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Characterization of hemispherical area X-ray detector based on set of proportional counters with needle anodes

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HIGHLIGHTS

- A hemispherical area X-ray detector is introduced.
- The detector employs gas proportional counters with needle anodes.
- The detector is robust, low cost and enables high rate counting (up to 10^6 counts/s).

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ABSTRACT

This work introduces a new, versatile and robust X-ray detector with hemispherical 2π geometry, based on a set of 15 small cylindrical proportional counters located in a hexagonal and pentagonal fullerene C60 pattern, at the same distance from the center (where a sample is placed). The counteranode consists of stainless steel sewing needles with spherical tips measuring approximately 80 μm in diameter. The space between the counters and the sample could contain air, the same gas as the counters or vacuum. This allows a significant increase in the count rates by a factor approximately equal to the number of counters connected. It is shown that an energy resolution of 20% for 5.9 keV photons can be obtained, and a global counting rate of around 10^6 counts/s is achievable by the 15 Needle Anode Proportional Counters (NAPCs) operating in parallel mode, in our setup.

1. Introduction

The high intensity of modern X-Ray generators requires detectors with a faster and more efficient response to high counts rates, while maintaining energy resolution. Gas Proportional Counters (GPC) are good candidates to meet these requirements, as they can provide high count rates with an energy resolution of around 20% (or better) in the detection of soft X-rays (5.9 keV) (Knoll, 2000; Sauli, 2004; Veloso et al., 2010). GPC detectors are available in various configurations: Micro Strip Gas Chambers (MSGC) (Oed, 1988) and its later variants: Gas Electron Multiplier (GEM) (Sauli, 1997), Micro Hole and Strip Plate (MHSP) (Veloso, 2000), plane-parallel gas chambers, cylindrical detector with a central anode (Albul and Isaev, 1968; Bateman, 1985a,1985b; Comby and Mangeot, 1980), (wire or needle), among others. However, the Needle Anode Proportional Counters (NAPCs) provide a low cost alternative to these detectors, due to their geometric versatility and integration capability (Comby and Mangeot, 1980). These detectors could be used in X-Ray Fluorescence applications that do not require a good energy resolution.

Wire Anode Proportional Counters (WAPC) and Needle Anode Proportional Counters (NAPC), have similar electric characteristics, with a homogeneous electric field surrounding the anode. However, their electric field properties differ in shape; while the wire anode has a cylindrical electric field, the needle anode has a spherical electric field on the tip (Knoll, 2000). Moreover, both have position-sensitive detection capabilities (Baiocchi et al., 2004; Sauli, 1977). Nevertheless, WAPC detectors allow a directly localized detection with more robustness and geometric versatility (Sauli, 1977).

Several designs of NAPCs have been reported (Albul and Isaev, 1968; Bateman, 1985a, 1985b; Baiocchi et al., 2004; Comby and Mangeot, 1980; Ranzetta and Scott, 1967). However, so far a compact array of needle detectors had not been considered in a 2π detection geometry as proposed here. This configuration would provide an increase in the geometric detection efficiency and a

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high improvement in the overall count rate (proportional to the number of detectors) when the NAPC system operates in parallel mode (Smith, 1991), without loss of energy resolution. The aim of this work is to introduce the preliminary results of a new hemispherical (2π) GPC detector based on a series of small NAPCs with frontal windows, operating in parallel or independent modes. This is a design that allows the adoption of various geometries for applications such as X-Ray Fluorescence (XRF) and Total Reflection X-ray Fluorescence (TXRF), which need a good performance for both the counting rate and energy resolution.

2. Description of the counter

The hemispherical detector is based on 15 small NAPCs of cylindrical shape and is made of aluminum. The NAPCs are arranged in a hexagonal and pentagonal semi-fullerene C60 pattern, formed by 10 hexagonal and 6 pentagonal dispositions, 15 occupied by the NAPCs and 1 open for the incident radiation. This detector array is designed to detect fluorescent radiation from a sample at the center in a solid angle of 2π (see Fig. 1). The dimensions of each NAPC are 40 mm long and 10 mm in diameter. Each anode has a frontal Mylar aluminized window of 4 μm. The diameters of its inscribed circles in the hexagon and pentagon are 125 mm and 100 mm, respectively, and are located at the same distance from the sample.

The detection energy range of the NAPC detectors is between 3 and 20 keV approximately (Bateman, 1985a). Since the electric field surrounding the anode depends on its shape. To guarantee that the differences in the shape of the electric fields of all the units would not affect the energy resolution of the entire system, the shape of the tip and the diameter of the needles were selected using a digital microscope, making sure that each tip had the same semi-spherical shape of approximately 80 μm in diameter.

This design allows a better geometric efficiency without a great loss of energy resolution, because the detected X-rays pass through the same sample-detector distance. The geometric efficiency of this detection system is the net total area of cylindrical detection divided by the hemispherical area. In the design described above, the geometric efficiency is nearly 60%. The fullerene patterns also makes it possible to adapt to different experimental geometries by adding a collimator at the hemispheric top (only for incident beam) and exchanging its position with the NAPCs. Then, normal incidence, 45° incidence, grazing incidence or total reflection arrangements can be accommodated, as shown in Fig. 2.

3. Experimental setup and results

A single NAPC unit was made and its characteristics were studied, in terms of energy resolution, pulse height and count rates, vs. applied voltage. The entire set of detectors was subsequently constructed, and its characteristics were studied. In both steps, a P10 (90% of Argon + 10% of Methane) fill-gas was utilized at a pressure 100 kPa and under a continuous 1.7×10^{-4} m^3/s flow.

In testing the single NAPC detector, two radiation sources, ^{55}Fe with 6.7×10^7 Bq activity and ^{241}Am with 3.7×10^9 Bq activity, were used, the first to directly irradiate the detector, and the second to excite a Pb sample to provide Lα and Lβ lines. A voltage in the range of 1.35–1.75 kV was applied to each detector, to ensure that it functioned as a proportionality counter. The pulses from the detector were pre-amplified by a customized charge-sensitive preamplifier constructed in-house, with features similar to those of the CREMAT CR 110 model, but with a higher gain. The pulses were then amplified and shaped by a Tennelec TC-244 amplifier, and recorded with a multichannel analyzer. The detector pulses were simultaneously monitored on an oscilloscope.

The entire system was tested with intense radiation produced by radiation from a synchrotron (LNLS Campinas Brazil) and an X-ray tube of 40 kV/100 μA, with silver (Ag) target and a beryllium end-window (FXR lab, Universidad de La Frontera). The synchrotron was used to ensure that every single NAPC functioned as designed under high intensity conditions. The X-ray tube was used

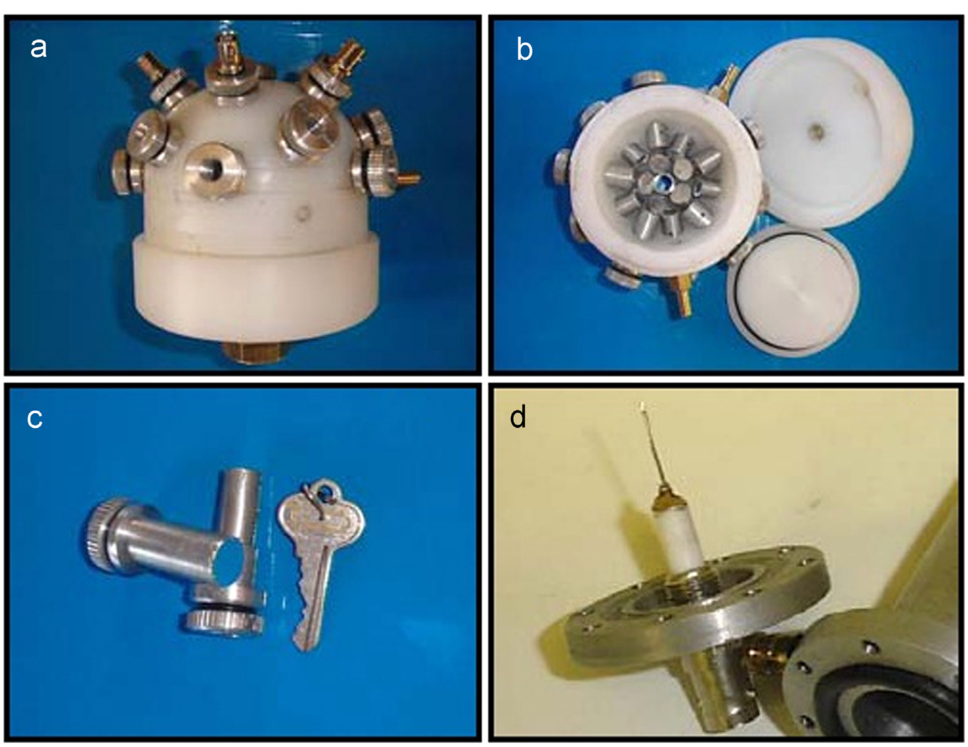

Fig. 1. (a) General view of detector, (b) open detector with sample holder, (c) NAPCs and (d) needles anode.