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Novel, High Brightness X-ray Source and High Efficiency X-ray Optic for Development of X-ray Instrumentation

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In the past two decades, laboratory x-ray analysis equipment has made significant strides, particularly toward higher resolution capabilities [1-2]. The major bottleneck to continued advances to achieving simultaneously achieving higher sensitivity, resolution, and throughput is the relatively low flux of x-rays at the sample for micro-characterization techniques such as SAXS, high resolution XRD, microXRF, and x-ray microscopy [3]. We present two major innovations of a microfocus x-ray source and a high resolution, high efficiency x-ray optic to enable delivery of flux comparable to second generation bending magnet synchrotrons.

The proprietary Sigray FAAST™ source features an anode comprised of arrays of metal (e.g. Cu, W) microstructures x-ray emitters embedded in a diamond substrate, which enables highly localized and large thermal gradients to passively and rapidly cool the metal microstructures as x-rays and heat are generated under the bombardment of electrons. Electron power densities of over 4X can be achieved on the target in comparison to conventional solid metal targets for the case of copper – and even greater for metals of lower thermal conductivity. The thermal advantages of the x-ray source will critically enable the use of many elements that were previously considered infeasible as x-ray source materials, and therefore will enable access to new x-ray characteristic lines to optimize performance in monochromatic x-ray analysis. The source enables linear accumulation of x-rays along a set of microstructures, which further increases the substantial brightness gain.

We will also discuss advances made to Sigray's proprietary axially symmetric x-ray mirror lens designs, particularly in regards to the key performance attributes that must be evaluated when considering an x-ray optic for microanalytical applications, including: focusing efficiency, numerical aperture (NA), FWHM of point spread function, working distance, focus chromaticity, energy bandpass, energy transmission, percent of source brightness preservation, and phase space acceptance.

Several of the key breakthroughs that Sigray has made in regards to the development of the mirror lens include optimizing the preservation of the ultrahigh brightness of small spot sized x-ray sources (e.g. the Sigray FAAST™ source, transmission nanofocus sources, and liquid metal jet anode x-ray sources). Additionally, the lens enables unprecedented capabilities for focusing low energy x-rays to microns-scale spot sizes, which can potentially unlock many applications for laboratory analysis, such as microXRF of low atomic number elements and increased sensitivity of grazing incidence and surface analysis. The imaging nature and achromatic nature of the lens moreover provide a single focal spot for x-rays of all energies, which has conventionally been a limitation to the accuracy of microanalytical techniques that rely on polycapillary lenses (which produce differing illumination spot sizes on the sample and thus results in the emission of interfering x-rays from outside of the intended focal spot). [4]

References:

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Table 1.

Performance Attributes	Polycapillary	Sigray Ellipsoid	Sigray Double Paraboloid
Imaging optic	Not an imaging optic (condensing optic)	Fair	Excellent
Transmission efficiency	~5-10%	~90%	~80%
Numerical aperture @ 8 keV#	<50 mrad	~10 mrad by Sigray	~20mrad by Sigray
FWHM of point spread function$	Minimum size equal to capillary diameter, inversely proportional to x-ray energy, proportionally increase with working distance	Independent on x-ray energy, determined by figure error (<10μm by Sigray)	Independent on x-ray energy, determined by figure error. (<10μm by Sigray)
Working distance for 10μm focus	1, 0.5, and 0.25mm for 17, 8, and 4 keV x-rays, respectively	1-10 cm depending on figure error (>2cm by Sigray)	1-10 cm depending on figure error (>2cm by Sigray)
Focus chromaticity	Focus size inversely proportional to x-ray energy	achromatic	achromatic
Spectral bandpass	Wide with a high energy cut-off which is dependent on specific optic	Wide with a high energy cut-off	Wide with a high energy cut-off
Spectral transmission	OK	Good	Good
Percent of source brightness preservation	Substantial reduction with a source of size smaller than the FWHM of point spread function	Fair	Excellent
Normalized Phase space acceptance	1	3	3