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Demagnified Projection Printing By A New X-Ray Lithographic System Using No Thin-Film Pattern Masks

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X-ray lithography is one of the most promising pattern-printing technology for future VLSI. However, since the patterns on a few μm thick film are projected onto a sample by the proximity printing method, it is not easy to fabricate such a thin film pattern mask and also it is impossible to demagnify the patterns. Additionally, if we use X-rays of wavelength longer than several-tens Å, which make X-ray resists more sensitive and also which are obtainable by using a low-cost synchrotron machine, it will be getting even more difficult to fabricate pattern masks due to the increase of X-ray absorption in the films.

This paper is to propose a new X-ray lithographic system which uses no thin film masks and in which circuit patterns can be demagnified. And this is also to demonstrate the experimental results which confirm the validity of the principle of this new system.

In the present new system, the difference between the critical angle for total reflection of X-rays from heavy materials such as gold and that from light materials such as silicon is utilized. A hard pattern plate is used instead of using the conventional transparent thin-film pattern masks. In the pattern plate, the pattern pictures are drawn by a heavy material on a hard substrate of a light material. The image of patterns is projected onto a sample by the total reflection of X-rays from a pattern plate, when the incident angle of the X-ray to the pattern plate is chosen at a value smaller than the critical angle of total reflection from heavy material of patterns but larger than that from light material of substrate. In this system, the reflected pattern image is demagnified only one-dimensionally by the sine of incident angle. However, two-dimensional demagnification is also possible, when the pattern plate in which the pattern pictures are already demagnified along one right direction is used.

The present new system is schematically illustrated in Fig.1. To minimize the influence of diffraction and divergence of incident X-rays, a focusing mirror with gold surface is placed between the pattern plate and the sample. Figure 2 demonstrates the experimental result for the contrast between reflected X-ray from gold and that from silicon as a function of incident angle of X-rays. Here, CuK_α X-ray of wavelength of 1.5 Å is used. This figure implies that the contrast of pattern image over 400 can be obtained if the patterns are drawn by gold on silicon wafers and also if the incident angle of X-rays is chosen at 0.5°. This value of contrast appears enough, since that of the conventional technique using thin-film pattern masks is 10 to 100. Figure 3, a) and b) show the photomicrographs of original pattern plate and the demagnified projected patterns, respectively. It is found that the line-and space-patterns of 210 μm width is demagnified by the sine of incident angle 0.5°, that is, 1/110. Here, the distance L in Fig.1 is set at 77 mm. And if the focusing mirror is not attached, the projected patterns are blurred by both the diffraction and the divergence of reflected X-rays, as shown in Fig.3, c). In this case, just to check the validity of idea of the present new system, X-ray films are used instead of resist-coated samples. The patterns less than 1 μm size is not clearly taken by micrographs because of the limit of the spatial resolution in X-ray films. Figure 4 shows the demagnified projected patterns of an original pattern whose size is a half of that shown in Fig.3, a). It is found that the demagnified printing less than 1 μm is also possible by the present system, although the pattern itself appears rough because of the resolution of X-ray films.

From these studies, the following are concluded;

1) The demagnified projection printing whose dimension is less than 1 μm is possible by using the present new lithographic system, which uses no thin-film pattern masks but utilizes the total reflection of X-rays from a hard pattern plate.
2) The diffraction and the divergence of X-rays can be avoided by using a proper focusing mirror to make fine projected patterns.
3) According to our theoretical estimation, the demagnified printing of dimension of 0.1 μm is also possible if a proper focusing mirror is used.

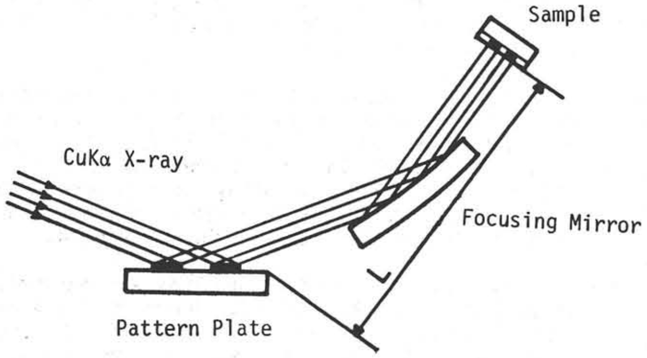

Fig.1 A new X-ray lithographic system.

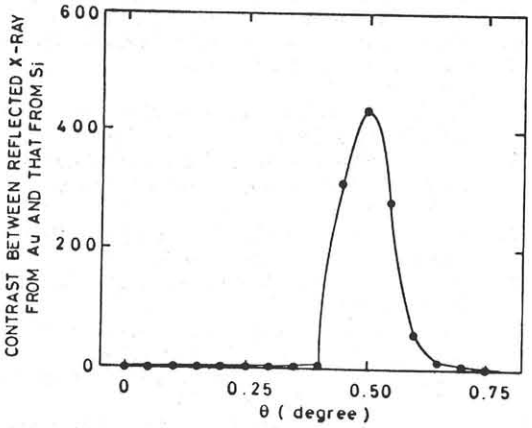

Fig.2 The contrast as a function of incident X-ray angle.

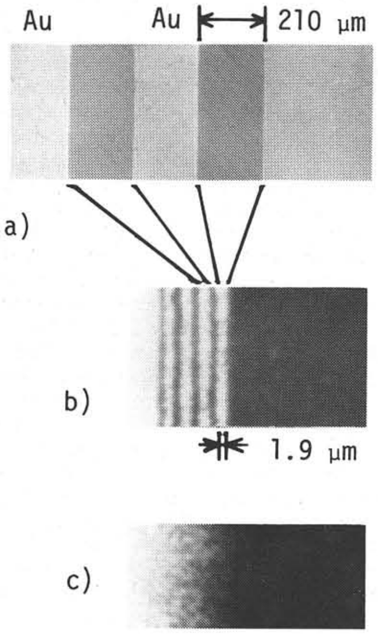

Fig.3, a) Original pattern, b) demagnified pattern, and c) projected pattern without using a focusing mirror.

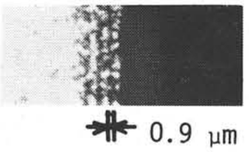

Fig.4 Demagnified line- and space-patterns less than 1 μm size.