Characterization of Focusing Properties of GaAs Bragg-Fresnel Optics

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Introduction

Bragg-Fresnel lenses (BFLs) are reflective Fresnel zone plates fabricated on the surface of single crystal substrates. BFLs possess the unique energy-independent focusing capability and have been used to focus x-rays up to 100 keV [1]. However, the physics of BFLs is not yet completely understood, due to coupling of the Fresnel diffraction to dynamical diffraction by the crystal substrates. We investigated the diffractive focusing properties of GaAs BFLs in a series of experiments conducted at beamline 1-ID (SRI-CAT) at the Advanced Photon Source (APS). A model was developed for linear BFLs based on Kirchhoff-Fresnel diffraction theory and compared with good agreement to the measured diffraction data.

Methods and Materials

The BFLs were fabricated using electron-beam lithography and reactive ion etching (RIE) methods in the National Nanofabrication Users Network (NNUN) facility at UCSB [2]. Linear and circular lenses were made on a variety of substrates including Si, GaAs, InP, and a MBE (Molecular Beam Epitaxy)-grown GaAs/AlGaAs heterostructure. We have focused our developmental effort on III-V compound semiconductor materials because their high densities (compared to Si) reduce the required zone depth for focusing (consequently the device aspect ratio) giving rise to much improved processing control and lens quality. Fig.1 shows a scanning electron microscope (SEM) image of a linear GaAs BFL. Long (with zone length up to 10 mm) linear GaAs BFLs with 0.3 µm diffraction-limited resolution (finest zone width = 0.2 µm) were fabricated using a multiple e-beam exposure field stitching technique for improved capability in high energy x-ray focusing.

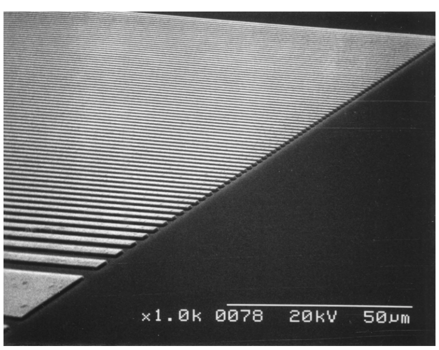

Fig. 1 SEM image of a lienar GaAs BFL.

Results and Discussions

In a series of experiments conducted at the Advanced Photon Source, we systematically characterized the focusing properties of linear BFLs in the energy range 8 keV – 40 keV [2-3]. The goal was to understand the diffractive focusing characteristics of the BFLs when used with a typical third-generation synchrotron source, where source parameters rather than optics often dominate the focusing performance. Focal plane intensity distributions of BFLs were measured using x-ray fluorescence probes. The intrinsic low background of this technique enables the mapping of higher order diffraction fringes, which are crucial for quantitative comparison with the theoretical model.

To simulate the diffraction data, we developed a simple model of linear BFLs based on classical Kirchhoff-Fresnel diffraction theory, with source properties explicitly incorporated in the calculation. For an extended source with a Gaussian intensity profile, the intensity distribution at the focus of the BFL can be written as:

$$I(y) \propto \int_{-\frac{s_0}{2}}^{\frac{s_0}{2}} e^{-\frac{y_0^2}{2\sigma^2}} dy_0 \left| -\frac{ik}{4\pi} \left|F_{hkl}\right| \sum_{-N_{zone}}^{N_{zone}} e^{i\varphi_n} \int_{r_n}^{r_{n+1}} \frac{e^{ik(r+s)}}{rs} d\eta \right|^2 \qquad (1)$$

where the Gaussian term represents the source intensity distribution (source size = S_0), $|F_{hkl}|$ the Bragg amplitude of the substrate, and r,s the optical path functions. For each spatially coherent source segment, the Fresnel amplitudes are summed over all zones with appropriate phase shifts; while for different segments which are mutually incoherent, the intensities are summed. Fig. 2 shows the comparison between the model predicted focusing pattern with the experimental data measured from a 0.2 •m linewidth linear GaAs BFL. The agreement is quite good given that no adjustable parameter was allowed in the model. The calculation revealed, not surprisingly, that the effective lens aperture (~40 µm) is determined by the transverse coherent size of the source. This effective and computationally efficient model will be used to optimize the design to match the source parameters at the APS for the next generation of BFLs.

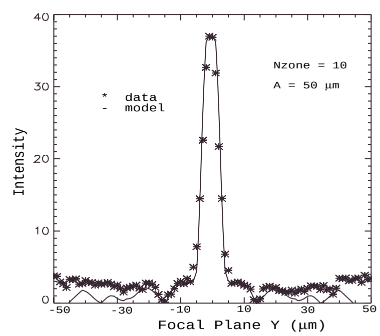

Fig.2 Comparison between experimental focusing data and model simulation based on equation (1). The diffraction data were measured using a 5 µm wide fluorescence probe. Deconvolution of data indicate a focus size of ~1 µm, which is consistent with the demagnified source size.

Acknowledgments

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References

1. Snigirev, A., *Rev. of Sci. Instrum.* **66**(2): p. 2053-2058 (1995).
2. Li, Y., G.C.L. Wong, C.R. Safinya, E. Caine, E.L. Hu, D. Haeffner, P. Fernandez, and W. Yun, *Rev. of Sci. Instrum.* **69**(8): p. 2844-2848 (1998).
3. Li, Y., G.C.L. Wong, R. Case, E. Caine, E.L. Hu, and C.R. Safinya, submitted to *Appl. Phys. lett*. (1999)