	<p><b>UPGRADE PROGRAMME – PHASE I</b></p> <p><b><u>CONCEPTUAL DESIGN REPORT</u></b></p>
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<b>BM05, Optics</b>	
Current designated sector:	Facility goes to:
BM05	BM05

**1.1 ID CARD**

BM05 serves as a test and development station of X-ray optical elements and detectors. The proposals submitted include the characterisation of X-ray optical configurations for the ESRF upgrade, in particular for ID19 UPBL5, and the development of an experimental station for manufacturing X-ray mirrors using at-wavelength and X-ray in-situ metrology methods. Manufacturing methods include ion beam profiling and sputter differential deposition. Metrology methods include X-ray shearing and speckle interferometry to evaluate the mirror surface figure, and X-ray reflectometry and diffuse scattering techniques to evaluate the density depth profile and the surface roughness. Until UPBL5 is completed, BM05 will continue performing Bragg diffraction and microtomography related imaging experiments.

**1.2 SCIENTIFIC CASE**

Beamline BM05 has presently a double identity: i) on one side, it is an X-ray imaging beamline providing instrumentation for Bragg diffraction related imaging and a micro tomography setup, ii) on the other side, it is a test and development station for characterising beam properties, X-ray optical elements and novel instrumentation and X-ray techniques. This CDR proposes to continue contributing in these areas, whilst evolving in order to address the new challenges generated by the ESRF upgrade program, particularly in the fields of optics and detectors. Three directions are envisaged for the future:

a) BM05 has been equipped since 2008 with instruments to perform parallel beam imaging experiments, which provides a unique opportunity to develop the optics and instrumentation prototypes needed for the **UPBL5 project** to be implemented later on in the new hutches of ID19. This strategy will allow novel optics concepts to be validated while reducing the downtime of the user programme at these beamlines. The UPBL5 instrumentation and prototypes will eventually move to ID17-19 once the radiation tests of the new hutches have been completed.

b) Early characterisation of optical elements and of detectors will probably be very useful to other UPBLs as well. Moreover, the proposed re-shuffling of the beamlines around the ring may delay for a while the creation of an ID beamline for high flux, heat load and micro-optics tests within the ISD Division. In contrast, BM05, not planned to move to another location, is readily available. However, as a

**general test facility, BM05** needs several upgrades to maintain the beamline at the state-of-the-art, to improve its efficiency and to cope with the near-future machine specifications. Eventually, the demonstrated flexibility of BM05, furnished with versatile instrumentation and providing a large and stable beam, will advantageously and naturally complement an ID beamline for X-ray characterisation and testing within the ISD Division. Interaction is particularly expected with the Optics and Detector Groups.

c) Many projects of the ESRF Upgrade Programme base their ultimate results on the availability of layer- and multilayer-coated aspherical X-ray mirrors pushed to diffraction-limited performances, components that are not readily available from commercial companies. This observation motivates the **OPTICX platform** based upon the OPTICS project presented in the Purple Book (vol. 2, p. 78) aiming at providing mirror substrates with a figure providing nanofocusing performance and a surface finish compatible with the growth of nanometre thin-films and multilayers. Such coatings are needed to increase the numerical aperture of the optics, thus lowering the diffraction limit barrier. The OPTICX platform would merge the ESRF know-how in surface metrology (reflectometry and diffuse scattering on surfaces, thin-films and multilayers, shearing and speckle interferometry) and in substrate profiling (ion beam figuring and differential deposition).

### 1.3 PROJECT HISTORY

a) The presence at the beginning of the ESRF of the bending magnet beamline BM05 dedicated to test and development proved to be extremely fecund. It helped to investigate new techniques and methods that eventually prospered at ID beamlines: phase contrast imaging, angiography, topography and tomography, microfocusing, high-resolution and high-energy diffraction, to name a few. At the dawn of the ESRF Upgrade, the concept of such success stories should be revived, as new ideas will require experimental verification and will almost certainly need further refinements. There are cases where an ID beamline with high brilliance and photon flux will be mandatory. In other cases, a BM beamline with characteristics such as beam stability and low intensity may help to disentangle problems related to the physics of the sample or the method from heat load issues and distortions induced by temperature gradients. The possibility of generating a broad beam and of delivering white beam radiation in any of the hutches is also attractive, e.g., for evaluating crystal-based optical elements by topography.

b) The plan to test components, in particular optical ones, for the future UPBL5 at BM05 is based on the fact that the added performance of the UPBL5 project is mostly based on a new optical concept. The risk factor of the project, which can be partly mitigated by BM05, due to the performance that this new optics will provide.

c) The idea of on-line mirror surfacing (OLMS), i.e., the fabrication of mirrors using at-wavelength metrology, is described in the CDR "OPTICS" (see ESRF Purple Book and Ziegler et al, 2006). Since then the scheme has evolved to accommodate longer mirrors (300 mm instead of 50 mm), implying in some cases a wider incoming X-ray beam.

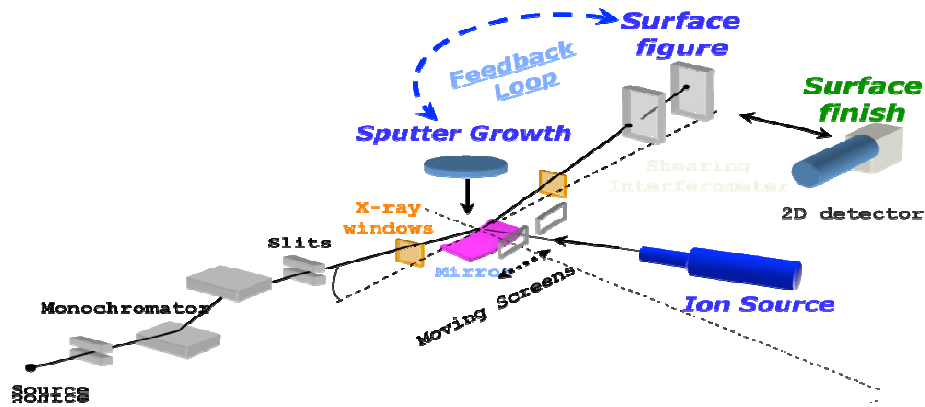


Figure 1: Schematic of the on-line mirror surfacing process.

#### 1.4 BASIC TECHNICAL CONSIDERATIONS

a) UPBL5 prototypes: The optics for UPBL5 will consist of the combination of a linear white-beam transfocator to collimate the beam horizontally and of a double multilayer monochromator (DMM), composed of a flat first mirror and of a second one slightly bent to collimate the beam in the vertical direction. The tests at BM05 will require reorganising the optics (OH) and the first experimental (EH1) hutches. Inserting the transfocator in the white beam section of OH will imply the removal of the chopper, suppression of the beam splitter, and relocation of the primary slits upstream from their present position. Installing the DMM in EH1 will require freeing a 3 m long section. This will imply re-installing the vertical reflectometer downstream and removing an optics table and a fast shutter. The chopper will require modifications and local shielding for implementation in the tunnel. The UPBL5 prototype will serve to evaluate the possibility of using the transfocator for imaging applications by estimating the wavefront distortion and the uniformity of the X-ray beam after passing through a high number of Be lenses (cumulative thickness around 1 mm), each presenting surface and bulk defects. Similarly, it will allow verifying the wavefront quality after reflection on a bent and cooled ML mirror, as these combined constraints may induce surface slope errors, which, in turn, may generate undesired contrast in the image of a sample. We expect this effect to be greater at BM05 than ID19 due to a five times shorter optics-detector distance. These tests will assess the quality of the optics under low thermal heat-load, typically two orders of magnitude lower than at ID19. The high-flux final testing will take place at ID19 starting in 2014.

b) As a general test facility the main component that needs to be upgraded at BM05 is the double-reflection crystal monochromator. The simplicity of the generic ESRF design, based on a channel cut system, would be adequate. The wide beam size, ~ 60 mm, will be the only unusual parameter. The present cooling will be improved to anticipate a greater flux in the future. New primary slits (HP type) are also needed. We plan to recycle the existing monochromator for horizontal diffraction, using an asymmetric crystal to compress the large horizontal beam. Laterally-graded SiGe crystals would allow a substantial gain in flux, the value of which will depend on the maximum crystal size the manufacturer will be able to provide (investigation in progress).

An extension of the control hatch, an air lock cabin, and a better temperature regulation of EH1 will be necessary for microfocus beam stabilisation, X-ray interferometry, and nanometre mirror surface corrections.

c) The OPTICX platform will materialise in the form of an experimental station located at BM05 EH1, capable of manufacturing aspherically-shaped mirrors up to 300 mm in length. The basic concepts of this facility are currently investigated on a small size prototype that incorporates most of the features of the final project. The process currently optimised will eventually have to be adapted to a larger surfacing machine and will require a broader X-ray beam for characterisation. A series of ion beam irradiation of silicon substrates and X-ray and AFM characterisation have allowed a process to be defined which is capable of preserving or recovering a low surface roughness (0.2 nm for spatial periods below 1  $\mu\text{m}$ ). An iterative algorithm based on scanning of a variable slit is developed to correct iteratively the figure of a silicon surface. A mirror was recently flattened to  $\lambda/15$  over a 40 mm length ( $\lambda=632$  nm) while flats were figured to mirrors with focal lengths between 5 cm and 30 cm. A prototype X-ray shearing interferometer showed picometre sensitivity during ion surface process. A PhD project was launched to infer mirror shape and slope errors through data modelling. The X-ray reflectometry and diffuse scattering characterisation setups are operational. However, an innovative angular-dispersive reflectometry setup using a bent multilayer mirror will be developed to monitor the mirror depth density profile without varying the mirror angle, whilst a 5-chip MAXIPX pixel detector is expected to improve the quality of the diffuse-scattered data. The surfacing of mirrors up to 300 mm in length will require broader ion and sputter sources for etching and differential deposition, whilst some online characterisations will require asymmetrically-cut crystals to expand the incoming horizontal X-ray beam. The stability of the online process will require a local temperature stabilisation of 0.1 degree, and clean room conditions around the station.

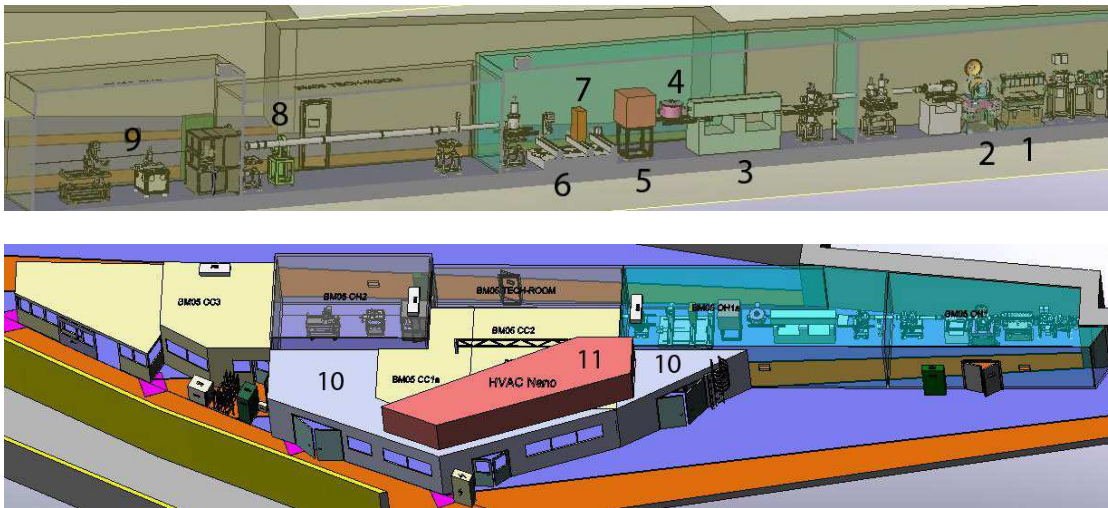


Figure 2. General sketches of BM05 showing the UPBL5 CRL translocator (1), channel cut mono (2), UPBL5 double multilayer mono (3), asymmetrical crystal mono (4), OPTICX surfacing chamber (5), Multi-Purpose-Platform MPP (6) with vertical reflectometer (7), beam chopper (8) and  $\mu$ -tomography and topography stations (9), control hatch extension (10) and HVAC nano system (11).

## 1.5 REFERENCES

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