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THE ADONE WIGGLER X-RAY LITHOGRAPHY BEAMLINE

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A soft x-ray beamline, utilizing the radiation produced by the six-pole wiggler of the Adone storage ring, has been realized. The beamline allows the exposure of large area resists by means of a double-mirror scanning system or mechanically moving the wafer. The mechanical, geometrical, and spectral characteristics of the beamline will be described.

INTRODUCTION

In this paper the soft x-ray beamline realized in Frascati to perform research activity in x-ray lithography (XRL) is described.

In planning the beamline, attention was principally focused on the problem of exposing large area resists. Two different solutions have been adopted; in one configuration the photon beam is moved vertically by means of a double-mirror oscillating system, in the other the beam is fixed and the system mask wafer is moved by using an x-ray stepper. Both configurations will be described; the spectral, geometrical, and optical characteristics of the beamline will be reported, together with some considerations on expected exposure time and mask contrast.

I. GENERAL

The soft x-ray beamline, called BX2L, utilizes the radiation produced by the Adone six-equivalent full poles wiggler; this source generates a flux more intense, with respect to the bending magnet also in the soft x-ray region. The horizontal uniformity of the source emission was verified in preliminary measurements.[1]

Figure 1 shows a layout of the beamline and Table I reports its main parameters. The BX2L accepts 2 mrad of radiation in the horizontal plane, giving a horizontal beam size of about 70 mm at the sample. The main optical element is a gold-coated mirror which cuts off the hard x-rays produced by the wiggler. The shieldings and the building geometry[2] forced a reflection in the horizontal plane (s polarization) and a grazing angle of 1.5°. This angle gives a cutoff energy of about 3 keV which is satisfactory for XRL requirements.

A 25-μm-thick Be window is installed on the stainless-steel plate of a VAT vacuum valve, to be easily removed when it is necessary to use radiation of energy lower than 1 keV or when other windows are used. The beamline can work in two configurations: (a) oscillating beam and (b) fixed beam. In the first configuration the beam is moved in

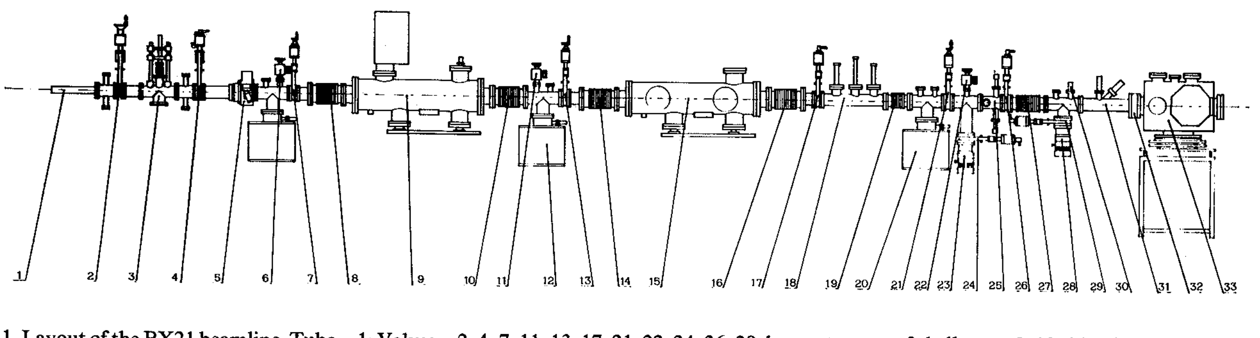

FIG. 1. Layout of the BX21 beamline. Tube—1; Valves—2, 4–7, 11, 13, 17, 21, 22, 24, 26, 29; beam stopper—3; bellows—8, 10, 14, 16, 19, 27; mirror box—9, 15; sputter ion pump—12, 20; filter—18; turbomolecular pump—23, 28; slits—25; sensor of fast valve—30; beam monitor—31; beryllium window—32; exposure chamber—33.

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TABLE I. BX2L beamline main parameters.

Source	6-poles wiggler ($B = 1.85$ T, $E_c = 2.7$ keV)
Horizontal angular acceptance	2 mrad
Beamline length	35 m
Distance source-first mirror	12.5 m
Distance oscillating mirror sample	13 m
First mirror grazing angle	1.5°
Typical energy range	0.8–3.0 keV

the vertical direction by a double-mirror system realized by means of two gold-coated plane mirrors, whose dimensions are $450 \times 70 \times 25$ mm^3. The gap between their reflecting faces, that do not overlap, is of 13 mm. The two mirrors can be put parallel using registers and kept in this position whenever it is necessary to move the whole system. The grazing angle can vary in the 0°–5° range and the top mirror can make oscillations up to $\pm 0.4°$ around this angle. Our working conditions are a grazing angle of 1.5° and an oscillation of $\pm 0.15°$, in order to obtain a vertical spot size of about 70 mm at the sample.

All movements concerning the oscillating mirror are outside the vacuum system and motions are transmitted through all-metal linkages and bellows. Ionic pumps are placed before and after the mirror box (Fig. 2), which is separated from the beamline by membrane bellows, to be moved up and down, tilted and translated, if necessary. The double-mirror system has the geometrical advantage that the direction of the outgoing beam is the same as the incoming one, in spite of a decrease of the beam intensity due to the second reflection. Using this configuration, exposures are done in vacuum in a dedicated sample box, which also contains a soft x-ray detector for beam calibration.

In the second configuration the vertical scan is performed moving the mask-wafer system by means of an x-ray stepper. In this case the mask-wafer system is in air, and a 12.5-μm Be window put a few millimeters away from the mask surface, keeps the beamline under vacuum. At the moment, the BX2L, is equipped with the stepper MAX-1, supplied by Karl-Suss (Munchen, FRG). It is a prototype that will be used only in a preliminary stage, mainly for x-ray resist photochemistry, not allowing multimask processes and high throughput exposures.

At the end of 1988 the beamline will be equipped with the new stepper XRS-200, shown in Fig. 3, that will be placed in a dedicated laboratory inside a clean room, temperature controlled and vibration proof. The characteristics of this stepper[3] are reported in Table II. The new laboratory will be ready for the first experiments at the beginning of 1989.

II. SPECTRAL CHARACTERISTICS

The spectral flux and the power of the beam in various configurations have been evaluated. Figures 4(a) and 4(b), show, respectively, the spectral flux after the Be window and one mirror reflection, corresponding to the fixed beam configuration, and after the Be window and three mirror reflections, corresponding to the oscillating beam configuration. In both figures the flux incident on the resist after a 2-μm-thick Si mask substrate is also reported.

The total power for the different configurations, reported in Table III, has been evaluated integrating the spectral

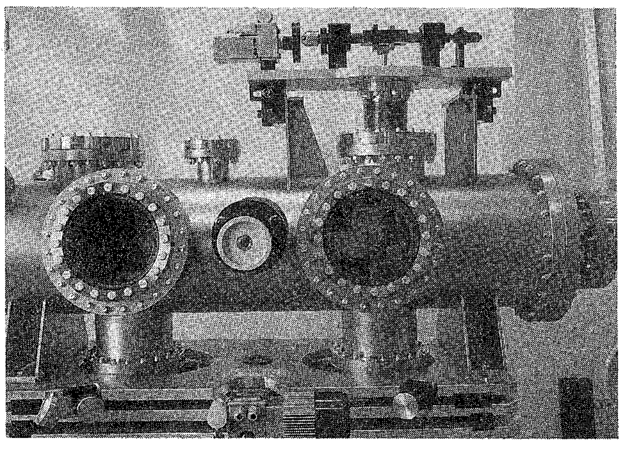

FIG. 2. Mirror box containing the double-mirror oscillating system.

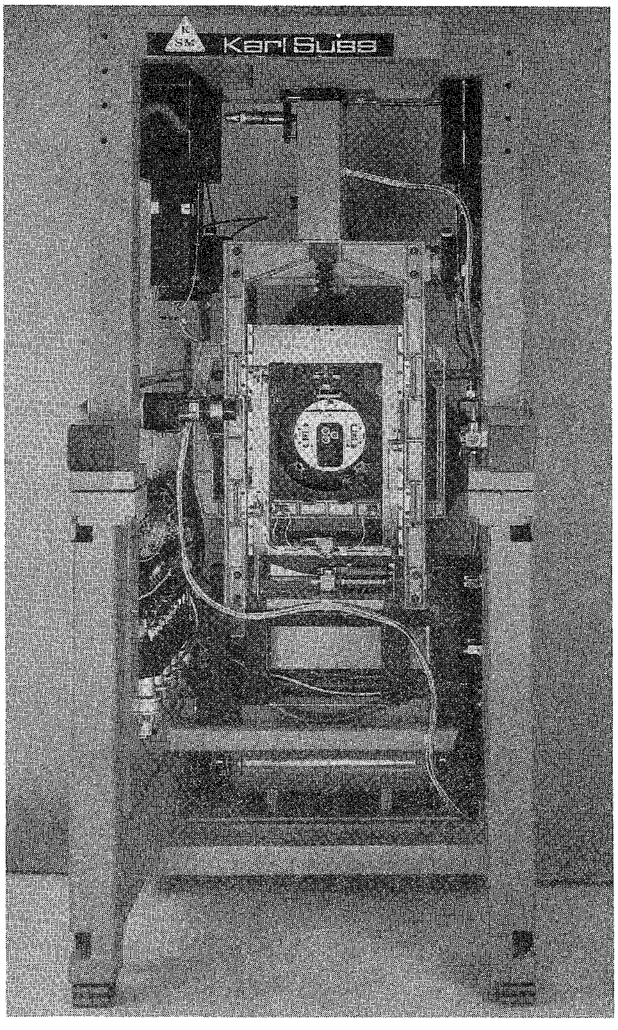

FIG. 3. The x-ray stepper XRS-200.

TABLE II. XRS 200 technical data.

Stepper stage	
Movement range in X and Y	200 mm
Step resolution	0.5 μm
Position control resolution	0.1 μm
Stepping time for one 25-mm field	1 s
Field size	25–45 mm
Printing gap	0–70 μm (typical 40 μm)
Wafer size	50–200 mm
Mask Alignment stage	
X-Y movement range	20 μm
Resolution	10 nm
Z movement range	30 μm
Resolution	20 nm
Scan drive	
Movement range	60 mm
Speed	0.5–20 mm/s

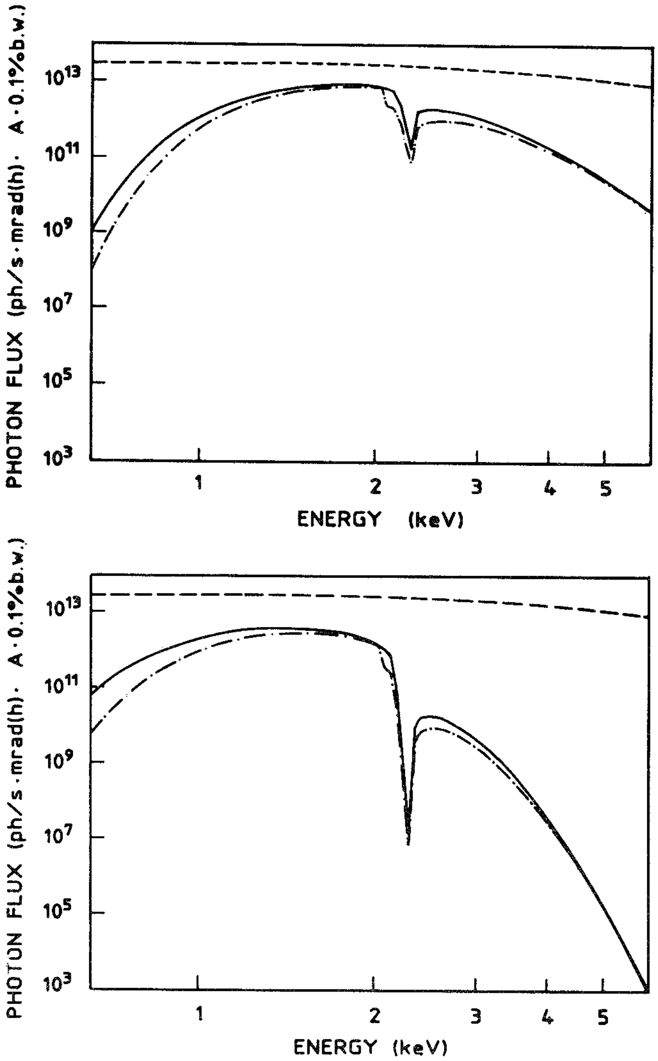

FIG. 4. (a) Spectral flux corresponding to the fixed beam configuration: one mirror reflection and 25-μm Be window (continuous line); spectral flux incident on the resist after 2-μm Si mask substrate (dashed and dotted line); source spectral flux (dashed line). (b) Spectral flux corresponding to the oscillating beam configuration: three mirror reflections and 12.5-μm Be window (continuous line); spectral flux incident on the resist after 2-μm Si mask substrate (dashed and dotted line); source spectral flux (dashed line).

TABLE III. Incident power (P_i) and power absorbed in 1-μm-thick PMMA resist (P_a) in the 0.65–6.0-keV energy range for various configurations: 1 = source; 2 = 1 + 25 μm Be + one mirror refl. 3 = 2 + 2 μm Si; 4 = 1 + 12.5 μm Be + three mirrors refl.; 5 = 4 + 2 μm Si.

Configuration number	P_i (mW/ mA·mrad)	P_i (mW/ mA·cm^2)	P_a (mW/ mA·mrad·μm)
1	111.0	...	...
2	10.1	1.38	...
3	7.3	1.02	0.60
4	3.8	0.53	...
5	2.7	0.38	0.34

power in the 0.65–6.0 keV energy range. The power outside this range being negligible. The mirror reflectivity has been calculated by using the scattering factors reported by Henke *et al.*[4] and extrapolating the real part of the scattering factor up to 6 keV by means of the Kramers–Kronig integral. The mirror surface roughness has been assumed equal to 10 Å rms, as required by the manufacturer. Table III also reports the values of the specific power (mW/mA cm^2) and the power absorbed in a 1-μm-thick poly-methyl-methacrylate (PMMA) x-ray resist.

To evaluate the vertical dimension of the beam, the vertical angular intensity distribution has been calculated assuming a gaussian intensity distribution for each wavelength and making a weighted sum at all the wavelengths for each angle. Figure 5 shows the vertical angular distribution of the beam at the source and after the optical elements in the oscillating beam configuration.

III. CONTRAST AND EXPOSURE TIME

Contrast and exposure time, which are two of the main parameters of the lithographic process, have been evaluated

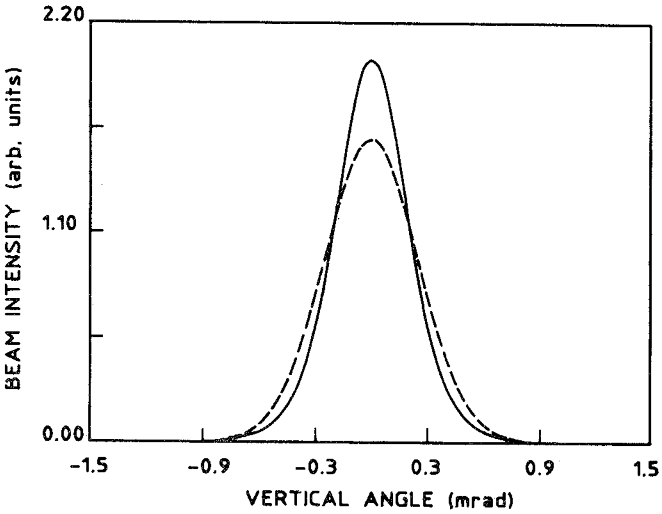

FIG. 5. Vertical angular distribution of the beam intensity at the source (continuous line) and after the optical elements of the oscillating beam configuration (dashed line).

TABLE IV. Exposure time (T_{exp}) and average mask contrast ($\langle C \rangle$), evaluated for the configurations 3 and 5—see Table III—assuming a resist sensitivity of 1000 J/cm^3 and considering a mask with 0.5-μm-thick gold patterns on a 2-μm Si substrate.

Configuration number	T_{exp} (s·mA/cm)	$\langle C \rangle$
3	583	23
5	1029	85

for both beamline configurations and are listed in Table IV. The average mask contrast has been calculated by using the expression reported in Ref. 5 and considering a gold/silicon mask with 0.5-μm-thick gold patterns. To evaluate the exposure time, the sensitivity of the PMMA resist has been assumed equal to 1000 J/cm^3. Contrast is high in both configurations, meaning a good aspect ratio for the replicated patterns. Concerning the exposure time (T_{exp}), the fixed beam configuration gives quite a low value of T_{exp}—of the order of 5 s per vertical cm, with 100 mA of circulating current—and, as a consequence, a reasonable throughput (of the order of 12 wafer/h). In the oscillating beam configuration the exposure time is quite a bit longer and has been realized mainly for research purposes.

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[3]XRS 200 Technical Data, Karl-Suss KG, GmbH & Co., Munchen, FRG.

[4]B. L. Henke, P. Lee, T. J. Tanaka, R. L. Shimabukuro, and B. K. Fujikawa, At. Data Nucl. Data Tables **27**, 1 (1982).

[5]E. Bernieri and A. Balerna (these proceedings).