Design of freeform illumination sources with arbitrary polarization for immersion lithography

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Polarized illumination and source mask optimization (SMO) are two prominent enhancements in immersion lithography. However, SMO with fixed polarization state limits the degrees of freedom during the optimization procedure. Recently, source-mask-polarization optimization (SMPO) has been developed to support photolithographic process shrinks[1]. Both the light intensity and polarization distribution in the pupil are arbitrary which have been challenges to design SMPO source exactly and efficiency in hyper numerical aperture (NA) illumination system.

In this paper, we propose a detailed design method for producing SMPO source with 1/2 wave plates group and mirror array in NA 1.35 immersion lithography system. The wave plates group contains three wave plates and all of them can be moved to any locations in certain planes perpendicular to the optical path. To produce SMPO sources, thousand spots reflected by mirrors are firstly optimized to approximate the target intensity distribution without regarding to the polarization. Then all the spots are distinguished into particular polarization states to meet the polarization distribution requirement. As the polarization state of income light can be changed 45° by one wave plate, the best positions of the wave plates are optimized to modulate the polarization of light incident upon the different mirrors, so that the spots number of specific polarization can be exactly obtained. The design example shows that only 4 mirrors of 5041 mirrors received wrong polarization light, which decreases light loss by 97.2%, compared with 144 mirrors using prior technology[2]. Finally, mirrors are tilted to reflect certain polarizations light for generating the target SMPO source.

Figure 1 shows the schematic representation of the illumination system to produce SMPO source. The designed SMPO source and center of spots with different polarization arrangement are indicated in Figure 2. Figure 3 shows the optimal positions of the wave plates group. Figure 4 illustrates the overall flowchart of design process. It is demonstrated that the any SMPO sources can be produced accurately and efficiency by the method proposed in this paper.

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[1]S. Hansen, "Source mask polarization optimization," J. Micro/Nanolith. MEMS MOEMS 10(3), 033,003 (2011)
[2]H. M. Mulder, S. Hansen, J. C. H.Mulkens, and M. Deguenther,"Illumination system and lithographic apparatus," US Patent, US 2011/0228247 A1.

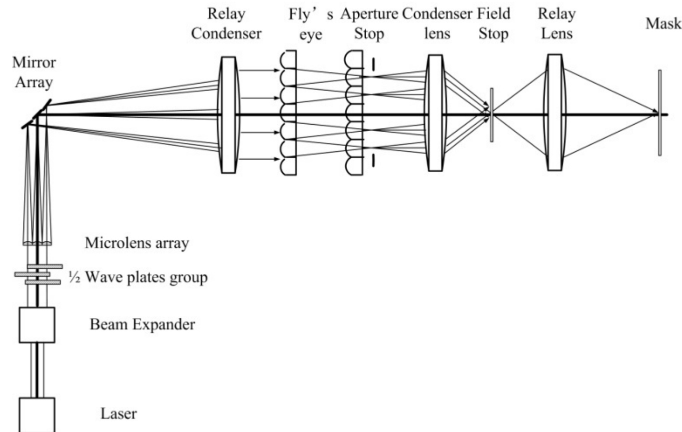

Figure 1 Schematic representation of the illumination system.

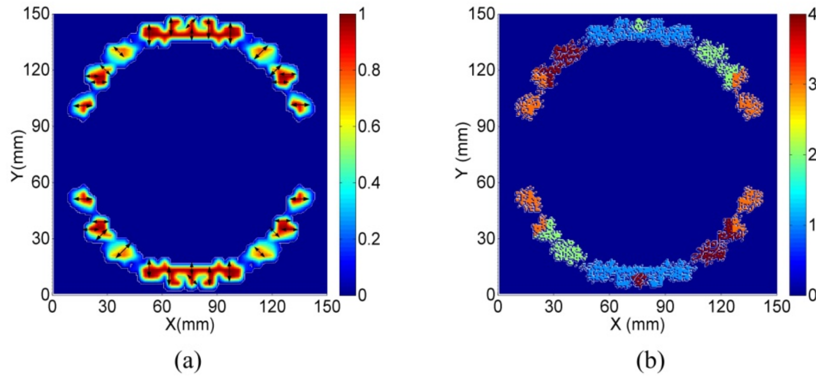

Figure 2 (a) Designed SMPO source. The arrow indicates the polarization state. There are four polarization states in the pupil: X, Y, + 45° and -45°. (b) Optimized center of spots arrangement in the pupil and the color indicates different polarization states.

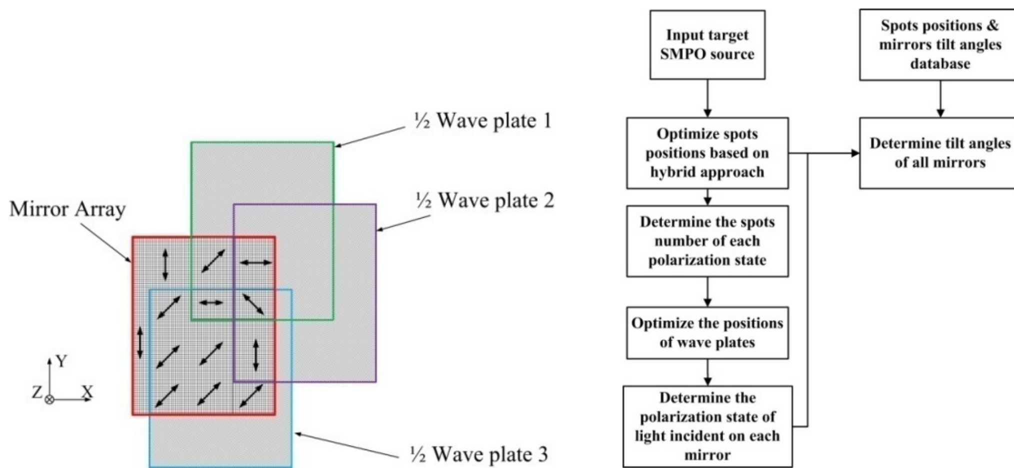

Figure 3 Optimal positions of 1/2 wave plates group. Figure 4 Flowchart of design process.