Indus-2 Synchrotron Radiation Source: current status and utilization.

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Abstract. Indus Synchrotron Radiation complex at Raja Ramanna Centre for Advanced Technology at Indore, India houses two synchrotron radiation sources: Indus-1 and Indus-2. Indus-1 is a 450 MeV source emitting in VUV/soft x-ray region and operating at 100 mA since 1999. Indus-2 is designed for 2.5 GeV, 300 mA operation and is operating at 2 GeV and 100 mA since March 2010 in 24x7 mode and a beam lifetime of about 22 hrs has been achieved. Operation at 2.5 GeV and 100 mA has recently been demonstrated with the addition of in-house developed solid state RF amplifiers. Indus-2 can accommodate 21 bending magnet (BM) and 5 insertion device (ID) beamlines. Sixteen BM beamlines have been planned and six BM beamlines namely i) Angle Dispersive XRD ii) Energy dispersive XRD iii) Energy dispersive EXAFS iv) Soft and deep x-ray lithography v) X-ray fluorescence micro-probe and vi) X-ray photoelectron spectroscopy beamlines have been commissioned. These are being used by researchers from different universities, national institutes and laboratories for carrying out several investigations. Two more beamlines namely ‘Grazing incidence x-ray scattering’ and ‘Protein crystallography’ are nearing commissioning. A number of materials research related problems have been investigated using these beamlines and several papers have already been published. Here we will report on the current status of the source, details of the beamlines already operational, beamlines to be commissioned soon and several upgradation schemes that are being planned. Five IDs consisting of two soft x-ray planar undulators, one superconducting wavelength shifter / wiggler, one APPLE II soft x-ray helical undulator and one hard x-ray undulator will be installed during the next few years. Three new ID based beamlines for Atomic and Molecular physics, Angle integrated / Angle resolved PES and Magnetic Circular Dichroism experiments will be commissioned.

1. Introduction

Synchrotron Radiation (SR) is emitted by charged particles travelling in curved trajectories at relativistic speed and has emerged as a highly important tool for basic and applied research in physics, chemistry, biology and industry. More than 80 SR sources are currently operating across the world and in India two dedicated synchrotron sources Indus-1 and Indus-2 have been built at the Raja Ramanna Centre for Advanced Technology, Indore. Indus-1 is a 450 MeV source with critical wavelength of 61Å, designed current of 100 mA and lifetime of 1.8 hrs. This was commissioned and made available for beamline installation by early 2000 [1]. On the other hand Indus-2 is a 2.5 GeV electron energy source with critical wavelength of ≈ 2 Å, designed beam current of 300 mA and a lifetime of ≈ 24 hrs. The first light was observed in December 2005 and presently it has been operating at 2.5 GeV and 100 mA. It can accommodate a total of 21 Bending Magnet (BM) beamlines and 5 Insertion Device (ID) beamlines, out of which six BM beamlines are operational, and seven more BM beamlines are in advanced stage of installation. In this paper we describe in detail the current status of the storage ring, the different beamlines and their utilization. We also discuss about the planned upgradation in the storage ring and the beamlines.

2. Indus-2 source

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The storage ring consists of 8 unit cells each, with 4.5 m Long Straight Section (LSS) and consists of two 22.5° bending magnets, several quadrupole and sextupole magnets. Both Indus-1 and Indus-2 are injected using a common 20 MeV Microtron and a 450-700 MeV Booster synchrotron. The RF system required to replenish the energy lost by the electron beam consists of four cavities to be powered by four stations excited by 64 kW RF power from klystron sources and the operating frequency of the RF system is 505.812 MHz. The first light from the storage ring was observed in December 2005 and round the clock operation was started in February 2010 and operation at 2 GeV and 100 mA beam current was achieved in March 2010. Since only two of the klystrons were functional, Indus-2 operation was restricted to 2 GeV and 100 mA. Due to continuous operation the vacuum in the ring improved to better than 1x 10^{-9} mbar and with application of closed orbit distortion correction the beam lifetime has improved from 0.5 hrs in March 2010 to 23 hrs in December 2011 as shown in figure 1. Due to the unavailability of klystrons, the RF Systems Division have indigenously developed solid state RF amplifiers of 20 kW and 30 kW power which have been deployed for Indus-2 operation. With the support of these RF amplifiers, Indus-2 operation have been enhanced to 2.5 GeV and 100 mA beam current in December 2011[2].

3. Indus-2 beamlines and their utilization

Indus-2 can accommodate 21 BM beamlines and 5 ID beamlines. Currently, a total of 16 BM beamlines have been planned and 6 beamlines are operational. Two beamlines are nearing commissioning and five other beamlines are in an advanced stage of installation and expected to be operational by 2013. The Indus-2 beamline layout is shown in figure 2 and Table I lists the primary specifications of six operational beamlines.

The Dispersive EXAFS (DEXAFS) beamline was the first to be commissioned and consists of a Rh coated cylindrical mirror and 460 mm long Si(111) crystal mounted on an elliptical bender which focuses the ‘pink’ x-ray beam to a spot of 200 μm x 400 μm on the sample. The transmitted intensity representing the EXAFS spectrum is recorded using an x-ray CCD camera with an energy resolution of ≈ 1 eV at 10 keV [3]. Many users from universities, national research laboratories and institutes have used the beamline for investigation of a wide variety of problems like determination of structural parameters of metal-organic Cu complexes at the Cu K-edge[4], Eu³⁺ assisted structural collapse of GaOOH nanorods [5], study of local structural changes in ZrO₂ due to Nd, La, Gd doping[6] among others.
An Angle Dispersive XRD (ADXRD) beamline has been installed and commissioned and it covers an energy range of 5 – 25 keV and consists of a bendable cylindrical Pt coated Si pre and post mirrors, a Double Crystal Monochromator (DCM) with a pair of Si(311) crystals. The beam can be focused to a spot size of 0.6 mm x 0.5 mm using bendable second crystal of DCM and the bendable mirrors. The experimental station consists of a six circle Huber 5020 diffractometer and a MAR 345 Image plate. A high pressure facility for carrying out measurements in Diamond Anvil Cell (DAC) and a liquid He cryostat for material station consists of a six circle Huber 5020 diffractometer and a MAR 345 Image plate. A high pressure size of 0.6 mm x 0.5 mm using bendable second crystal of DCM and the bendable mirrors. The experimental station consists of a six circle Huber 5020 diffractometer and a MAR 345 Image plate. A high pressure facility for carrying out measurements in Diamond Anvil Cell (DAC) and a liquid He cryostat for measurements over 3 – 400 K have been commissioned. Several studies have been carried out using this ADXRD beamline and we discuss results on effect of annealing on the microstructure and magnetic properties of soft magnetic Fe40.5Co40.5Nb7B12 amorphous alloys [7]. The samples were isochronically annealed for ~1 hr from 300 to 973 K and XRD pattern recorded using 15 keV X-ray shows broad diffraction pattern characteristic of amorphous phase which transforms to nano crystalline pattern. For temperature > 450°C the sample consists of α and α’-(Fe-Co) nanocrystalline phases dispersed in remaining amorphous matrix. Further, anomalous XRD at Fe K-edge (7.112 keV) has been used to distinguish between the ordered ferromagnetic α’-(Fe-Co) alloy from the disordered α-(Fe-Co) alloy. The presence of the (100) superlattice reflection suggests the formation of atomically ordered α’-(Fe-Co) nano crystalline phase.

The Energy Dispersive XRD (EDXRD) accepts the full white synchrotron beam ranging from 5 to 40 keV at 2.5 GeV and is primarily meant for high pressure XRD measurements in Diamond Anvil Cell. It is equipped with a Ruby fluorescence setup for pressure calibration. The spot size can be varied from 8 mm x 8 mm to 100 μm x 100 μm and the XRD pattern is recorded with a HP Ge detector with an overall energy resolution of ~100. It has been used to carry out high pressure measurements on several compounds upto ~ 25 GPa, grazing incidence diffraction from Co thin film deposited on CoO with q vector in and perpendicular to the thin film plane [8] and in-plane diffraction study of melting in Cd-arachidate LB thin films.

The microprobe X-Ray Fluorescence (μ-XRF) beamline covers an energy range of 5-20 keV and the X-ray beam can be focused to a spot size of ~5 x 7.5 μm using a KB mirror, allowing recording of selected area element-specific fluorescent image from spatially in-homogeneous sample. It can also be used in the macro mode for conventional XRF sample analysis and also in total reflection XRF (TXRF) mode for ultrasensitive detection [9]. This beamline has been used to calibrate detector for the Indian Lunar mission “Chandrayan-1” using lunar stimulant sample JSC-1A. The beamline in micro-focus scanning mode has
been used to obtain the distribution of Pb, Fe, Ni and Co over the cross-sectional area of coating in archaeological tile samples collected from the St. Augustine church of old Goa (India).

A Soft and Deep X-ray Lithography (SDXRL) beamline to undertake microfabrication research has been designed, installed and commissioned and it covers an energy range of 1.5 keV to 20 keV which can be operated in ‘pink beam’ mode using two mirrors. The x-ray beam is ribbon shaped with size \(\approx 70 \text{ mm}(H) \times 10 \text{ mm}(V)\). For the fabrication of three dimensional high aspect ratio (few hundred) structures with minimum feature size of few microns, a custom built x-ray scanner is installed as an experimental station. As test experiments, the beamline has been used for the fabrication of few micro fluidic devices, compound x-ray refractive lenses, micro pillars and test patterns with minimum feature size of 15 \(\mu\text{m}\) and aspect ratio of about 40. The structures are fabricated in PMMA and SU8 photo resists.

The X-ray Photoelectron Spectroscopy (XPS) beamline consists of a homemade Si(111) DCM, an indigenous Hemispherical Analyzer (HSA). Test XPS spectrum on Au has been recorded using 5 keV x-ray. The resolution obtained requires considerable improvement and efforts are going on to optimize the resolution of DCM and HSA.

4. Future plans
The Indus-2 performance will be enhanced by replacing all the klystrons with solid state RF amplifiers of 50 kW each, application of fast orbit correction and gradual increase of the beam current to 200 mA and more. It is also planned to install 5 Insertion Devices (IDs). Out of these three are undulators for installation of i) Atomic Molecular and Optical Sciences ii) Angle Integrated/ Resolved Photoelectron Spectroscopy and iii) Magnetic Circular Dichroism beamlines, one superconducting wavelength shifter for the EDXRD beamline and one hard x-ray undulator for Protein Crystallography beamline.

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