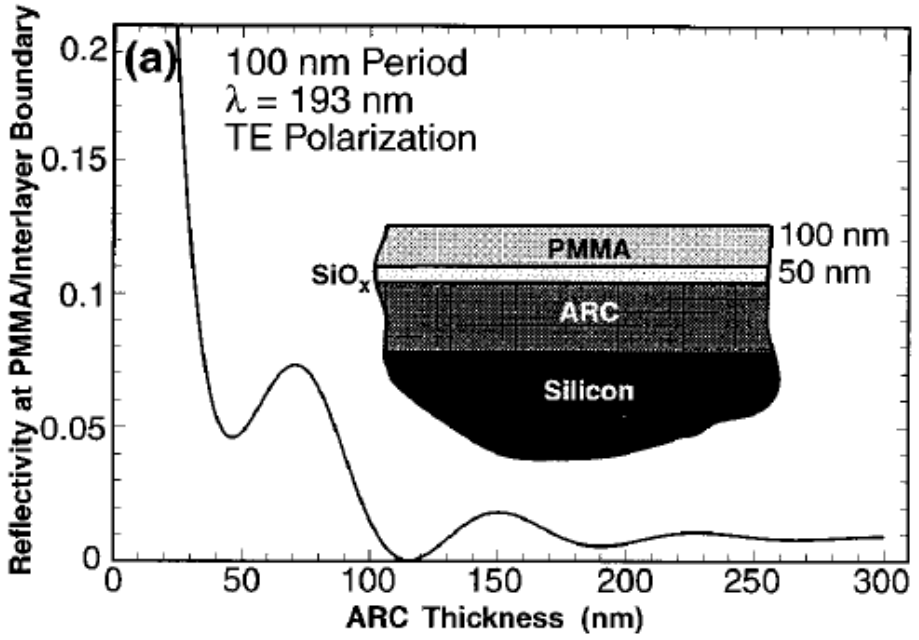
Yen, et al, Applied Optics 31 (1992)

Substrate

- Method is compatible with any photoresist
- ARC required on the back side of the resist as standing waves can wash out the interference pattern. Needed especially because of the large reflections at large incidence angles
- Depth of focus large and dependent upon coherence of light source

$$DOF \approx \frac{\sqrt{p^2 + {\lambda_0}^2}}{2\Delta\theta} \quad [1]$$

- Where p is the periodicity of the grating and Δθ is the laser's spacial coherence



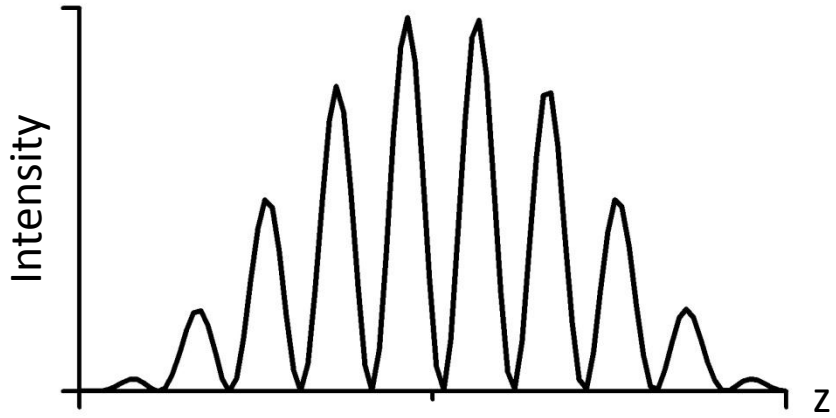
[1] Yen, et al, Applied Optics 31 (1992)

Savas, et al J. Vac. Tech. B 14 (1996)

Challenges

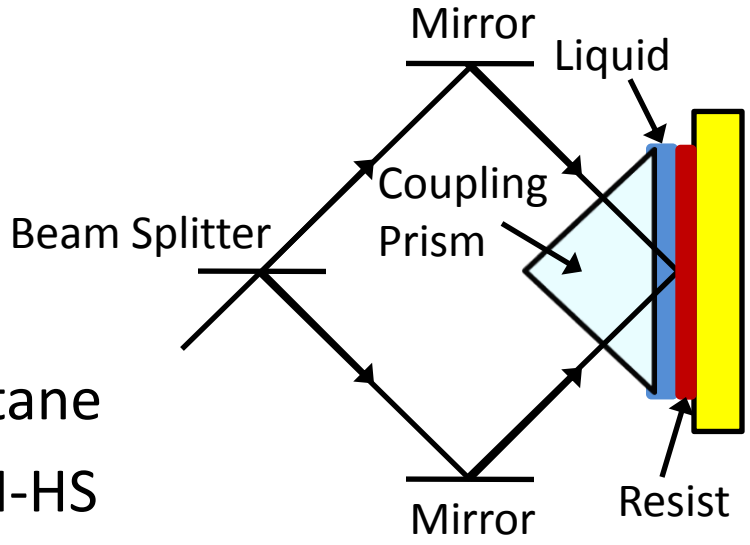
- Much less efficient use of light (diffraction gratings, polarization effects)
- Laser only *approximates* a planewave. For an ArF laser, $\Delta\lambda \approx 0.5$nm and $\Delta\theta \approx 6$mrad. The path length difference $\Delta\Phi$ affects contrast also
- Actual intensity given by $I(z) = I_\Delta \cos^2\left(\frac{2\pi z \sin\theta}{\lambda}\right)\cos^2\left(\frac{\pi\Delta\Phi \sin\theta}{\lambda}\right)$

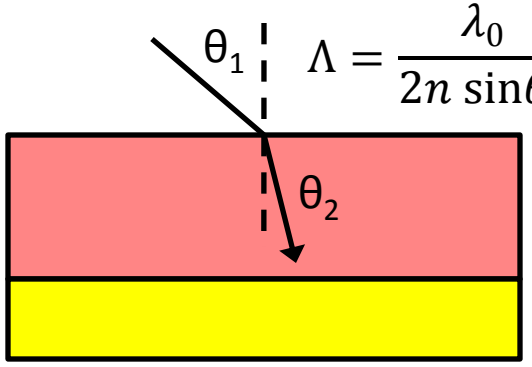
  Where I_Δ is a slowly varying periodic function of substrate position z and whose spacial period is inversely related to both $\Delta\lambda$ and $\Delta\theta$



Extension

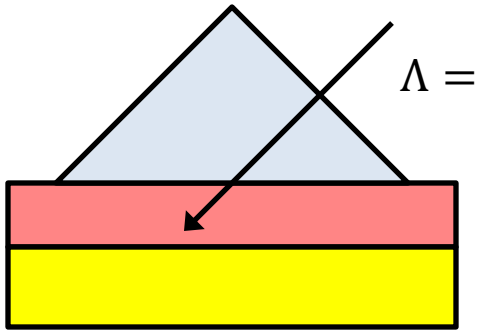
- Liquid Immersion slightly modified
- Coupling prism the key to method
- Further feature size shrink by a factor of $n_{prism} = \sqrt{\epsilon_r \mu_r}$
- Fused silica prism (n=1.50), cyclo-octane coupling liquid (n=1.51), Shipley UVII-HS resist diluted 75% in propylene glycol methyl ether acetate (n=1.68)





$$\Lambda = \frac{\lambda_0}{2n \sin\theta_2} = \Lambda_0$$

$\theta_1 = \sin^{-1}(n \sin \theta_2)$, $\lambda = \lambda_0 / n$



$$\Lambda = \frac{\lambda_0}{2n \sin\theta_2} = \frac{1}{n}\Lambda_0$$

$\theta_1 = \theta_2$, $\lambda = \lambda_0 / n$

Information derived from Hoffnagle, et al, J. Vac. Sci. Tech. B 17 (1999)