Optical lithography method for generation of sub-35nm line/space patterns for use in complementary lithography

Harun H. Solak, Christian Dais, Francis Clube

Eulitha AG, 5232 Villigen PSI, Switzerland
Phone: +41 56 310 4279 email: harun.solak@eulitha.com

Complementary lithography method has recently been proposed for printing semiconductor circuits with dimensions 20 nm and below [1]. This method starts with the formation of a uniform grid pattern, e.g. a linear grating, whose lines are cut in a subsequent, lower-resolution lithographic step to obtain the desired circuit features. Exposure of about 40 nm half-pitch gratings with an immersion ArF stepper tool followed by a pitch-division step is considered as a possible way to form the necessary grids. Here, we show through optical simulations that an alternative, low-cost technology, the recently introduced Displacement Talbot Lithography (DTL) method can be used to print the required grids down to a resolution of 35 nm or below.

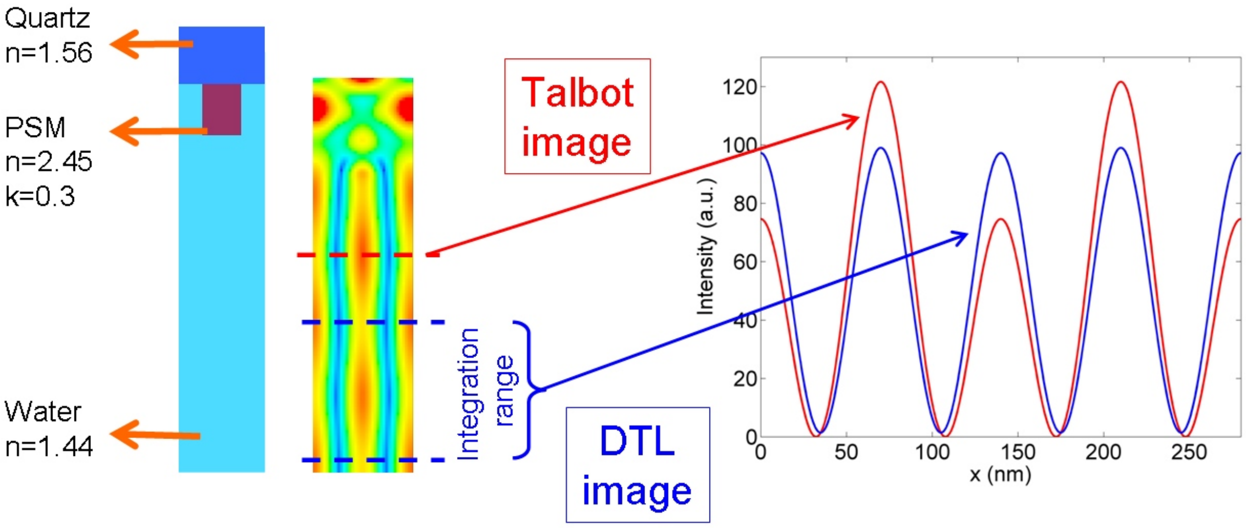
DTL is a mask-based interference method being developed for high-throughput production [2]. The key advantages of DTL are the attainment of an effective image that has practically unlimited depth of focus and a relatively simple proximity exposure system. The patterns are printed by moving the wafer along the optical axis by a “Talbot period” during the exposure to obtain an integral of the diffracted field. The scheme proposed in this paper is illustrated in Fig. 1, where a grating mask is placed in an immersion liquid and illuminated with a beam from an ArF laser. Optical field intensity shown in Fig 1(b) varies periodically with distance from the mask, forming the well-known self-images. A plot of the result of the DTL integral shows that a very high-contrast frequency-doubled image of the mask is achieved.

A survey of potential materials in the literature has shown that common phase shifting materials, e.g. MoSi or Si_3N_4, have high enough refractive index [3] to provide sufficient diffraction efficiency in an immersion liquid. Simulations have been carried out to examine the dependence of the DTL image on the mask pattern parameters. An example of the results is shown in Fig 2, where the image contrast is seen to remain over 80% as the height of the phase shifting lines varies from 60 nm to 130 nm. The analytically calculated curve in Fig. 3 provides some insight into the reason underlying this inherent and remarkable insensitivity. In that plot the contrast of the DTL image is shown as a function of the ratio of the first order diffraction efficiency to the zeroth order. This plot shows that even a poor phase grating where this ratio is only 2 is able to provide a DTL image with 80% contrast. Furthermore, unlike projection lithography, use of high index liquids [4] is possible with DTL since there is no other optical material (e.g. lens) between the diffracting mask and the wafer. This will enable patterning with significantly higher resolution (down to about 30 nm) than what is available from projection tools.

Our results show that immersion DTL can be used to print high resolution grids needed in complementary lithography. The necessary optical materials and light sources are available.

References:

1. Y. Borodovsky, Lithovision 2010, Feb. 21 2010, San Jose, CA.
2. H. Solak, C. Dais, F. Clube, Optics Express, Vol.19, No.11 (2011)
3. B. W. Smith, S. Butt, Z. Alam, S. Kurinec, R. Lane, J. Vac, Sci. and Tech. B 14, (1996).
4. M. Yang, S. Kaplan, R. French, J. Burnett, J. Micro/Nanolith. MEMS MOEMS (2009).



(a) (b) (c)

Fig 1 Immersion DTL scheme for printing high-resolution line/space patterns. (a) The simulation cell is shown on the left. The mask pattern has 140 nm period. Light (λ=193 nm) is incident from above. (b) Optical simulation result showing the intensity distribution inside the cell. The image oscillates with distance from the mask with a Talbot period. (c) Plots showing the image cross section in one of the self-image planes as well as the result of the DTL integral. Whereas the intensity peaks in the Talbot image change strongly as a function of distance from the mask the DTL image has equal intensity peaks with double the frequency of the mask pattern. This high contrast image can be used to print a 35 nm L/S pattern.

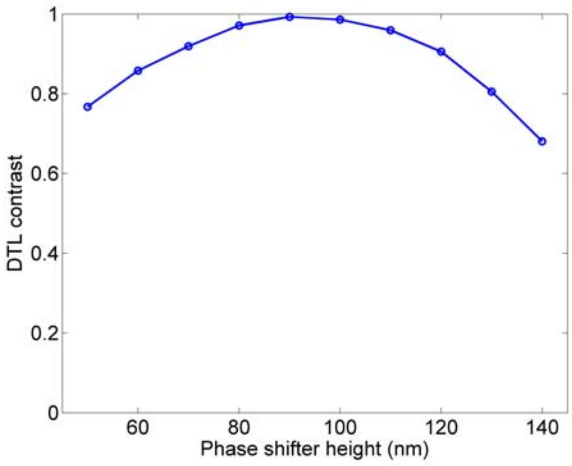


Fig 2 DTL image contrast as a function of the height of the phase shifting lines on the mask. Note the extremely robust contrast over a large range of line height.

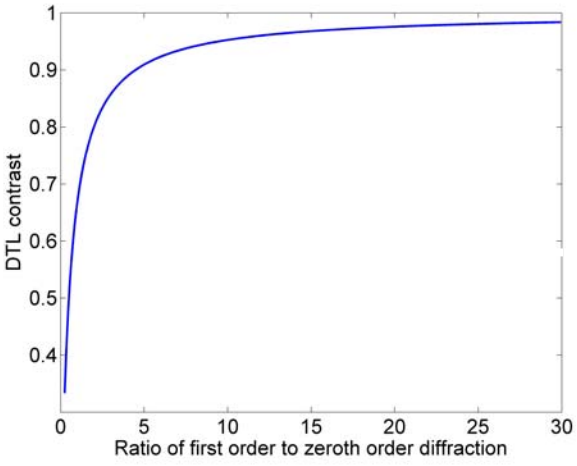


Fig 3 DTL image contrast as a function of the diffraction efficiency of the grating mask as expressed by the ratio of the first order to zeroth order intensity. Better than 80% image contrast is obtained when this ratio is above 2.