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High Resolution Camera for Resonant Inelastic Soft X-Ray Scattering Spectroscopy

N.C. Andersen[1], P. Denes[1], J. Farrington[2], A. Goldschmidt[1], J. Joseph[1], A. Karcher[1] and C.S. Tindall[1]

[1] Lawrence Berkeley National Laboratory (LBNL), 1 Cyclotron Road, Berkeley, CA 94720, USA

[2] Sydor Instruments LLC, 291 Millstead Way, Rochester, NY 14624, USA

ABSTRACT

Resonant inelastic scattering spectroscopy (RIXS) in the soft x-ray regime is a powerful technique to probe the electronic structure of mater. The technique utilizes energy dispersive spectrometers to disperse a scattered x-ray beam from a sample in such a way as to translate each x-ray energy into a corresponding position on a detector active area (Fig.1). Thus, in these spectrometers energy resolution is dependent on the position resolution of the detectors used. To increase the energy resolution of a detector, either the distance between the dispersive element and the detector is increased, or the detector pixel pitch in the energy dispersive axis is reduced.

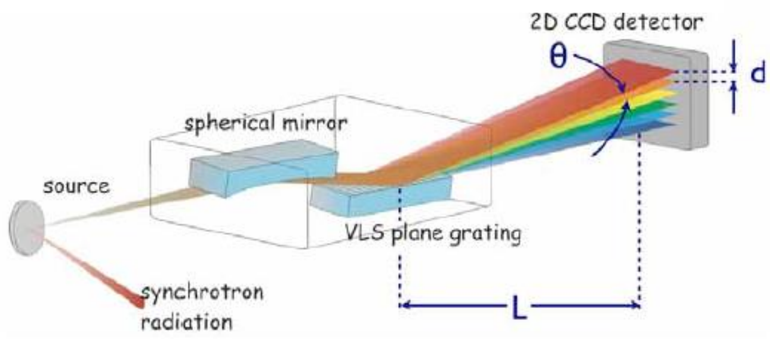

Figure 1 Energy dispersive spectrometer operation.

Researchers at the Lawrence Berkley National Laboratory (LBNL) have demonstrated the technical feasibility the Spectro CCD, a novel direct-detection, soft x-ray imaging camera with up to 3 times better position resolution than the current commercial offering.

THE SPECTRO CCD

Centroiding is a technique that utilizes the relative differences of the collected charges between adjacent pixels to determine the position of an incident x-ray to subpixel dimensional accuracy. This technique could be quite accurate for measurements with high photon counts. However, the accuracy of this technique is compromised for low photon count measurements since the difference in the collected charge between adjacent pixels could be comparable to the intrinsic statistical fluctuations or noise level of the measurements. The Spectro CCD employs a 5 µm x 45 µm pixel geometry to increase resolution in the energy dispersive axis (5 µm direction) eliminating the need of utilizing centroiding (Fig. 2a).

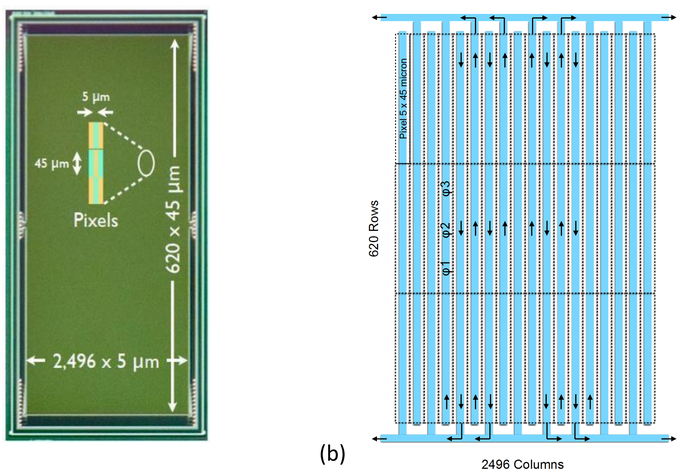

Figure 2 (a) Spectro CCD sensor format. (b) Spectro CCD interdigitated architecture.

LBNL implemented innovative design features on the sensor to achieve this small pixel size. Current manufacturing techniques applicable to the Spectro CCD sensor limit the minimum pixel size to approximately 10 µm. To overcome this size limitation, LBNL designed the Spectro CCD sensor to shift charges in opposite vertical directions for adjacent columns, thus reducing the linear density of pixels in the horizontal (shift) register by a factor of two (Fig.2b). In addition, the new CCD does not utilize channel-stops in order to further reduce the inter-column distance. Channel stops are commonly used in standard CCDs to avoid charge spilling onto neighbor columns.

In addition to having a small pixel size, the Spectro CDD sensor is fully depleted, built with high-resistivity n-type silicon and employs thin back entrance window in order to maximize charge collection. The back entrance window is single contact layer on the opposite side of the pixel gates which is used to bias the sensor in order to achieve full depletion and is the incident sensor surface for x-rays. A thin 10 nm back entrance window is utilized in the Spectro CCD to increase the sensor efficiency in the soft x-ray regime.

BEAMLINE TESTING

The Spectro CCD performance was characterized at the Advanced Light Source (ALS) beam lines 8.0.1 and 6.3.2. Beamline 6.3.2 is a metrology beamline with NIST calibrated silicon photodiodes and beam line 8.0.1 is a RIXS spectrometer with a 1.2 m arm length. Figure 3 shows the camera attached to the end of the RIXS spectrometer arm with a 6-inch flange. After reaching a vacuum pressure of $1x10^{-8}$ Torr, the camera was cooled to its -120º C operating temperature.

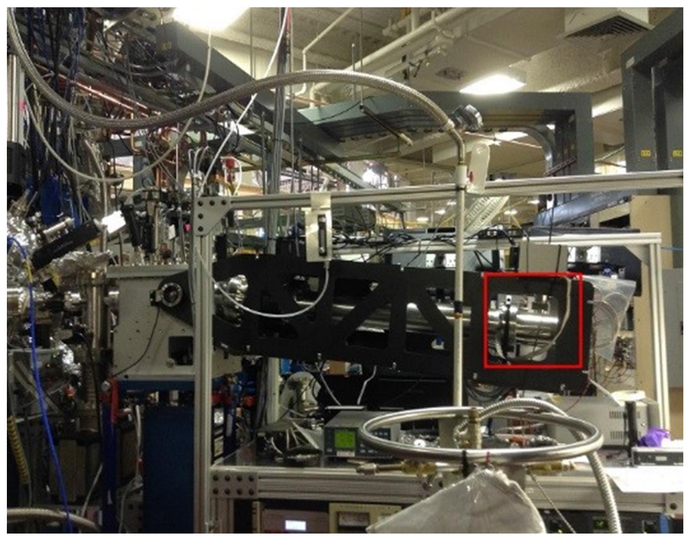

Figure 3 Spectro CCD installed at the Advanced Light Source (ALS) beam line 8.0.1 RIXS spectrometer.

Spectral Measurement

The Spectro CCD testing at the beamline 8.0.1 RIXS spectrometer utilized a graphite sample illuminated with ~280eV eV C_k X-rays . The resulting RIXS spectrum image of the graphite sample is shown on the top of Figure 4. Pixels are shown here with square proportions while in reality are elongated 9-fold vertically. The image captures the first order diffraction from the grating on the right. The projected spectrum (bottom of figure 4) shows the bright elastic peak and the broad inelastic features. The solid line in the inset shows the spectra obtained with the Spectro CDD which shows clear evidence of an oscillatory pattern for energies below the peak. For comparison, the dotted line is the same spectrum taken with a commercial 13.5 x 13.5 micron pixel camera.

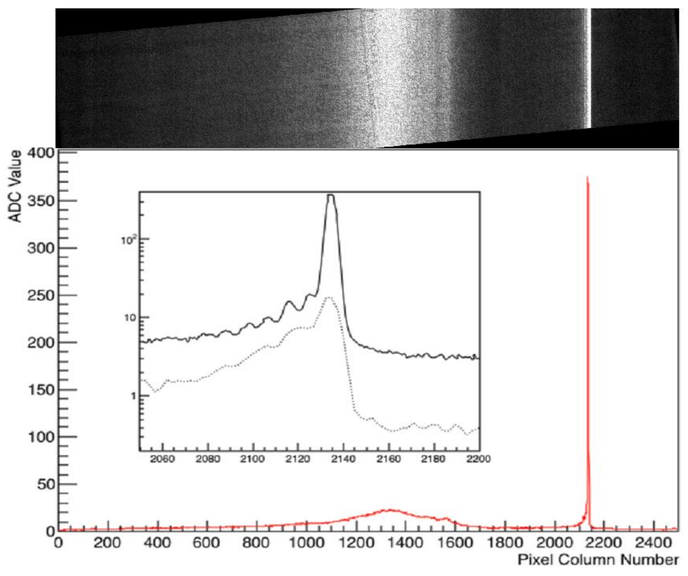

Figure 4 RIXS spectrum of a graphite sample. Spectrum obtained with Spectro CCD (solid line) shows more detailed spectral features than spectrum obtained with commercial 13.5 µm pixel camera (dotted line).

X-Ray Mask Test

A special mask with various holes of different shapes and sizes was installed within a few hundred microns of the CCD back-window in order to measure the position resolution of the CCD for soft X-rays. The mask, fabricated at the Center for X-ray Optics at LBNL, is a 5 µm-thick gold film of 1 x 1 mm^2 area supported on the edges by a 500 µm silicon frame (Fig. 4).

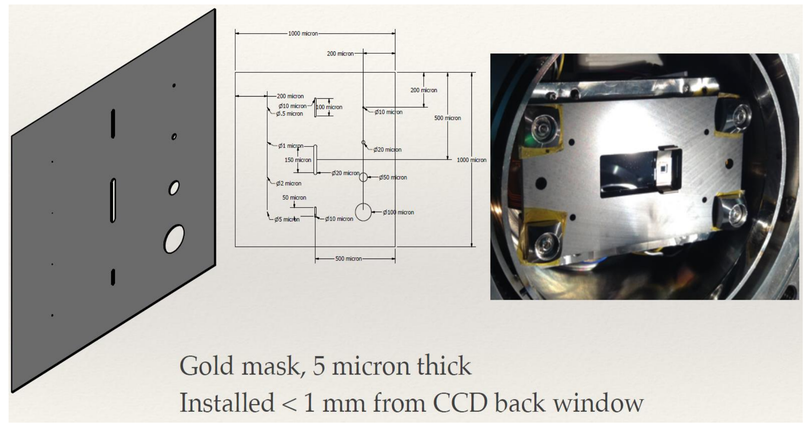

Figure 4 Gold mask with different features to measure the position resolution of the Spectro CCD with low flux soft x-rays.

A set of RIXS images with ~500 eV O_k incident on the mask demonstrated that the mask features could be readily seen in the images with the correct shapes, sizes and locations. Of particular interest were two images with an 500 eV x-ray in the position of an isolated 1 µm-diameter hole. For both images, two pixels contain the bulk of the charge and their charge-weighted centroids are 3.5 µm apart. This provides a measure of the expected position accuracy and resolution for low energy x-rays with low flux soft x-rays.

Quantum Efficiency Measurement

A dedicated measurement of the CCD quantum efficiency as a function of energy was performed at the ALS 6.3.2 metrology beam line. The metrology beam line is equipped with retractable NIST-calibrated silicon photodiodes that provide absolute beam power measurements. For the measurement, the CCD was operated as a single large diode with a beam that illuminated the center of the CCD with a spot of about 0.5 mm diameter. The energy of the beam was scanned from 100 eV to 1 keV with small gaps near 220 eV and 850 eV. With the absolute beam power and the current measurement, the quantum efficiency was computed.

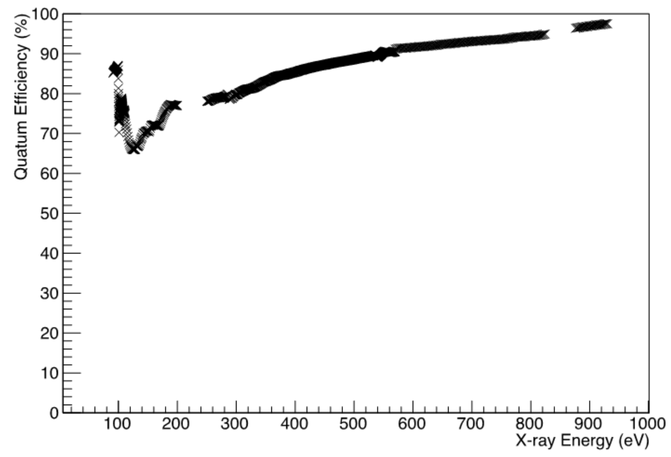

Figure 5 Calculated quantum efficiency of the CCD versus energy in the soft x-ray regime, which is larger than 75% in the 200 eV-1 keV region.

CURRENT DEVELOPMENT

The aforementioned results demonstrate that the Spectro CCD is an ideal camera for soft x-ray RIXS spectrometry. The electronics, software and mechanical systems of the camera are currently being upgraded by Sydor Instruments, via a DOE SBIR grant in collaboration with LBNL. Prototypes for beta testing are under development and the commercial Spectro CCD variant will be available in the near future.

Figure 6 Spectro CCD commercial version developed by Sydor Instruments.

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. DOE Office of Science, Office of Basic Energy Sciences, and the SBIR and STTR award Number DE-SC0007482. Use of the NSLS II was supported by the U.S. DOE, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-SC0012704.