Study of Air Bubble Induced Light Scattering Effect On Image Quality in 193 nm Immersion Lithography

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Outline

- Optics and scatter from a microbubble
- Mie Scatter of micro-bubbles and synthetic spheres
- Variable Angle Spectroscopic Scatterometry (VASS)
- Lithographic imaging of spheres in a water gap

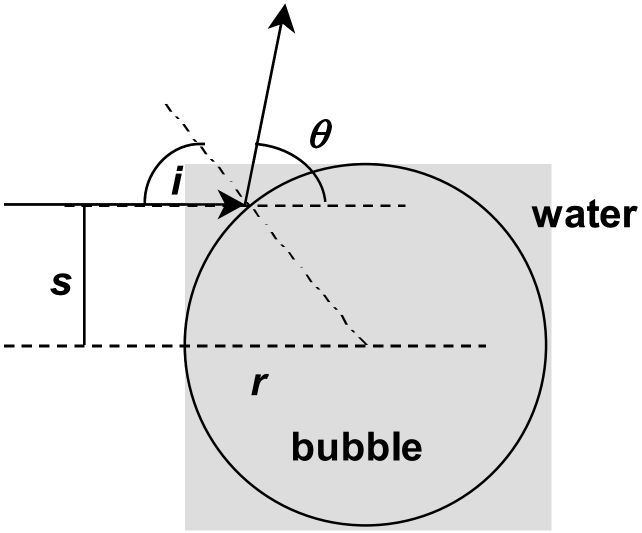
Is Scattering a Big Fear in Immersion Litho?

- Schemes for introducing water:
  - Shower designs: thin layer of water between wafer and final lens
  - Bathtub designs: entire wafer being immersed
- Bubble generating mechanisms :
  - Over saturation due to changes in ambient temperature, pressure
  - Trapping at the interface
  - Out-gassing from photoresist
- Effect on Imaging
  - Causing scattering of exposure light
  - Causing defects when bubbles are close to surface of wafer

Reflection and Scatter from Bubbles

Microbubbles at 193nm are a unique particle case

Spherical shape > 1μm diameter
Refractive index < surrounding
Air/water index ratio at 193nm ~ 1/√2
Geometrical optics give 1st order insight
Exact partial-wave (Mie) solutions needed



Total Reflection from Bubble

Scatter "enhancement" when $\theta > \theta_c$

$n_i = 1.0$, $n_w = 1.437$

$$\theta_c = 180° - 2\sin^{-1}\left[\frac{n_i}{n_w}\right] = 92°$$

All rays reflected into region $0 \le \theta \le \theta_c$ are totally reflected

Exact Computation of Scatter – Mie Series

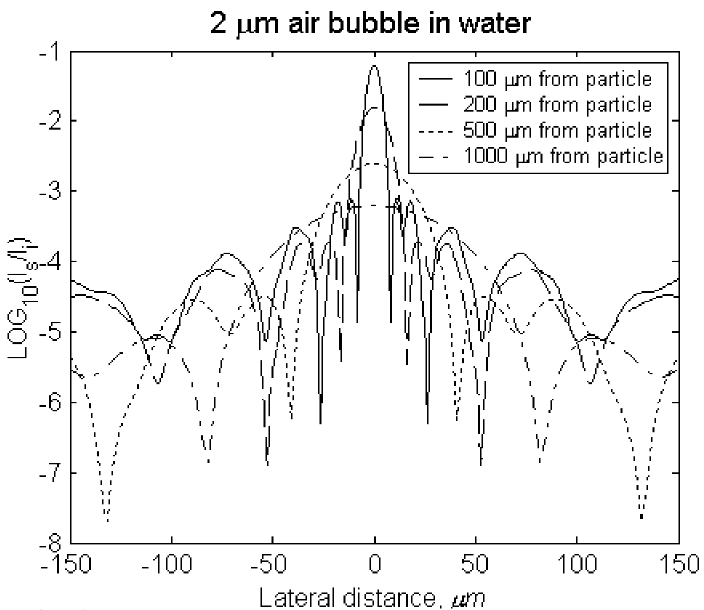
Bubble particle parameters

Size parameter $ka = 2\pi \frac{n_w a}{n_i \lambda_i}$

Polarization parallel (*j=1*) or perpendicular (*j=2*)

Scatter irradiance $i_j = i_{inc} I_j a^2 / 4R^2$ **(R = distance in far-field)**

Normalized irradiance $I_j = \left|S_j\right|^2 (2/ka)^2$ **($S_j(\theta,ka)$ = complex scatter amplitude)**

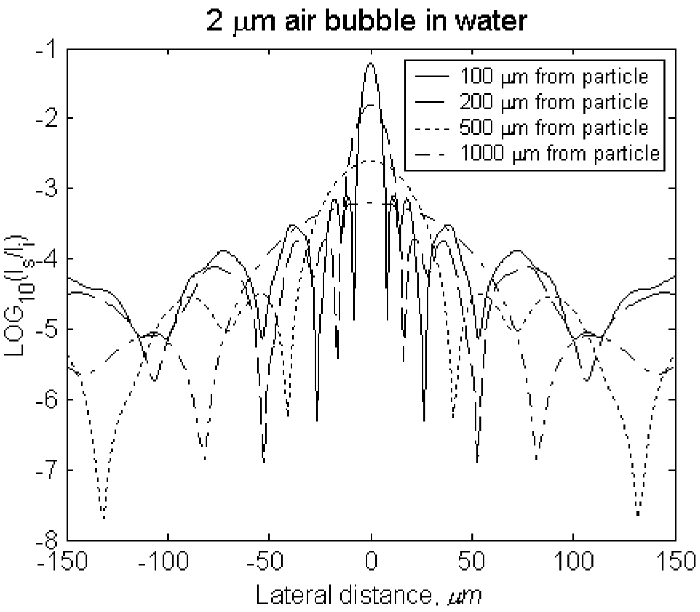


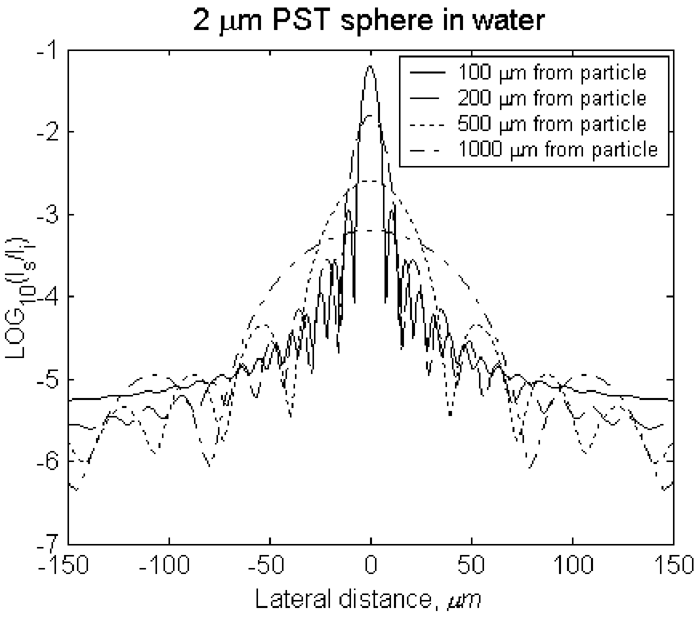
Scatter intensity relative to incident intensity

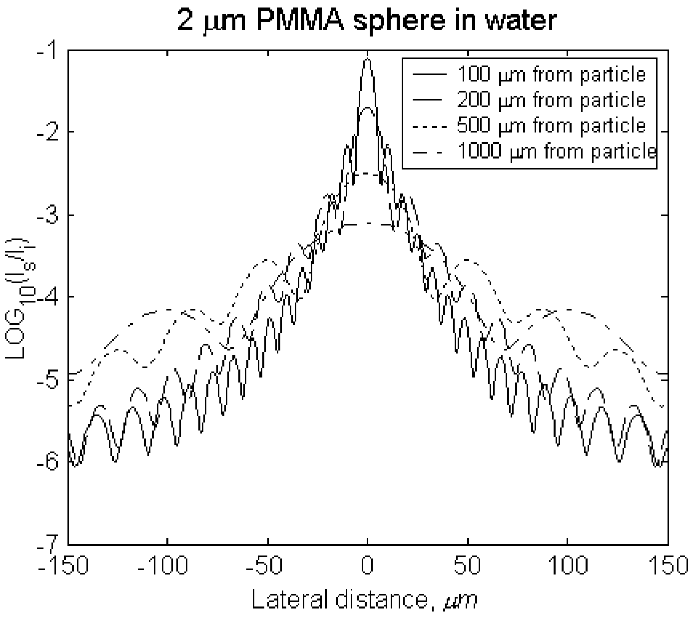
Comparison of Microbubbles and Synthetic Spheres

2µm spheres

- **Air bubble (*1.00, 0.00*)**
- **Polystyrene (*1.67, 1.02*)**
- **Polymethyl methacrylate (*1.55, 0.01*)**


2 µm air bubble in water

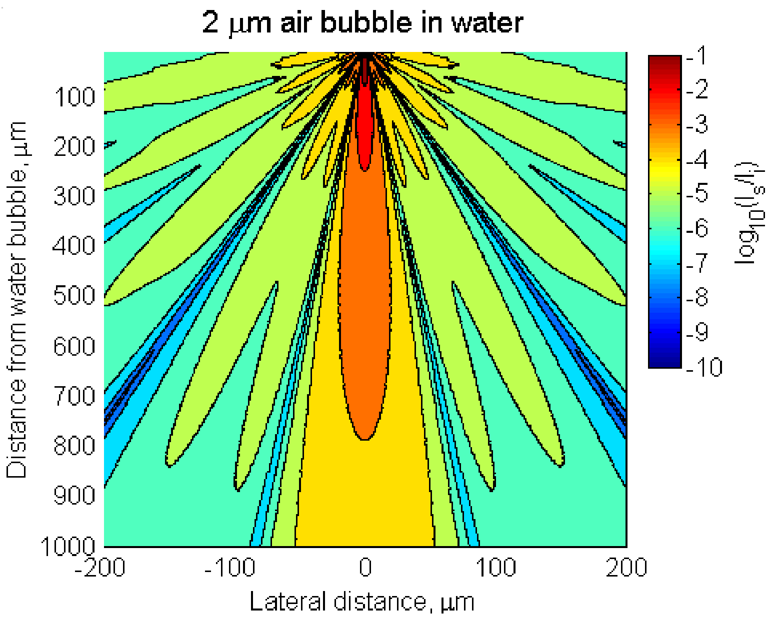

2 µm PST sphere in water

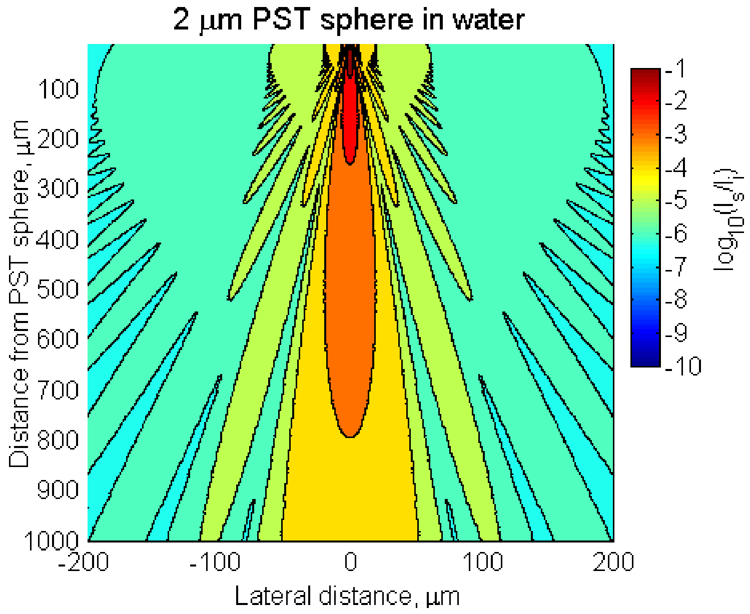

2 µm PMMA sphere in water

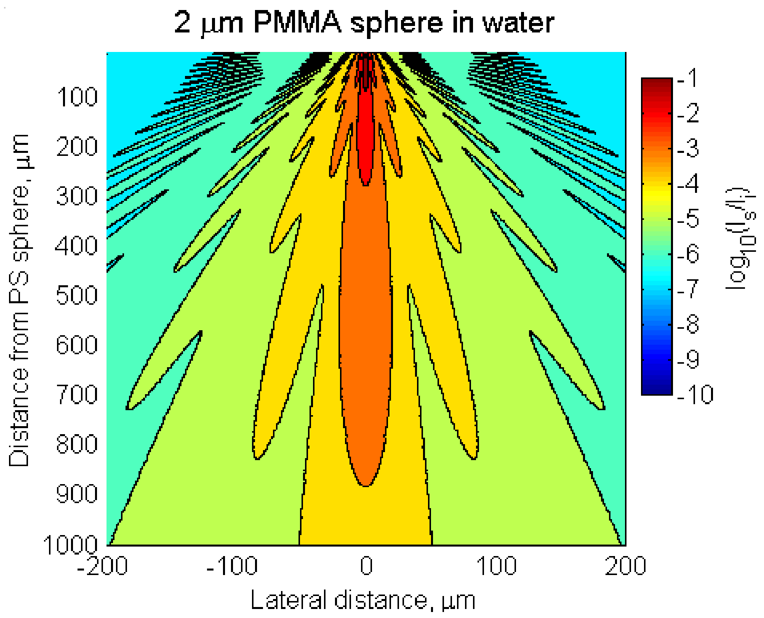
Comparison of Sphere Types

Microbubble vs. Synthetic Sphere

Scatter behavior into the water gap
Normal incidence of single sphere

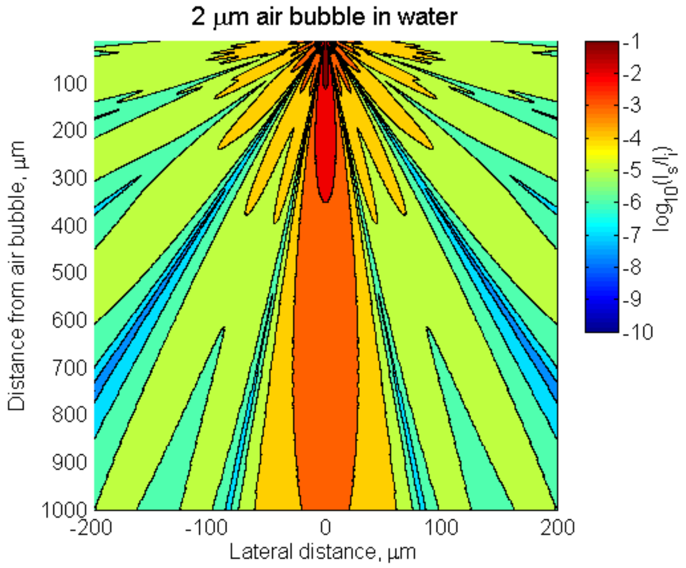


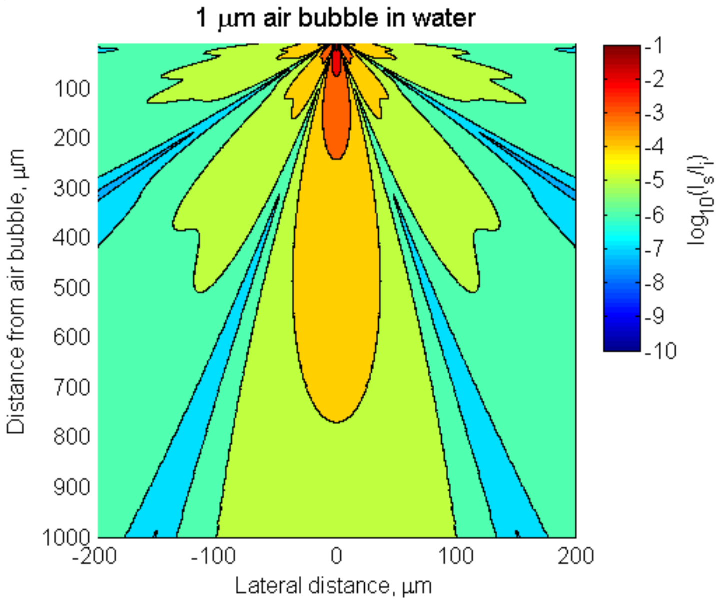


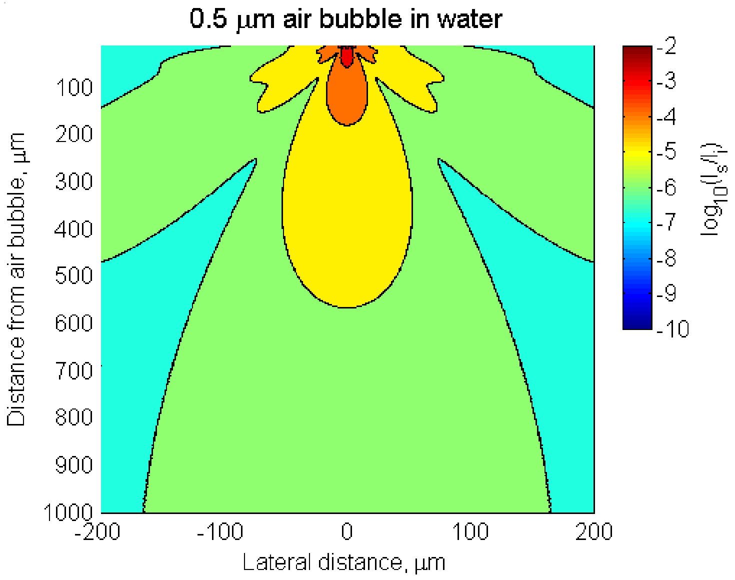


Comparison of bubble sizes

Scatter behavior into the water gap
Normal incidence of single bubble


2 µm air bubble in water


1 µm air bubble in water

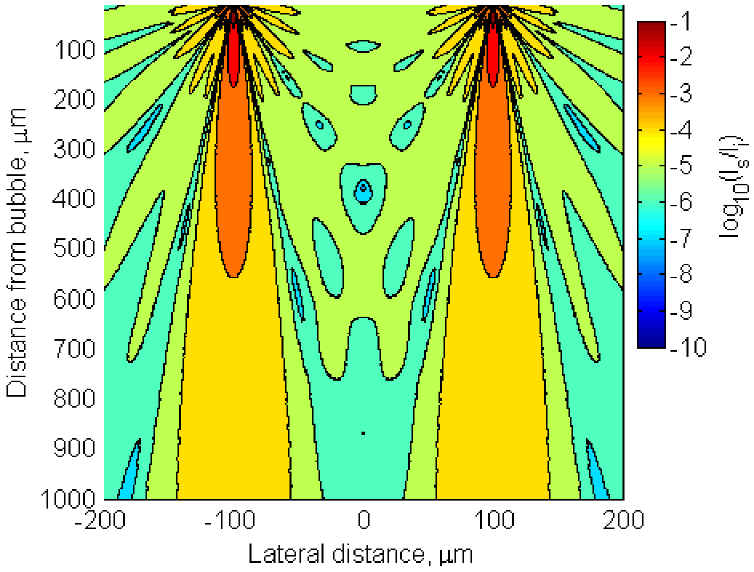

0.5 µm air bubble in water

Multiple Bubble Effect

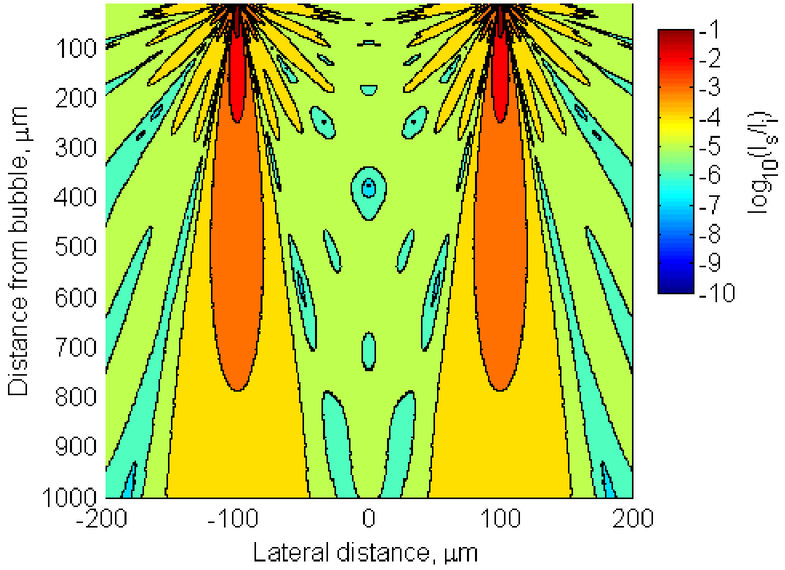
Polarization (TE, TM, Unpolarized)

Large separation – individual scattering into water gap
Normal incidence

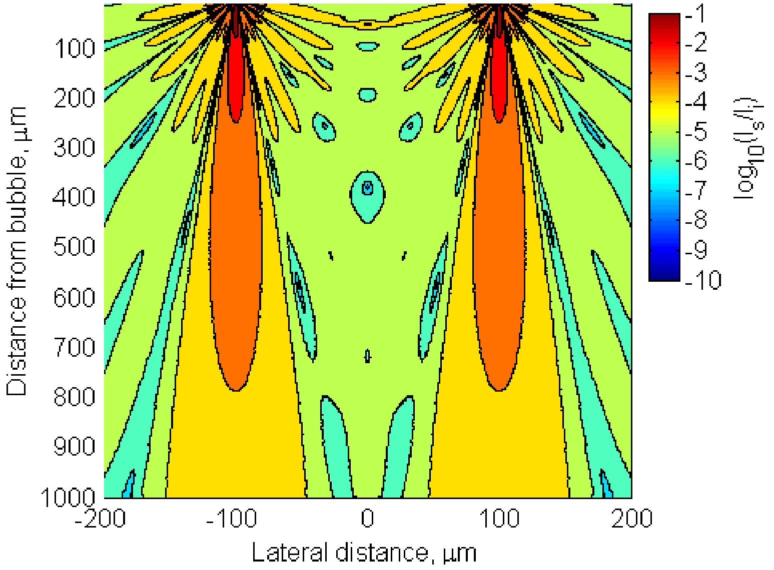
2 μm bubble pair with100 μm separation, unpolarized



2 μm bubble pair with100 μm separation, TE



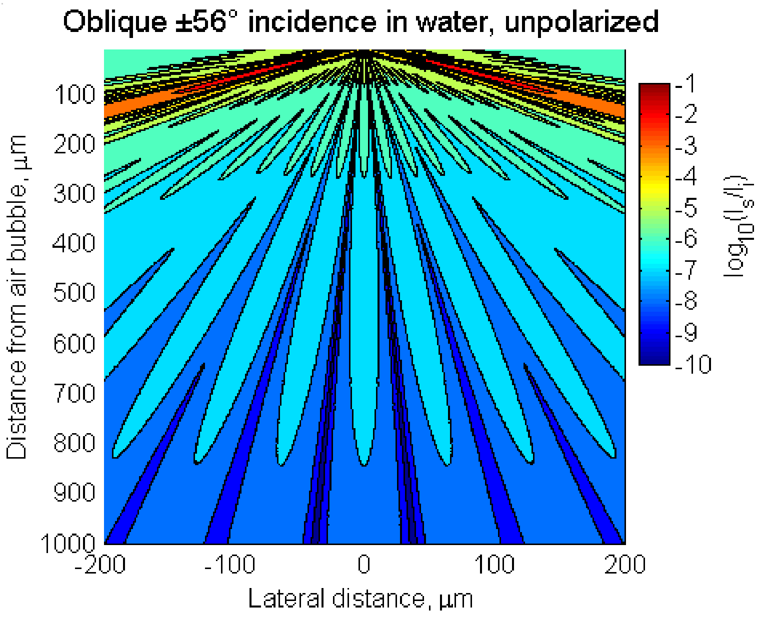
2 μm bubble pair with100 μm separation, TM

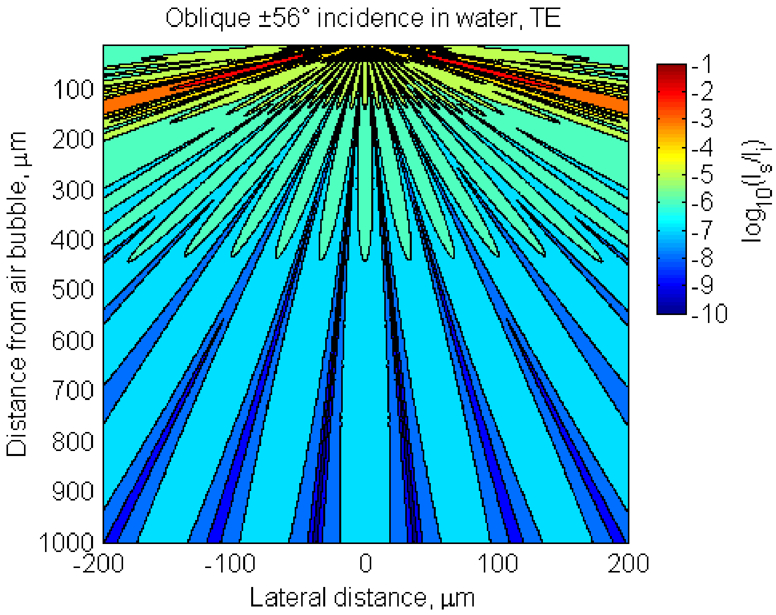


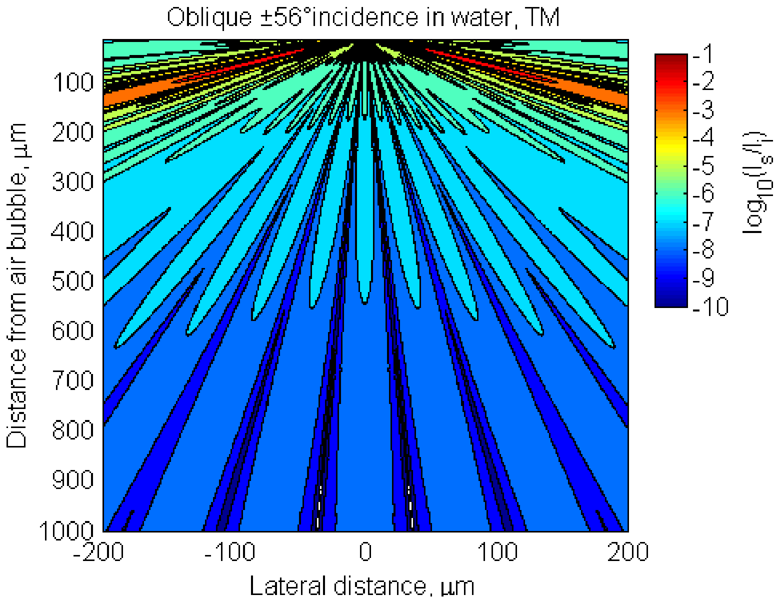
Oblique Incidence

Diffraction orders at 1.20NA

Coherent incidence at largest angle – Two diffraction beams


Oblique ±56° incidence in water, unpolarized

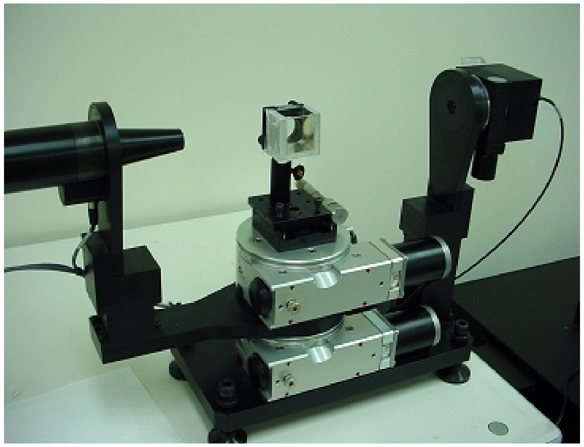

Oblique ±56° incidence in water, TE

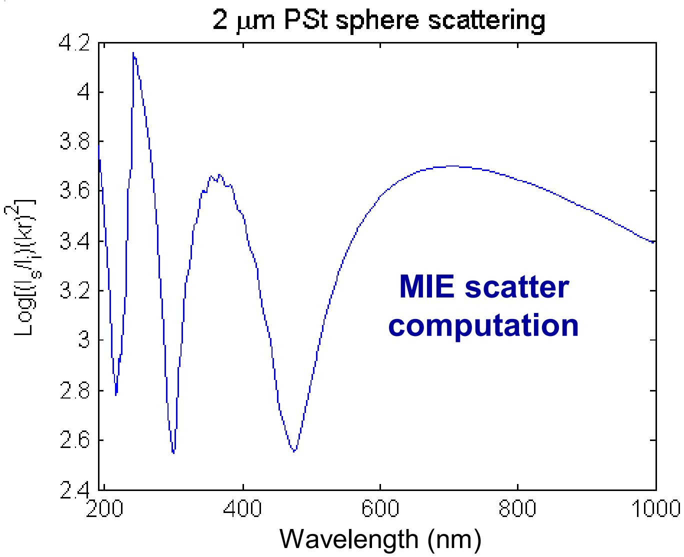

Oblique ±56°incidence in water, TM

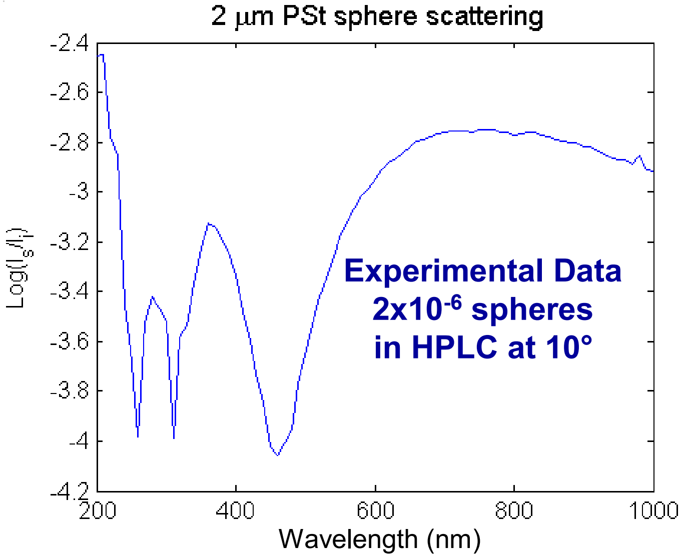
193nm Scattering Measurements

Modification of UV VASE tool to Variable Angle Scattering (VASS)

- **Verification of Mie scatter modeling**
- **Measurement of PST and PMMA spheres, degassed, gassed water**
- **VASS measurement of intrinsic scatter (Rayleigh, Raman) of water**

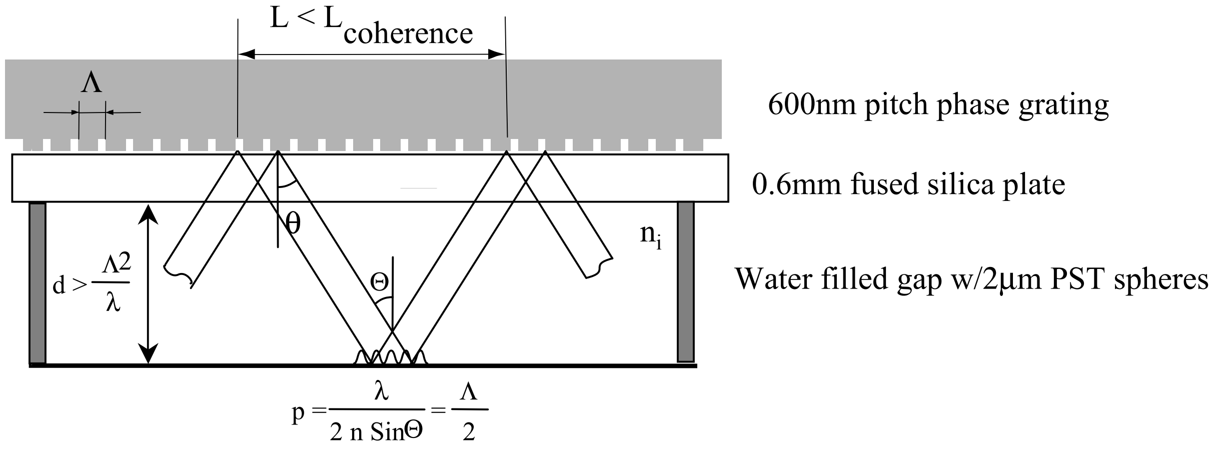






Direct Lithographic Imaging of “Bubbles”

Direct interference immersion lithography

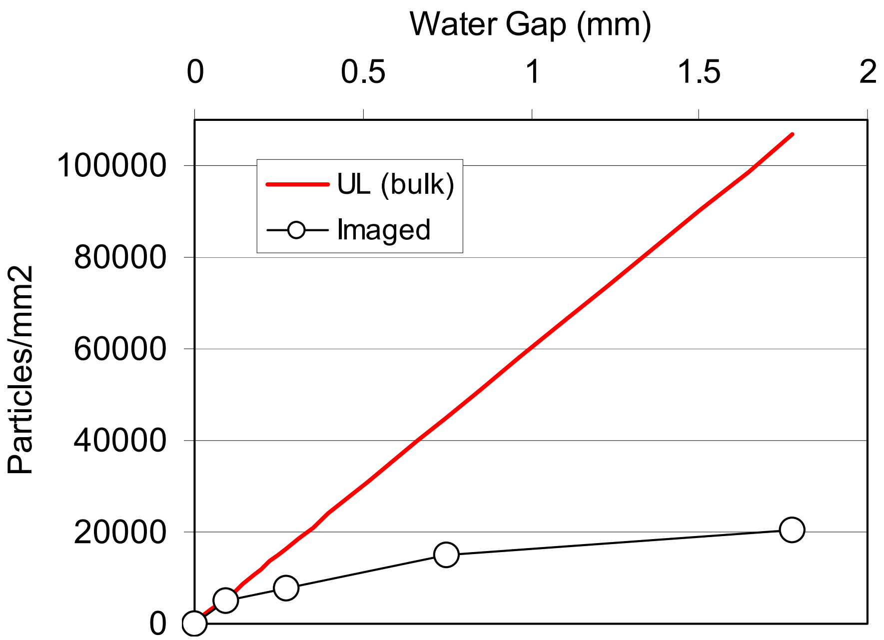


Method:

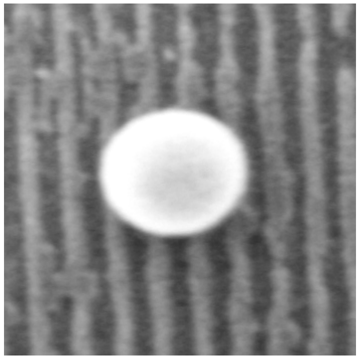
- Direct interference lithography of 150nm lines (1:1)
- TOK resist 200nm (115°PAB, PEB) / thick AR
- 2 µm monodisperse PST spheres 2×10^{-4} in HPLC water
- Water gap values of 0.090, 0.27, 0.74, 1.78 mm controlled with spacers
- Image resist lines w/ particles and count
- Plot density and correlate to printability

Direct Lithographic Imaging of “Bubbles”

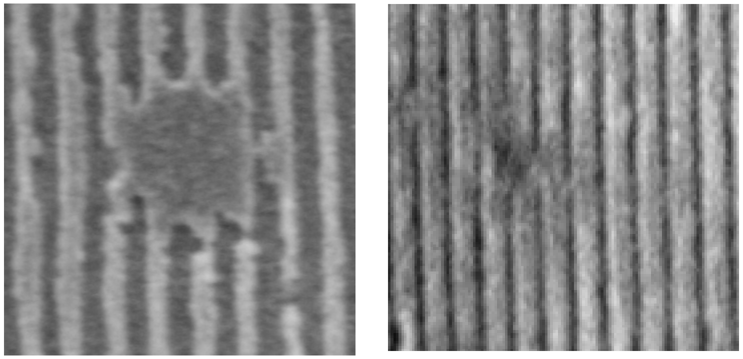
- Count of particle “image”
- Gap values of 0.090, 0.27, 0.74, 1.78 mm
- LL for spheres at resist
- UL for all spheres in gap
- Influence of spheres well into the gap
- Establishes intolerance to microbubbles at distances less than ~0.3mm



2 µm sphere



Images in resist



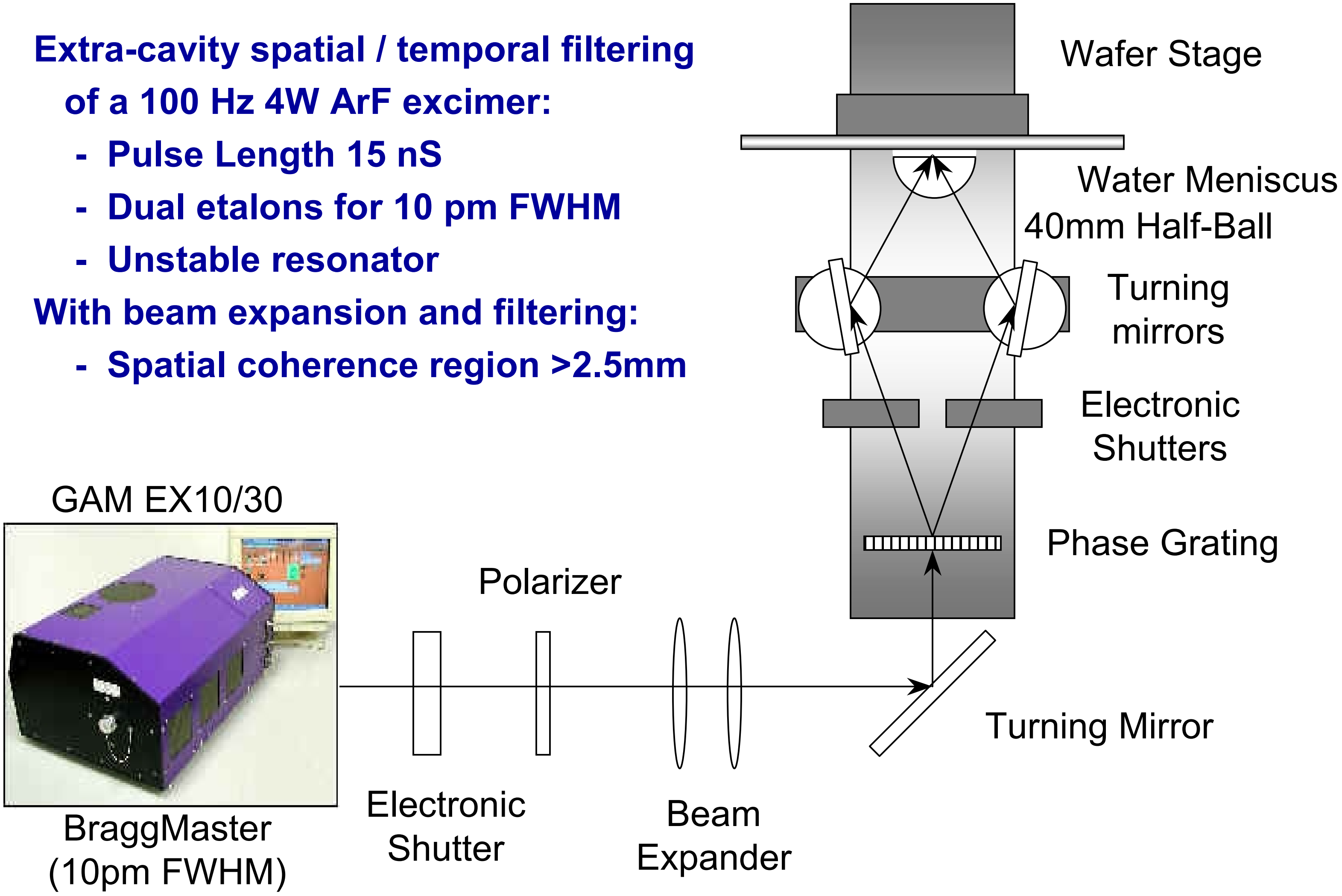
193 nm Interferometric Imaging in Scattering Media

Extra-cavity spatial / temporal filtering of a 100 Hz 4W ArF excimer:

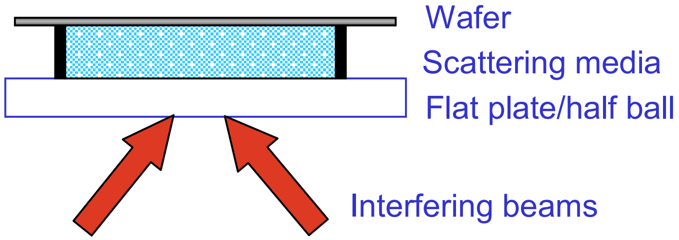
- **Pulse Length 15 nS**
- **Dual etalons for 10 pm FWHM**
- **Unstable resonator**

With beam expansion and filtering:

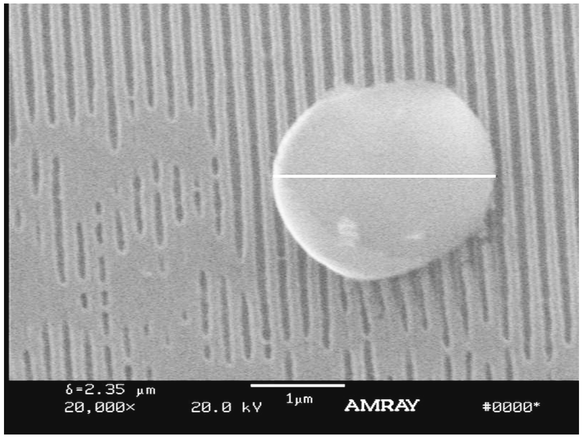
- **Spatial coherence region >2.5mm**



Scattering Effect on Interferometric Imaging

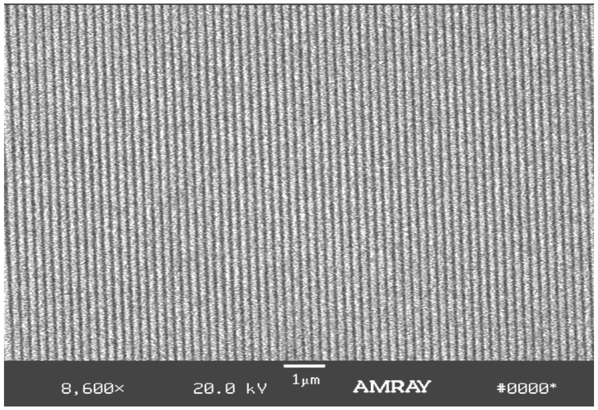


Experimental set-up for two-beam interference through scattering media.



Interferometric image in water with polystyrene beads of diameter of 2 µm at $5x10^{-5}$ weight concentration.

- **Imaging at NA=0.5.**
- **PST beads of 2 µm diameter within 1.3 mm from the wafer are printed. No image printed beyond 1.3 mm.**
- **No appreciable images are observed for PS beads of 0.5 µm.**



Interferometric image in water with polystyrene beads of diameter of 0.5 µm at $2.5x10^{-5}$ weight concentration.

Summary

- Geometrical optics modeling
- Mie scattering of microbubbles and synthetic spheres
- Microbubbles >1 μm close to wafer will image in resist.
- Micro bubbles >1 μm far from wafer and small bubbles will not image in resist. Scattering due to those bubbles forms a DC term in imaging.
- Microbubbles are not technical barrier to immersion litho.
  - Degassing is necessary
  - Trapping of air during introducing water needs to be avoided by suitable design.
  - Exposure to air needs to be controlled