A Multiple CCD X-ray Detector and its Basic Characterization

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1. Introduction

X-ray imaging sensors based on charge-coupled-devices (CCD) have been considered as one of the most promising detectors in various scientific fields of synchrotron radiation, especially in protein crystallography where high precision are required in determining the positions and the intensities of the scattered x-rays [1]. In the collaboration of EEV in UK the SR Structural Biology Research Group of RIKEN has developed an array of CCD detectors to proceed advanced protein crystallography at the RIKEN beamline of SPring-8 [2]. The detector constructed is called the ‘Multiple Charge-Coupled-Device X-ray Detector (hereafter referred to as MCCDX),” realizing the largest detection area ever constructed among this type of CCD-based X-ray detectors.

2. Basic Characterization of MCCDX

The MCCDX is structured in such a way that 16 modules of CCD x-ray detectors are integrated into a [4 ×4] rectangular matrices as Fig.1 illustrates. Each modules of the CCD x-ray detectors is composed from a scintillating screen, a fiber optic taper, and a large format scientific CCD.

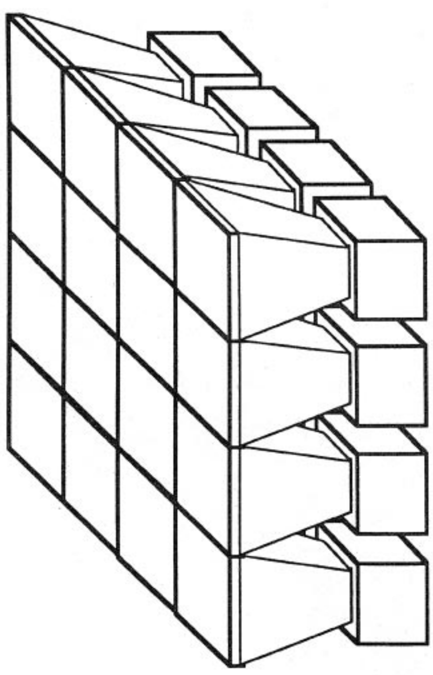

Fig.1 Schematic of the MCCDX

The scientific CCDs (EEV, CCD05-30) employed have an image area of 27.95 mm × 25.92 mm covered with 1242 × 1152 pixels [3]. When operated at 0˚C in the inversion mode, these CCDS typically indicate the peak signal of 200k electrons/pixel and the dark signal fluctuation of 6 electrons/pixel/sec. The nonuniformities in the response and the dark signal of these CCDS are ± 3% and ±2%, respectively.

The readout electronics mounted on each module is a variant of CCD driver assembly (EEV, CDB01-X) [4] that can comply the geometrical constrain of the MCCDX. These driver assemblies accept an external trigger pulses of which width define the integration time of the system. Upon detecting the end of the external trigger pulse, the diver assemblies start reading out the CCDs, and process the charge signals based on the correlated double sampling technique. The readout rate selectable are 50, 100, 200, 500 kHz, and 1 MHZ in the present system. The readout noise levels of the assemblies are around 25 electrons at a readout frequency of 1MHz, which practically dominate the overall noise levels of the entire system. Each assembly outputs the analogue video signal, which is submitted to a digitization system described below.

The fiber optic tapers coupled to the CCDs have input and output square ends of 50 mm × 50 mm and 25 mm × 25 mm, respectively, with a length of 50 mm. The fiber size is designed to be 10 µm at the input end, and extramural absorbers are included The shear distortion and the pincushion-type distortion evaluated at the input end are < 40 µm and < 3%, respectively. The CCDs are attached to the output ends of these fiberoptic tapers by using gel to make the optical and mechanical contacts reliable.

After assembling the 16 modules of the CCD x-ray detectors, the input ends of the fiber optic tapers are precisely aligned and uniformly coated with a layer of Gd_2O_2S:Eu having a thickness and a grain-size of 20 µm and 4.0 µm, respectively. The scintillating screen based on Gd_2O_2S:Eu has a maximum emission around 625 nm with a fwhm of 10 nm, of which decay time is reported about ◆ msec. The quantum efficiency of the CCDs used exceed more than 40% at this region of wavelength [2].

The [4 × 4] array structure of the CCD x-ray detectors is placed in an air-and light-tight aluminum vessel. The vessel has an x-ray entrance window with an effective opening area of 200 mm × 200 mm, which is made of carbon-doped black mylar with a thickness of 150 µm. A flow of chilled ethylene glycol is supplied to the vessel in order to regulate the operational temperature of the CCDs to be 0˚C. Pure nitrogen gas is also supplied to the vessel during the operation with a flow rate of 200 cc/min at 1.2 atm to avoid moisture condensation on the CCD packages and/or the electronics mounted.

The data acquisition system linked to the MCCDX consists of a digitizer (MCCDX I/F, System Design Service Corp.) and a workstation (DEC Alpha station 600 5/266). The digitizer is a VME-based system equipped with 16 modules of ADCs. Upon receiving an external start pulse synchronizing with the MCCDX operation, these ADC modules start digitizing ail the MCCDX video output signals simultaneously into digital signals of 16 bits with a sampling rate of 1MHz. Each module has a buffer memory of 3 MB, and the stored data are transferred to a workstation via a VME/PCI interface with a data transfer rate of 12 MB/s for data storage and further analysis. It takes about 6 sec for this data acquisition system to readout the 16 CCDS and locate all the data onto the memories of the workstation.

3. Preliminary Resuits and Prospective

The initial test on the MCCDX system was carried out by using the setup illustrated in Fig. 2. The MCCDX was placed on an x-y stage that can be moved in either (Erection with a precision of 50 µm. The stage itself was located on an x-ray optical bench together with another components such as a mirror, a monochromator, a shutter, and a pair of x-y slits. The x-ray generator used was a high brilliance type with a rotating-anode made of Mo, and was operated at 60 kV and 40 mA in this work. The monochromatized x-ray beam of 0.71 Å was focused upon the entrance window of the MCCDX with an approximate beam size of 100µm (fwhm) × 100µm (fwhm).

By using the x-y stage and the shutter synchronously operated each other, the MCCDX was irradiated with the x-ray beam in such a way that the final image should result in forming an lattice pattern composed of the x-ray beam spots with horizontal and vertical intervals of 2 mm. Figure 3 shows a typical example of the lattice image preliminary obtained with a single module of CCD x-ray detector. The resultant image observed contains a lattice pattern as expected, confirming the basic operation of MCCDX system. It is also confirmed that there exist substantial image distortions as anticipated during the coarse of this work.

At the time of writing this report, 9 of the 16 modules have been submitted to this basic test procedure, and the SR Structural Biology Research Group of RIKEN expects to complete this initial test by the end of March 1997. An intensive research program will then follow to characterize the MCCDX system with a various detector parameters such as the sensitivity over the entire detection area the dynamic range, the point spread function, and so forth. After completing the intensive characterization, the SR Structural Biology Research Group will install the MCCDX system into their beamline during the autumn 1997.

References

[1] See, for example, N. A. Allinson, J. Synchrotron Rad. 1, 54 (1994) for review.

[2] See, for example, M. Yamamoto and H. Iwasaki, SPring-8 Annual Report 1995, p.76, 1995.

[3] EEV, A1A-CCD05-30 Series Scientific Image Sensor, Issue 3, January 1994.

[4] EEV, CCD Driver Assembly CDB01-x, User Manual, Issue 1, April 1994.

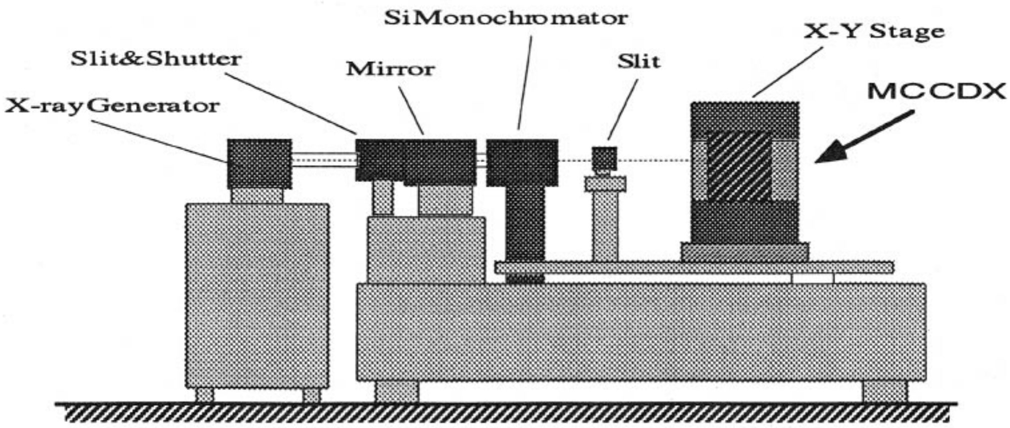

Fig. 2 Experimental setup used for the initial test on the MCCDX system

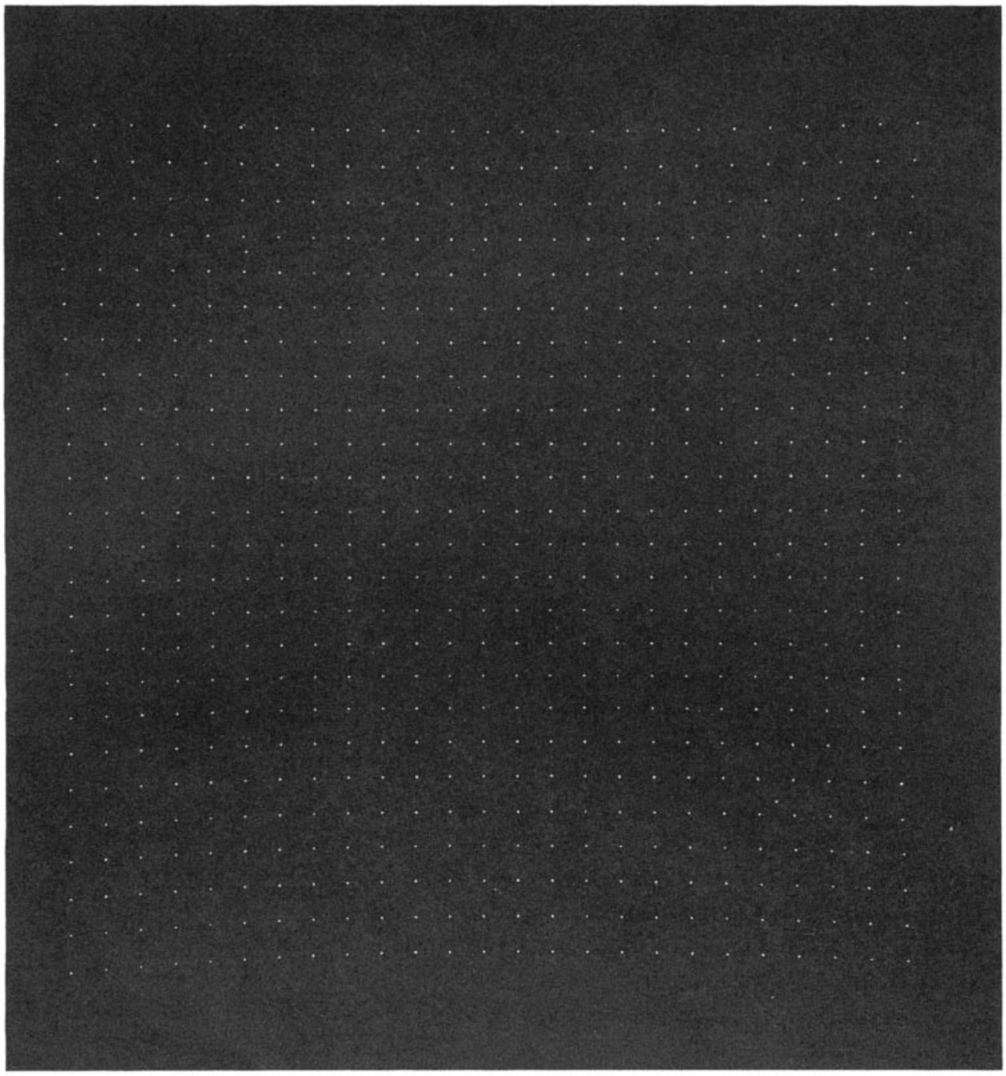

Fig.3 A lattice image composed of x-ray beam spots measured with a single module of CCD x-ray detector.