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<u>Distortion Free Projection Lithography</u>

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Abstract

Soft x-ray projection lithography (SXPL) may be used to fabricate high resolution structures for future devices, but will require an all-reflecting optical system with ~ 100 nm resolution and < 10 nm image distortion over large fields-of-view. In present designs, the lithographic tool for SXPL is envisioned as a "ring-field" scanning system with multiple (3-5), possibly aspheric, imaging optics fabricated to $\sim < 1$ nm figure precision. In its present form, several technologies must be developed before this tool can become practical. A simple, non-scanning optical system with less expensive optics, reduced mirror reflection losses and lower source power requirements would be very attractive.

We have developed a technique, called Encoded Mask Lithography (EML), which allows for distortion free, high resolution reticle replication over a large field-of-view while using an imaging system with substantial inherent distortion. When applied to SXPL, EML allows us to use a simple, two spherical mirror imaging system. The simplified optical system used in EML eases optic fabrication requirements, obviates the need for mask-to-wafer scanning, and decreases multilayer mirror reflection losses and source power requirements.

Although developed for SXPL, this concept is applicable to all forms of projection lithography (i.e. ion beam projection lithography, e-beam projection lithography, etc.) where distortion over large fields may be a problem.

Introduction

Soft X-ray Projection Lithography (SXPL) is a promising new technique for the replication of high resolution patterns suitable for the fabrication of ultra-high density circuits (1-3). The development of SXPL into a practical tool for lithography will depend critically upon the design and fabrication of a practical, high resolution (<100 nm), low distortion (<10 nm) optical imaging system. Two different strategies for optical systems have been proposed: "Step and Repeat" optical systems, which image the entire chip but require large aspheric optics, versus "Step and Scan" optical systems which image a small annular segment of a chip, requiring smaller aspheric optics but also dynamic alignment between the moving mask and wafer. Many simple, high resolution imaging systems using spherical optics exist but do not meet the distortion requirement for lithography. To date, several optical designs that meet the resolution and distortion requirements for lithography have been suggested (4-8). However, the optic figure requirements for even the smallest aspheric optic in the above designs exceeds present state-of-the-art metrological and fabrication techniques. Using spherical optics with a curved mask has been suggested (1,9) but is considered impractical because of the anticipated difficulties in writing the mask and aligning the optical axis of the curved mask to the optical axis of the imaging system.

Encoded Mask Lithography

We have found a solution to the twin problems of writing and aligning curved reflection masks. In an imaging system which is free of point aberrations, each point in the object maps to a unique, diffraction limited point in the image. If such an optical system produces a high resolution, but distorted, image of a reticle, then a pattern made from the distorted image will produce an undistorted image of the original reticle when viewed through the same optical system in the reverse direction, figure 1. There is no significant loss in resolution provided the spherical aberration, coma and astigmatism are small. We call the pattern created from the distorted image an "Encoded Mask" because this mask contains the information of the original reticle, encoded with the distortions of the imaging system. If the imaging system has both field distortion and field curvature, then the surface of the Encoded Mask must follow the surface of the field curvature, to within the depth of focus of the imaging system. The Encoded Mask is recorded only once and can be used many times to replicate the original reticle onto many wafers, figure 2. We call this process Encoded Mask Lithography (EML).

The major benefit of EML is that one can use simple optical systems with a small number of spherical mirrors and still perform high resolution, low distortion lithography. In particular, a high resolution imaging system using two spherical mirrors can be used regardless of its intrinsic distortion. Alignment of the Encoded Mask to the optical system can be achieved by aligning the Encoded Mask to the original reticle, if necessary. The major difficulty with Encoded Mask Lithography is the need to fabricate a 1X reticle, although the optical system can have arbitrary magnification between the reticle and the Encoded Mask.

Analysis

We have developed a ray-tracing code to calculate the performance of various optical systems using EML. Using this code, we calculated the spot size imaged onto a wafer from various points on the Encoded Mask. We have analysed several optical systems with spherical mirrors, where the geometrical spot size was less than the diffraction limited spot size (i.e. geometrical aberrations did not limit system resolution) and which use either two or three bounces between the reticle (or wafer) and the Encoded Mask. All systems that we analysed have appreciable distortion and would normally be unacceptable for lithography. One attractive design is shown in figure 3. This design uses two spherical mirrors (100 and 300 mm in diameter with radii of curvature ~ 560 and 1400 mm respectively) and three bounces between the reticle and the Encoded Mask. The Encoded Mask itself is spherical, but its radius of curvature is very large (1.6 meters). (One variation on this design places the Encoded Mask in front of the smaller mirror, obviating the need for a hole in this mirror. The performances of these systems are virtually identical.) Using our ray-tracing code, we calculated the spot size at the wafer as a function of radial position. For an f#/6 optical system with a 30 mm diameter field-of-view, the spot size determined by the geometrical aberrations is less than the diffraction limited spot, figure 4. Therefore, the actual performance of this optical system will be diffraction limited (10). Using EML, this spherical optical imaging system with modest mirror sizes is capable of < 100 nm resolution with negligible distortion over a 30 mm diameter field of view.

EML can be extended to optical systems with larger fields-of-view and/or lower f#'s (smaller minimum feature sizes); however, this will generally require systems with larger mirrors. Eventuallty, the geometrical aberrations (primarily the spherical aberration) will exceed the diffraction limited spot size. The largest field and smallest structures that can be made using EML will be determined by the choice

of optical system design and our ability to correct for any geometrical aberration. If the optical design shown in figure 4 is enlarged to an f#/5 system, then the spherical aberration limits the diffraction limited field-of-view to approximately 10 mm. However, adding a very small aspheric correction (~3 nm) to each mirror will correct the spherical aberration and once again produce a diffraction limited optical system with a large (~30 mm diameter) field-of-view. Notice that the magitude of the aspheric correction to each mirror is only (approximately) one quarter of the wavelength (13 nm).

Conclusions

We have presented an innovative optical design, Encoded Mask Lithography for high resolution, low distortion lithography. In EML, a simple optical system is used to record the image of a reticle onto an "Encoded Mask". This image is "played-back" through the same optical system, canceling both field distortion and field curvature and producing a distortion-free replication of the original reticle. We have shown a simple, two spherical mirror optical system which is capable of < 100 nm spatial resolution with negligible distortion over a > 30 mm diameter field-of-view.

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References

1) A.M. Hawryluk, et al; J. Vac Sci Tech B; Vol. 6, No. 6, p 2162, 1988

2) J. Bjorkholm, et al; J. Vac Sci Tech B; Vol 8, No. 6, 1990

3) H. Kinoshita, et al; J. Vac Sci Tech B; Vol 7, No. 6 p 1648, 1989

4) T. Jewel, et al; Conference Proceedings of the OSA Annual Meeting; Boston, Ma, Nov. 1990

5) D. Shafer; Conference Proceedings of the OSA Meeting on Soft X-ray Projection Lithography; April 1991

6) V. Viswanathan, et al; Conference Proceedings of the OSA Meeting on Soft X-ray Projection Lithography; April, 1991

7) D. Shealy, et al; Conference Proceedings of the OSA Meeting on Soft X-ray Projection Lithography; April 1991

8) N.M. Ceglio et al, J. Vac. Sci and Tech.; this issue

9) F. Bijkerk, et al; Conference proceedings of the OSA Meeting on Soft X-ray Projection Lithography; April 1991

10) We use the Raleigh criteria for diffraction limited resolution; i.e. $\delta \sim 1.22 \lambda f^{\#}$ where lamda=13 nm.

Figure Captions

Figure 1

In an optical system free of point aberrations, there exists a unique mapping between each point in the object plane and each point in the image plane. Therefore, a replica of a distorted image can recreate the original pattern with no distortions when imaged through the optical system in the reverrse direction.

Figure 2

(Top) An Encoded Mask is generated from a reticle using a high resolution optical system with arbitrary distortion. All the information in the reticle, along with the distortion of the optical system, are recorded in the Encoded Mask.

(Bottom) The Encoded Mask can now be used to pattern wafers. By imaging the Encoded Mask through the optical system in the reverse direction, the distortions in the optical system are exactly canceled.

Figure 3

An example of Encoded Mask Lithography using a simple, all spherical optical system, design. This system has < 100 nm spatial resolution with zero distortion over a > 30 mm diameter field-of-view.

Figure 4

The geometrical aberrations for a point imaged from the Encoded Mask onto the wafer are less than the diffraction limited resolution for this f#/6 optical system using 13 nm radiation. The radial field size at the wafer is > 15 mm (the full field size of this symmetric optical system is > 30 mm in diameter).

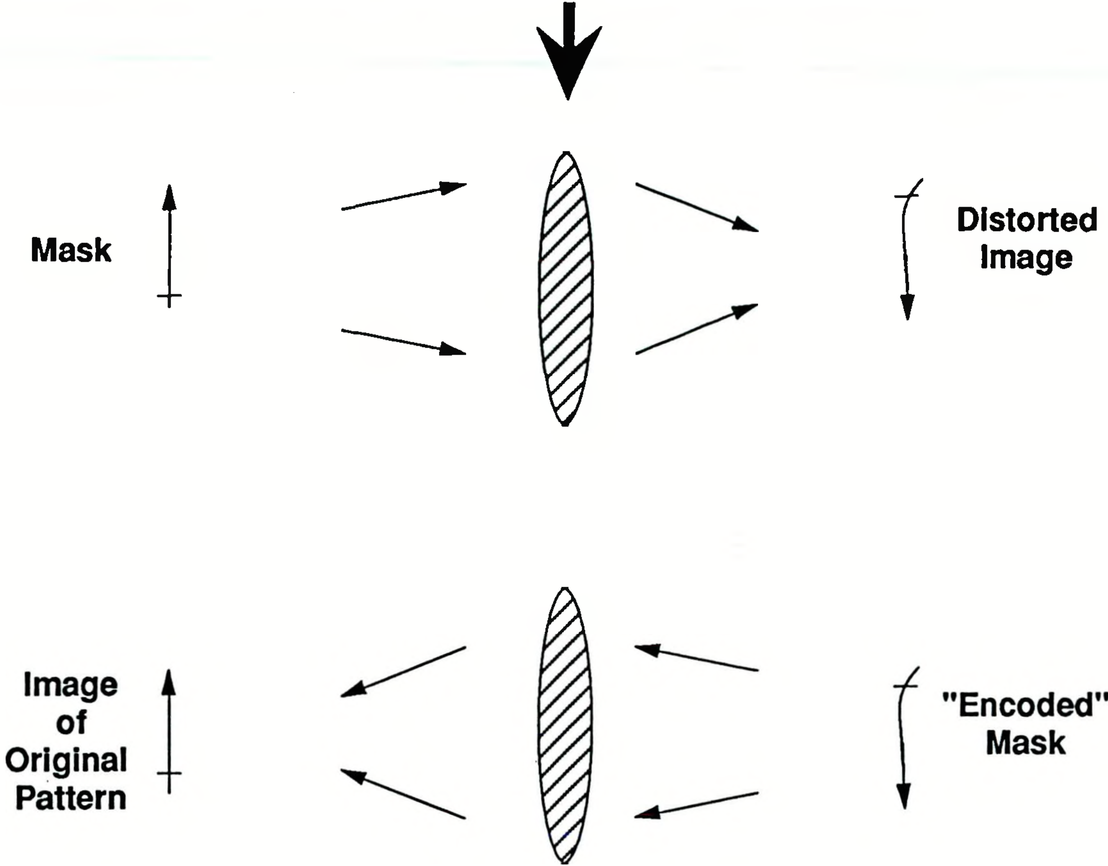
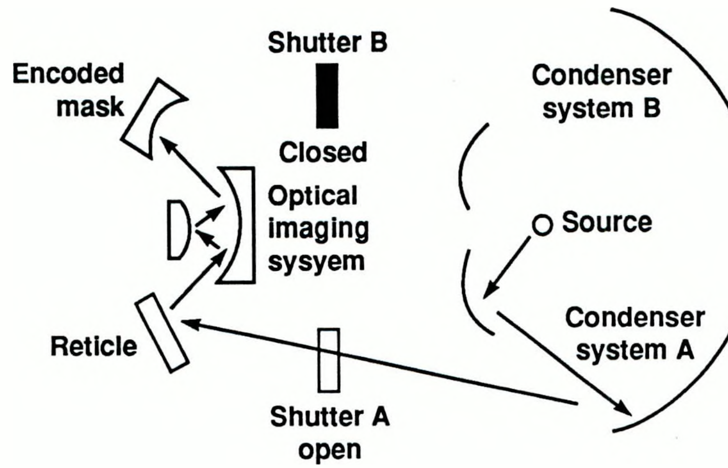


Figure 1

Encoding Process



Wafer Writing

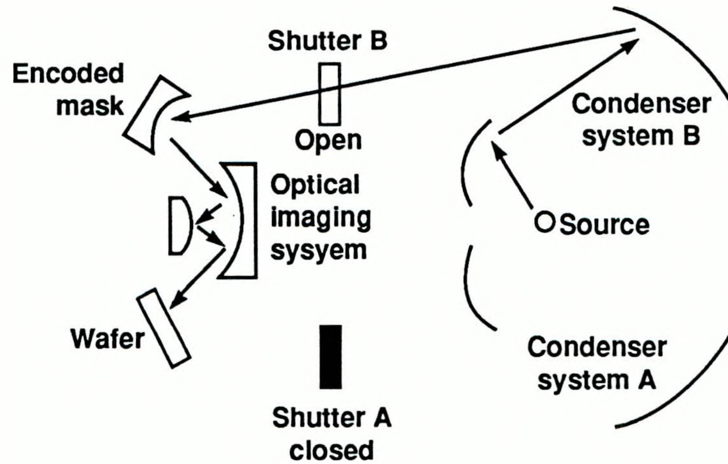


Figure 2

Illustration of possible EML design

Small mirror: 100 mm diameter
Radius of curvature ~ 560 mm

Spherical encoder
Radius of curvature
~ 1.6 meters

300 mm
diameter

Wafer

Encoder

Radius of
curvature
~ 1.4 meters

30 mm diameter
field of view

1.8 meters

Figur. 3

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Geometrical Spot Size for
30 mm Diameter Field-of-View Optical System

Spot diameter at wafer (Å)

1000
800
600
400
200
0

Diffraction limited resolution
for f# = 6 system

Geometrical ray tracing
calculations

0 2 4 6 8 10 12 14 16

Radial wafer position (mm)

rigure 4

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