HESEB: The Helmholtz state-of-the-art Soft-X-Ray Undulator beamline at SESAME

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Abstract. SESAME and a consortium of five Helmholtz Centers are designing and installing a state-of-the-art soft X-Ray undulator beamline at the SESAME light source in Amman, Jordan. Funding is provided by the Helmholtz Association over a four year project cycle that started in January 2019. This is an interim report covering the first 36 months of the project where the construction and installation has been almost completed and commissioning and characterization of the beamline is about to start. Additionally, seminars, workshops, and a training program are part of the project aimed at establishing a broad user community.

1. The concept of the beamline

SESAME, the Synchrotron light source for Experimental Science and Applications in the Middle East, is an international research facility under the umbrella of UNESCO that has been constructed near Amman in Jordan. This light source is based upon a 2.5 GeV storage ring and it is operated jointly by the Member countries of SESAME (Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, The Palestinian Authorities, and Turkey). SESAME has started operations in 2017 and presently it has three beamlines accepting proposals from the user community.

The Helmholtz-SESAME Beamline (HESEB) has been funded by the Helmholtz Association of Research Centers in Germany and the design, construction, installation, and commissioning is performed as a joint project of five Research Centers of the Helmholtz Association (DESY, FZJ, HZB, HZDR, KIT) which are active in the research field "Structure of Matter" and SESAME. The overall project leadership is at DESY. It is worthwhile to point out that a soft x-ray spectroscopy beamline has been part of the SESAME strategic plan, which was endorsed by the SESAME Council already in 2009.

HESEB is a soft x-ray undulator based beamline that is designed to cover a photon energy range from about 90 eV to 1800 eV. The soft x-ray science is essential to develop an understanding of the electronic structure and chemical bonding of matter whereas hard x-rays predominantly determine the atomic structure. Soft x-ray spectroscopy enables to understand the chemical environment and bonding of many important elements and the resulting materials properties. These elements include chemically and environmentally relevant carbon, nitrogen, oxygen, sulfur and (magnetic) metals such as chromium, manganese, iron, cobalt, nickel, copper, magnesium and aluminum as well as silicon, the all-important base material for information technology. Controlling not only the photon energy, but also the polarization of the light enables unique insights into magnetic materials allowing for an element specific determination of the magnetic properties.

The beamline design follows the collimated plane grating monochromator (PGM) concept as originally developed by R. Follath and F. Senf [1]. This design has been successfully implemented at several facilities around the world. As photon source an APPLE II undulator will be used. This is the first undulator to be installed at the SESAME storage ring. The APPLE II design offers complete control of the polarization parameters of the beam, enabling circular polarized beams as well as a linear polarization with a selectable orientation of the polarization vector [2]. The device chosen for HESEB is a 1.7 m long undulator with 30 periods of 56 mm length each, which is based on a device that had been previously installed at BESSY II. It has been significantly refurbished and upgraded by the undulator team at HZB in terms mechanical performance and control systems, including a complete replacement of all magnets. A picture of the device and the performance curves, as calculated for the SESAME storage ring, are shown in Fig. 1. As shown, all important L-edges of the magnetic transition metals as well as the Si L-edge are covered in the first harmonic of the undulator with the minimum gap of 12.8 mm.

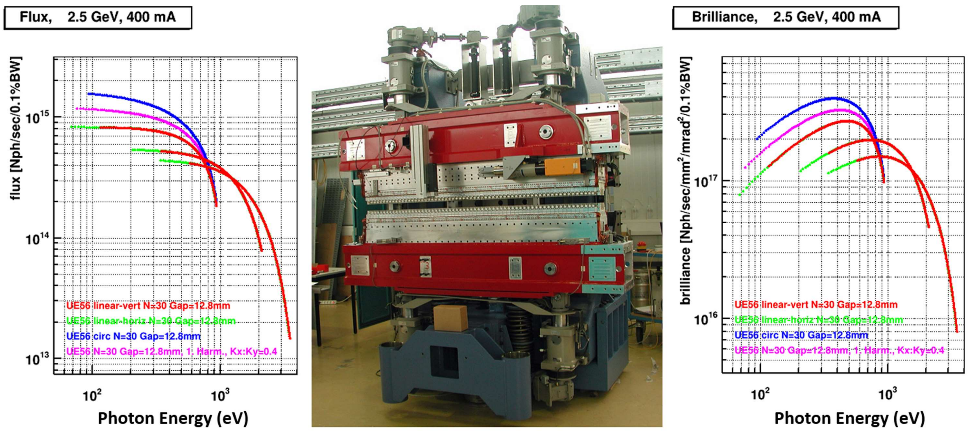

Fig. 1 The Apple II undulator for HESEB (center picture) as well as the photon flux and brilliance calculated for the SESAME storage ring operating at 2.5 GeV with 400 mA beam current.

The optical layout of the HESEB beamline is shown in Fig. 2. The total available length from the center of the straight section to the focal spot at the experiment was set at 27.5 m for branch line A and 28.5 m for the second branch line (B). Branch A is going to be equipped with an experimental chamber for absorption (electron/fluorescence yield) spectroscopy (see below). The second branch (B) is foreseen for an ambient pressure photoemission (APXPS) experimental station planned by a consortium of scientists from Turkey. This is still in the funding stage. APXPS enables in-

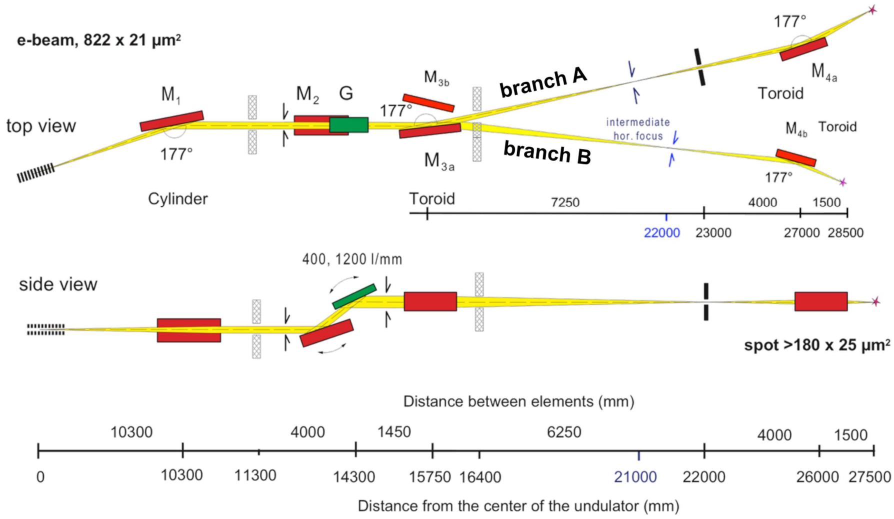

Fig. 2 Optical layout of the HESEB beamline. The storage ring shield wall is indicated at 11.3 m.

situ/operando studies for analysis and improvement of catalysts, battery materials during charging and discharging cycles, as well as for corrosion and environmental research. These are all very important and current research areas with wide scientific interest.

The first cylindrical mirror (M1) is located inside the shield wall deflecting the beam horizontally, collimating it vertically and forming a horizontal focus as indicated. The vertical dispersion section (PGM) has a plane mirror (M2) and two interchangeable plane gratings with 400 l/mm and 1200 l/mm groove density. The ultimate energy resolution is about 10,000 for the 400 l/mm grating and 20,000 for the 1200 l/mm grating with a photon flux at the sample of 10^{12} photons /s / 400 mA (Fig. 3). The dispersed beam is offset by 15 mm vertically from the original beam. The toroid M3 focusses the beam onto the exit slit. Finally, a refocussing toroidal mirror (M4) images the exit slit onto the sample position, creating a focal spot of 180 x 25 μm^2. This spot size is largely determined by the source size of the beam in the undulator. In order to accommodate the power load of the undispersed beam, M1, M2 and the gratings are water cooled by side cooling. In regular operation, e.g. M1 absorbs 170 W of 200 W incident power.

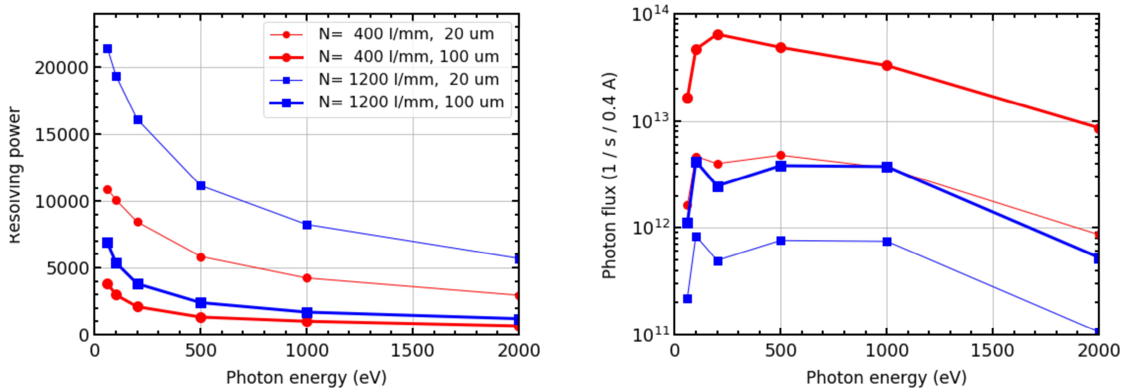

Fig. 3 Calculated resolving power and photon flux (branch A) at different exit slit settings.

2. Technical realization and installation

The contract for the technical realization and installation of the HESEB beamline (Fig. 4) was awarded to FMB Berlin, a well-established company that has already successfully constructed and installed several of these types of beamlines at various facilities around the world. Over time this design has matured considerably. For example, we here use the compact mirror chamber design, first implemented at the MAX IV facility in Lund [3]. The design of the PGM was further developed by FMB for HESEB in order to decouple the drive mechanism and the optical elements from the vacuum chamber in terms of vibration. This new design feature is expected to further improve the overall stability and resolution. The mirrors and grating blanks were produced by Carl Zeiss GmbH (Germany). The mirrors are made of single crystal silicon with meridional slope errors of 0.5 arcsec (rms) for toroidally shaped mirrors and < 0.1 arcsec (rms) for plane and cylindrically shaped mirrors. Their surface roughness is approx. 0.2 nm (rms). The specifications were verified by the

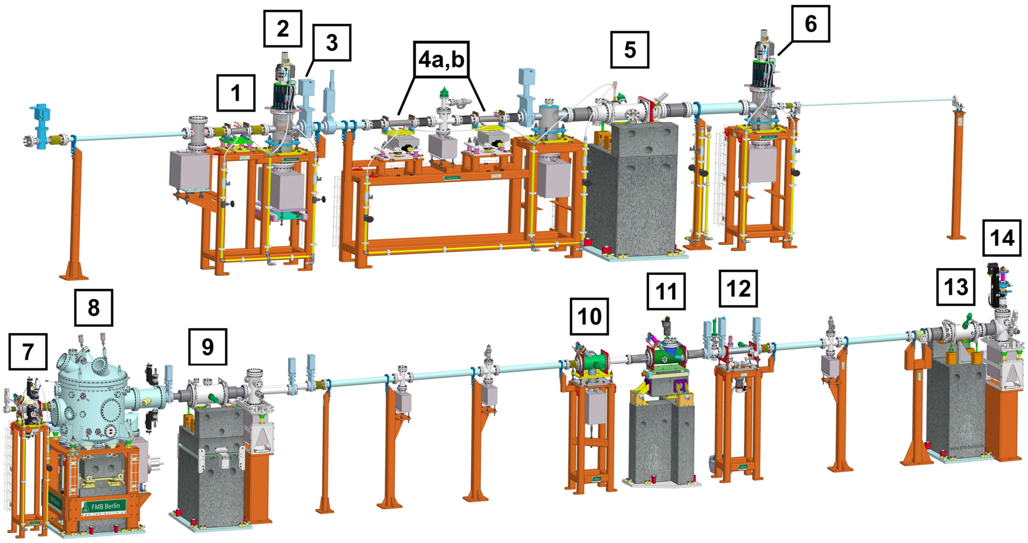

Fig. 4 Technical implementation of the HESEB design. The top part shows the components installed inside the shield wall, whereas the components in the bottom part are installed outside (branch A, experimental chamber not shown). These are:
(1) fixed aperture, (2) photon shutter, (3) fast valve, (4a,b) beam defining apertures, (5) M1 mirror, (6) radiation shutter, (7) 4-blade aperture, (8) PGM, (9) beam splitter mirror chamber, (10) horizontal slit, (11) vertical exit slit, (12) ionization chamber, (13) refocussing mirror, (14) beam diagnostics

metrology group at HZB. The grating blanks were ruled using the recently established facility at HZB [4], again all specifications were met. The beamline (branch A) as described has been installed at the SESAME facility in January 2022. A picture taken of the crew after the installation was finished is shown as Fig. 5. After completing the bakeout the base pressure throughout the beamline is in the 10^{-10} mbar range without beam. The beamline control and operations has been incorporated into the SESAME environment by the local SESAME controls staff. The experimental chamber and the undulator are expected to arrive at SESAME in early April. After successful installation of the undulator the beamline is scheduled to be commissioned and tested in the summer and fall of 2022.

Fig. 5 Crew picture taken after the completion of the installation of the HESEB beamline in January 2022.

3. The variable pressure experiment chamber: a unique distinguishing feature of HESEB

As part of the funded HESEB project, there will be an experimental station with a motorized sample scanning stage and a solid-state detector allowing fluorescence yield spectroscopy in addition to the conventional electron yield spectroscopy for probing elemental structure of matter with a focus on studying artifacts of regional cultural heritage. In addition, this setup will allow spatially resolved energy dependent x-ray absorption spectroscopy for obtaining the elemental and chemical composition of materials. The use of circular polarization as provided by the undulator also allows to determine the element specific magnetic properties of materials.

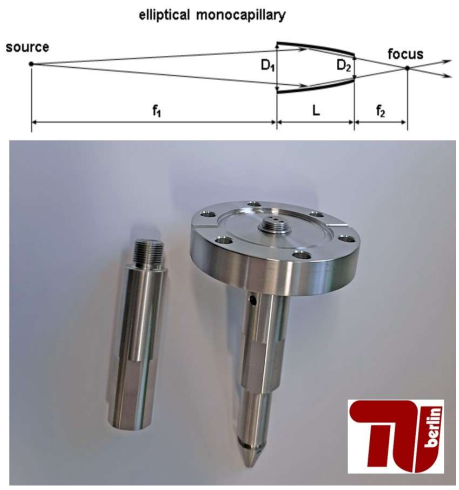

Fig. 6 Elliptical monocapillary and holder for focussing and differential pumping

Additionally at the entrance of the chamber there is the option to install an elliptical focussing capillary, which serves a dual purpose. First of all, it creates a focus of about 20 µm diameter at a distance 5 mm from the end of the capillary. With the motorized sample holder this will enable 2-D mapping of the samples. Secondly, the capillary holder has been designed to establish a differential pumping stage, where the only vacuum connection is through the elliptical capillary, which has a length of 95 mm and a diameter narrowing from 100 µm down to 20 µm. The capillary holder assembly was designed and built at TU-Berlin and is shown in Fig. 5. Jointly with a second differential pumping stage this will allow to study (archeological) samples at atmospheric pressure. For the reason of X-ray transmission this has to be a He atmosphere.

For experiments on solids there is a sample exchange and transfer mechanism installed with three sample positions at the manipulator. A temperature range between -160 ºC and >800 ºC can be held at the sample. Together with the possibility to study the fluorescence or electron yield at mbar pressures this will enable unprecedented insights into chemical processes and reactions at the sample surfaces. This is a worldwide distinguishing feature of the HESEB beamline which will be of great interest for catalysis, battery research, corrosion chemistry and other applications.

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