Feasibility Study of Wide-angle Incidence X-ray Waveguides Prepared by Nano-technology

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We have investigated the possibility of preparing wide-angle incidence waveguides with a nano-scale structure. Grazing incidence x-ray waveguides have been most studied because of its simple geometry and its applicability for all photon energies. However, wide-angle incidence waveguides are also essential for modern x-ray optics, as far as coupling/guiding x-ray beams into given directions are concerned. In this experiment, we have observed wave guiding effects in both horizontal and vertical directions in the Au/Si/Au waveguides system at the photon energies near E = 8.878 keV. In addition, 2θ-scan shows the oscillatory intensity distributions near E = 8.878 keV due to the constructive interference between wavefields of different modes., Also, we have noted how the diffracted beam, Si(113), is propagating in the Au/Si/Au waveguides system if the photon energy is not close to 8.878 keV.

The schematic diagram of Au/Si/Au waveguides with Si as the guiding layer and Au as cladding layer, is shown in Fig.1(a). The basic ideal of the design for x-ray waveguides is to utilize the total reflection which occurs if the angle between surface diffracted beam, Si (113), inside a waveguide and Au layer is smaller than the critical angle θ_C, 0.46°, which is determined by the refractive indices of Si and Au. Then the surface diffracted beam, Si (113), is, in principle, confined by waveguides. Figure 1(b) shows the the experimental setup.

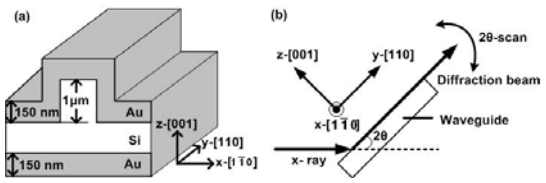

Fig. 1: (a) The sizes of the waveguides are 5-mm-long, h-μm-high and w-nm-wide, respectively. The 150-nm-thick Au thin films are grown on the top and bottom of the silicon waveguides. (b) The experimental setups.

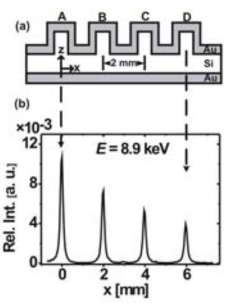

Fig. 2: (a) The structure of waveguides with 1-μm-high and varying widths of 700 nm (A), 450 nm (B), 400 nm (C), and 350nm (D), respectively. (b) The guiding effect is observed in horizontal direction.

The translation-scan in x-direction with different widths of waveguides at an x-ray energy of E = 8.9 keV is shown in Fig. 2(b). Four peaks in Fig. 2(b) show the guiding effect in horizontal direction, i.e., x-ray beam is confined in the waveguides. The distance between two adjacent peaks is 2 mm, which is in good agreement with the waveguide geometry designed. This shows the guiding effect in horizontal direction of the Au/Si/Au waveguides system.

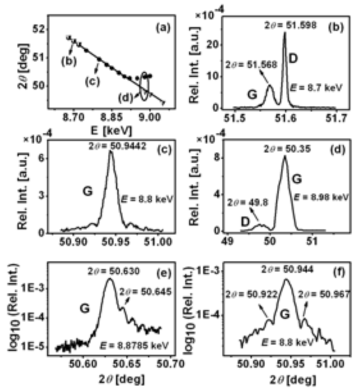

Fig. 3: The 2θ-scan of the diffracted beam through the waveguide for varying photon energies: (a) 2θ versus E, and the waveguide is 0.5-μm-high and 400-nm-wide. (b), (c) and (d) are the 2θ-scans, and the waveguide is 0.5-μm-high and 400-nm-wide. (e) and (f) for the waveguides of 1-μm-high and 700-nm-wide, and 0.5-μm-high and 350-nm-wide, respectively.

The 2θ-scan of the diffracted beam through the waveguide with varying photon energies shows the guiding effect in the vertical direction. In Fig. 3(a), – (solid line) is due to Bragg's law. ● and ▼ indicate the guided and the diffracted beams, respectively. The results for all waveguides we fabricated show the same behavior as in Fig. 3(a). The guiding effect in the vertical direction is observed from E = 8.68 keV to E = 9 keV. According to theoretical calculations, the surface diffracted beam, Si(113), is not propagating along the crystal surface if the photon energy is 150 eV lower or higher than 8.878 keV. However, we still observed this wave guiding effect at E = 8.7keV. In Figs. 3(b) and 4(d), there are 2 peaks, where the peak, D, is due to the diffraction, Si(113), and the other peak, G, is due to the guided diffraction beam, Si(113), propagating along the waveguide at E = 8.7 keV, and E = 8.98 keV, respectively. The oscillatory intensity distributions in 2θ-scan in Fig. 3(c), Fig. 3(e), and Fig. 3(f) is at E = 8.8 keV, E = 8.8785 keV, and E = 8.8 keV, respectively. The oscillatory intensity could result from the constructive interference between wavefields of different modes of wave propagation inside the silicon crystal, which we believe is a dynamical diffraction effect.