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Theoretical Consideration on New Reflection Type X-Ray Lithography

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A new X-ray lithographic technique, in which patterns are projected by reflection of X-rays from a hard pattern plate, is presented. Optical focusing system in this new technique is theoretically studied, based on geometrical optics. It is found that the field area of size of blur less than 0.06 μm can be 1mm X 7mm for 1X1 projecion system using an ellipsoidal mirror, and also that the similar field can be 1mm X 1mm for 1/3 demagnified projection system using two spherical mirrors.

1. Introduction

X-ray lithography is expected as a promising fabrication technology of future VLSI. However, in the conventional technique, since the patterns are projected by transmitting X-rays through a thin "pattern mask", it is impossible to use X-rays of wavelengh longer than several Å because of increase of X-ray absorption in the mask, although X-ray resists become sensitive for X-rays of long wavelength and also such X-rays are obtainable even by a low-cost synchrotron machine.

Therefore, we have proposed a new X-ray lithographic technique named "Reflection Type Lithography"[1,2], in which the patterns are projected by reflection of X-rays from a thick and hard "pattern plate", and have reported on the preliminary experimental results. In the method, the influence of thermal expansion[3] during exposure of strong X-rays is expected to be minimized by easy cooling, X-rays of almost any wavelength can be used, and the patterns can be demagnified by using focusing equippments.

In this paper, the focusing systems using an ellipsoidal mirror (1X1 projection system) and using two spherical mirrors (demagnified projection system) are theoretically studied, based on geometrical optics. The field area for the printing of fine lines is evaluated for the various parameters of focusing mirrors, and the positional relation among the pattern plate, mirrors and a sample is also estimated. It is found that the field area of the size of blur less than 0.06 μm can be 1mm X 7mm for 1X1 projection system, and that the similar field can be 1mm X 1mm on a sample plane for the 1/3 demagnified system.

2. Fundamentals

In the new technique, first, the pattern plate is exposed in collimated X-ray beams, then, the X-rays reflected from the pattern plate, which contains pattern images, are focused by using mirrors, and finally the focused beams are projected onto a resist-coated sample. In the pattern plate, the pattern pictures are drawn on a hard and thick substrate with a material having the reflectivity different from the reflectivity of substrate material.

There are some methods to make the difference of reflectivity between patterns and a substrate. We have reported on a method in which the difference of critical angle of total reflection between pattern and substrate materials is utilized[1,2]. However, the incident angle of X-rays is almost automatically determined in the method from both the wavelength of X-rays and the used materials. Therefore, an other method, in which the pattern plate is made from a multi-layer reflector, is proposed.

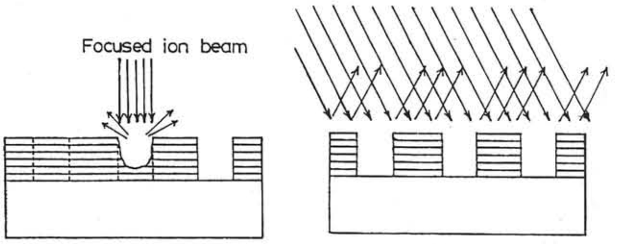

Fig.1 Schematic illustration of fabrication of multi-layered pattern plate, a), and fabricated pattern plate, b).

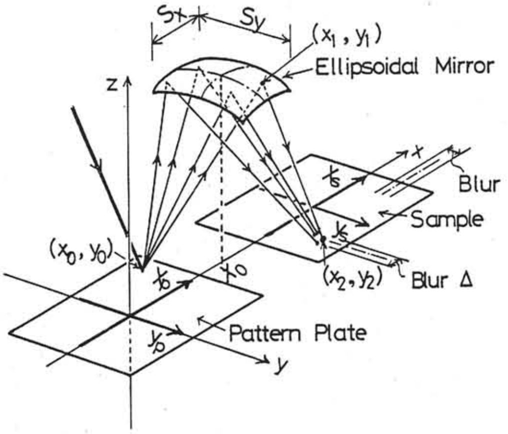

Fig.2 Focusing system using an ellipsoidal mirror.

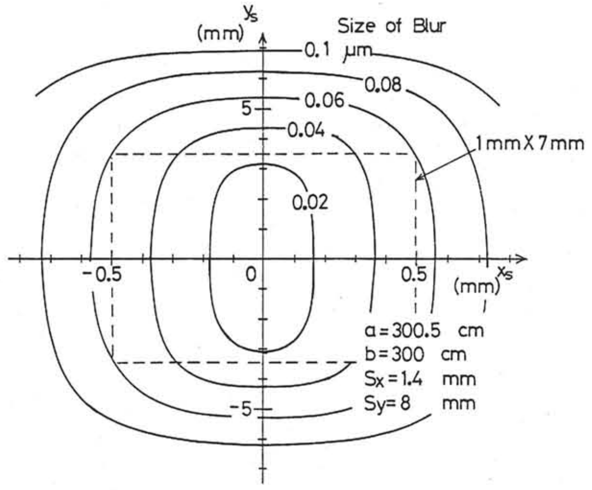

Fig.3 Contours of blur size in x_s-y_s plane on a sample.

It is known that the reflectivity of X-rays can be increased by more than 10^3 times or more when the plate is made from multi-dielectric-layers[4,5]. Thus, if a part of the multi-layer reflector is damaged or removed along pattern pictures by focused ion beam, as schematically illustrated in Fig.1 for instance, the reflectivity at such a part of reflector becomes much different from that of the substrate. In this method, both the incident angle of X-rays and the wavelength are almost arbitrarily decided when the multi-layer reflector itself is designed and fabricated. And when this multi-layer pattern plate is used, the contrast of more than 10^3 is expected in the projeted pattern image.

3. 1X1 Projection System

The 1X1 projection system using an ellipsoidal mirror is schematically illustrated in Fig.2. Among several methods to realize 1X1 projection using a concave mirror, here, the case of simplest structure is described.

The size of blur on a sample is evaluated by following all trajectories of X-rays which are reflected at a point (x_0,y_0) on the pattern plate toward all directions, reflected again at arbitrary point (x_1,y_1) on a mirror and finally reach to a certain point (x_2,y_2) on a sample plane. When the point (x_1,y_1) is varied, the point (x_2,y_2) is moved around within a certain area on a sample plane. The size of the maximum blur is estimated as twice of the maximum deviation of such an area from the average value of point (x_2,y_2). This method of evaluation is based on the geometrical optics. However, since the size of blur evaluated here is much larger than the wavelength of X-rays, the results are believed to be realistic.

Figure 3 shows the contours observed on the sample plane, within which the size of blur are less than the values described there. In this case, the parameters of an ellipsoidal mirror, a, b and c in $(x-X_0)^2/a^2+y^2/b^2+z^2/c^2=1$ are 300.5 cm, 300 cm and 300 cm respectively, and X_0 is about 16 cm. The field is strongly dependent on the size of mirror. In the calculation, the size along x-direction, S_x, is chosen at 1.4 mm and that along y-direction, S_y, is 8 mm. Because of the divergence of incident collimated X-ray

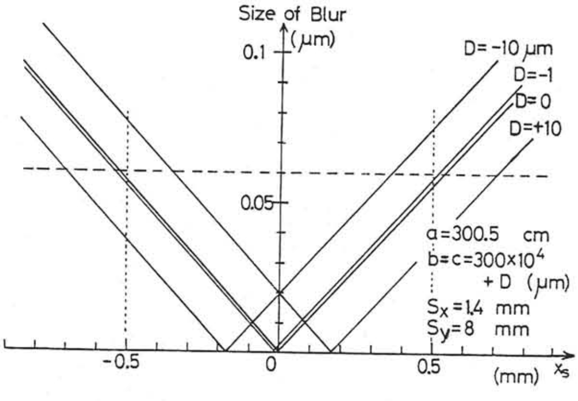

Fig.4 Dependency of blur size on position of x in x_s-axis on a sample plane.

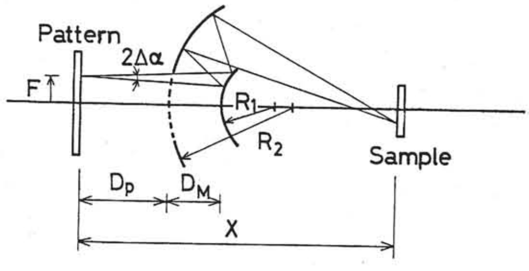

Fig.5 Relation among a pattern-plate, mirrors and a sample in demagnified system.

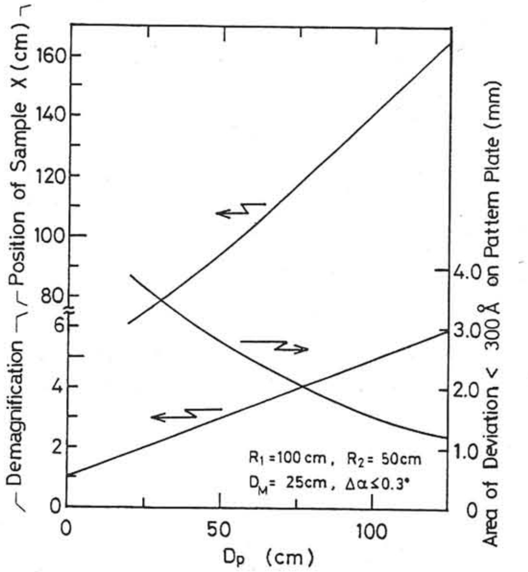

Fig.6 Calculated results for demagnified projection system.

beam, the reflected X-ray beam has also a certain divergence. The present method to evaluate the blur size itself includes the effect of divergence in the reflected x-rays. However, since the size of mirror is so small, the divergent angle is actually expected to be less than 0.008°.

It is believed that the minimum line width of future VLSI is about 0.25 µm and that the tolerable blur size in printing of such a fine line is about 0.06 µm to 0.09 µm. It is found from the figure that the field area with the blur size less than 0.06 µm is 1mm X 7mm.

Figure 4 shows the blur size at y=0 as a function of the position along x-axis, taking two minor axes, b and c, as parameters. As shown in the figure, the relation between the blur size and x-position is quite simple, and it is found that the field area is not so strongly affected on the error of mirror parameters when it is less than ±10 µm. For this focusing system, it is similarly derived that there are no changes in the field area if the positional errors in both the pattern plate and the sample are less than a few tens µm.

4. Demagnified Projection System

Next, the optical focusing of the demagnified projection system using two spherical mirrors, so-called the Schwarzschild system[6], is theoretically studied. The position of the pattern plate, two spherical mirrors and the sample is schematically illustrated in Fig.5. The blur size is estimated by following the trajectories of X-rays emitted from a point of the pattern plate with the divergence of an angle of 0.6 . There is no special reason to adapt this value as the divergent angle. However, since the divergent angle of X-rays generated by a synchrotron machine is less than 0.3°, the value is believed to be enough for accurate calculation of the blur size.

Figure 6 shows the field of the blur size less than 0.06 µm, the demagnification ratio and the position of sample measured from the pattern plate, X, as a function of the distance D_p between the pattern plate and the second spherical mirror of radius, R_2. From this figure, it is found that about 3mm X 3mm area on the pattern plate is demagnifiedly projected to 1mm X 1mm area on the sample, for instance.

5. Discussions

In the Schwarzschild system, the incident angle of X-rays to the mirrors is almost 90°, and in the 1X1 projection system, it is about 80°. According to theoretical study by Spiller[4], the reflectivity for normal incidence is about 0.4 when the thickness of one mono-layer, d, is equal to (wavelength of X-rays)/8 and the number of periods of layers exceeds over 100, and it becomes about 0.8 when d=(wavelength)/32. Thus, if we use X-rays of wavelength longer than 100 Å, the reflectivity more than about 0.4 can be easily expected even by the present fabrication technology of multi-layers. Actually, Spiller et al.[5] revealed experimentally that the reflectivity of multi-layers with only 27 periods becomes 15 % for the incident angle of 80° and the X-rays of wavelength of 130 Å.

In the conventional lithographic system using a thin film pattern mask, probably, the size of 20mm X 20mm may be the present target for the size of the pattern mask. To cover the same area by the 1X1 reflection type lithography, about 60 times shots are required. The sensitivity of photo-resists is believed to increase by about two orders of magnitude when the wavelength of X-rays increases from around 10 Å to the value of 100 to 200 Å. Thus, if we can obtain the multi-layer reflectors of the reflectivity of several tens %, the through-put of the new system is almost equivalent to the value expected by the conventional method. Additionally, by using this new system, since the X-rays of long wavelength can be used, the direct patterning, utilizing the photo-chemical reaction, is also expected.

6. Conclusions

From the above results, the follows are concluded;

1) By using an ellipsoidal mirror as a focusing equippment in a reflection type X-ray lithography, 1X1 projection of patterns is possible with a field area of 1mm X 7mm for the blur size less than 0.06 μm.
2) By using two spherical mirrors, the demagnified projection of patterns is also possible, and the similar field area is about 1mm X 1mm on a sample for 1/3 demagnified projection, for instance.
3) If X-rays of wavelength of a few hundreds Å are used, the through-put of this new technique using an ellipsoidal mirror will be equivalent to that of the conventional technique.

[Acknowledgement]

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