One- and Two-Coordinate Detectors in BINP

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One- and two-coordinate detectors with proportional chambers developed at the Budker Institute of Nuclear Physics (BINP) are presented. The parallax-free 10 MHz one-coordinate OD-3.1 and OD-3.2 detectors are used in synchrotron radiation powder diffraction and SAXS experiments. The two-coordinate DED-3 detector with a multiwire proportional chamber (MWPC) is used in Laue diffraction. The latest modification of this detector, DED-5, with a working area of 384×384 mm, is briefly described. The micro-strip detector prototype MSGC-100 has passed test synchrotron radiation experiments and the next modification (MSGC-500), with 500 channels for high energy, is under construction. The one-coordinate MWPC OD-160 detector, with an angle aperture of $160°$ and a count rate of 3.3 GHz, is under construction. It will be used for high-resolution powder diffraction. Two types of gas chamber will be used: L for low energies (5–30 keV) and H for high energies (30–70 keV). A $16°$ section with an H-chamber has been produced and tested on the synchrotron radiation beamline.

Keywords: X-ray detectors; time-resolved diffraction.

1. Introduction

The Institute of Nuclear Physics has been designing and fabricating one- and two-coordinate X-ray detectors (Aulchenko & Feldman, 1987; Baru & Proviz, 1983) for research in X-ray diffraction since 1975 (Gaponov *et al.*, 1989). For quanta detection, proportional chambers that operate in direct quanta count mode are employed.

The direct quanta count mode is natural for a proportional chamber. It has practically no background and therefore gives an opportunity to detect very weak intensities. It has a large dynamic range of measured intensities, allows on-line energy selection, a fast frame-by-frame regime and has all the advantages of an on-line computer mode.

2. Parallax-free 10 MHz one-coordinate detectors OD-3.1 and OD-3.2

The basic part of the detection system (OD-3) is a proportional chamber with a drift gap that overlaps the absorption volume. The photons enter the detector through a 0.4 mm-thick Be window (see Fig. 1) and can be absorbed within 50 mm in the chamber gas mixture. Electrons appearing due to the photo-effect drift through the field-shaping wire-grid cathode to the anode wires where avalanche amplification occurs. The coordinate of the avalanche transverse to the direction of the anode wires is measured using induced charge distribution over the cathode strips, which serve as a second chamber cathode. The cathode has a fan-like shape of strips with the focus at the sample in order to obtain parallax-free images.

The preamplifiers and shapers are located close to the strips outside the clean chamber box. The signals are transmitted into the basic crate, where they are digitized by a flash ADC. The number of strips with maximal amplitude, amplitudes from the two neighboring strips $A(n-1)$ and $A(n+1)$, and external-timer time signals are transmitted to the processor for the selected events. Using this data the processor defines the photon coordinate and a photon energy (Aulchenko & Dubrovin, 1995). Image exposure is defined by the external timer. The minimum image exposure is 1 µs.

The detector was installed and tested at the synchrotron radiation beamline 15-A at the Photon Factory, KEK, in Tsukuba (see Fig. 2).

Two experiments were performed to carry out the counting-rate test. A narrow straight beam was used in the first experiment, while scattering from an aerosol sample was used in the second. A counting rate of 850 kHz was achieved for one strip in the first experiment. However, this result does not mean that the total counting rate could be calculated as 850 kHz $\times$ 52 strips = 44.2 MHz. In reality, when all strips are under irradiation, the total counting rate of the detector cannot exceed 10 MHz.

Table 1
Detector parameters.

Detector name	Working field (mm)	Focal length (mm)	Channel size (mm)	Space resolution FWHM (mm)	Number of channels	Photo-absorption length (mm)	Working energy (keV)	Minimal time frame (μs)	Count rate (MHz)
OD-3.1	200 × 10	350	0.07	0.18	3328	50	5–20	1	10
OD-3.2	200 × 25	1500	0.07	0.15	3328	50	5–20	1	10
DED-5	384 × 384	No	1.5 × 1.5	1.5 × 1.5	65536	10	5–20	100	5
MSGC-100	10 × 20	No	0.2	0.2	100	5	5–20	100	100
MSGC-500†	10 × 100	500	0.2	0.2	500	50	5–70	1	1000
OD-160-L(H)†	20 × 2760	1350	1.2	1.2, 0.12‡	6600	50	5–30, (30–70)	1	3300

† Under construction or testing.　　‡ In scanning mode.

The second experiment was performed with the aerosol. The aerosol sample gives very strong scattering in the small-angle region. Therefore, it is very convenient to use these samples in testing OD-3.2 at very high counting rates.

Scattering from the aerosol takes place in the region below $2\theta = 0.34°$. This means that all the photons scattered from the sample cover only two strips (128 channels) above the straight beam and the same below the straight beam. The first strips (upper and lower) account for 86% of the total flux, and the second strips account for 14%. The total flux was 1.5 MHz. It is easy to calculate that the flux at the first strips was 1.29 MHz and at the second 210 kHz. This test showed that OD-3.2 can operate under extreme conditions with a photon flux much higher than that declared in the specification.

An experiment on frog muscle contraction was used to test the time resolution of the detector. The single-frame time interval was 1 ms for horizontal and vertical orientations of the muscle. An external pulse generator was used to control the beam shutter opening, muscle contraction, and the starting point of the fast frame-by-frame regime of OD-3.2. The experiment was carried out in accumulation mode and included 20 cycles of contraction. The total number of frames was 128. Each frame contained 512 channels. In order to obtain information on the kinetics of frog muscle contraction, the profile was fitted according to a special procedure.

3. Micro-strip gas chamber prototype MSGC-100

The basic part of the detection system is a proportional chamber with a drift gap that overlaps the absorption volume. A cross section of the detector is shown schematically in Fig. 3. A cylindrical high-pressure box of diameter 30 cm is attached to a special crate with front-end electronics. The cover of the box has an inlet window (1.5 × 3 cm) with a 1 mm Be foil. The micro-strip plate is attached by plastic rods to the bottom of the box. The distance between the micro-strip plate and the inner side of the Be window is 5 mm. The drift cathode is made of aluminized mylar, 100 μm thick.

The MSGC is made on electronically conductive C85-1 glass. The golden micro-strip pattern has 80 μm cathodes, 10 μm anodes and a 200 μm anode-to-anode pitch. The micro-strip structure contains 100 anodes and 101 cathodes
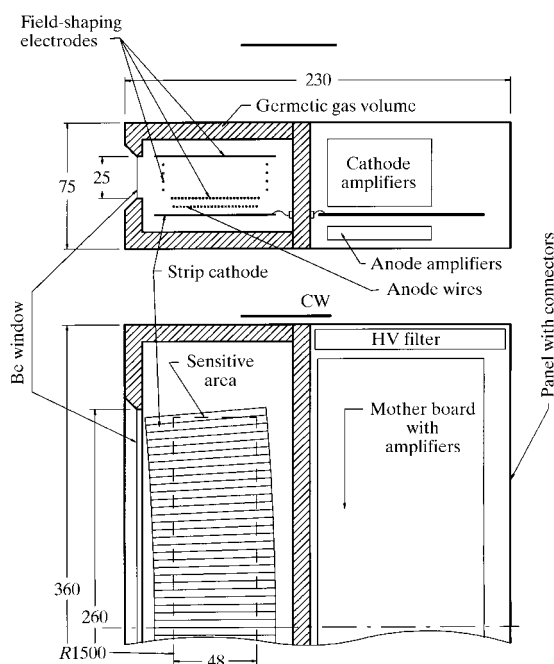
Figure 1
Cross sections of the OD-3.2 proportional chamber.
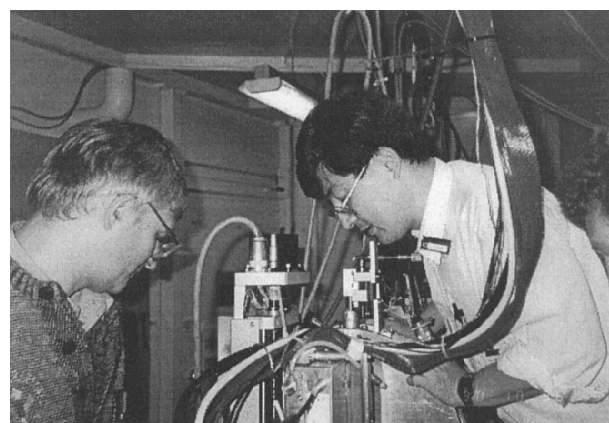
Figure 2
B. P. Tolochko (left) and Y. Amemiya (right) during OD-3.2 detector test experiments at synchrotron radiation beamline 15-A at the Photon Factory, KEK, in October 1996.

fanned out directly on the plate to a 0.8 mm pitch. 96 anodes are connected with the front-end electronics consisting of eight 12-channel cards with fast current amplifiers and discriminators. The outputs of the front-end cards are connected to CAMAC scalers.

The spatial resolution depends essentially on pressure. At 5 bar, a spatial resolution of about 200 μm FWHM was achieved. The spectrum of ^{109}Cd (22 keV) was obtained. The energy resolution (FWHM) was 8.7%.

The high rate properties of the detector were demonstrated by testing it at synchrotron radiation beamline 7 of VEPP-3. Here the counting rate reaches a value of about 700 kHz per channel, which permits measurement of a fast process with high accuracy at one shot.
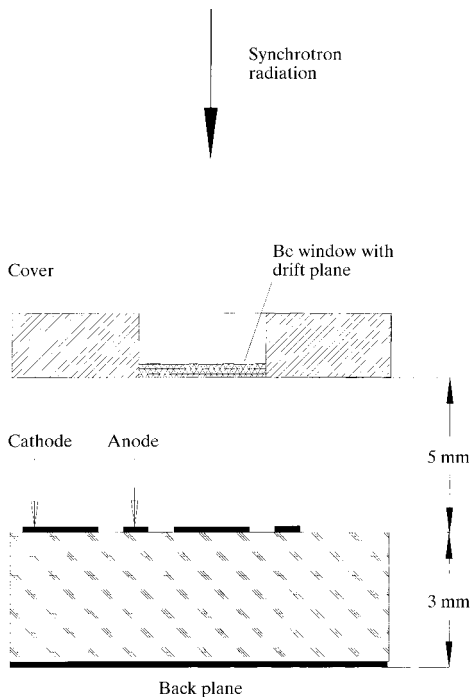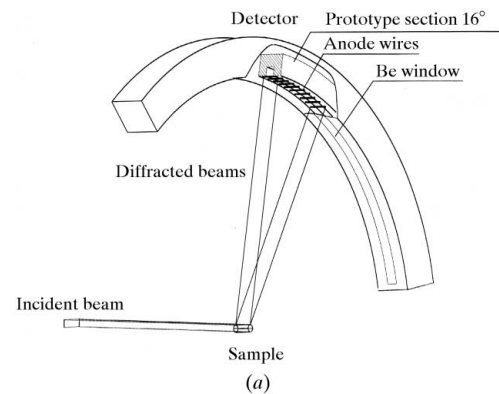
Some obvious improvements can bring the performance of the detector to a much higher level. We are developing a detector (MSGC-500; see Table 1) having a wedge-shape geometry and positioned parallel to the X-ray beam. Therefore, we will solve the problems of spatial resolution, quantum efficiency and rate capability at the same time. A new section of micro-strip will connect the micro-strips with each other and it will be possible to assemble a large detector with a few micro-strip plates. Based on the present results, the rate capability can reach several MHz per channel in a future detector. We plan to put such a detector into operation by the end of 1997.

4. The 160° 3.3 GHz detector OD-160 and test experiments with the prototype

This detector will operate with a one-coordinate multiwire proportional chamber (MWPC) with an angle aperture of 160°. It will be used for high-resolution powder diffraction. A schematic diagram of the detector is shown in Fig. 4(a). Two types of gas chamber will be used: L for low energies (5–30 keV) without drift gap and H for high energies (30–70 keV) with a drift gap that overlaps the absorption volume. At present, the 16° section with a 30–70 keV chamber has been produced and tested at the VEPP-3 synchrotron radiation beamline 2-b (see Fig. 4b).

In order to obtain a sufficiently high rate capability and quantum efficiency, the anode wires in the H chamber are stretched along the direction of the diffracted beam. To avoid parallax, they are directed to the sample. The pitch of the anode wires is 1.2 mm, their length is 50 mm, and the distance between the anode and cathode planes is ~2 mm. The working mixture is Xe + 20% CO_2 at 3 atm. The quantum efficiency of this H chamber for 60 keV X-rays is ~30%. The geometrical size of the channel of such a detector is equal to the pitch of the anode wires of 1.2 mm.
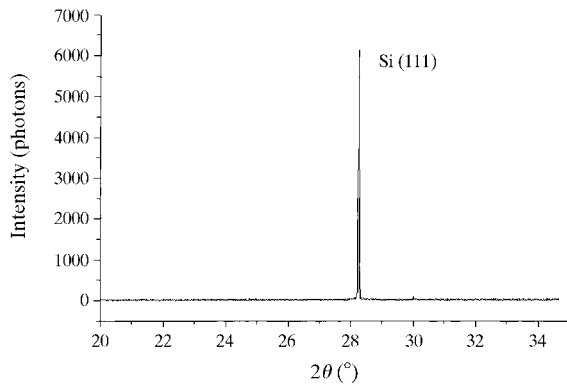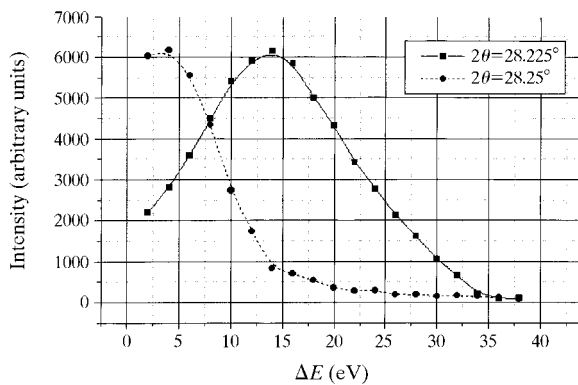

(a)

(b)

Figure 4
The OD-160 detector: (a) schematic diagram of the detector, (b) a photograph of one section of the detector with an aperture of 16° installed at VEPP-3 synchrotron radiation beamline 2-b.

Figure 3
Schematic cross section of the MSGC-100 prototype detector.

The spatial resolution of the multiwire proportional chamber with parallel readout from anode wires is determined by the wire spacing and the range of secondary particles appearing after the absorption of the X-ray quantum in the gas volume of the chamber. If an X-ray quantum is absorbed near the center between two neighboring anode wires, the primary ionization in the majority of cases is divided into two parts, and the two channels of the detector count simultaneously. In the case when the range of a photoelectron is about half of the distance between the two wires, the number of double hits (coincidences) comes close to the number of single-hit events. Under such a condition, one can get an improvement of spatial resolution by about a factor of 2 if the coincidences of neighboring channels are counted in a separate scaler.

To realize this method, a special readout circuit was developed. It consists of the following elements: amplifiers–discriminators, new selecting circuits and a doubled number of scalers. The selecting circuit contains the gate and coincidence elements. The readout electronics were connected to 320 anode wires of the MWPC. Output information was stored in 640 16-bit scalers.

Si powder was used as a test sample. The (111) diffraction peak is shown in Fig. 5(a). Approximately all intensity is in one channel and it is impossible to receive the profile from this experimental data. It is possible to overcome these problems if the sharp trapezium apparatus function of each channel is taken into account. It gives the possibility of increasing the angular resolution by at least 10 times. We have realized these possibilities in two ways: (i) scanning the detector with a step equal to 1/10th of the detector pitch, (ii) scanning the energy of the synchrotron radiation with a step equal to 2 eV, which corresponds to 1/16th of the detector pitch. The result of the energy scanning is shown in Fig. 5(b), from which it is obvious that by this method it is possible to determine the profile of the diffraction peak. The improvement obtained with this method can give a resolution near 1/100th of the detector pitch.
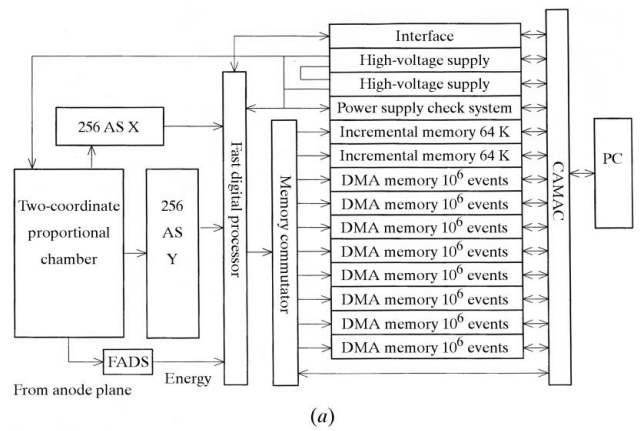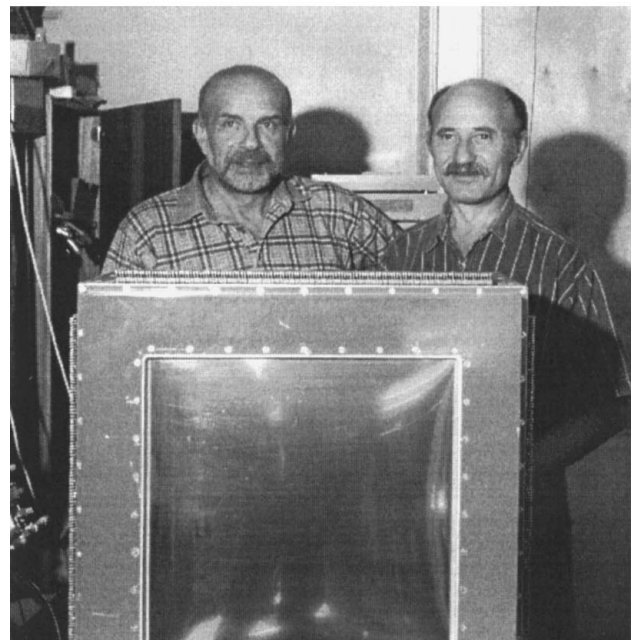

(a)

(b)

Figure 5
Experimental results obtained with the OD-160 detector: (a) Si(111) diffraction pattern obtained in direct count mode (angular resolution 0.025°); (b) the same peak obtained in scanning mode with an energy step of 2 eV (angular resolution 0.0015°).

(a)

(b)

Figure 6
The two-coordinate DED-5 detector: (a) readout of information from chamber (AS = amplifier shaper); (b) a photograph of DED-5 with its designers, S. Baru (left) and G. Savinov (right).

5. The fast two-coordinate detector DED-5

This detector is a two-coordinate MWPC with an aperture of 384 × 384 mm. The quanta absorption in the chamber gives rise to an avalanche close to the nearest anode wire. The information is read out from the two cathode planes with mutually orthogonal wires. An amplifier and shaper are connected to each wire. Both coordinates of the X-ray quantum are defined by the fast digital processor as the center of the triggered shaper 'spot' (Fig. 6).

The detector has two working modes: incremental accumulation of data and frame-by-frame recording. In the first regime, the information after equalization is stored in a special 64 K incremental memory in a CAMAC crate. In the second mode, the data are recorded in a special CAMAC memory (event after event); moreover, along with the coordinates, the quantum energy and time of the event are recorded. The memory volume in frame-by-frame mode is 8 million events. The minimum frame time is limited to about 100 µs. The parameters of the detector are presented in Table 1.

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