A—1—2 X-ray replication of masks by Synchrotron Radiation of INS-ES

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Synchrotron orbital radiation (SOR) has been used recently as a X-ray source for X-ray lithography[1.2.3]. Chracteristics of SOR in comparison with the case of conventional X-ray sources are high intensity, small divergence of the beam, and the continuous spectrum extending to the visible region from the cut off at the short wavelength side which is critical on the energy of electron and the orbital radius. These characteristics lead to the following advantages for X-ray lithography.

1) High intensity gives the short exposure time on the order of seconds.

2) The thinner absorber can be used by using X-ray of longer-wavelength, because the contrast of the mask increases. Therefore, the mask pattern which has the higher resolution can be made. Moreover, the possibility to use organic thin films such as mylar and parylen-N as mask substrates is given in the soft X-ray region.

3) The small beam divergence (~1 mrad) gives the small penumbral blurring and the replication of a large height-to-width pattern would be expected.

In this paper the result on the third characteristics is demonstrated by using the synchrotron orbital radiation of the electron synchrotron at the Institute of Nuclear Study in University of Tokyo.

A schematic diagram of INS-ES experimental system is shown in Fig. 1. Electron synchrotron INS-ES can be operated at a beam current of 60 mA at 1.3 GeV. The electron energy of 1.1 GeV was used in this experiment. The calculated photon flux[4] from INS-ES as a function of wavelength with 24 mA beam current, which was the condition used for this experiment, is shown in Fig. 2. The change of a beam current only results in multiplying the intensity by a scaling factor.

Pattern masks used were gold on silicon. The thickness of Si membrane was 3 μm and the thickness of gold absorber layer was 0.4 μm. Two kinds of patterns were used. One is 1.5 μm-wide bubble pattern made by conventional photolithographic method and the other is the grating pattern with 692 nm period made by holographic method by using 325 nm He-Cd laser. Ion-beam etching technique was used in both cases for etching the gold. Samples used were silicon wafers coated with 1.5~2 μm-thick PMMA resist. Mask and wafer were plated in contact and the assembly was positioned in vacuum inside the direct output line at a distance of 10 m from the orbit.

Development was done by a solution of methyl-isobutyl-ketone in isopropanol for 2 minutes. After development the sample was rinsed in isopropanol for 30 seconds.

Without a mask an exposure time of 60 seconds was sufficient for perfect removal of 1.5 μm PMMA resist. For 3 μm Si mask the exposure time of 45 minutes was sufficient for removal of 1.5 μm PMMA resist. This value is in rough agreement with the calculated value from the absorption coefficient of Si[5].

Fig. 3 shows the SEM photograph of 1.5 μm wide bubble pattern. The 0.4 μm gold layer was sufficient for obtaining enough contrast in PMMA for a direct SOR total beam at 1.1 GeV. Fig. 4 shows the SEM photograph of the grating with the period of 692 nm. The thickness of PMMA resist was 2.2 μm in this case. The large height-to-width ratio clearly demonstrates the very high collimation (~1 mrad beam divergence).

These preliminary results demonstrate that the synchrotron radiation from an electron synchrotron such as INS-ES provides a useful X-ray source for X-ray lithography. At an electron energy of 1.1 GeV, 0.4 μm gold layer was sufficient for obtaining good contrast in PMMA for the direct SOR total beam. A good collimation of SOR beam was demonstrated. It was possible to obtain a large height-to-width ratio pattern.

Exposure time necessary for 1.5 μm thick PMMA resist in the case of 3 μm Si mask was about 45 minutes at a beam current of 24 mA at 1.1 GeV. It is expected to shorten this time to less than 1 minute by choosing mask material such as parylene-N and resist such as P(MMA-co-MA) by using SOR of INS-ES.

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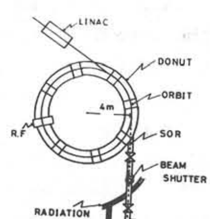

Fig. 1 Schematic diagram of the experimental system at INS-ES.

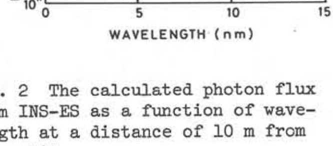

Fig. 2 The calculated photon flux from INS-ES as a function of wavelength at a distance of 10 m from the orbit.

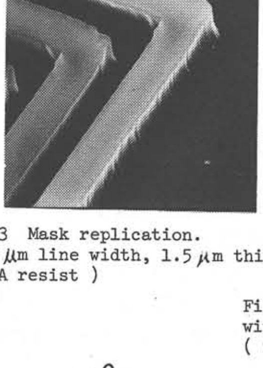

Fig. 3 Mask replication.
(1.5 μm line width, 1.5 μm thick PMMA resist)

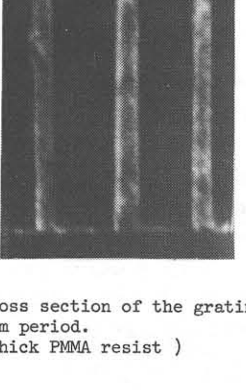

Fig. 4 Cross section of the grating with 692 nm period.
(2.2 μm thick PMMA resist)