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An X-ray scanner prototype based on a novel hybrid gaseous detector

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Abstract

We have developed a prototype of a new type of hybrid X-ray detector. It contains a thin wall (few μm) edge- illuminated lead glass capillary plate (acting as a converter of X-rays photons to primary electrons) combined with a microgap parallel-plate avalanche chamber operating in various gas mixtures at 1 atm. The operation of these converters was studied in a wide range of X-ray energies (from 6 to 60 keV) at incident angles varying from 0° to 90°. The detection efficiency, depending on the geometry, photon's energy, incident angle and the mode of operation, was between a few and ~40%. The position resolution achieved was ~50 μm in digital form and was practically independent of the photon's energy or gas mixture.

The developed detector may open new possibilities for medical imaging, for example in mammography, portal imaging, radiography (including security devices), crystallography and many other applications.

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Keywords: Mammography; Capillary plates; Gaseous detector

1. Introduction

In last decade, there has been a fast development of X-ray imaging techniques as a result of which traditional films began to be replaced by electronic devices. The main efforts, of course were concentrated on the development of 2D pixelized imaging systems. However, for some applications, for example airport security devices or radiology, 1D scanning systems were developed as well [1]. Scanning systems allow a very efficient rejection of the scattered radiation, improving contrast and the signal-to-noise ratio. The other important feature of the scanning systems is that they have much simpler electronics and as a result have a possibility of simultaneous photon counting and measuring of their energy. The cost of the scanning system is usually much lower than for the 2D imagers. In the last few years, several groups and companies tried to develop mammographic scanners based on solid-state detectors (GaAs, Si) or high-pressure Xe gaseous detectors (see for example Refs. [2–4]). Each of these detectors has advantages and disadvantages, for example high-pressure devices are bulky and finally not so cheap.

Several year ago, we have demonstrated that top illuminated CsI coated thick wall (~20 μm) capillary plates (CPs) can be used as converters of soft X-rays and combined with gas multiplication structures operating at 1 atm [5,6]. This may offer a new way to build a simple and cheap large-area avalanche X-ray detector. This hybrid detector had around 10% efficiency for soft X-rays (<30 keV) and offered an excellent position resolution of 50–150 μm; however, the efficiency for the hard X-rays was only around 1%. One should note, of course, that micro channel plates (MCPs) operated in vacuum were used as X-ray coverters for a long time (see for example Ref. [7]), however, it is not easy to build a large-area device based on

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MCPs, also such attempts were recently done [8]. In this work, we continue the efforts to develop a hybrid detector with capillary converters operating in gas at 1 atm. Considerable modifications of the previous device were done: (1) thin-wall CPs were used in edge—on illumination mode instead of thick-wall top illuminated CPs, (2) no CsI coating was applied, and (3) the drift space between the CP and the gas detector was removed. As will be shown below, this allowed one to achieve both high position resolutions and high efficiencies even for hard X-rays. This paper describes our first preliminary results obtained in this very promising direction.

2. Experimental set up

Our experimental set up is shown schematically in Fig. 1. Essentially, it contains a test chamber and an X-ray gun with a tungsten anode. In most measurements, a filter and a collimator were placed in front of the chamber. The test chamber was installed on a special step motor-controlled table that allows for 3D alignment to take place with up to a few μm accurately. The table also allowed chamber rotation for up to 90°. Behind the test chamber, a PM with a NaI scintillator was installed. When the chamber was removed from the table, this detector was used for the measurements of the X-ray intensity mainly in the range of the photon energies of 10–60 keV. For low-intensity beams, we also used a CZT detector. The measurements with the CZT detector show that a heavily filtered X-ray beam had a sharp peak in the spectrum at a photon energy E_{max} slightly below the voltage V_g applied to the X-ray gun. Thus, after heavy filtering one can obtain an almost monochromatic beam with a characteristic energy $E_{max} \sim V_g$. Inside the test chamber various CPs and gas multiplication structures could be installed (see Fig. 1). The CPs tested were made of lead glass and had thicknesses of 0.8–1 mm; the holes had diameters of 12, 30 and 100 μm and the wall thickness was of 2.5, 6 and 20 μm, respectively. A readout plate was placed 0.4 mm below the CP. It was a ceramic plate with Cr strips of a 50 μm in pitch. A voltage of 1–3 kV could be applied between the CP and the readout plate. This made it possible for avalanche multiplication to be achieved in this region (called microgap parallel-plate chamber or MGPPC). Depending on the measurements one of the two readout plates was used. The first one had all of the strips interconnected together to a single charge sensitive amplifier. This allowed one to use this plate for counting rate measurements (counting rate N_{CP} of avalanches produced in the amplification region). The second readout plate had 120 strips in the central region of the plate connected to an ASIC. This allowed for accurate position resolution measurements.

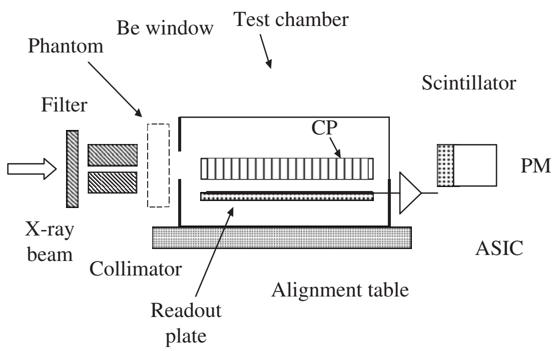

Fig. 1. A schematic drawing of the experimental set up for measurements of the position resolution of the hybrid gaseous detectors.

3. Results

The CPs' efficiency η was determined as

$$\eta = N_{CP}/N_D$$

where N_D is the counting rate from the PM or CZT for a heavily filtered X-ray beam. The cross checks of the efficiencies were also made with several X-ray radioactive sources: ^{55}Fe, ^{109}Cd and ^{241}Am.

Table 1
Some results of the CPs efficiency measurements in He + 10% CH_4 gas mixture at $p = 1$ atm

Capillary type	Efficiency η (%) for different angles φ (data in bracket-X-ray tube voltage V_g in kV):			
Hole's diameter (μm)	$\varphi = 0°$	$\varphi = 30°$	$\varphi = 45°$	$\varphi = 90°$
12	$\eta = 2\cdot1$ (22) $\eta = 12.8$ (35) $\eta = 37$ (60)	$\eta = 9\cdot3$ (30)	$\eta = 7\cdot5$ (30)	$\eta = 3\cdot2$ (10) $\eta = 6\cdot3$ (30) $\eta = 3\cdot75$ (60)
30	$\eta = 5\cdot2$ (35) $\eta = 23$ (60)	$\eta = 3.8$ (35)	$\eta = 3.2$ (35)	$\eta = 2$ (10) $\eta = 2.8$ (35) $\eta \sim 1$ (60)
100	$\eta = 0\cdot1$ (10) $\eta = 0\cdot8$ (30) $\eta = 6$ (60)	$\eta = 1.8$ (10)	$\eta = 2.2$ (10)	$\eta = 2.6$ (10) $\eta = 1\cdot5$ (30) $\eta = 0\cdot8$ (60)

This mixture was chosen because its stopping power was too low, so basically only CPs contributed to the measured efficiency. Note that 22 and 60 keV photons were produced by ^{109}Cd and ^{241}Am sources. Photons of other energies were from the heavily filtered X-ray gun radiation. The value of $\varphi = 0$ corresponds to the X-ray entering the CP parallel to their flat electrodes, whereas $\varphi = 90$ corresponds X-rays hitting the CPs from the top.