FINITE ELEMENT ANALYSIS OF THERMAL EFFECTS IN AN X-RAY MASK

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ABSTRACT

For the mass production of upcoming ULSI generations in the latter part of this decade, X-ray lithography with synchrotron radiation has the potential to become the dominant patterning technique to fabricate microchips with critical dimension down to quarter micron and below. To carry this powerful technique out of the research phase into manufacturing environment, however, the greatest obstacle to overcome is the 1:1 X-ray masks, where considerable improvements are still needed for industrial application. One of the key issues not fully resolved is the dimensional stability of X-ray mask during scanning exposure because the high radiation doses required to expose resist (~100 mJ/cm^2) may cause temperature rise in the mask materials leading to thermoelastic distortions of X-ray mask and the loss of overlay accuracy in pattern transfer operation.

It is the aim of the persent paper to numerically study the thermoelastic response of an X-ray mask under synchrotron storage ring irradiation. The concept of design-oriented analysis was employed in the calculations to obtain reasonable numerical solutions. In other words, the models and assumptions used herein were carefully designed beforehand to approach the realistic physical conditions in X-ray lithography exposure. An X-ray mask structure with a 2 μm thick Si membrane and a W absorber of 0.8 μm thick was considered for computer simulations. The Si membrane was a rectangle of 6 μm × 7 μm, and the W absorbers (0.25 μm

minimum linewidth) consisted of standard feature types normally used in practical X-ray mask, such as square pad, line and space gratings, window or via, and pillar. All structures were assumed to be surrounded by a vacuum environment, a helium atmosphere, and an air ambient, respectively. For scanning the narrow X-ray beam (beam height 10mm) across the mask membrane with 40-mm window size, three distinctive regions of scanning rate were used in this case, namely, quasistatic scanning region, transient scanning region, and saturated scanning region. In addition, incident X-ray fluxes on mask with a power density of 150 mW/cm^2 (The resulting effective flux at the resist will thus be $\sim$100 mW/cm^2.) and the wavelength of 1nm were assumed in the calculations.

By applying the finite element MSC/NASTRAN program with IDEAS pre-post processor system, numerical simulations were executed in a powerful CONVEX C201 mini-supercomputer to calculate the temperature and thermal stress distributions in the X-ray mask. The SOL 89 capability in MSC/NASTRAN was used for transient analysis of heat conduction. After the temperature distribution was obtained, SOL 24 was employed for the stress analysis by assuming free of intrinsic stress. In order to simulate the bending effect more accurately, the three layer elements in the thickness direction were considered. Accordingly, the total number of the solid elements and grids are 6480 and 7760 respectively. In this study, the simulation results indicate that the thermal effects in X-ray mask are strongly dependent on the surrounding atmosphere during operation. Especially the effects are remarkable in vacuum. It is also observed that the maximum temperature rise and thermal stress centralize in the areas where the density of absorber coverage is highest. Besides, the maximum response regarding temperature and stress is found to take place at the end of each scanning, and the position of the maximum resopnse occurs at the interface of Si and W.

Based on the simulation results mentioned above, it is suggested that there is need for experimental studies of X-ray mask distortion as well as the interface cohesion between Si membrane and W absorber. If satisfying combinations of the numerical and experimental results are acquired, it can be anticipated that the extension of the finite element methods used herein will enable us not only to understand the thermomechanical behavior of X-ray mask, but also will permit us to explore other important aspects including mask design optimization and fatigue life prediction.