POSITION SENSITIVE GAS DETECTORS AT SIBERIAN SYNCHROTRON RADIATION CENTER. THE DEVELOPMENT, TESTING AND USING AT SR BEAMLINES.

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1.Introduction

The Institute of Nuclear Physics has been designing and fabricating one and two-coordinate X-ray detectors [1-4] for research in X-ray diffraction since 1975 [5]. 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 therefor gives an opportunity to detect very weak intensities. It has large dynamic range of measured intensities, allows on-line energy selection, fast frame-by-frame regime and has all advantages of on-line computer mode. The multistrips ionization chamber can not work with a weak intensity and will be very useful for high flux experiments.

2. 10 MHz parallax-free one-coordinate detectors OD-3.1-350 and OD-3.2-1500

The basic part of the detection system OD-3 is a proportional chamber with a drift gap overlapping the absorption volume. The photons come into the detector through 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 the avalanche amplification occurs. The coordinate of the avalanche in the transverse to the anode wires direction 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 the parallax-free images.

The preamplifiers and shapers are located close to the stripes outside the clean chamber box. The signals are transmitted into the basic crate, where they are digitized by the flash ADC. A number of strip with a maximal amplitude, amplitudes from the two neighboring stripes A(n-1), A(n+1) and external timer time signals transmitted into the Processor for the selected events. Using this data the Processor defines the photon coordinate and a photon energy [2]. The image exposure is defined by the external timer. The minimal image exposure is 1 μs. The detector was installed and tested at the SR beam 15-A at Photon Factory KEK in Tsukuba (see Fig.2).

Two experiments have been made to carry out the counting rate test. A narrow straight beam was used in the first experiment, while scattering from an aerosil sample was used in the second one. The counting rate of 850 kHz on the one strip has been achieved in the first experiment. However, this result does not mean that the total counting rate could be calculated as 850 KHz*52 strips = 44.2 MHz. In reality, when all strips are under irradiation, the total counting rate of the detector cannot exceed 10 MHz. The second experiment was made with the aerosil. The aerosil sample gives very strong scattering in the region of small angles. So, it is very convenient to use these samples in testing OD-3.2-1500 at very high counting rates.

Scattering from aerosil takes place in the angle region below $2\Theta=0.34^{o}$. This means that all the photons scattered from the sample cover only two strips (128 channels) above the straight beam and quite 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 second 210 kHz, respectively. This test has shown that OD-3.2-1500 can operate under extreme conditions with photon flux much higher than that declared in the specification.

The experiment on the frog muscle contraction was used to test time resolution of the detector. A single-frame time interval was 1 ms for the 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 «FAST» frame-by-frame regime of OD-3.2-1500. The experiment was carried out in the accumulation mode and included 20 cycles of contraction. The total amount of the frames was 128. Each frame contained 512 channels. In order to obtain the information on the kinetics of the frog muscle contraction, the profile was fitted according to a special procedure.

The parameters of detectors OD-4 and OD-5 are presented in the table 1.

3. Micro strip gas chamber prototype MSGC-100

The basic part of the detection system is a proportional chamber with a drift gap overlapping the absorption volume. A cross-section of the detector is shown schematically in Fig. 3. Cylindrical high-pressure box 30 cm in diameter is attached to a special crate with front-end electronics. The cover of the box has an inlet window (1.5x3 cm) with 1 mm Be foil. The microstrip plate is attached by plastic rods to the bottom of the box. The distance between the micro-strip plate and the inner side of Be window is 5 mm. The drift cathode is made of aluminized mylar 100 μ thick.

The MSGC is made on electronically conductive C85-1 glass. A golden micro-strip pattern has 80 μ cathodes, 10 μ anodes and 200 μ anode-to-anode pitch. The MS structure contains 100 anodes, 101 cathodes 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 front-end cards are connected to CAMAC scalers.

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

High rate properties of the detector were demonstrated by testing it at the SR beamline-7 of VEPP-3. Counting rate reaches here the value of about 700 kHz 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 project MSGC-500 (see table 1) having a wedge shape geometry and positioned parallel to the X-ray beam. Therefore, we will solve the problem of spatial resolution, quantum efficiency and rate capability at the same time. New section of micro-strip will connect with each other and it will be possible to assemble large detector with a few micro-strips plates. According to the present results, rate capability can reach several MHz per channel in future detector.

4. The 160 degree 3.3 GHz detector 1D-160 and test experiment with the prototype

This detector will operate with a one coordinate multiwire proportional chamber (MWPC) with angle aperture 160 degree. It will be used for high resolution powder diffraction. The scheme of the detector is shown on the Figure 4-a. The two type of gas chamber will be used: «L» for «low» energy range 5-30 keV without drift gap and other «H» for «high» energy 30-70 keV with a drift gap overlapping the absorption volume. At this moment the 16 degree section with 30-70 keV chamber was produced and tested at the SR beam line 2-b VEPP-3 (see Fig. 5-b).

In order to obtain sufficiently high rate capability and quantum efficiency, the anode wires in this chamber are stretched along the direction of the diffracted beam. To avoid parallax, they are directed to the sample. The pitch of 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 chamber for 60 keV X-rays is ~ 30 %. The geometrical size of the channel of such a detector is equal to the pitch of anode wires of 1.2 mm.

The spatial resolution of the multiwire proportional chamber with parallel readout from anode wires is determined by their 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 a majority of cases is divided into two parts, and two channels of the detector count simultaneously. In the case when the range of a photoelectron is about one half of the distance between 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 doubled number of scalers. The selecting circuit contains the gate and coincidence elements. This readout electronics was connected to 320 anode wires of the MWPC. Output information was stored in 640 16-bit scalers.

The Si powder was used as a test sample. The diffraction peak (111) is show at the Figure 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 problem if one takes into account that each channel has sharp trapezium apparatus function. It gives the possibility to increase the angular resolution at least 10 times. We have realized these possibility by two ways: 1) scanning the detector with step equal 1/10 of the detector pitch, 2) scanning the energy of the SR with step equal to 1 eV which corresponds to 1/16 of the detector pitch. The result of the energy scanning is shown at the Figure 5-b from which it is obvious that by this method it is possible to receive the profile of the diffraction peak. The improvement of these method can give resolution near 1/100 of the detector pitch.

5. The fast two-coordinate detector DED-5

This detector is a two coordinate MWPC with an aperture 384*384 mm. The quanta absorption in the chamber gives rise to the avalanche near the nearest anode wire (Fig. 6). 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 shapers "spot".

The detector has two working modes: the increment accumulation of data and frame-by-frame recording. In the first regime, the information after equalizing is stored in a special Incremental Memory 64K 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 event are recorded. 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 presents in the Table 1.

6. The multistrips ionization chamber MIC

The Multistrips Ionization Chamber MIC is a flat capacitor. The signal electrode consist of 1024 strips with the step of 0.4 mm, each strip of 60 mm length is directed to the focal point. The drift electrode is uniform with applied positive potential of 2000 V. The gap between electrodes is 4 mm, the dead space between the entrance window and electrodes is 3 mm. The detector is filled with pure Xe at 10 atm pressure. The vertical gap of the entrance collimator is 0.4 mm. The detector operates in the saturated regime. The strips are made by subtractive technology. All strips are joint in 16 groups with 64 channels in each group. Each group is connected with the individual electronic module that performs the charge collection on capacitors and data readout in the analog form. The electronics has been developed and produced by the plant "Vostok" (Novosibirsk, Russia). Information from the capacitors are readout consequently with a period of 10 ms. The general scheme of the MIC is shown in Fig. 7.

The calculated quantum efficiency of the MIC is 70% for 50 kV X-rays. Both the detector dead space 3 mm and the thickness of the entrance window (1 mm Al) were taken into account. The measured value of the quantum efficiency is 72%. The charge produced by one detected photon is accepted to be 1200 e^-.

The value of the signal depends on "charging up" effect. When detector is irradiated, a fraction of the ions sticks the surface of the insulator between strips and reduces the signal. This continues up to full charging of the insulator. The value of the effect is about 10%.

There are main factors influencing on the spatial resolution of the MIC: diffusion of charge particles while they drift in the detector volume and the initial photoelectron range. The FWHM when ions are collected is 400 μm. When electrons are collected, the FWHM is about 500 μm and is defined by diffusion. Increasing of the vertical channel width due to the drift time of a positive ions

Table 1. The parameters of the detectors are developing in BINP

Detector name	Working field (mm), [grad]	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)
1D detectors									
OD-3.3-350	200 ^{x}10, [30]	350	0.07	0.18	3328	50	5-20	1	10
OD-3.3-1500	200 ^{x}25, [9]	1500	0.07	0.15	3328	50	5-20	1	10
OD-4-350*	800 ^{x}10, [120]	350	0.07	0.18	13312	50	5-20	1	40
OD-5-350***	200 ^{x}10, [30]	350	0.1	0.1	2000	50	20-60	0.1	no limits
OD-5-1500***	200 ^{x}25, [9]	1500	0.1	0.1	2000	50	20-60	0.1	no limits
MSGC-100	10 ^{x}20	no	0.2	0.2	100	5	5-20	100	100
*MSGC-512	100 ^{x}200	500	0.2	0.2	512	50	5-70	1	1000
MIC – Ionization Chamber	410 ^{x} 10, [17]	1350	0.4 (0.2*)	0.4 (0,2*)	1024 (2048*)	50	50-70	10000	no limits
1D-160-L*	2760 ^{x}10, [160]	1350	1.2	1.2; 0.12**	6600	50	5-30	1	3300
1D-160-H*	2760 ^{x}10, [160]	1350	1.2	1.2; 0.12**	6600	50	30-70	1	3300
Pseudo area detectors									
2D-Cylinder	200 ^{x} 200	1000	0.1	0.2	2000	300	10 - 30	1	1
Area detectors									
DED-5	384 ^{x} 384	no	1.5 ^{x} 1.5	1.5 ^{x} 1.5	65536	10	5-20	100	5

* - under testing of the prototype, ** - in scanning mode, *** - R&D stage

is small. In these conditions, the ions drift time is 0.7 ms which is less than the full charge collection time (10 ms).

Because the capacitors are connected directly with strips, there are crosstalks with neighbor channels, when the data from a channel is reading. The value of crosstalks was measured directly and it is about 10% of signal value. This effect is removed by data processing.

The signal-to-noise ratio (SNR) itself is proportional to the SNR_{in} of incident beam (in this case, $SNR_{in} = \sqrt{N}$, from Poisson statistics, and N - number of the incident photons per one channel). The detective quantum efficiency (DQE) of the detector is given by $DQE = SNR^2_{out} / SNR^2_{in}$.

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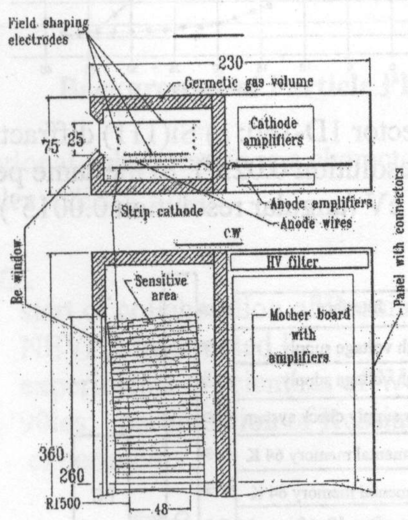

Fig. 1. Cross-sections of the proportional chamber OD-3.2-1500.

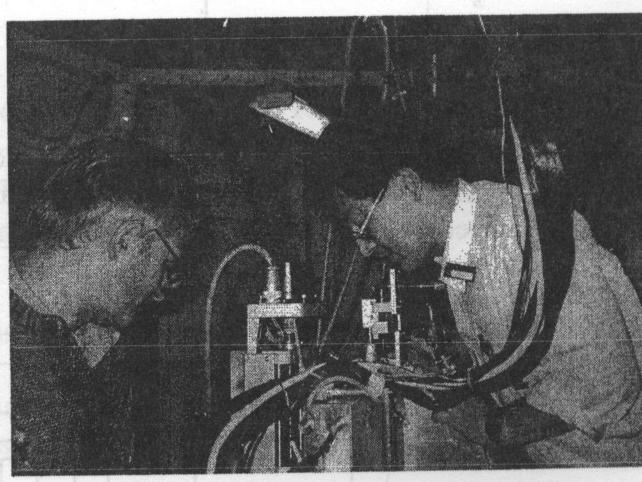

Fig. 2. Detector OD-3.2-1500 during test experiments at SR beam line 15-A at Photon Factory KEK in October 1996.

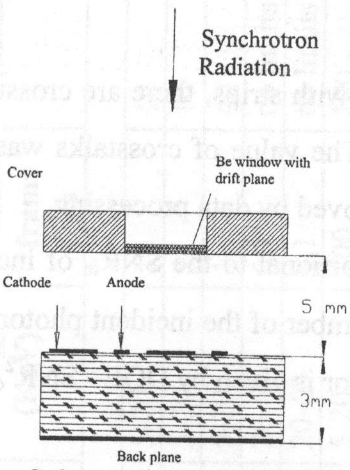

Fig. 3.: Schematic cross-section of the detector prototype MSGC-100.

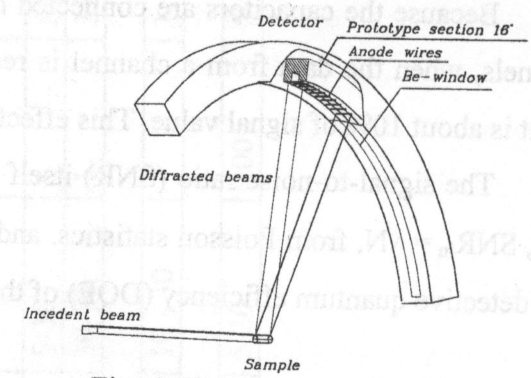

Fig. 4. The detector 1D-160.

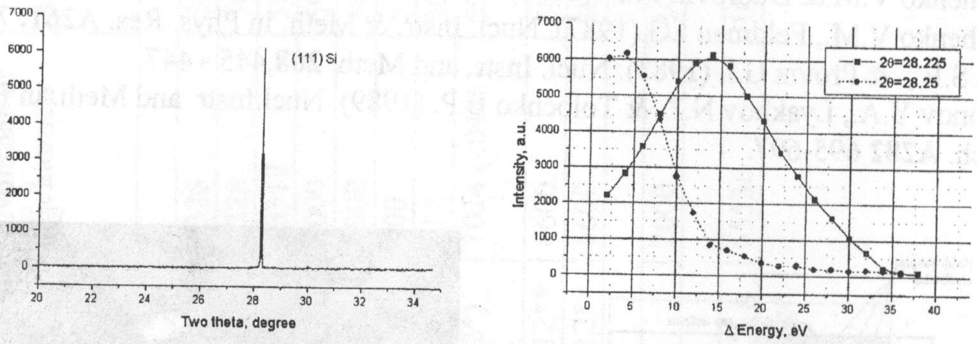

Fig. 5. The experimental results received on detector 1D-160: a) Si(111) diffraction pattern received in direct count mode (angular resolution 0.025°); b) the same peak received in scanning mode with energy step 1 eV (angular resolution 0.0015°).

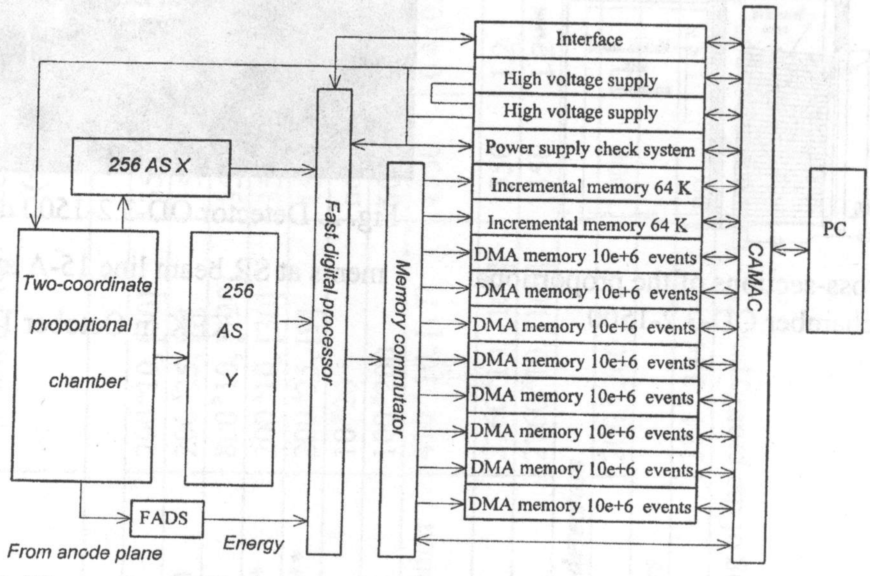

Fig.6. The readout of information from chamber (AS-amplifier-shaper) of the two-coordinate detector DED-5.