High-Speed CCD Camera as X-ray Photon Correlation Spectroscopy Detector

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Introduction

Traditionally, so-called "scientific CCDs" have been used as direct-detection x-ray photon correlation spectroscopy (XPCS) detectors.[1] Though these detectors have very low noise levels (approx. 10 e^- rms.), their readout speed is relatively low (~1 MHz). The low readout speed severely limits their data collection efficiency at short exposure times. If one realizes that, in a direct detection scheme, the detector noise is negligible compared to photon shot noise, one can sacrifice readout noise to improve speed. This report shows the possibility of using a faster and noisier camera as a more efficient XPCS detector.

Methods and Materials

A typical scientific CCD used in XPCS measurements is the Princeton Instruments EEV 1152 x 1242 3ph camera. This camera has 1152 x 1242 pixels; reading out the whole chip takes 3.6 seconds. If one would like to collect data on shorter time scales than the readout speed, one has to use the so-called kinetics mode. Kinetics mode allows us to take multiple (for example 16) slices in rapid succession using only a fraction (ideally 1/16) of the CCD. In this method we loose photons two ways: first we use only 1/16 of the CCD, and second we are not taking data while reading the data out. For a 20 ms exposure, for example, we expose the CCD for 16 x 20 ms=320 ms and read out the CCD for 3600 ms. We are not taking data 90% of the time!

What allows us to improve this situation is that this CCD is too sensitive. A direct-detected 8 keV x-ray photon corresponds to a couple hundred detector units, while the readout noise is just 2 detector units. By finding a less sensitive detector, we will still be able to distinguish individual photons but may be able to read out the CCD faster. The SMD 1M60 camera is such a faster detector. It has a 60 MHz readout speed, while its noise level is still much smaller than the x-ray photon level. It is able to transfer the data from the CCD chip in less than 1 ms and is capable of digitizing the data while it is exposing the next frame. These two differences tremendously increase the new camera's data collection efficiency, promising a better signal-to-noise ratio.

We were able to determine this new camera's quantum efficiency and point spread function.[2] Based on these data and the readout speeds at different exposure times, we calculated the relative signal-to-noise ratios of the Princeton and SMD cameras under the same experimental conditions. By analyzing XPCS data taken on the same colloidal sample, we verified our theoretical predictions.[3]

Results

In an XPCS measurement, the signal-to-noise ratio of correlation functions is dominated by counting statistics. The signal-to-noise improves linearly with the number of photons collected and also improves as the square root of the number of regions averaged.[4] So for the same sample, same slit settings, same angular acceptance of detectors, the XPCS S/N ratio can be compared as:

S/N=(exposure time)*(quantum efficiency)*sqrt (number of pixels read out per second)

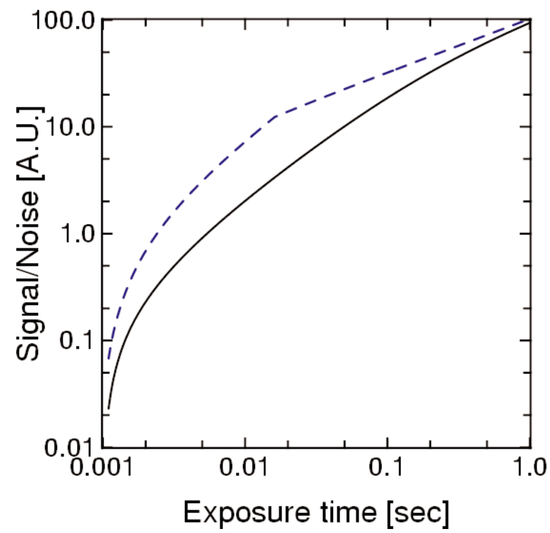

FIG. 1. Calculated relative signal-to noise-ratio of the Princeton and SMD cameras in an XPCS measurement (SMD camera on the upper curve, Princeton on the lower curve).

Figure 1 plots the results of this calculation. It is clear that the new camera is better than the old one at all exposure times between 2 ms and 1s. The new camera has the biggest advantage around 1/60 s exposure time, where the S/N is 4 times better than the old camera, or in other words a 4 times faster system can be studied with the same signal-to-noise ratio. It is notable that despite the fact that the readout rate of the new camera is 2 orders of magnitude faster than the old one, the S/N did not improve that much because of the new camera's 4 times smaller quantum efficiency.

It is also notable that, due to the high volume of data generated by the new camera, it is not practical to store the measurement results and analyze them later "off line." A new computer system is under development that should be able to analyze the data while it is being taken. When this computer system will be functional, it will allow doing multichannel XPCS measurements as conveniently as they are done with single-channel correlator boards; the correlation function will be available to the user immediately.

Discussion

The possibility to use a fast CCD as a direct-detection XPCS detector has been explored. The new camera has been commissioned. It has a better signal-to-noise ratio than the previous detection scheme, though there is still room for improvement if one can increase the detectors quantum efficiency.

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