Commissioning of the endstation for projection propagation imaging at P10/PETRA III

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To implement lensless hard x-ray propagation imaging (or holographic imaging) with nanoscale resolution, contrast formation by free space propagation has to be combined with geometric projection. To this end, we have commissioned a dedicated endstation at beamline P10/PETRA III, based on a high flux Kirkpatrick-Baez (KB) mirror optics in combination with x-ray waveguides (Salditt et al., 2008, Giewekemeyer et al. 2010, Krüger et al. 2010), to provide nanoscale beam with tailored cross section and coherence properties. The instrument is devoted to propagation imaging and tomography of biological cells and tissues, and is compatible with cryogenically immobilized samples as well as with microfluidic systems. The instrument and its optical components are described in (Kalbfleisch et al., 2010). During commissioning the focus was characterized, both in view of intensity distribution and the coherence properties. First test of propagation imaging were performed on lithographic patterns and on biological specimen.

After careful alignment and commissioning of the KB, the waveguide module, detectors and optical in-situ microscopes, the near-field and far-field intensity distributions were measured. Fig.1 (a,b) shows the results of the x-ray waveguide (diagnostic) scans through the focal plane of the KB to characterize the near-field intensity distribution, see the schematic in (c). The lateral and vertical focal intensity distribution were measured to determine the spot sizes and the field of depth. In (a,b), the beam cross section (FWHM) are plotted as a function of z after batch fitting of scans along the x (vertical) and y (horizontal) directions for each z to a Gaussian peak profile. Along with the experimental results (circles), the values determined from simulations of beam propagation (solid black line) and an empirical fit to a Gaussian beam profile (solid red line) are shown. Beam propagation taking into account the geometrical parameters (undulator source size, distances) and measured height profiles of the mirrors, has been simulated, as shown in Fig.1(e), for the case of the vertical direction, and can be compared to the experimentally measured 2D intensity distribution, as shown in (f), obtained from a series of waveguide scans. An isotropic spot size of about 200nm was measured, with exact values depending on alignment state and lineshape used in fitting. For example, in (d) a vertical focus scan along with a Lorentzian fit is shown, yielding a (best case) FWHM of 186nm. The measured flux in the focal spot was $2.13 \cdot 10^{11}$cps (PIN diode), at a storage ring current of 60 mA and a photon energy of E = 7.9 keV. Comparable flux densities, have to our knowledge only been achieved in pink beam mode before, but not at the low bandpass of a Si(111) double cystal monochromator. Next, the spatial coherence properties of the KB and waveguide beams, as well as coherence filtering effects, were characterized by Talbot interferometry. Propagation imaging with KB only as well as with the additional waveguide module was tested, first on lithographic test patterns, clearly resolving the available 200nm and 50nm lines and spaces, respectively. Holographic images as well a first tomographic data set on freeze-dried cells was recorded, as well as propagation images of black lipid membranes freely suspended in solution, generalizing the work of (Beerlink et al. 2009) to divergent beams, with correspondingly higher resolution. Fig.1(g,h) show first preliminary results on imaging of Deinococcus Radiodurans (D.radiodurans) (Deutsche Sammlung für Mikororganismen und Zellkulturen GmbH), pipetted on a Si_3N_4-membrane, and cryogenically fixed by plunge freezing in liquid ethane, and subsequently freeze dried. The cells were illuminated by a crossed $Ge/Mo/C/Mo/Ge$ waveguide (Krüger et al. 2010), however at very small integrated flux. Fig.1(h) represents a first single-step holographic reconstruction. Analysis based on more powerful, iterative algorithms (Giewekemeyer et al. 2011) is presently in progress.

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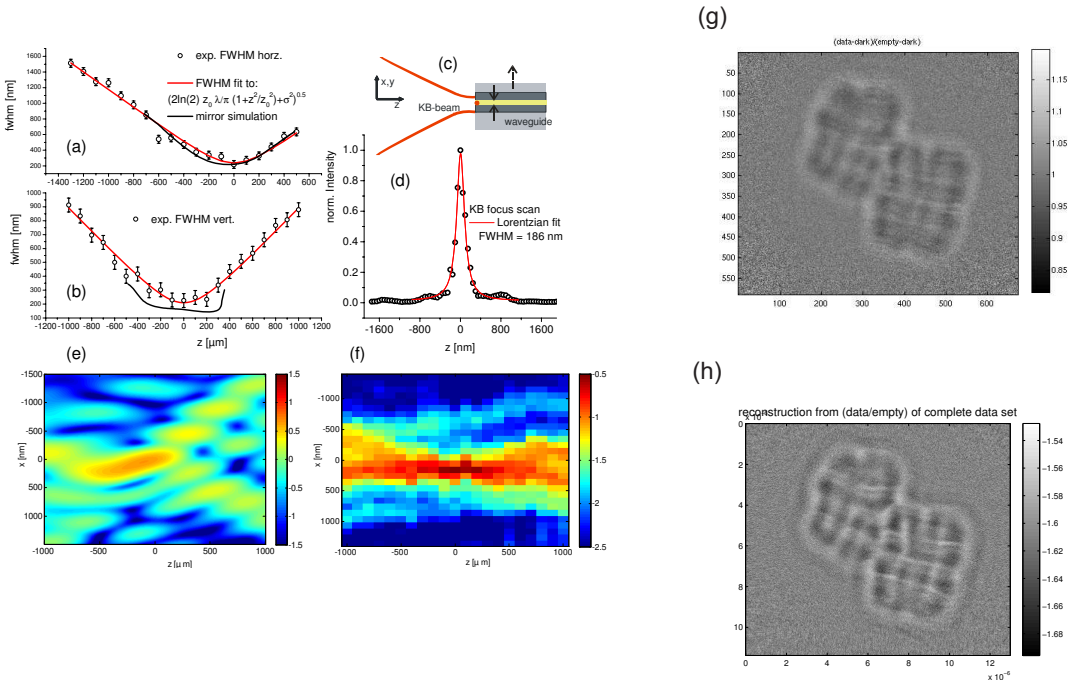

FIGURE 1. Beam width (FWHM) along the (a) horizontal (y) and (b) vertical (x) direction, as a function of z along the optical axis, as measured by scanning the waveguide through the focus, along with the Fresnel-Kirchhoff simulations (solid black line) and a fit to a Gaussian beam profile (solid red line), convolved with a residual width (see text). (c) Schematic of the waveguide scan. (d) Focus intensity profile along the vertical direction in the focal plane after iterative alignment, along with a Lorentzian fit (solid red line). Side minima and maxima are observed around the central focus. Two-dimensional (e) simulated and (f) experimental intensity profile in the focal region (vertical plane), after logarithmic color encoding (see colorbar). (g) The hologram of freeze dried D.radiodurans bacteria, as measured with waveguide illumination, after division by the empty beam, along with (h) a (preliminary) holographic reconstruction.

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