Resolution improvement review for the immersion lithography

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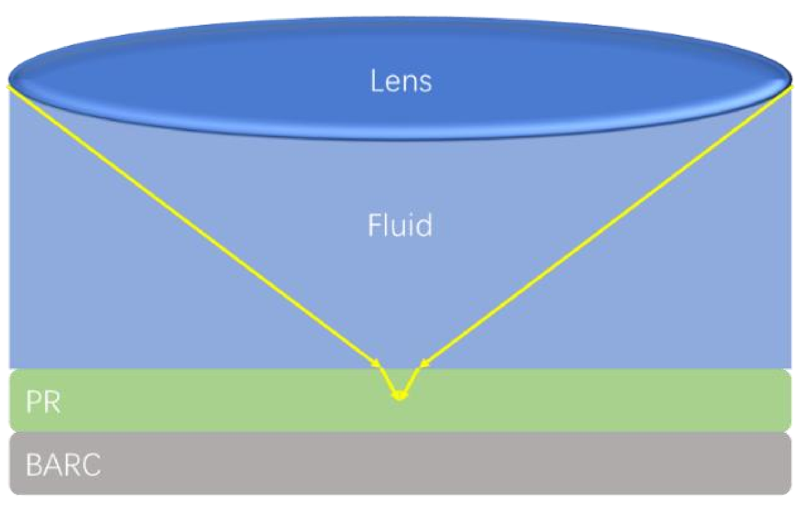
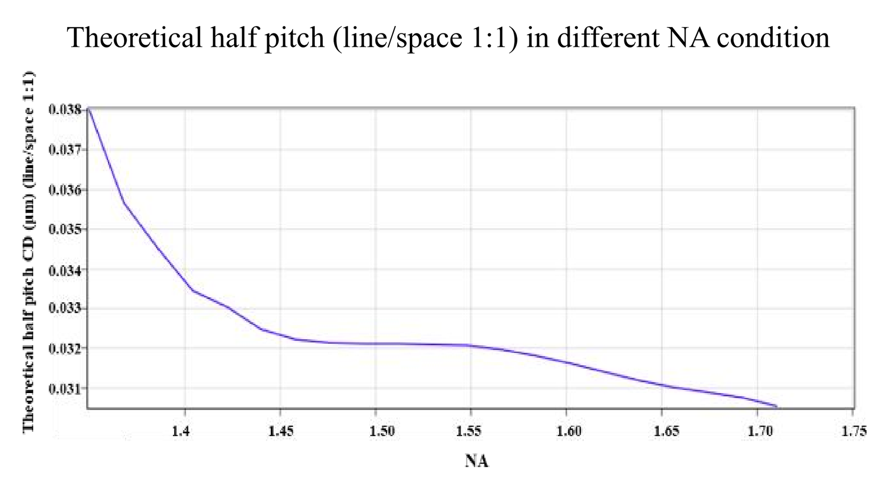
INTRODUCTION

Immersion lithography still plays an important role in current wafer foundry around the world. Thus, it is still valuable to have a review on the resolution capability improvement status for immersion lithography. Since increasing RI is the key to improve NA, we discussed those RI impact factors and possibilities to further improve NA in this paper, especially on fluid, lens and photoresist material. Some alternative high-resolution methods are also discussed, such as curved lens design, solid immersion interference lithography and elastomeric conformable phase mask.





NA SYSTEM BREAKDOWN

Fluid

Since current medium(water) is the bottleneck for the system NAs, changing from water to higher RI fluids is a promising solution to improve resolution, which is also supported by simulations in theory.
A few studies showed high RI fluid up to 1.56 can be produced in past years. Fluid should satisfy the following conditions: low light absorption at specific wavelengths, temperature stability, lens friendliness, and viscosity. But the first two high RI factors are still difficult to meet for immersion lithography system in practical.

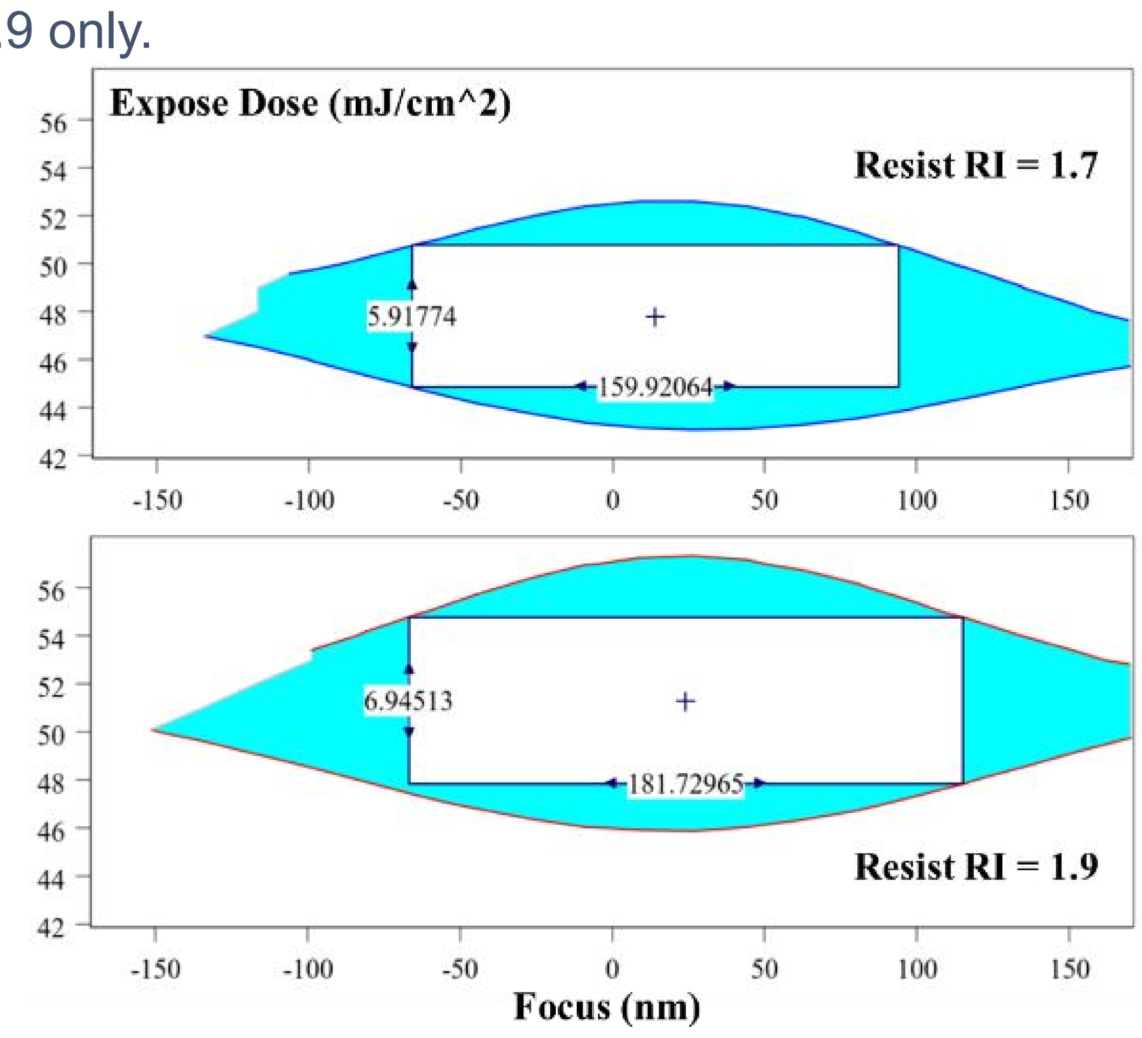
Lens materials

The main parameters to evaluate the lens material are refractive index, absorbance, and intrinsic birefringence(IBR).
The high RI of the lens materials is the premise of NA scaling. The lens RI should be sufficiently high(n>1.7) for a higher resolution. Low absorption effect on exposure light can avoid image quality degradation by thermal aberrations. The absorption coefficient is required for less than 0.005 cm^{-1} for energy saving and avoiding the image degradation. Finally, the IBR value of lens material above 30nm/cm is considered unacceptable because the higher IBR value of lens materials, the worse stress birefringence and inhomogeneity of RI will happen inside the lens material. The strain birefringence should be lower than 10nm/cm for these lens materials.

Resist

The photoresist RI should be changed along with fluid RI and lens RI, so as to keep refracted light convergent inside resist. The current resist RI is around 1.75 and next generation resist should achieve value of 1.9 to 2.5.

For photoresist, a lower absorptivity should also be considered on top of higher refractive index. In the whole NA system, the RI of resists will be the bottleneck when the RI of lens materials and fluids meet the requirements. It determines whether the light rays will be completely reflected at the fluids-resist interface. The current commercial resist has a refractive index of about 1.75, while the next generation of resist should have a minimum RI of 1.9 to avoid the total reflection effect. Next generation of resists is still a technical challenging for a period of time to be foreseeable. On top of resolution, high resist RI is benefit for DoF. Simulation below showed, for a L/S 50nm line pattern, over 13.6% of more focus window can be obtained by increasing photo resist RI from 1.7 to 1.9 only.



ALTERNATIVE RESOLUTION PATH

Curved lens design:
A curved design at the last lens element enables a higher incident angle between lens-fluid interface, giving a possibility of higher NA. However, the different thickness of fluid would cause non-uniform transmission, and minor turbulence may happens during high speed exposure.

Solid immersion interference lithography(SIL):
The sphere solid immersion lens design eliminates the refraction at interface between air and lens, so NA can be improved by enhancing objective lens material. Theoretically, the resolution can be improved by using higher RI lens material, but so far no work mentioned such material had been implemented in 193nm.

Elastomeric phase mask:
A conformable type of mask is another possibility to skip the liquid medium, as the photoresist can be directly in contact with elastomeric phase mask. There is no liquid medium between mask and substrate, as the air pressure already enabled a closed contact. Meanwhile, the photo resist was placed upside down, so there is no contamination problem between mask and photoresist. Theoretically a half pitch of 35nm can be achieved with 193nm wavelength light. The limitation of this method is only suitable to generating single level structures.

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