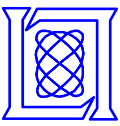

Prospects for 157-nm Liquid Immersion

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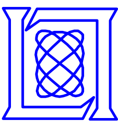
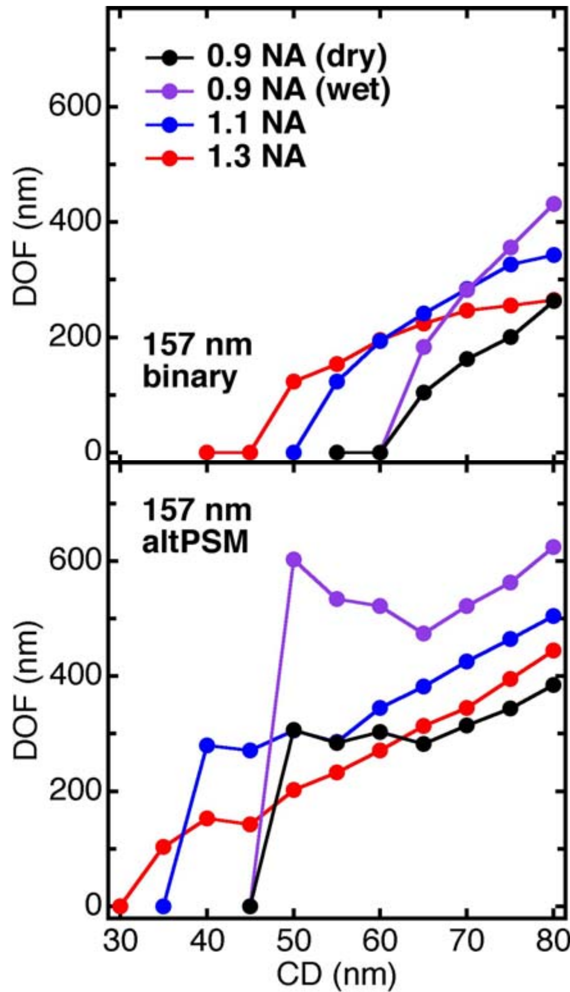
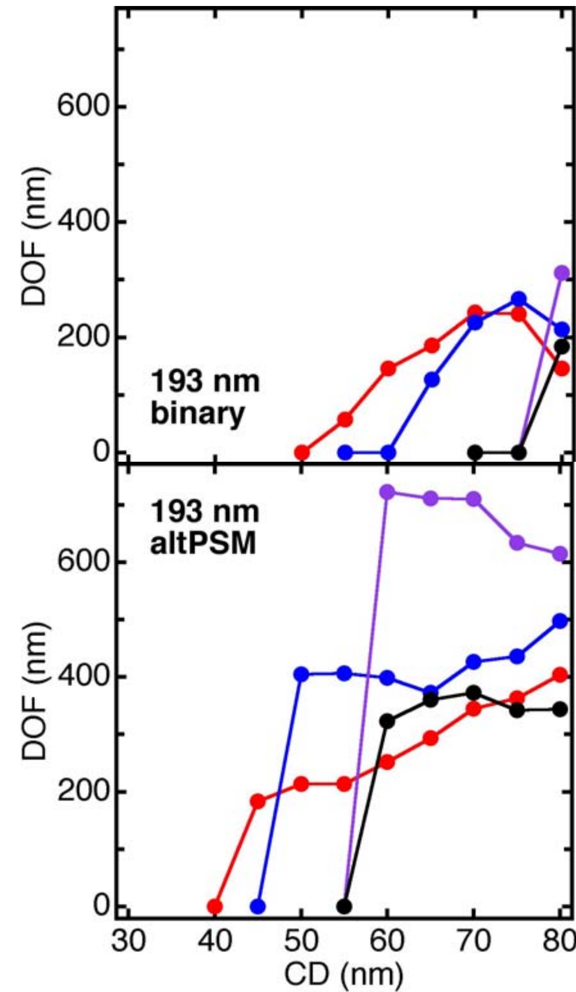
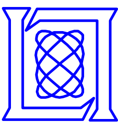


Process Latitude with Liquid Immersion







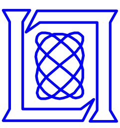
Resolution with 157-nm Immersion

- For dense lines-and-spaces, the smallest linewidth is

$$LW = (157/0.95)\,(k_1/n)$$

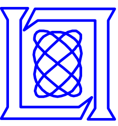
n	$k_1 = 0.35$	$k_1 = 0.25$
1.38 (present liquid)	42 nm	30 nm
1.45 (water at 193 nm)	40 nm	28 nm
1.56 (n_{157} of CaF_2)	37 nm	26 nm
1.68 (n_{157} of F-SiO_2)	34 nm	25 nm

- A combination of low k_1 and high n can achieve sub-32 nm resolution
  - K_1 is an optics/process parameter, n is a property of the liquid
  - They can be optimized separately

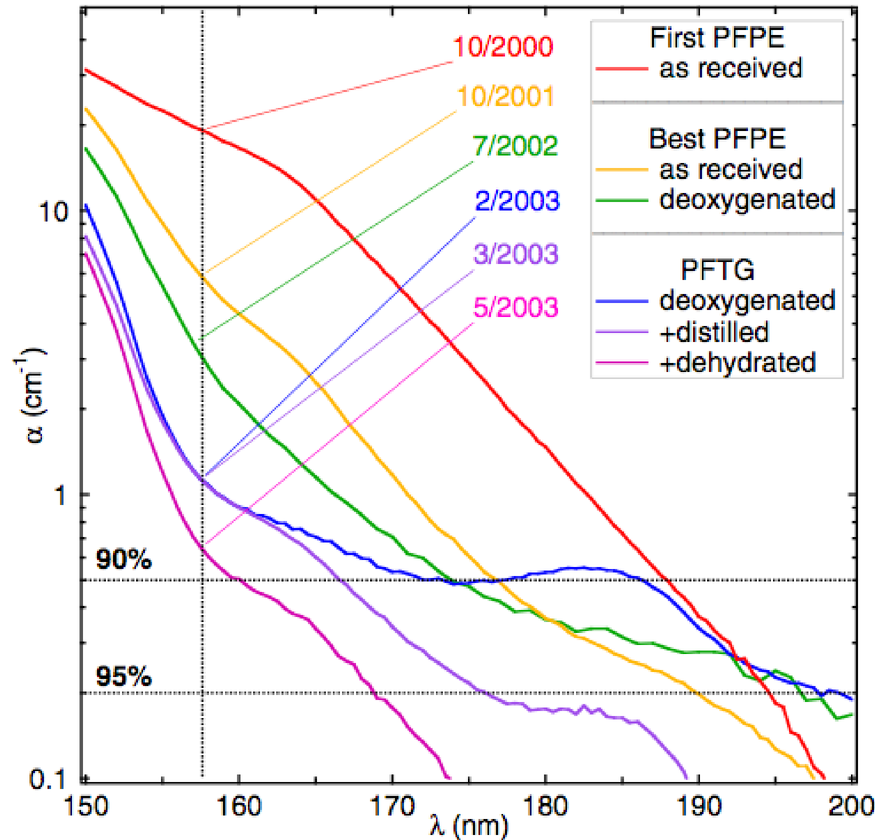


Properties of Liquids for 157-nm Immersion

- The primary properties are
  - Absorption coefficient
  - Index of refraction
- Additional properties to optimize
  - Photo-reactivity
  - Viscosity, surface energy, …
- The maximum allowable absorption coefficient is determined by the minimum working distance
  - Probably 0.5 – 1.0 mm
  - This, combined with throughput and apodization considerations, determines α_{Max} = 0.2 – 0.4 cm^{-1}

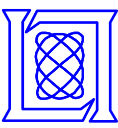


Improvements in Liquid Absorption

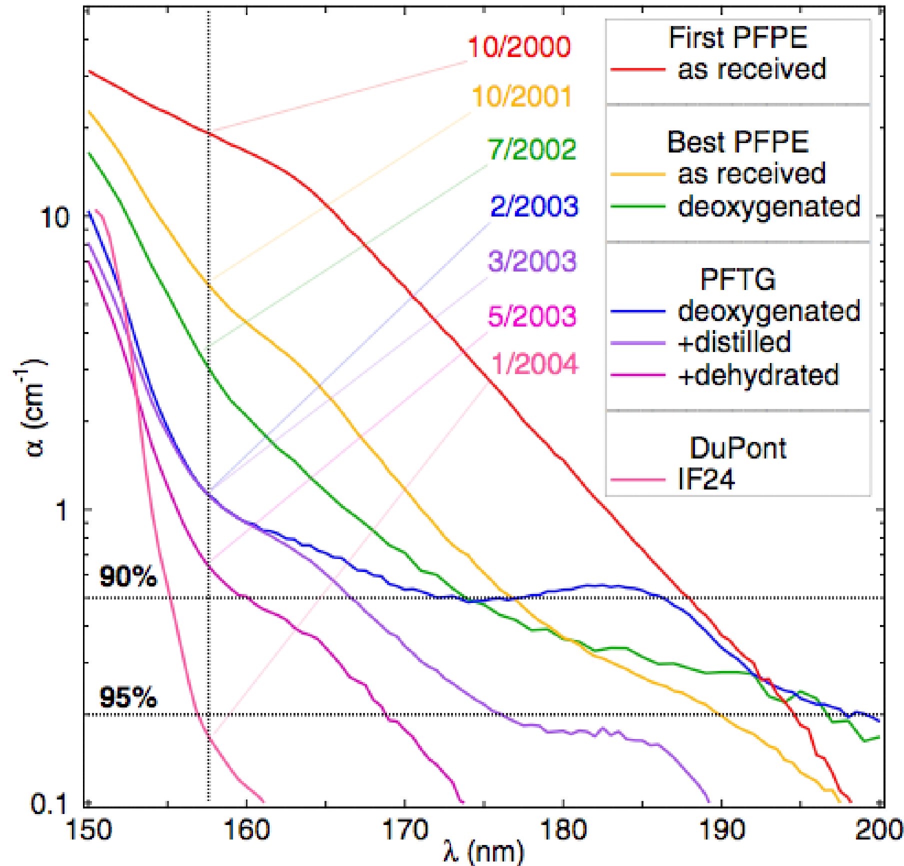


- **MIT/LL has reduced the absorption coefficient of PFPEs by 10×, from ~5 cm^{-1} to ~0.5 cm^{-1}, within 18 months**

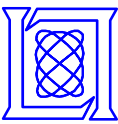
MIT Lincoln Laboratory



Improvements in Liquid Absorption
Part 2

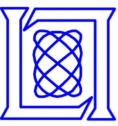


- **Recent results by DuPont have reduced the absorption level to below 0.2 cm^{-1}**



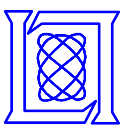
Prospects for Improved Liquids

- MIT/LL and DuPont are collaborating on the development, testing, and optimization of 157-nm immersion liquids
- Current lowest absorption coefficient is ~ 0.17 cm^{-1}
  - Preliminary index measurements show: 1.33 ~ 1.38
- Next target is to increase the index
  - Will require trade-off between absorption coefficient and index, because of the dispersion properties of the liquids
- Ongoing dialog with the tool suppliers is essential, in order to identify the right parameter space



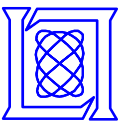
Future Work

- Under the MIT/LL – DuPont collaboration,
  - Liquids will be characterized for photo-reactivity, interaction with optics, resists, etc.
  - Purification, scale-up processes will be identified
- Lithographic testing will be started at MIT/LL with a 157-nm liquid immersion microstepper (1.3 NA)



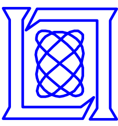
157-nm Liquid Immersion Microstepper at MIT/LL

- All-refractive
- 1.3 NA
- Being qualified at MIT/LL



Summary

- Even with current liquids, 157-nm liquid immersion is close to enabling 32-nm lithography
- Recent progress in increasing transparency indicates that a suitable combination of absorption and index will be found
  - Requirements for the 32-nm node and possibly beyond can be met
- Immersion lithography at 157 nm has very good chances of extending optical lithography by utilizing
  - Capabilities developed for “dry” 157 nm
  - Capabilities being developed for liquid 193 nm



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