Talbot effect immersion lithography by self-imaging of very fine grating pattern

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It is well known that the resolution limit of the projection optics is determined by the wavelength λ of the light source and the numerical aperture (NA). The pattern size L that gives the spatial cutoff frequency of the lens is given by

$$L = 0.25\frac{\lambda}{NA}. \quad (1)$$

NA is the product of refractive index n and $\sin\theta$, where θ is the aperture angle of the projection lens. Currently, immersion optics is wildly used for high NA ArF lithography[1]. For higher resolution, although high-index glass such as LuAG for projection optics had been developed[2], development has not progressed in recent years. On the other hand, since Talbot lithography employing self-imaging does not use any projection optics, it does not need LuAG glasses, either[3]. In this report, on the basis of simulation results, we discuss Talbot effect immersion lithography to obtain higher resolution and wide depth of focus.

Figure 1 shows the mask assumed in this study. The ArF laser of 193 nm is the light source, which illuminates the quartz mask plate with the 60 nm-thick Cr patterns. It is also assumed that the gap under the mask is filled with high-index immersion fluid of n=1.64. Figure 2 shows FDTD optical simulation results for various pitches from 110 nm to 200 nm. The duty ratio of line and space is 1:1. The light is TE polarization. Because the wavelength of the ArF laser is 118 nm in the high-index fluid, 1st order diffraction ray is not generated at the 110 nm pitch grating. Therefore, self-images are observed at larger pitch pattern than the wavelength and they appear at Talbot period. The Talbot period Z_T is expressed as

$$z_T = \frac{2p^2}{\lambda}. \quad (2)$$

At the three different pitches of 120 nm, 140 nm and 160nm, the Talbot periods were expected to be 245 nm, 333 nm and 435 nm from eq. (2), but they were 146 nm, 256 nm and 366 nm from FDTD simulation. The differences arise because eq. (2) is insufficient owing to the 2nd order approximation. More accurate approximation is required for very fine pitch patterns[4]. More accurate periods Z_{T4} from the 4th order approximation were 197 nm, 283 nm and 383 nm respectively. The errors were significantly reduced.

Figure 3 shows an optical intensity distribution of hexagonal array holes of 70 nm pitch. The mask patterns for a contact hole layer are assumed. High contrast self-images at X and Y polarization were obtained. From this result, contact holes on half-pitch 35 nm lines are expected to be made.

We will also discuss CD control such as focus latitude at the conference.

References
1. Burn J. Lin, "Immersion lithography and its impact on semiconductor manufacturing", J. Microlithogr. Microfabrication, Microsyst. 3, 377 (2004).
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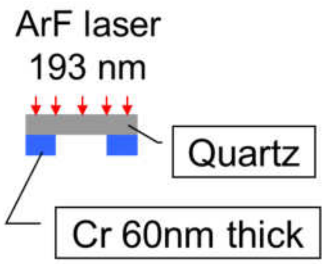

Figure 1. Mask and source. The ArF laser of 193 nm is the light source, which illuminates the quartz mask plate with the 60 nm-thick Cr pattern.

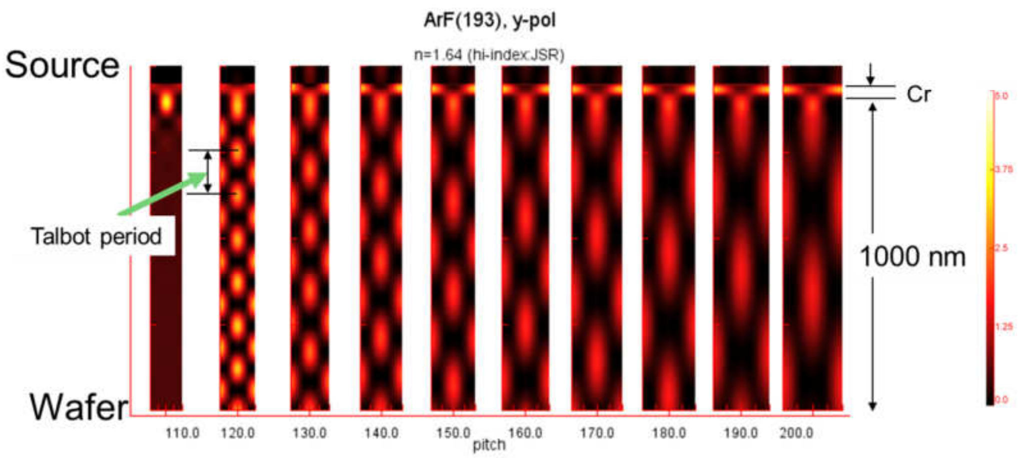

Figure 2. FDTD optical simulation results for various pitches from 110 nm to 200 nm at x-z plane. The duty ratio of line and space is 1:1.

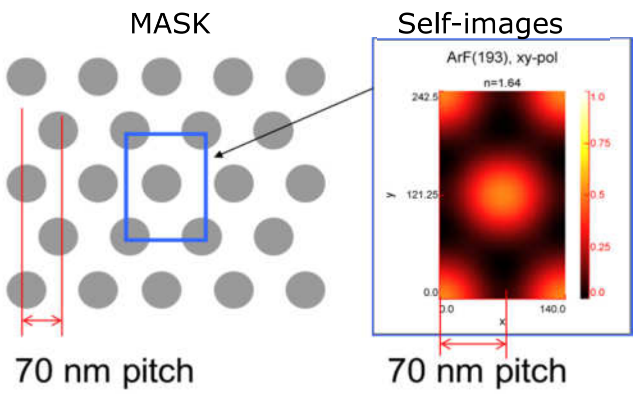

Figure 3. Hexagonal array holes illuminated at 193 nm. High contrast self-images are obtained.