SXR LITHOGRAPHY USING A HIGH PERFORMANCE PLASMA FOCUS SOURCE

S. Lee, V. Kudryashov[1], P. Lee, G. Zhang, A. Serban, M. Liu, X. Feng, S.V. Springham, T.K.S. Wong[2] and C. Selvam

Nanyang Technological University, National Institute of Education, 469 Bukit Timah Road, Singapore 259756
[1]*Microelectronics Technology Institute, Russian Academy of Sciences, Chernogolovka, Moscow dist. 142432 Russia*
[2]*School of Electrical and Electronic Engineering Nanyang Technological University, Nanyang Avenue, Singapore*

1. Introduction

By considering drive parameters, operational speeds and yield performance we had developed two plasma focus devices into powerful SXR sources, the NX1 and NX2, for microelectronics lithography [1,2]. Although the NX1 appeared to be the more efficient machine, with a wall plug conversion efficiency into SXR of up to 4%, we have made our first attempts at SXR lithography using the NX2 source since the NX2 had watercooled electrodes and hence could be operated in longer bursts at higher repetition rates. The requirements for a point SXR microelectronics lithography source may be summarized as follows:

a. point source with dimension less than 1mm (viewed end on)

b. emission in the wavelength range 0.8-1.4nm

We have fulfilled (a) (Fig. 1) and (b) (Fig. 2) . For industrial throughput purposes there is a third requirement.

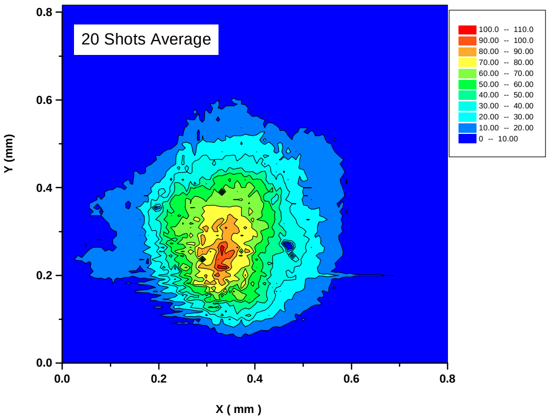


Figure 1. End-on x-ray pinhole image (equi-density contour of 20shot overlay)

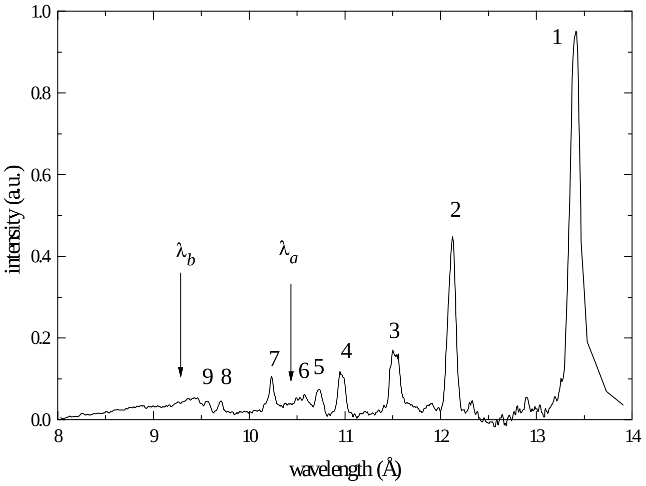


Figure 2. Neon plasma x-ray spectrum

c. Average SXR power of 1kW at source over 4π delivered over a prolonged burst.

The NX2 produces 20J per shot at up to 16 shots per second giving up to 300W of SXR power. For demonstration purposes even operation at the 50W level allows convenient accumulation of the required exposure dose.

2. Apparatus

The NX2 is a 2kJ focus operated in Neon. The capacitor bank consists of 48 capacitors with a total capacity of 30μF. These are arranged in a square, 12 capacitors on each side of the square connected to the plasma focus via a rail gap switch by parallel plates, folded to save space. A general view is shown in Fig. 3. The capacitors are charged to 11.5kV by ALE model 802 chargers with a total charging capacity of 32kW. The short circuit rise time is 1 μs. the on-load current peaks at 400kA at a repetition rate of up to 16 shots per sec.

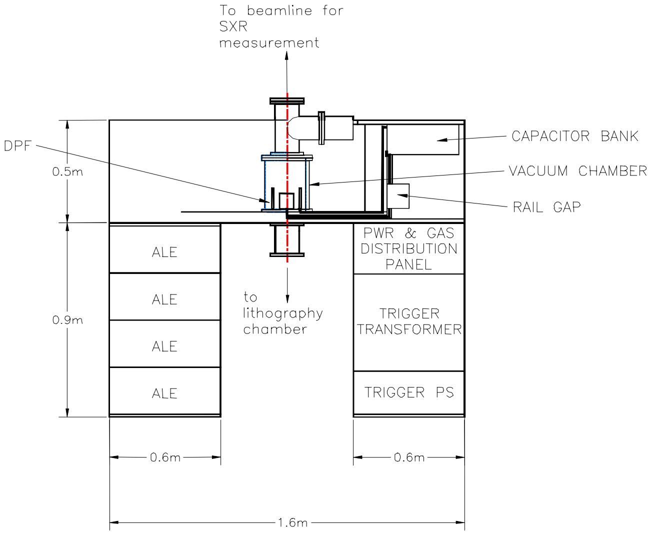


Figure 3. General view of the NX2

The design (Fig. 4) enables measurement of SXR yield via the upper beam lines at the same time as the lithographic exposure is made in the chamber below the plasma focus electrodes. The system is completely shielded against electromagnetic radiation and has a footprint of 1.6m x 1.6m. A schematic of the stainless steel watercooled electrodes is shown in fig. 4. Cooling of the electrodes is achieved by ducts in the anode and outer squirrel cage cathode through which chilled water flows. A quartz disc is found necessary to protect the inside base of the anode against the electron beam emitted from the plasma focus. A 3.5mm hole in the centre of the quartz disc and through the anode extracts SXR onto the lithography assembly (Fig. 4) in the lithography chamber. The plasma focus chamber is evacuated by a turbo-molecular pump. During focus operation, the turbo molecular pump is isolated and a continuous flow of neon is admitted into the upper section of the plasma focus chamber whilst a rotary pump, connected to the lower end of the lithography chamber pumps out the neon through the anode SXR extraction hole. In this way using a choking aperture (say 1.5mm in diameter) at the anode extraction hole a low pressure (10^{-2}mbar) may be maintained in the lithography chamber whilst operating the focus chamber at the correct focussing pressure of 4-5mbar.

The lithography assembly (see Fig. 4) uses a clamping magnet to attract a steel washer thus evenly clamping a mask to a resist coated wafer. The SXR passing through the mask falls on the resist. The clamped mask-resist structure is centered in a light –tight structure with an entrance aperture closed by 10μm Be foil which allows in SXR but blocks out UV and the visible spectrum. The SXR from the plasma focus point source is extracted through the hole at the bottom of the anode and passes through an array of magnets, which deflects the electron beam to the side, before entering the lithography assembly via the Be window.

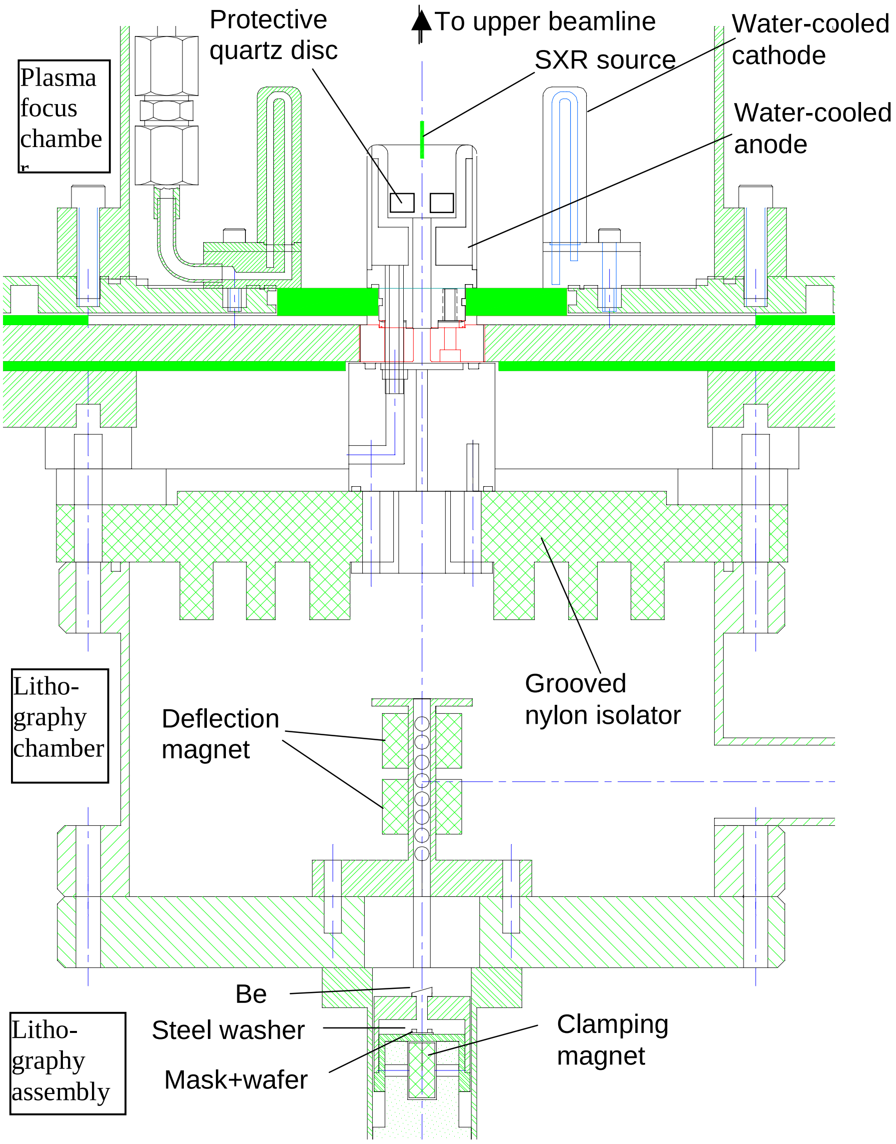


Figure 4. Detail of the focus and lithography assembly

3. Experiment, Results

Experiments in X-ray lithography include a range of positive and negative resists exposure with a specially designed test x-ray masks. The high resolution test mask, given in Fig. 5(a) consist of a 0.5 μm thick Ni absorption layer with smallest elements dimensions below 0.1 micrometer on 100 nm thick Si3N4 membrane. The high contrast masks have a similar design Fig. 5(b), but the absorption layer is 0.3-0.6 micron Au with smallest line width from 0.2 to 0.4 μm depending on Au thickness. Positive resists, PMMA495 and ERP40 (from

NII MV, Russia) with low sensitivity, but high resolution and good development flexibility, were used with high resolution masks to show that mask membrane vibration during the high rep-rate pulsed discharge does not affect the exposure resolution.

The aim of experiment was to demonstrate the possibility of forming 0.2 μm elements in chemically amplified negative resists AZPN114 and SAL601. The Au mask and wafer covered with 0.5 μm resist layer were clamped with a magnet to provide a small gap and to avoid mask shift during exposure. To get high resist sensitivity, a Post Exposure Baking (PEB) scheme with 2 minutes at 110 ^{0}C on hotplate was used. This PEB provides resist resolution better then 0.1 μm, as seen from sharp corners of the 0.2 μm width structure in AZPN114 resist, seen in Fig. 6(a), but makes the exposure time approximately twice shorter in comparison with the recommended (1 min at 100 ^{0}C) PEB parameters. The structures shown in Fig. 6(b) is a mirror image of the test mask structure shown in Fig. 5(b), in AZPN114 resist.

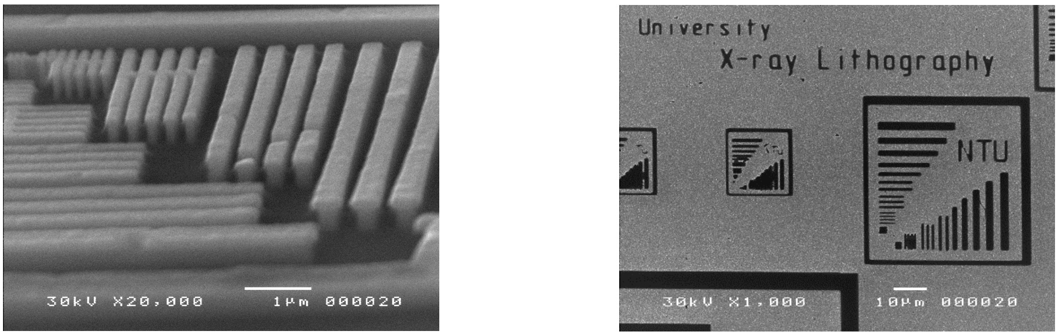
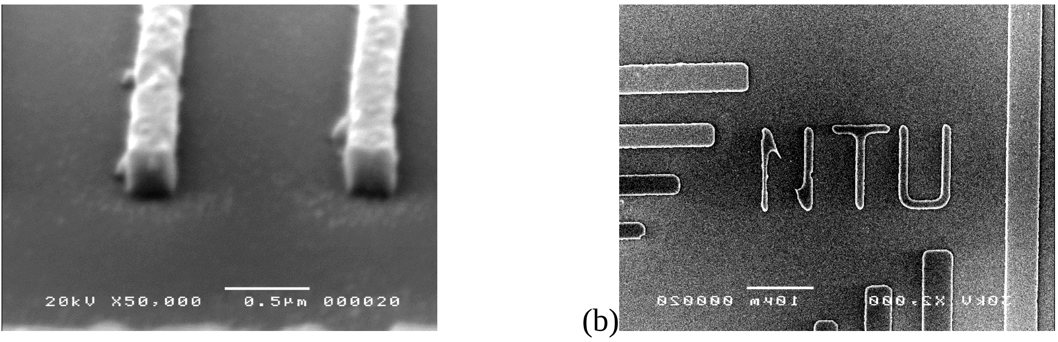


Figure 5. SEM pictures of the Ni (a) and Au (b) masking layers on test x-ray masks.



(a) (b)

Figure 6. SEM pictures of test structures produced in AZPN114 with x-rays from NX2

References

[1] S. Lee, X. Feng, G.X Zhang, P. Lee, M.H. Liu, A. Serban, S.V.Springham, T.K.S.Wong, K.Wira, C.Selvam and A.Thang: “Preliminary results on x-ray lithography using a compact plasma focus”, *SPIE* 3183, 123-127 June 1997.

[2] S. Lee, P. Lee, G. Zhang, X. Feng, V. Gribkov, M. Liu, A. Serban, T.K.S. Wong: “High Rep Rate High Performance Plasma Focus As A Powerful Radiation Source”, *accepted in* IEEE Trans. of Plasma Science, 1998