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Cite as: Review of Scientific Instruments **63**, 764 (1992); https://doi.org/10.1063/1.1142656
Published Online: 04 June 1998

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X-ray lithography at the VEPP-3 storage ring

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(Presented on 16 July 1991)

The paper deals with an x-ray lithography station at the VEPP-3 storage ring of the Institute of Nuclear Physics (Novosibirsk) and some recent results are reported. The utilization of rather high quantum energies is shown not to deteriorate the quality of x-ray replication. The presented work is an extension of the studies that were performed at VEPP-2M [E. S. Gluskin, A. A. Krasnopyorova, G. N. Kulipanov, V. P. Naz'mov, V. F. Pindyurin, A. N. Skrinsky, and V. V. Chesnokov, Nucl. Instrum. Methods **208**, 393 (1983)].

I. INTRODUCTION

The fabrication of microelectronics devices with submicrometer patterns using x-ray lithography covers a broad range of technological problems to be solved. Among them are the technology of x-ray mask fabrication, resist processes, studies on radiation resistance and stability of x-ray masks, the problem of alignment of multilayer structures, and some others.

In 1978 work aimed at solving the above problems was started at the INP on synchrotron radiation (SR) from the storage ring VEPP-2M. After operation shutdown of VEPP-2M for its modernization in 1987 work on x-ray lithography was continued at the storage ring VEPP-3.

In this paper the x-ray lithography station that is currently in operation at VEPP-3 is described. The examples of produced submicrometer patterns illustrating the capabilities of the station are presented. The range of problems that are being solved and to be solved in the near future is considered.

II. RADIATION SOURCE

The VEPP-3 storage ring is widely employed as a radiation source for various SR studies.[1,2] The usual operation mode of the storage ring ($E=2$ GeV, $\lambda_c=2.7$ Å) is not adequate for x-ray lithography experiments because of a considerable hardness of the spectrum which leads both to low contrast of an x-ray mask and to radiation damage of wafers. Therefore x-ray lithography experiments are being performed at decreased electron energy. Table I lists the calculated data on the exposure time and the contrast of an x-ray mask versus the storage ring energy taking the real parameters of the beam line into account.

The P here is the power absorbed in a polymethylmethacrylate (PMMA) resist of 1 μm thickness (the absorption in the beam-line windows and in the x-ray mask membrane described below are taken into account) at 100 mA current in the storage ring. The exposure time t_{exp} was calculated for a PMMA resist with an absorbed dose of 1000 J/cm^3. K_1 and K_2 are the contrast factors of a silicon x-ray mask with an absorbing gold layer of 0.8 and 1 μm thickness, respectively. According to these data, a storage ring energy of 1.2 GeV was chosen for x-ray lithography experiments due to both a short exposure time and still high enough x-ray mask contrast. The uniformity of the exposure area in the vertical direction was achieved via scanning by the SR beam.

III. SR LITHOGRAPHY BEAM LINE

The beam line is schematically shown in Fig. 1. Radiation is extracted from the bending magnet. The distance from the radiation point to the exposure chamber is 10 m. The length of the beam line from the entrance valve to the exposure unit is not large, about 5 m, and therefore the beam line has only a minimal set of elements: vacuum operative and emergency fast closing valves, a radiation shutter, and pumping sections. The beam line also contains Be and kapton windows of 28 and 13 μm thickness, respectively. The 20×8-mm^2 Be window is in the beginning of the beam line and serves to conserve the vacuum in the storage ring in abnormal situations. The kapton window separates the high-vacuum section of the beam line from the exposure chamber filled with helium during the exposure. The vacuum in the beam line is 10^{-6} and 10^{-4} Pa at the beginning and at the end, respectively, and the helium pressure in the chamber is about 130 Pa. Figure 2 demonstrates the SR spectrum transmitted through the beam-line windows and x-ray mask membrane as well as that absorbed in a PMMA resist. The sample area that is uniformly illuminated is 28×8 mm^2 (28 mm in the horizontal and 8 mm in the vertical due to the beam scanning).

TABLE I. Calculated absorbed power P in a PMMA resist of 1 μm thickness, exposure time t_{exp} and contrasts of an x-ray mask with 0.8-μm (K_1) and 1.0-μm (K_2) absorbing gold layers at the lithography station at 100 mA electron current in VEPP-3. E: electron energy; λ_c: critical wavelength; λ_{max}: maximum of absorbed power spectrum.

E (GeV)	λ_c (Å)	λ_{max} (Å)	P (W/cm^2)	t_{exp} (s)	K_1	K_2
1.2	10.0	6.8	5.4×10^{-3}	19	11.7	18.8
1.0	17.2	6.8	1.6×10^{-3}	64	15.1	26.6
0.8	33.6	6.8	1.6×10^{-4}	645	17.2	31.8

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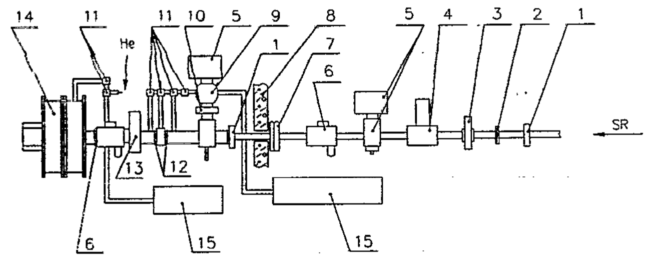

FIG. 1. Layout of the SR beam line. 1,13: operative valve; 2: Be foil; 3: fast vacuum valve; 4: radiation safety shutter; 5: pumping unit; 6: SR shutter; 7: Pb shield; 8: concrete wall; 9: nitrogen trap; 10: manual valve; 11: vacuum valves; 12: filters; 14: exposure unit with stepper; 15: forevacuum pumping system.

IV. EXPOSURE UNIT

This unit has a prototype of the stepper that is being developed at the VOSTOK Company. The basic design ideas of the stepper are tested and verified with this prototype. The unit offers the possibility of exposing in the vacuum or under a helium pressure of a few Torr. The 8×28-mm^2 exposure area can be multiplied over a wafer of up to 100 mm in diameter. The pattern alignment of an x-ray mask and a wafer is made optically using a dual-plane microscope. Its first focus is adjusted to the plane of the x-ray mask, while the second is adjusted to that of the wafer. The gap between them is 30 μm. The x-ray mask and wafer stages are not connected to each other, and the gap is monitored by measuring the capacitance between the wafer and the x-ray mask. The wafer stage can be moved coarsely for a multiplication owing to three step motors. The x-ray mask stage is set in motion by three step motors as well; a special alignment stage with restoring guides provides a motion precision of 30 nm.

The possibility of displaying the alignment targets on the monitor screen with further digital processing is also envisaged in the prototype. For the time being, the alignment is made visually by an operator. The layout of the unit is depicted in Fig. 3.

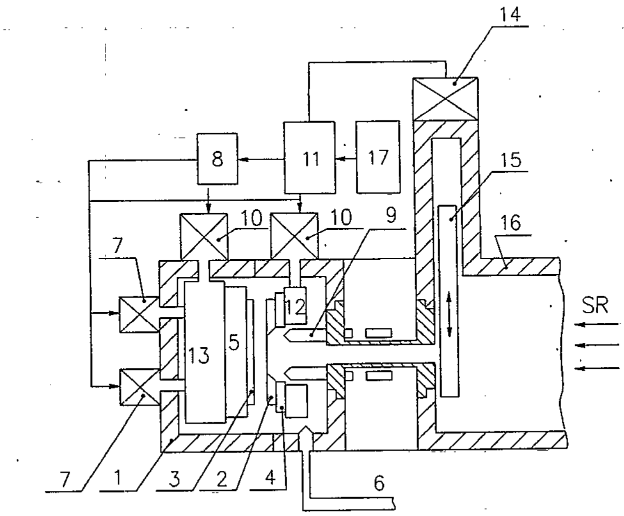

FIG. 3. Layout of the stepper. 1: the chamber; 2: x-ray mask; 3: wafer; 4: x-ray mask holder; 5: wafer holder; 6: pumping and He leak-in system; 7: motors for the microgap set up; 8: electronic unit of the microgap set up; 9: microscope objectives; 10: motor drives for precise movements; 11: control unit; 12: x-ray mask fine stage; 13: wafer stage; 14: drive motor of the shutter; 15: shutter; 16: SR beam line; 17: power supply unit.

V. STATUS AND RESULTS

The range of studies that are being carried out at the station involves the development of the technology of x-ray mask fabrication and testing, the examination of various types of resists, the development with the prototype of the new stepper design, and the development of field-effect transistor technology.

The technology of x-ray mask fabrication is being developed at the VOSTOK Company. X-ray masks now in use have a 2-μm-thick Si membrane with a gold pattern of about 1 μm thickness. Gold is deposited by electroplating through a trilevel resist layer which already has a pattern formed by an E-beam writer. In the target region, the membrane is transparent to visible light. The patterns with vertical walls and with sizes up to 0.2 μm have been fabricated in an x-ray mask. Several types of resists were an-

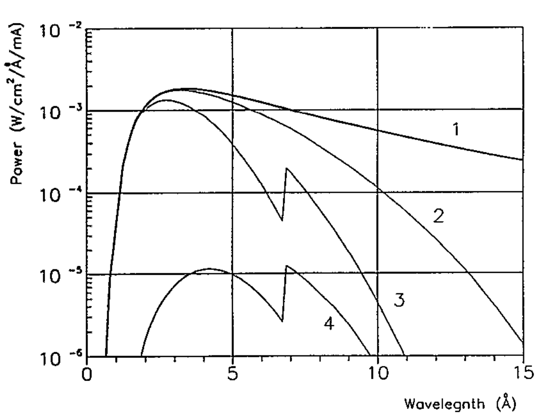

FIG. 2. SR spectra at the lithography station. 1: initial SR beam from the VEPP-3 bending magnet; 2: SR spectrum after Be window; 3: SR spectrum after Be and kapton windows and Si membrane; 4: x-ray power absorbed in 1.0-μm-thick PMMA.

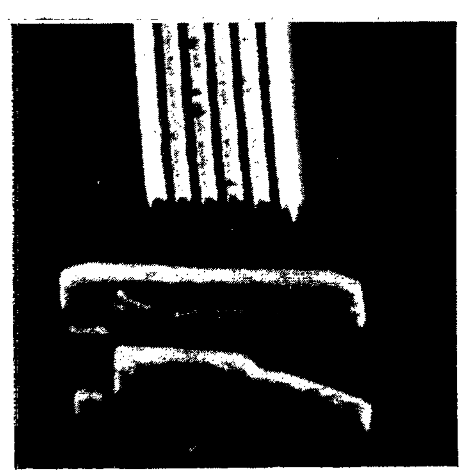

FIG. 4. The test pattern of 0.4-μm linewidth in a 1.2-μm-thick resist.

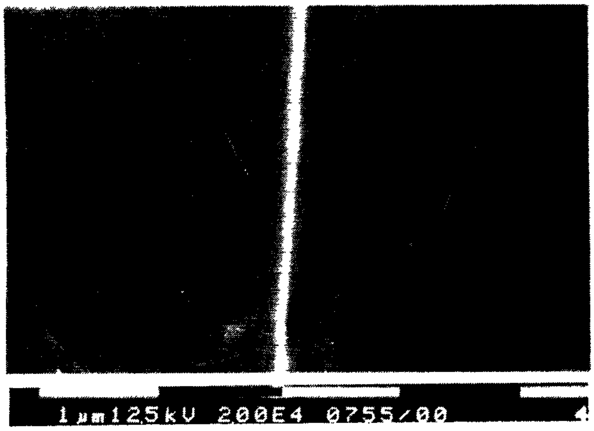

FIG. 5. The gap in a resist of 0.24-μm width and 1.2-μm height.

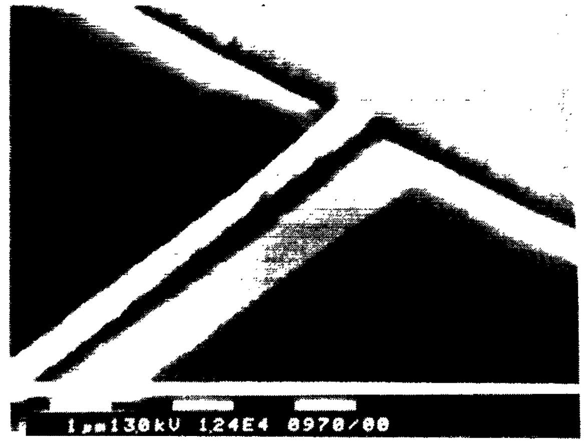

FIG. 6. The 0.24-μm gate in a transistor.

alyzed using synchrotron radiation from the point of view of the replication of submicrometer patterns. As an illustration, we show the replications of the test pattern with a 0.4-μm linewidth and 1.2-μm height on a resist ERP-40 (Fig. 4) and the 0.24-μm single gap in a 1.2-μm-thick resist (Fig. 5). Good verticality of the walls and precise replication of the x-ray mask dimensions may be noted.

Now we undertake efforts in the development of field-effect transistors with 0.2–0.3 μm gate length as a particular submicrometer device. Figure 6 demonstrates such a gate made from metal. The prototype of the stepper has an alignment accuracy that is not high but quite satisfactory for these purposes (about 0.3 μm).

VI. CONCLUSIONS

After putting the VEPP-4 storage ring into operation, VEPP-3 will serve as a booster for it, thereby limiting the time of its operation for SR experiments. The studies on x-ray lithography are expected to be restarted again at VEPP-2M this year (at present this storage ring is being put into operation after its reconstruction). Instead of the prototype, a new stepper will be mounted at the x-ray lithography station of VEPP-2M. This stepper is expected to provide an alignment accuracy of up to 0.1 μm. Such a stepper will enable us to extend the range of problems that can be solved and to begin to develop the fabrication procedures for multilayer devices.

[1] G. N. Kulipanov, in *Proceedings of the 6th All-Union Meeting on Utilization of Synchrotron Radiation SR-84, Novosibirsk, 1984*, edited by G. N. Kulipanov (INP, Novosibirsk, 1984), p. 4 (in Russian).

[2] *Catalogue of High-Energy Accelerators*, Revised Version, XIVth International Conference on High Energy Accelerators, compiled by S. Kurokawa (S. N. Tsukuba, 1989), p. 93.