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Imaging in Real and Reciprocal Space at the Diamond Beamline I13

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Abstract. The Diamond Imaging and Coherence beamline I13 consists of two independent branchlines for imaging in real and reciprocal space. Different microscopies are available providing a range of spatial resolution from 5µm to potentially 5nm. The beamline operates in the energy range of 6-35keV covering different scientific areas such as biomedicine, materials science and geophysics. Several original devices have been developed at the beamline, such as the EXCALIBUR photon counting detector and the combined robot arms for coherent X-ray diffraction.

Keywords: Imaging, Coherence, In-line phase contrast, Microscopy, Synchrotron
PACS: 07.85, 41.50,41.85,42.25, 42.30

INTRODUCTION

The Diamond beamline I13 for imaging and coherence consists of two independent operating branchlines (see figure 1). The experimental stations host microscopy techniques for science on the micro- and nano-lengthscale.

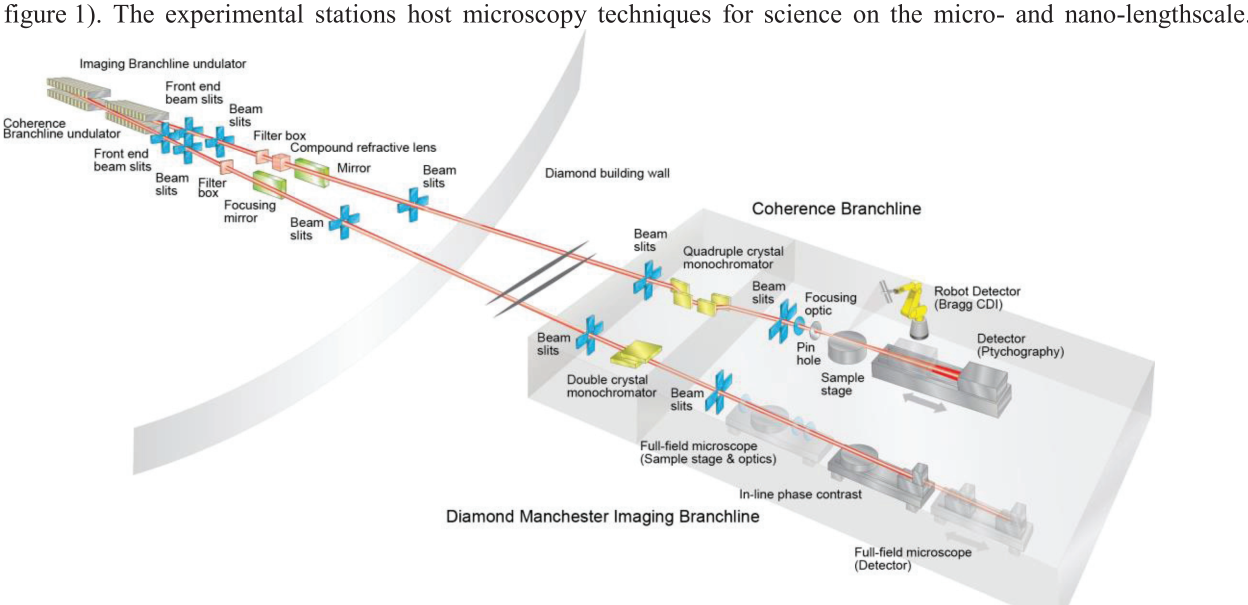

FIGURE 1: Schematic of the Diamond Coherence and Imaging beamline I13. The distance from the source to the experimental table is about 220m, the length of the experimental hutches are 15 and 20m (Diamond.-Manchester Imaging and Coherence Branchline).

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The imaging branch, also called the Diamond-Manchester Imaging branchline provides imaging in real space namely for in-line phase contrast imaging and full-field microscopy. More recent coherent imaging techniques such as ptychography and coherent X-ray diffraction have been developed on the coherence branch in collaboration with other teams. Because of the availability of large lateral coherence, this long beamline has been applied for numerous other microsopy experiments.

DIAMOND-MANCHESTER IMAGING BRANCHLINE

The Diamond Manchester Imaging branchline has been operational since April 2012. Predominantly in-line phase contrast imaging has been employed, while a full-field microscope has been developed in parallel. Specific details of the beamline layout have been described elsewhere[1-6]. The modification of the storage ring to the so-called ‘mini-beta’ layout provides one order in flux increase compared to a standard long straight section because of the minimized undulator gap[7]. Currently we are using a 2m long U23 insertion device, providing about 10^{12}ph/s at 10 keV. For the future a cryo-cooled device is planned, enhancing the beamline capabilities in particular in the energy range above 25keV. The beamsize is controlled by sets of slits, the energy width by the combination of different sets of X-ray filters and the reflecting strip of the X-ray mirror. The operation mode using only filters and the mirror is called ‘pink-beam’. Further a double crystal Si (111) monochromator can be inserted in the beam for element specific measurements. In the near future, a multilayer monochromator will be installed, providing an energy bandwith of $\Delta E/E=10^{-2}$.

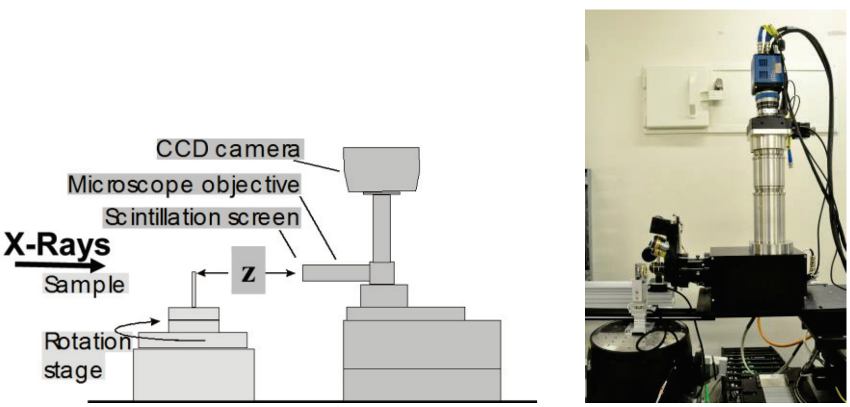

FIGURE 2: Scheme for in-line phase contrast imaging setup at the Diamond-Manchester Imaging branchline.

The experimental station for in-line phase contrast imaging is located 220m from the source. It consists of a high precision air-bearing rotation stage (about 25nm run out) for the sample and a detector stage which can be translated over a distance of 2 meters. The detector system consists of scintillation screen coupled through a microscope optic to the detector. Objective lenses and scintillation screens are fixed units and can be rapidly changed and focused with a revolver system. The different combinations of scintillation screens and objective lenses cover the resolution range between 5 to 1 microns and the field of view range of about 9x6mm^2 to 1x1mm^2. The detectors available for different applications are PCO4000, PCO.edge, PCO.dimax (note: the latter is equipped with a slightly different optical system). More details can be found elsewhere[1,4].

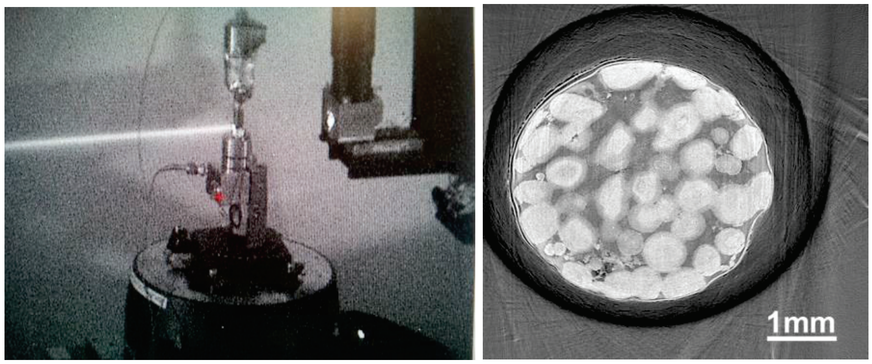

FIGURE 3: ‘Pink-beam’ imaging with the PCO.dimax detector system (left) for time-dependent experiments. Right side: Reconstructed slice, showing the solution of supercritical CO_2 in brine and sandstone (experiment B. Bijeljic, M. Andrew, Imperial College London).

Currently bio-medical and engineering/materials science applications are the most popular, while geo-physical (see figure 3) experiments have also been carried out with great success[8-11]. Mainly pink beam is used with filtering towards higher photon energies for materials science experiments. Tomographic scans can now be performed in as little as 4 seconds and will be further improved. Especially for bio-medical applications, in-line phase contrast provides an essential improvement for weakly absorbing structures in special sample environments. For example when measuring cartilage in buffer solution, structures become reasonably visible when extending the detector-sample distance to its full range (2m).

The beamline closely collaborates with Manchester University which supports funding and operation of the imaging branch. The collaboration is enhanced by the strong Manchester presence on the Harwell campus and their expertise in custom made sample environments such as stress rigs, cold chambers, furnaces etc..

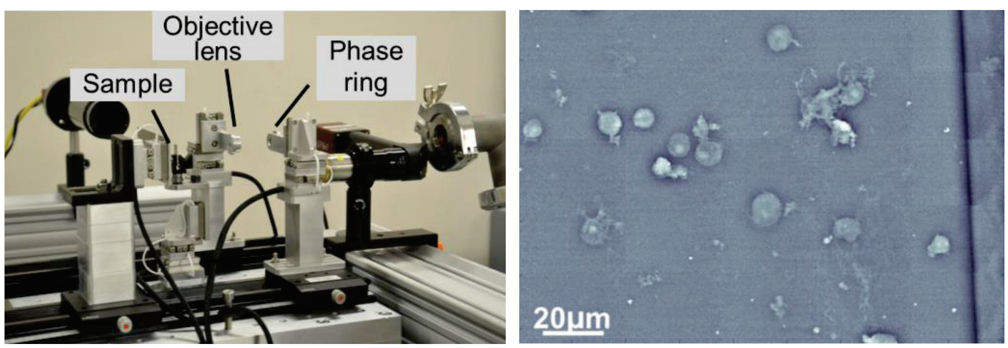

FIGURE 4: Full-field microscope with Zernike phase contrast (left). The detector is placed on a separate rail at several meters distance. Right: Radiograph of chromosomes with Zernike phase contrast. Several images are stitched to increase the field of view (Experiment: Y. Mohammed, I.K. Robinson, UCL; data stitching J. Vila-Comamala).

For resolution beyond the limitation of the detector system, a full-field microscope is currently tested and implemented on the beamline (see figure 4 and also article J. Vila of the current conference proceedings[12]). The instrument will achieve typically 50-100nm spatial resolution over a large field of view in the order of 100microns. A large working distance enables the setup to be used with customized sample environments. For weakly absorbing samples Zernike phase contrast is available. The main X-ray optics employed are Fresnel-Zone plates for the objective lens and a so-called ‘beam-shaper’ as condenser optic. The latter can in particular provide a large field of view. The instrument will operate mainly between 8-14keV, again targeting bio-medical and materials science applications. The project is carried out in collaboration with PSI (C. David, J. Bosgra).

COHERENCE BRANCH

The coherence branch focusses in particular on the development and implementation of imaging techniques in reciprocal space[13], but also hosts numerous microscopy experiments requiring large lateral coherence lengths[14-16]. At 8keV photon energy the beam can be considered fully coherent in the vertical direction. In the horizontal direction the coherence length can be adapted by slits installed in the front-end. Again the mini-beta layout plays a role, since the electron beam can be focused on the location of these slits and so the X-ray beam, creating a virtual source[7]. Similar to the imaging branch layout filters, the mirror and monochromator can be used for adjusting the X-ray beam. All optics are horizontally deflecting, preserving the coherence in the vertical direction[5].

The experimental station uses either a KB mirror system or Fresnel-Zone plates (FZP) to focus the X-rays on the sample. The focus size varies between 5µm, (KB) and 100nm. The sample stage –similar to the one at the imaging branch- consists of a stack of elevation, tilt and rotation stages[6]. In the forward direction two detector positions are available. On a long translation rail the detector can be moved in particular for ptychography experiments. For coherent X-ray diffraction experiments, the detector can be placed on a robot arm (see figure 5). This robot arm is moved in coordination with a second robot arm which holds a vacuum tube in front of the detector. For this purpose custom made software has been purchased. The (thermal) stability of the robot arms has been tested extensively in the past and the drift is found to be about 5µm/24h under realistic conditions[6]. This is sufficient for operating with the EXCALIBUR detector, which has 55 µm pixel size. The latter is a photon counting device based on the MediPixIII chip[17].

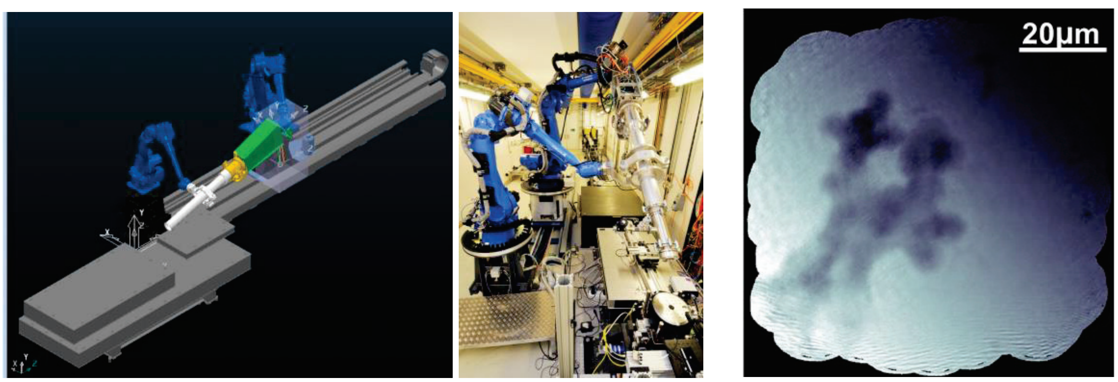

FIGURE 5: Left and middle: Scheme (sideview) and photo (frontview) of robot setup for coherent X-ray diffraction experiments on the coherence branch station. Detector (green) and vacuum pipe (white) are jointly supported by two robot arms. Right: From ptychographic data reconstructed phase information for a chromosome sample (Experiment Y. Mohammed, I.K. Robinson, UCL, data reconstruction A. Parsons).

SUMMARY

The Diamond Imaging and Coherence beamline I13 provides imaging capabilities on the micro- and nano-lengthscale. The two independent operating branches host techniques in real and reciprocal space. The beamline can be regarded as an 'extended workbench' for scientific applications from different areas such as bio-medicine, materials science and geo-physics. The use of techniques will be driven by the scientific questions and is especially of benefit for the more recently developed methods such as ptychography and Coherent X-ray diffraction. The Diamond-Manchester collaboration enhances the scientific portfolio and capabilities of the beamline.

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