Fourier X-Ray Scattering Imaging and Biological Applications

Han Wen*, Vinay Pai, Susanna K. Lynch, Camille K. Kemble, Eric Bennett
National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, MD, US
Wah Keat Lee, Xianghui Xiao, Lahsen Assoufid, Chian Liu
Advanced Photon Source, Argonne National Laboratory, Argonne, IL, US
*wenh@nhlbi.nih.gov

Grating-based phase sensitive techniques can potentially enhance the sensitivity and specificity of x-ray computed tomography as it is applied to biological research and clinical diagnosis[1]. The predicted sensitivity improvement is based on the two orders of magnitude difference between the phase shift and magnitude attenuation in soft tissue of x-ray beams in the 10 to 100 keV range. The enhanced specificity may come from the ability of the grating-based techniques to detect small-angle scattering, or diffraction, and in turn characterize microscopic structures that are much below the image resolution itself.

A key requirement for biological applications is speed. When the camera resolution is sufficient to resolve the grating fringes directly or indirectly through a Moire pattern, analysis in the Fourier domain provides both phase-contrast and scattering images from a single exposure[2,3]. The scattering extinction coefficient is related to the size of the scatterers, and reaches maximum when the size of the scatterers are equal to an autocorrelation distance defined by the imaging device[4,5]. Taking advantage of this size selectivity, one can highlight externally injected particle contrast agents of the appropriate sizes, while suppressing tissue and bone background[6].

The sensitivity of grating-based techniques are determined by the achievable density of the gratings. With silicon and polymer grating structures, grating periods below 2 microns require high structural aspect ratios that are challenging to fabricate. We are developing two alternative methods to achieve high phase sensitivity: grazing angle Mach-Zehnder interferometers[7], and multilayer grating arrays[8]. The grazing-angle interferometer uses reflective phase and intensity gratings[9] to achieve high sensitivity, since the effective periods of such gratings are orders of magnitude smaller than the physical periods. An inherent symmetry of our interferometer design results in phase-locked fringe patterns from any wavelength and a range of incidence angles, making it suitable for broadband, un-collimated sources. A basic limitation of the method is the narrow field of view in one direction. The multilayer grating arrays are inspired by multilayer Laue lenses and multilayer-coated reflective EUV gratings. By depositing a multilayer structure on a staircase-like substrate, the result is a concatenated array of small gratings[8], and the period of each grating is controlled by the layer thickness in the deposition process. In this approach the grating period can be as low as tens of nanometers in principle, and the field of view is not limited. The design of such multilayer grating arrays involves the coordination between multilayer deposition and the resulting x-ray optics. The first results from both methods will be discussed.

[1] T. Weitkamp *et al.*, Optics Express **13,** 6296 (2005).
[2] M. Takeda, H. Ina, and S. Kobayashi, Journal of the Optical Society of America **72,** 156 (1982).
[3] H. Wen, E. Bennett, M. M. Hegedus, and S. C. Carroll, IEEE Transactions on Medical Imaging **27,** 997 (2008).
[4] H. Wen, E. E. Bennett, M. M. Hegedus, and S. Rapacchi, Radiology **252,** 910 (2009).
[5] W. Yashiro, Y. Terui, K. Kawabata, and A. Momose, Optics Express **18,** 16890 (2010).
[6] A. F. Stein *et al.*, Optics Express **18,** 13271 (2010).
[7] C. K. Kemble *et al.*, Optics Express **18,** 27481 (2010).
[8] S. K. Lynch *et al.*, SPIE Optics and Optoelectronics, EUV and X-ray Optics: Synergy between Laboratory and Space 8076 (2011).
[9] L. A. Sayce and A. Franks, Proceedings of the Royal Society of London Series A-Mathematical and Physical Sciences **282,** 353-357 (1964).