# Adaptation of a Commercial Optical CMOS Image Sensor for Direct-Detection Fast X-ray Imaging

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## Introduction

Fast area detectors are essential for photon correlation studies using x-ray scattering techniques, primarily because of the two - dimensional nature of the scattering pattern and the need to analyze both spatial and temporal scattering fluctuations. Additionally, area detectors can significantly improve the signal-to-noise ratio of acquired data in the low photon count rate situations encountered in both small angle x-ray (SAXS) and x-ray photon correlation spectroscopy (XPCS) experiments.
Area detectors used for x-ray scattering have traditionally utilized charge-coupled devices (CCDs). CCD detectors have excellent spatial resolution, but are relatively slow in reading out images due to the requirement to read out an entire row at a time. Although there have been some techniques developed to achieve data acquisition rates of 30 msec [1], acquisition times in the sub millisecond range are needed to see dynamics for many samples. CMOS detectors offer the advantages of faster, per pixel charge readout at a much lower cost then CCDs. However, there are some potential disadvantages such as overall efficiency (incident photons vs. converted voltage), dark current levels, and noise levels. The objective of this experiment was to explore the potential uses of CMOS based area detectors for SAXS and XPCS applications.

## Methods and Materials

Commercially available CMOS cameras are designed for a variety of optical applications, so we selected one from Silicon Imaging, Inc. that provided for fast image data acquisition (up to 2000 frames/second) and fast data readout (up to 500 frames/second). In order to improve the overall efficiency of the SI 1280F CMOS detector, an "active pixel" architecture is used, resulting in charge-to-voltage conversion taking place in each pixel, reducing conversion losses. The imager chip is a 1024 x 1280 array of 6.7 square micron pixels with a 15 micron silicon epitaxial layer, manufactured by Cypress Semiconductors, Inc. There is a second timing board that houses a 12 bit AD converter, system clock (20 MHz – 60 MHz) and CameraLink (100 MB/s) interface to a frame grabber board. A temperature controlled, vacuum housing was designed to enclose both the pixel array and the timing boards. A Peltier cooling chip and recirculating copper housing was used to hold the pixel imager chip at a constant temperature, with the intent of reducing overall dark current and particularly dark rms noise. The housing was designed so it could be rotated about the horizontal central axis of the pixel array to increase the effective thickness of the epitaxial layer and hence the overall efficiency of the camera. Experiments were performed at the 8-ID beamline at that Advanced Photon Source using a 7.49 keV photon source. Calibration data was also taken at the X-Ray lab of Northern Illinois University. Data acquisition software was modified to provide support for the SI-1280F CMOS camera by Brian Tieman of the ANL Controls & Data Acquisition group.

## Results

ADUs per photon is the key measure of the conversion of absorbed photons. We found signal-to-noise ratios (SNR) of around 25:1 (peak ADUs/average temporal dark rms) after subtracting reference dark current. ADUs per photon were linear with amplifier gain, as expected.
Total efficiency is a measure of the ratio of detected photons to incident photons and is obviously a key measure for the low photon count rate situations typical of many SAXS and XPCS experiments. We calculated the total efficiency by comparing the static structure factors produced by the SI 1280F (Fig. 1.) and a calibrated Princeton Instruments CCD camera for the same sample. Overall efficiency ranged from 11.5% (no tilting) to 22% (tilt angle of 56 degrees).
We analyzed the dynamics of polystyrene latex spheres in glycerol at various temperatures. Time autocorrelation functions are indicative of the dynamic motion of the sample at various wave vectors. Our results compare favorably with those of the more efficient CCD detectors, showing good optical contrast at an order of magnitude increase in image acquisition speed (2 vs.30 msec) with no loss in SNR, as shown in Fig 2.

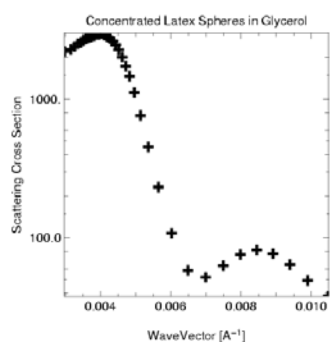


*Fig.1. Static Structure Factor of Latex Spheres*

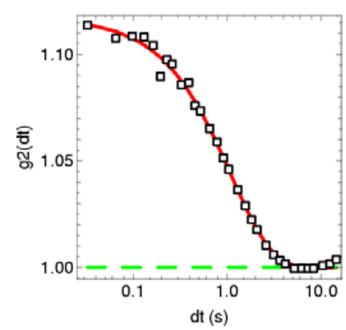


*Fig.2. Time Autocorrelation Function g2(Q,t), of Latex Spheres*

## Discussion

The results to date are encouraging given the low cost of the CMOS camera (<$2,000). Tilting of the camera doubles the overall efficiency to a reasonable level. We are looking at CMOS pixel arrays with a 40 micron depletion layer that should result in efficiency levels commensurate with CCD area detectors. Analysis of the noise levels of the CMOS camera are ongoing, but as reported above SNRs are acceptable. We used a clock speed of 45 MHz, resulting in minimum exposure times of 2 msec and will test shorter exposure times in the future.

[1] D. Lumma, L.B. Lurio, and S. G. J. Mochrie, Rev. Sci. Instrum, Vol **71**, No. **9**; September 2000