Nuclear Instruments and Methods in Physics Research A 623 (2010) 600–602

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Fast high resolution gaseous detectors for diffraction experiments and imaging at synchrotron radiation beam

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ARTICLE INFO

Available online 19 March 2010

Keywords:
Gaseous detectors
GEM
Position-sensitive detectors

ABSTRACT

The series of high-rate and high spatial resolution gaseous detectors for diffraction studies and X-ray imaging at SR beam developed in the Budker INP is reviewed. The detectors are based on wire and micro-pattern gas technologies and provide spatial resolution at the level of 0.1 mm together with rate capability in the range from 10 MHz per detector to $\sim 10^{10}$ Hz/channel.

1. Introduction

Synchrotron radiation (SR) remains an important tool for studies of structure of complex biological molecules, chemical reactions and physical processes happening during formation of new materials and many other objects at the edges of different scientific domains. Each type of study demands an adequate detector that has to provide necessary spatial and time resolution as well as dynamic range that will allow to measure data with necessary precision. This paper will review several detectors that were developed in the Budker Institute of Nuclear Physics during last few years. All detectors are one-dimensional devices based on gaseous technology.

2. High resolution multi-strip ionization chamber

High-pressure multi-strip ionization chamber (MIC) with 100 μm pitch of the readout strip structure was constructed for imaging at SR beam in a wide range of energies from 15 to 70 keV (Fig. 1). The chamber has cylindrical aluminum body with thickness in the region of the inlet window of 1 mm (1). X-ray photons pass through the window, then through 3 mm PMMA insert (2) that removes pressurized Xe from the path and provides insulation between the high voltage anode (3) and readout strips (4). Inner part of the PMMA insert is positioned inside the sensitive volume 20 mm thick in the direction of the beam. The chamber is filled with pure Xe at 20 atm. Each strip is connected to an input of the integrator-multiplexer chip (6) with effective noise level of $\sim$1000 electrons (about one 60 keV photon). The chamber contains 2560 channels with full aperture of 256 mm.

For the tests MIC was exposed to X-rays from an X-ray tube with tungsten anode. DQE and spatial resolution were measured at 40, 60, 80 and 100 kV X-ray tube voltages. DQE as a function of rate for different tube voltages is shown in Fig. 2. The drop of DQE at low fluxes is caused by the electronics noise while the value of

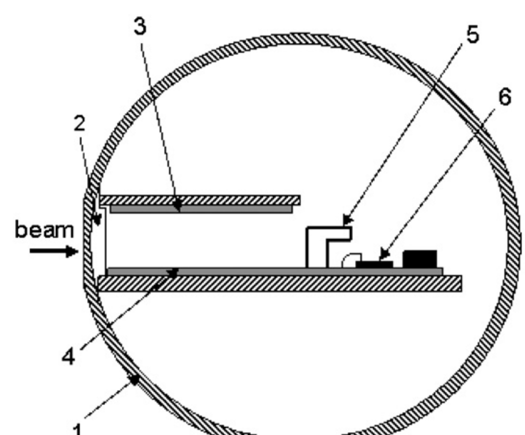

Fig. 1. Schematic view of the MIC design. 1—aluminum body, 2—PMMA insert, 3—HV anode, 4—strip structure, 5—protection of the electronics, 6—integrator chips.

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doi:10.1016/j.nima.2010.03.083

DQE at the plateau is equal to the fraction of photons absorbed in the sensitive volume. We can see that DQE is always higher than 50% at photon flux above 1000 Hz/channel and increase up to 70% at 60 kV tube voltage. This is probably because most of the X-ray spectrum in this case is just above Xe K-edge.

Spatial resolution of the chamber was measured by the edge method and FWHM of the line spread function was found between 100 and 130 μm in full range of energies.

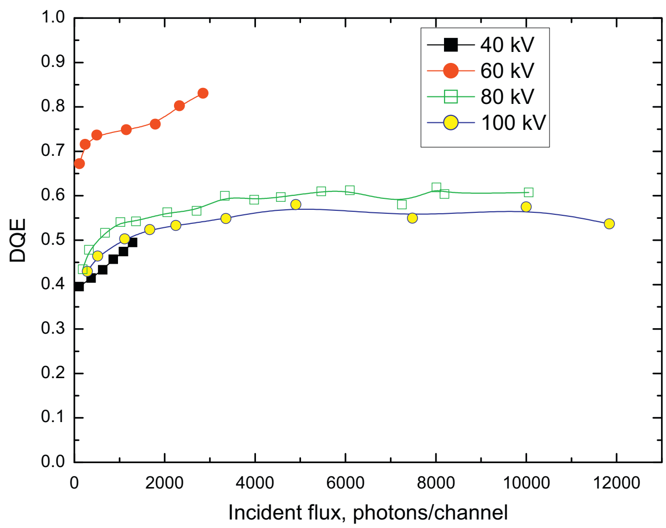

Fig. 2. DQE as a function of photons rate for different tube voltages.

3. One-dimensional detector for SAXS OD3

The X-ray detectors of OD-3 series are developed in Budker INP, have been made in various modifications since 1995. The detectors are aimed for angular measurements in the diffraction experiments at the synchrotron X-ray beam. The distinctive features of the OD-3 detector are as follows:

- the registration rate up to 10^7 photon/s with efficiency up to 50%;
- parallax-free in the angular range from 0° to 30° (depends on the focal distance of cathode strips);
- photon coordinate resolution in transverse to the beam direction $\sigma \sim 100\,\mu m$.

The basic principles of operation and design of detector OD-3 were described in detail in [1,2]. Conceptual design of OD-3 is shown in Fig. 3.

The detector is based on the multi-wire proportional chamber with cathode readout filled with Ar-CO_2 (80%–20%) at ~1 atm absolute. The signals from 54 cathode strips positioned with the pitch of ~4 mm are digitized by 12-bit ADC simultaneously with time discrete of 25 ns and transmitted to the buffer for conveyor processing. The photons with close location in space and in time are rejected by the trigger logic, but photons separated by sufficient space (at least 3 strips) could be registered simultaneously. Final position of a photon is calculated using interpolation between 3 adjacent strips based on look-up tables technique. As was mentioned above the spatial resolution that is achieved based on this method is ~100 μm (σ) for 8 keV photons. The last

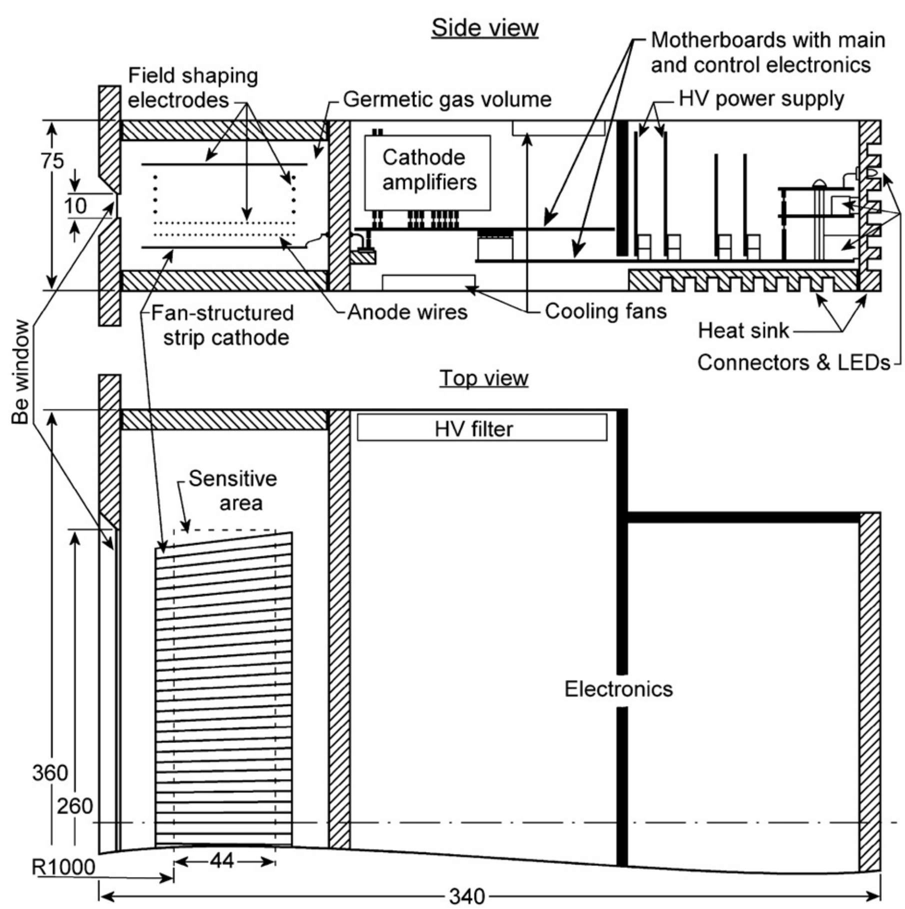

Fig. 3. Conceptual design of detector OD3.

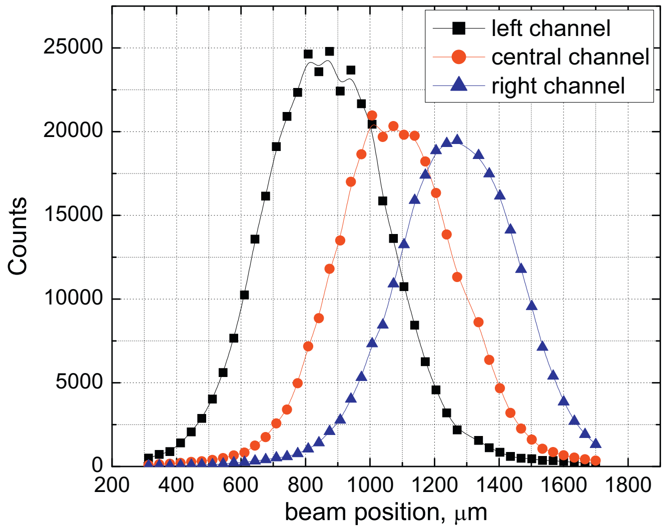

Fig. 4. Channel response curves measured with 8 keV X-ray beam. the detector is filled with Ar–CO_2(3–1) mixture.

version of electronics allowed to achieve differential non-linearity of $\sim 0.2\%$ [3].

4. One-dimensional detector for WAXS OD4

Detector for diffraction studies at large angles needs to have essentially curved geometry and thus cannot be based on wire technology. The first full-size prototype of the detector OD4 with 67° aperture is based on cascaded Gas Electron Multipliers (GEM) [4,5]. X-ray photons are absorbed between top GEM and high-voltage drift electrode that are parallel to the direction of photons. Primary electrons drift through triple-GEM amplifying structure and induce charge at the multi-strip board. The strips of this board are directed to the focus spot at 350 mm distance and has 0.2 mm pitch at the front edge. Total number of strips is 2048. At present only 256 strips in the central part are equipped with electronics that consist of amplifier-shapers, discriminators and scalers in each channel.

Main parameters of OD4 were tested with SR 8 keV beam. Fig. 4 demonstrates channel response curves in the condition when the discriminator threshold is adjusted such that counting efficiency is close to 90%. FWHM of the channel response curve in this case is close to 470 μm. Because the detector has electronics with independent counting channels its rate capability is determined by physical limitation of the GEM technology. The rate capability was measured in conditions similar to the measurements of the resolution with 8 keV SR beam and appeared to be better than 100 kHz/channel [4].

5. Detector for imaging of explosions DIMEX

Detector for imaging of fast processes at SR beam was developed during last 6 years [6,7]. DIMEX is one-dimensional detector that can collect signal from SR of individual electron bunch during the time between consecutive bunches. The detector is based on ionization chamber with multi-strip readout structure with 100 μm pitch and GEM as a Frisch-grid that provides shielding of positive ions and allows to collect signal from electrons only. SR photons get into the detector volume between high-voltage drift electrode and GEM parallel to the beam. Electrons of primary ionization drift through GEM and induce signal at the readout strips. DIMEX works with white SR beam from 2T wiggler at VEPP-3 accelerator with average energy close 20 keV. Sensitive volume is filled with Xe–CO_2(3–1) mixture at 7 atm absolute pressure. Electrons drift path is about 2 mm and the collection time for the gas pressure and electric field used is less than 50 ns. Time period between bunches in VEPP-3 is equal to 250 ns. Spatial resolution measured in the detector is less than 200 μm. Readout electronics of DIMEX is integrating and dynamic range reaches ~ 100 that allows signal measurement with the precision at a percent level [6]. Maximum photon flux registered by the detector corresponds to $\sim 10^{10}$ photons/channel. The detector is used for the studies of detonation wave structure by direct imaging as well as SAXS studies of the formation of nano-diamonds behind a detonation wave. Fig. 5 demonstrates the reconstructed density profile of detonation wave in some particular explosive [8].

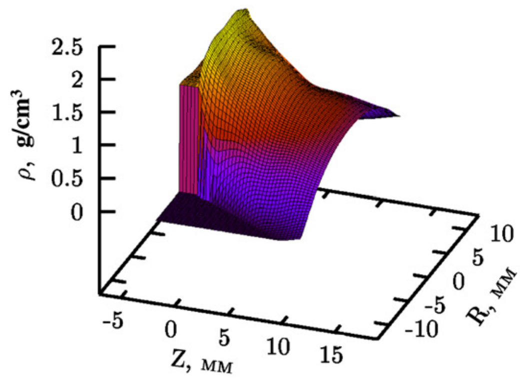

Fig. 5. Reconstructed density profile of the detonation wave.

6. Conclusions

Several position-sensitive detectors based on gaseous technology were developed for the experiments with SR beam. High resolution multi-strip ionization chamber demonstrates the possibility of operation with spatial resolution close to 100 μm (FWHM) in a wide range of photons energies. Detectors OD-3 and OD-4 allow for diffraction imaging with small angle and wide angle diffraction with spatial resolution at the level of 100 and 200 μm (σ) in counting mode. Detector DIMEX provides the possibility to view SR flashes from individual bunches and thus to have outstanding time resolution of the method determined by the length of one bunch.

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