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Report:

Planar x-ray waveguide structures as resonant beam coupling devices have been demonstrated as new tools to produce coherent and divergent x-ray beams with cross-sections in the sub-micrometer range in one dimension. However, for many nano-microscopy and nano-spectroscopy applications, a two-dimensionally confined *point* beam instead of one-dimensional *line* beam is needed.

In this experiment we have demonstrated for the first time that a two-dimensional beam compression using the resonant beam coupling principle can be achieved. Applying state of the art e-beam lithography techniques, we have fabricated laterally and vertically patterned nanostructures, where the beam is channeled in two-dimensions. Figure 1 shows a schematic of such a ‘x-ray fiber’ consisting of an approximately 500Å x 2000Å, spin-coated, rectangular patterned PMMA core coated with evaporated Cr metal on silicon substrate.

Just like in the optical analogue, the resonantly enhanced electromagnetic field distribution of a x-ray waveguide can be described by a set of discrete and precisely defined modes (at the respective angles α_i and ϕ_i), which are determined by the geometry of the structure and the choice of materials. Accordingly, the guided modes are excited by shining a parallel beam onto the waveguide at grazing incidence at a set of angles $\alpha_{i,n}$ and $\phi_{i,m}$. A coherent beam

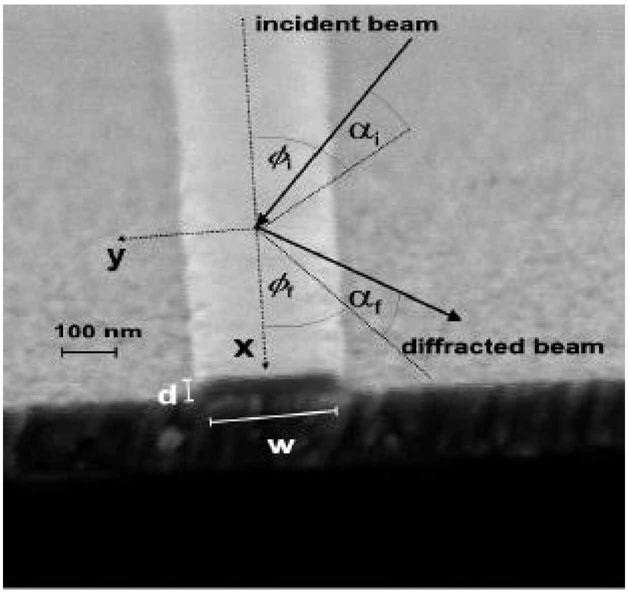

Fig. 1: Scanning electron micrograph of a tw-odimensinal waveguide consisting of an e-baem patterned PMMA-core coated with Cr.

exists the structure at the side with a cross section corresponding to the thickness of the guiding layer and a divergence in the range of some mrad.

To experimentally demonstrate the waveguide effect due to resonant beam coupling, we have measured the reflectivity of the nanostructure both as a function of α_i (ϕ_i = const., $\alpha_f = 2\alpha_i$) and ϕ_i (α_i = const., $\phi_f = 2\phi_i$). The waveguide effects readily manifest themselves in the reflectivity curve as cusps in the plateau of otherwise total external reflection. Importantly, the evidence for the resonances can be clearly seen in both the α_i / α_f [Fig. 2 top] and ϕ_i / ϕ_f – geometry [Fig. 2 bottom, respectively]. In a simplistic argument valid for infinite samples and beams, photons get trapped under the resonance conditions in the guiding layer propagating over an active coupling length (in our case ~ 500µm - 1000µm) parallel to the tunnel, and are therefore more likely to get absorbed. The enhanced absorption loss manifests itself as a pronounced decrease in the reflectivity. At the same time, the 'point source' has been characterized by translating a knife edge in a distance of ~1.8mm across the divergent beam exiting the end of the 'fiber' for the $\alpha_{i,0}$ / $\phi_{i,0}$ – resonance [Fig. 3]. The resulting FWHM – beam crosssections of 4.1µm /8.4µm in z-/y-direction correspond well with the expected value of 3.6µm in that distance due to the ~0.12° divergence of the exiting mode. The broadening (particularly in y-direction) is most likely caused by the diffuse background of the primary beam and diffraction at the imperfect knife-edge.

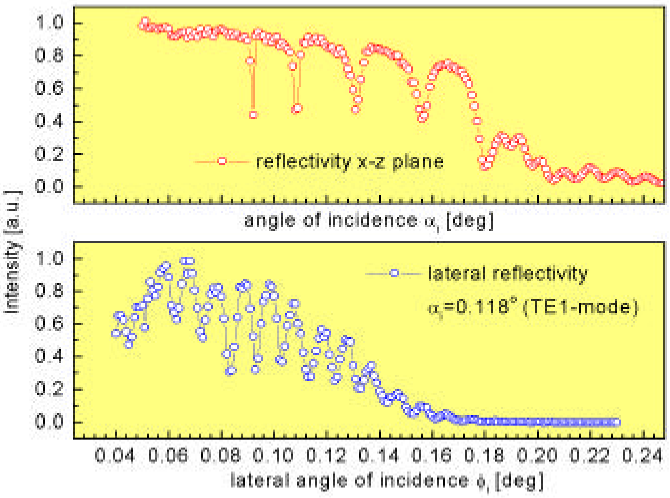

Fig. 2: Reflectivity of the waveguide nanostructure both as a function of a_i (f_i = const., $a_f = 2a_i$,top) and f_i (a_i = const., $f_f = 2f_i$, bottom).

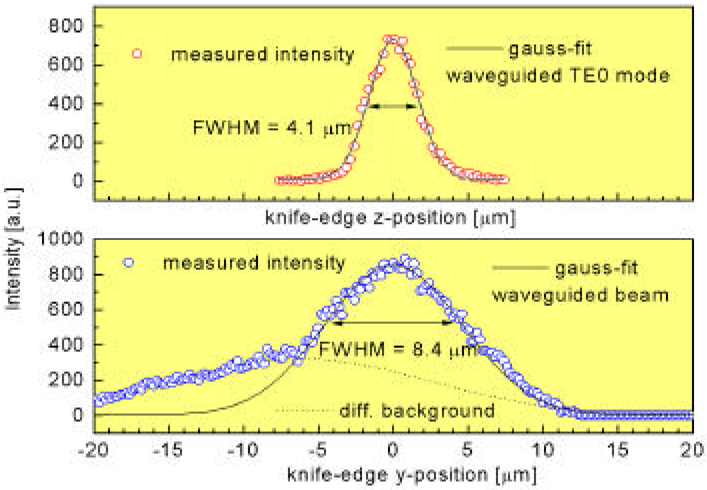

Fig. 4:. Beam-crosssections in a distance of ~1.8mm across the divergent beam exiting the end of the 'fiber' for the $a_{i,0}$/ $f_{i,0}$ – resonance

To gain an more detailed understanding of the properties of the resonance-excitation of modes in such patterned struture, their farfield intensity-distributions, the achieved waveguide gain and the absolute performance of the device a series of detector mappings as a function α_i and ϕ_i were recorded with a high resolution CCD camera. The corresponding data evaluation is still in progress, Fig. 4 already gives a first idea of the complexity of the diffraction pattern and thus of the potential of twodimensional x-ray waveguides. More detailed information, particulary concerning the topics discussed above (farfield-intensity-distribution, performance, gain) as well as input for improved structures will be published within the next few weeks.

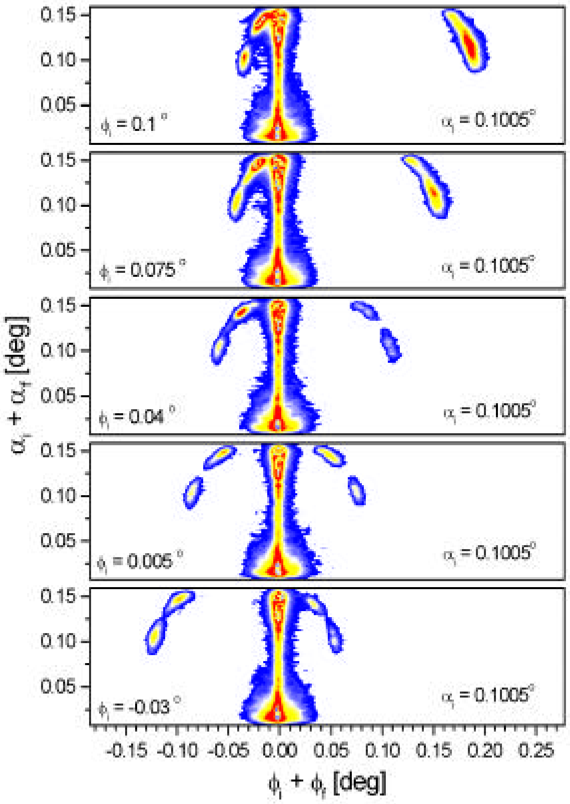

Fig. 4: Contour-plots of a series of detector mappings collected for various α_i / ϕ_i values.