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Phase-Contrast Multi-Point-Projection X-ray Microscopy.

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In our recent paper, we demonstrated that intrinsic point defects, by breaking the periodicity of polycapillary arrays directly lead to the formation of high resolution X-ray projections [1]. However, this defect-assisted imaging requires numerical decoding of resulting image and it is not suitable for phase contrast microscopy. In addition, the fabrication of tailored polycapillary optical elements is a difficult and demanding problem. Transferring the setup to synchrotron source would be a solution for some issues. Nonetheless, a lot of the hard X-ray imaging experiments are table-top setups. This become a motivation to propose a table-top X-ray multi-point projection microscopy, realized by using a pair of compound polycapillary optics that generates over one thousand submicron secondary X-ray sources multiplexed at the object [2].

The experimental scheme of multi-point projection microscopy based on multiplexing and demultiplexing is presented in Fig. 1. Polychromatic radiation from an X-ray tube (50 Watt, tungsten anode) is collected by collimating optical element, and it is directed through a multi-pinhole mask (each pinhole of 7µm diameter) towards a focusing optical element. The detector was 256x256 pixels, photon counting, Timepix based detector with discriminator in each pixel. Thus, the detector is free of dark noise [3]. A sparse distribution of the pinholes in the mask defines the distribution of single capillaries used for imaging. Each capillary generates an X-ray secondary micro-source. Therefore, the object placed in the focal spot is illuminated by an array of mutually incoherent but partially coherent sources. Projections of the object at the detector plane are magnified by $M=(D-f)/f$, where D is the detector-object distance, f is the working distance of the optics. Each micro-beam generates an X-ray projection of the object at the detector plane. For high magnification ($M>>1$) and capillary spacing at the exit plane of the optics greater than the lateral dimension of the beam at the object plane, beams do not overlap in the detector [4], or are spatially demultiplexed. The free-space propagation give rise to projections of highly-absorbing samples at submicron resolution with only a few photons per detector pixel.

The main result of using multi-point projection microscopy is presented in Fig. 2. The resulting image consists of nearly one thousand shadow projections of the object, which can be averaged to improve the signal-to-noise ratio. Most importantly, multi-point projection microscopy enable one to achieve propagation based in-line phase-contrast imaging realized with the Gabor holography geometry [5,6]. The phase shift variations were large enough to observe clear X-ray projections of a several weakly absorbing objects (carbon fiber of 8µm diameter, a group of polystyrene spheres of 3µm diameter each and a diatom frustule) as shown in Fig. 3. The spatial resolution was limited to ~0.4-0.5µm by a single capillary channel diameter at the exit of the focusing element.

In conclusion, unlikely other multiplexing phase-contrast methods [7], multi-point projection microscopy does not require synchrotron sources and can be used in table-top laboratories equipped with standard X-ray tubes. Moreover, multi-pinhole mask can be designed to permit multimodal experiments that combine high resolution transmission imaging with scanning X-ray fluorescence imaging [8]. Hence, we believe that the concept of multi-point projection microscopy has potential to

improve the performance of laboratory X-ray imaging, i.e. imaging of biological samples, and could be integrated with other optical devices. For acknowledgements see [9].

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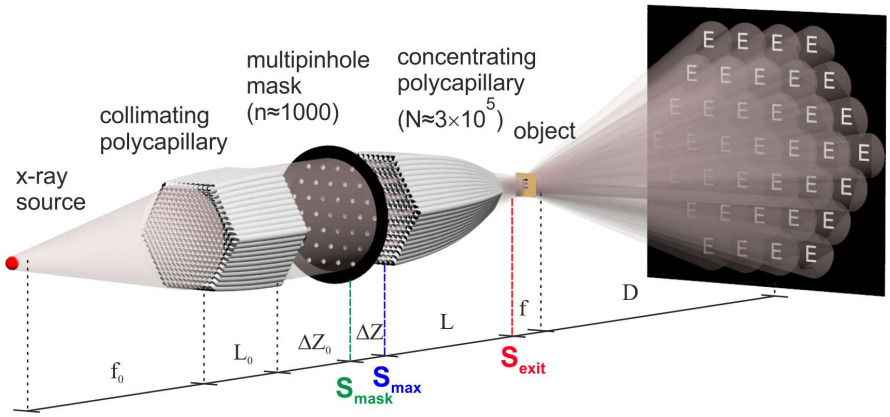

Figure 1. Concept of multi-point projection microscopy. A laser-drilled multi-pinhole mask is placed in between two polycapillary optical elements. The mask selects over 1000 capillaries, which generate secondary microsources.

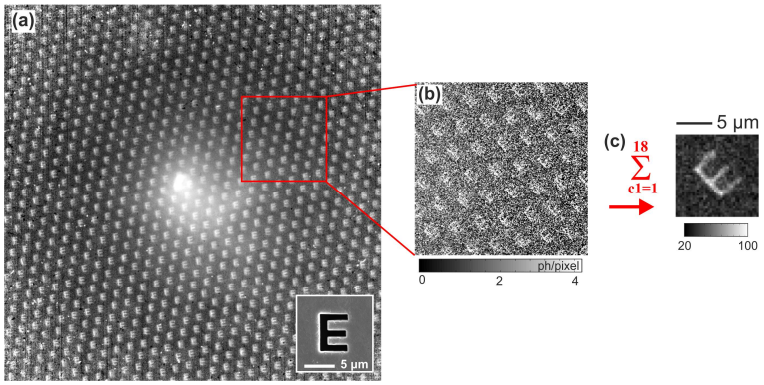

Figure 2. a) Multiple projections of highly absorbing object (letter "E" in golden foil) acquired with an X-ray camera; **b)** zoomed image acquired with hybrid-pixel detector in a 10s exposure; **c)** image calculated by summing over 18 selected secondary sources.

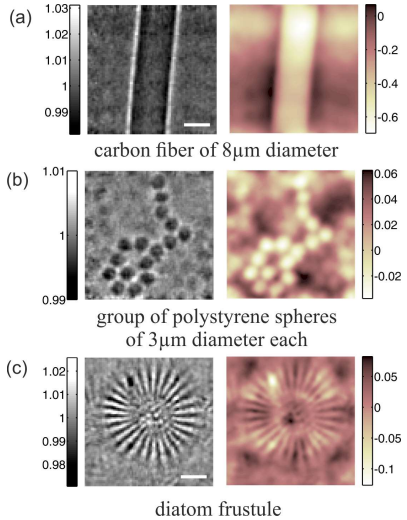

Figure 3. Images of weakly absorbing objects Left: X-ray images, right: retrieved phase maps.

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