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Noiseless direct detection of electrons in Medipix2 for electron microscopy

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Abstract

We describe the application of a hybrid pixel detector (HPD), Medipix2, containing 256×256 pixels to electron microscopy. Our previous tests on HPDs were made with Medipix1, which was an earlier version of the present detector. Apart from an increase in the size and number of pixels, the main advantage of Medipix2 for our applications is in the ability to set a fairly high threshold voltage. We show that Medipix2 has a high detection efficiency for 120 keV electrons, with no readout noise. The spatial resolution is also excellent as measured by comparing the power spectrum obtained by imaging a standard electron microscopy grid: at Nyquist frequency the power is 76% compared to film. The special properties of Medipix2 allow electron detection in single pixels. No radiation damage was detectable up to a dose of ~6 Mrads—equivalent to many years normal usage in the electron microscope.

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1. Introduction

Data collection in all forms of electron microscopy would benefit enormously from the substitution of film with electronic detectors. Since this subject is discussed in more detail in a recent review [1] and a companion article in this issue [2], it will only be mentioned very briefly here. Electronic detectors avoid the need for film processing and densitometry providing high signal-to-noise data immediately in digital format.

CCD detectors, combined with phosphor-coated fibre optics, have been used for some years for electron microscopy. The spatial resolution in such detectors is restricted, however, by multiple light scattering within the phosphor grains and at the CCD–fibre optics interface. In imaging terms, the modulation transfer function (MTF) falls off much more rapidly than for films at higher spatial frequencies leaving the film as the detector of

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choice for high-resolution cryo-microscopy [2]. Direct detection in conventional CCD detectors, without the intermediate step of conversion to light, is not a practical option due to limited dynamic range and severe problems of radiation damage. With the increasing interest in structural determination by cryo-microscopy [3], it is important to have tools for electronic data collection that bypass the slow and tedious process of processing images recorded on photographic film. At very low doses, the film also has a high background noise due to fog and dust.

We have previously evaluated Medipix1 [4], consisting of 64×64 pixels with 170 μm edge at 60 and 120 keV [5]. The newer chip, Medipix2 [6,7], which is designed in 0.25 μm CMOS technology with 256×256 pixels of 55 μm edge, covers an area of $\sim 2\,cm^2$. Each pixel consists of a preamplifier, a discriminator with a lower and an upper threshold (equivalent to an energy window) and a 13-bit shift register. There are 504 transistors in a pixel and about 33 million transistors in the chip. The two main improvements for electron microscopy are:

- increase in the size of the detector to $2\,cm^2$ and in the number pixels, to 256×256, which makes the detector better matched to the requirements of electron microscopy, and
- the ability to operate with much higher discriminator thresholds (we only use the lower threshold as incident electrons are mono-energetic) resulting in significantly improved spatial resolution due to the elimination of extra counts resulting from charge sharing in pixels adjacent to the one with maximum deposited energy.

Our main objective was to carry out a series of tests on Medipix2 measuring sensitivity, resolution and radiation damage, three of the most important parameters associated with a potential detector. These results are described below.

2. Experimental details

The Medipix2 assembly was installed in a 120 kV electron microscope (Philips CM12) for tests and general evaluation. Some of the initial tests were made with the assembly mounted in the 35 mm camera port (details of mounting very similar to those described for Medipix1 [5]), but was later transferred to a position just below the film plane, as shown in a photograph in Fig. 1. The electrical connections and bias voltage are connected via high vacuum compatible feed-through connectors installed on a viewing port, seen on the left side of the main viewing chamber. All control electronics, including the Muros2 interface board [8] are outside the vacuum chamber. Most of the readout electronics on the Medipix2 chip is covered by a 300 μm wafer of silicon which acts as the detector. A protective metal plate prevented incident electrons from direct irradiation of any exposed parts of the electronics chip.

2.1. Sensitivity

The sensitivity of Medipix2 was measured indirectly by comparing the counts recorded in a calibrated detector, i.e. the film, for near-identical exposures. The counts on the film used for these tests can be reliably estimated from the optical density if the development is carried out under controlled conditions. As in previous tests, the

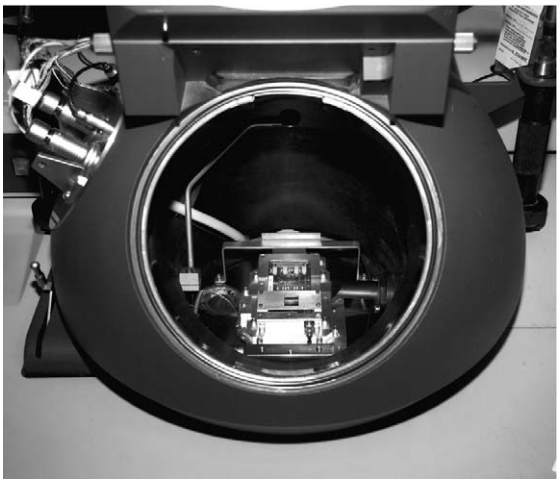

Fig. 1. View of the Medipix2 detector installed in a CM12 electron microscope. Medipix2 is located just under the metal shield with a square hole cut in it. Electrical wiring to the chip is in the viewing port (glass plate replaced with a metal plate) on the left. The detector is mounted just beneath the plane of the film (with the film holder removed).