ACCELERATOR PROGRAM

A.1 Soft and deep X-ray lithography (SDXRL) beamline on Indus-2

Synchrotron radiation sources, with their high brightness and high photon flux, are useful for high spatial resolution (~100nm) X-ray lithography (E~1.5keV) and for the fabrication of high aspect ratio (~100-1000) three-dimensional structures (E ~ 4-20keV). It is proposed to install soft and deep X-ray lithography (SDXRL) beamline on Indus-2. Application includes, the fabrication of hard X-ray optics, micro machining devices, photonic band-gap crystals, quantum wires and quantum dots devices, 3D microstructures, and MEMS related sub-components. Optical design of the beamline is completed [CAT-2004–12].

***Fig A.1.1** Optical design of SDXRL beamline on Indus-2*

Optical layout of the SDXRL beamline is shown in fig. A.1.1. The beamline can also operate in no optics mode, with mirrors moved out of the beam path. The beamline optical elements consist of a plane mirror and a torroidal mirror. The angle of incidence on these mirrors, in combination with the filters defines the energy window. Energy spectra at various incidence angles and in no optics mode are shown in fig. A.1.2. The horizontal and vertical acceptances of the beamline are 5mrad and 1mrad respectively. Beamline performance is optimized on the following parameters: run out error (< ± 2.1mrad), penumbral blur (< ± 0.8mrad), power delivered at wafer location (5-75 mW), beam size at sample/mask (55 (H) x 2 (V)mm^2) and horizontal intensity uniformity (< ±3%). Detailed ray tracing calculations of the beamline optics are done using software packages RAY and SHADOW and power calculations are done using XOP modules.

Using the beam line configuration with mirror(s) angle $\theta_1 = 1.7^0$ and $\theta_2 = 1.75^0$) aerial image formed at mask-wafer stage is shown in fig. A.1.3. Beam size is enlarged at mask-wafer stage by scanning X-ray stepper/scanner in vertical direction. Considering beamline acceptance and performance, mirror sizes are limited to 100mm (width) and 750mm (length). Surface roughness values of 3Å, 5Å and 10Å for mirrors are used to study its effect on image at the mask-wafer stage. Effect of slope errors (0 to 271μrad) in meridional plane, on beam image are simulated. Torroidal mirror misalignments (0-1000 mm in translation and 0 to 207 seconds in rotation) and their effects on beam shape and size are simulated.

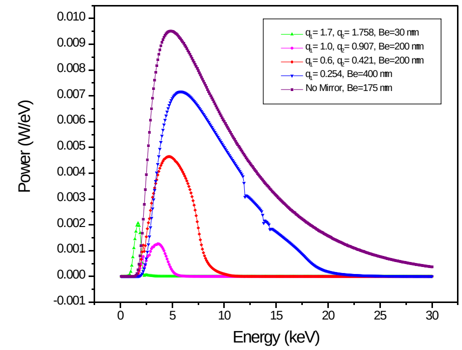

***Fig. A.1.2** Energy-power spectrums offered by SDXRL beamline for various mirror angle settings*

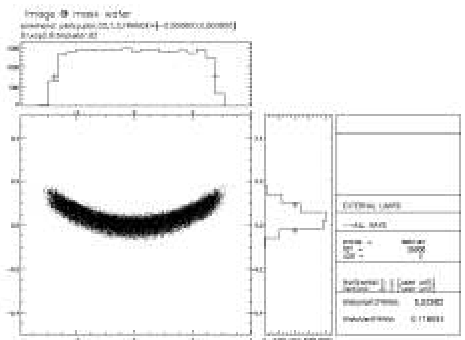

***Fig. A.1.3** Spot diagram of beam image at mask wafer stage grazing incidence angles of plane mirror ($\theta_1 = 1.7^0$) and torroidal mirror ($\theta_2 = 1.75^0$).*

The calculations are done by considering 300mA beam stored in Indus-2 storage ring at 2.5GeV with 5mrad horizontal acceptance and vertically integrated power.

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A.2 Growth of CuO and FeO nanorods

Quasi one-dimensional nanostructures, such as nanowires and nanorods have attracted great attention during past few years due to their unique physical, chemical and electronic properties and for their potential applications in the field of nanodevices, field-emitters, and catalysts. For commercial exploitation of these nanoscale structures, it is necessary that the technique used for their growth is reproducible and simple, which still remains a challenge. CuO is an indirect band semiconductor and its nanorods exhibit large field emission and catalytic properties. Over the past couple of years nanorods of CuO have been produced by various techniques. We have carried out the synthesis of CuO and FeO nanorods by annealing a commercial grade Cu and Fe foil in oxygen atmosphere at high temperature. Our detailed investigations reveal that *(a)* the aspect ratio (the ratio of length to diameter of the nanorod) and density (number of nanorods per unit area) critically depends on the growth conditions, like the oxygen flow rate, annealing temperature, annealing time, *etc.* and *(b)* the growth of nanorods proceeds in three steps. During the initial stages of annealing of foil under the optimized growth condition results in the formation of hills and valley structure, which is due to the anisotropic surface diffusion of oxygen atoms. The CuO nanorods grow only in the valleys while on the hills only sparse growth of very small nanorods is observed. In the second step, a porous structure is formed in the oxide film. The pores have pyramid structure and act as the nucleation sites for the growth of the nanorods. The nanorods grow from these pyramids due to the relaxation of stress accumulated in them during the process of annealing.

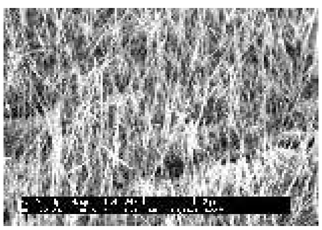

Fig. A.2.1 *CuO nanorods grown on Cu foil*

Fig. A.2.2 *FeO nanorods grown on Fe foil*

The CuO nanorods produced by this method are almost unidirectional with high aspect ratio as is evident from the scanning electron micrograph shown in fig. A.2.1; the average length and diameter of these nanorods are ~7μm and ~110nm, respectively. Further, the growth of these nanorods is perpendicular to the substrate (foil) and they almost uniformly cover the complete area of the substrate. FeO nanorods also grows perpendicular to the foil (fig. A.2.2). The aspect ratio of these nanorods with respect to annealing temperature, time and oxygen flow is yet to be optimized.

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A.3 Development of front-end components for Indus-2 beam lines

A font-end is a device, which is placed in between a beam line and a dipole chamber from where synchrotron radiation (SR) is tapped. It is basically a set of ultra high vacuum components with associated controls and interlocks. The main functions of front-end are:

Protection of storage ring vacuum from any vacuum leaks from a beam line.

Absorption of heat load and radiation when a beam line is not in operation.

Defining the maximum excursion of the X-ray beam, so that the beam does not strike any uncooled surface along beamline

Establishing the photon beam position including its average take-off angle.

Filter out soft X-rays and isolate beamline vacuum from the vacuum of front-end using a beryllium window.

The following components of the front-end are designed and fabricated:

1. Collimator (CM)

Collimator is the first active component to interact with beam in the front end. The collimator is a beam-defining aperture made of OFE copper solid block with rectangular tapered hole along its central axis coinciding with the beam axis. Collimator will receive around 24mrad of beam out of which only 7mrad beam will pass through it resulting in heating the collimator block by a heat load of around 420 watts. Water cooling channels of diameter 6.3 mm are drilled along and across the aperture to avoid direct vacuum – water joints. Copper block is vacuum brazed with two S.S. conflat flanges at the ends by means of brazing alloy BVAG8 foils.

2. Photon beam absorber (BA)

The photon beam shutter completely intercepts the SR beam in the closed position. It is designed to absorb the full thermal power of the beam to isolate downstream components from the thermal load of X-ray source. The time necessary to close this shutter is few seconds. A Cu tube is brazed over the plate and taken out through a conflat flange such that there is no direct vacuum to water joint. The shutter block can be moved up and down inside a vacuum chamber by means of a pneumatic cylinder through a solenoid valve.

Fig. A.3.1 *Prototype front end*