Vibration-Proof High-Pressure Xenon Electroluminescence Detector

Alexander Bolozdynya and Raymond DeVito

Abstract—**We have developed a high-pressure [electroluminescence (EL)] detector with a sensitive volume of $\varnothing 5\ \mathrm{cm} \times 5\ \mathrm{cm}$ defined by a cathode, five drift rings, and an EL-generating structure. The EL-generating structure consists of two parallel-plate chemically etched grids and a high-pressure optical window, which is optically coupled to an external photomultiplier tube. Ionizing radiation that is absorbed in the sensitive volume generates electrons, which drift into the EL region and produce an EL flash. The detector was filled with 20-bar Xe gas that was highly purified (>1 ms electron-life time) using a spark purification technique. To evaluate the potential for using an EL detector under adverse conditions, we disturbed the detector using a 10-W electric engraver working at 60 Hz. The action of the engraver had practically no effect on spectra acquired from an $^{241}\mathrm{Am}$ gamma ray source.**

Index Terms—**Detector, electroluminescence, high-pressure xenon, spectrometry.**

I. INTRODUCTION

In the past decade, significant progress has been achieved in the development of high-pressure xenon (HPXe) ionization chambers (see, for example, [1] and references therein). These detectors have demonstrated that good energy resolution is achievable with kilograms of compressed Xe operating at room temperature. The most common method of acquiring data from HPXe detectors is to measure the charge induced on electrodes by drifting ionization electrons. To eliminate the dependence of the pulse amplitude on interaction position, the ionization chamber is often divided into two parts by a screening Frisch grid [2]. The grid is maintained at an intermediate potential between the cathode and the anode, making it electrically transparent to drifting ionization electrons. The maximum voltage pulse amplitude induced at electrodes from collection of n_0 electrons is given by $V_{\max} = en_0/C_D$, where C_D is a capacitance of the grid relative to the anode. The electronics noise in the input circuit of the amplifier is proportional to $(C_D)^{1/2}$ [3]. So, value of signals and electronics noise of readout system of ionization detectors is sensitive to variations of the capacitance due to microvibrations of the grid and the anode. This microphonic effect is the most important factor limiting performance of HPXe detectors.

Another method to acquire information from high-pressure noble gas ionization chambers is to detect excitation light generated by ionization electrons drifting along the electric field through the gas (see, for example, [4] and references therein).

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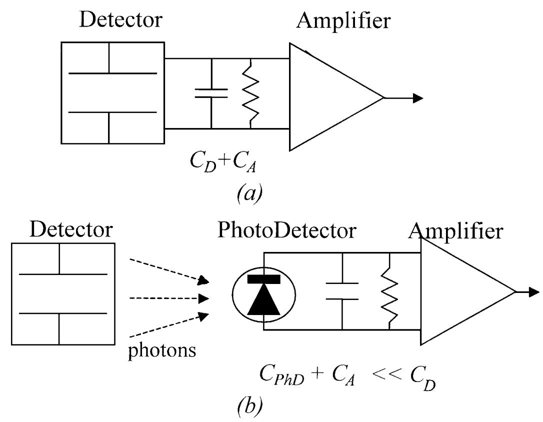

Fig. 1. Readout of (a) ionization and (b) EL signals from HPXe detectors.

In the presence of high enough electric field, ionization electrons can gain sufficient energy between successive collisions to cause excitation of atoms or secondary ionization. If the energy of drifting electrons is slightly below the ionization threshold, they do not initiate charge-multiplication avalanches but rather effectively excite noble gas atoms A and generate intensive electroluminescence (EL) light by the following processes

$$\begin{aligned} &e + A \rightarrow e + A^* \\ &A^* + 2A \rightarrow A_2^* + 2A, \quad \text{at gas densities} > 10^{10}\ \mathrm{cm}^{-3} \\ &A_2^* \rightarrow 2A + h\nu. \end{aligned}$$

For a given gas pressure, the EL process does not occur below a certain field threshold. In a uniform electric field, the number of photons, N_{ph}, generated by one drifting electron is proportional to the drift path x [cm], the reduced electric field strength E/p [kV/cm/bar], and the gas pressure p [bar]

$$N_{ph} = 70\left(\frac{E}{p} - 1.0\right) p\,x \quad \text{UV photons/electron/cm} \qquad (1)$$

the best value of the intensity of EL has been measured to be 1700 photons/cm at $E/p = 3.4\ \mathrm{kV/cm/bar}$ in 9 bar xenon [5]. EL has been observed in all noble gases and their mixtures. In gas mixtures containing >0.1% Xe, the light-output and spectrum of EL is very similar to that of pure xenon. The EL process is not something specific only for noble gases. The effect is widely used in solid semiconductor devices such as LEDs [6].

Most importantly, as one can see from (1), the **EL signal is not sensitive to the capacitance of the electrode system, and in a uniform electric field, the signal is proportional to the voltage drop across the electrodes rather than the electric field strength**. With optical readout, the capacitance of the detector's electrodes system is decoupled from the amplification circuitry (Fig. 1). This means that the principal factor limiting

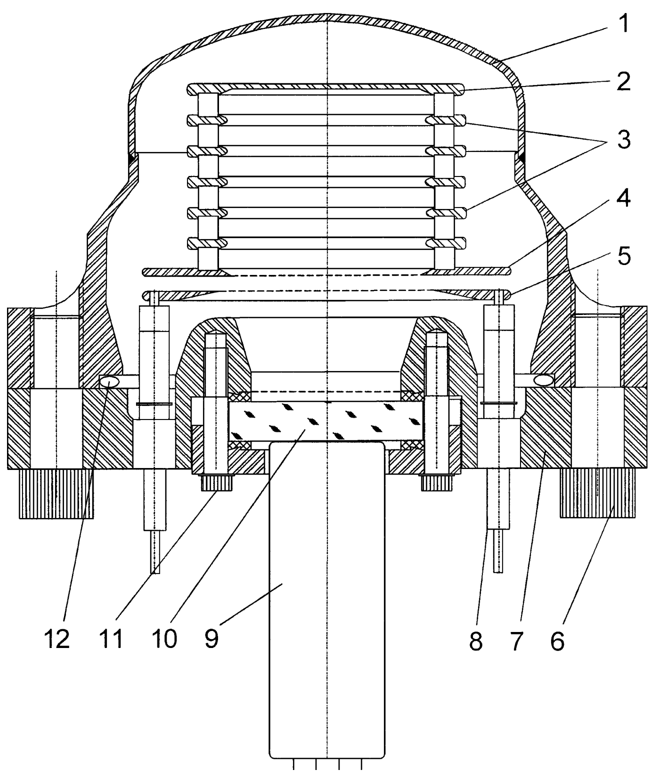

Fig. 2. EL high-pressure xenon detector with parallel-plate electrode system and photomultiplier readout: 1—high-pressure vessel, 2—aluminum cathode, 3—drift electrodes separated by stand-off ceramic insulators, 4 and 5 grid electrodes forming EL region, 6—bolt, 7—flange, 8—HV feedthroughs, 9—photomupltiplier, 10—optical window, 11—bolt, 12—Helicoflex gasket in aluminum jacket. Sensitive volume of the detector enclosed by the electrode system of 2–4 has 5-cm diameter and 5-cm depth.

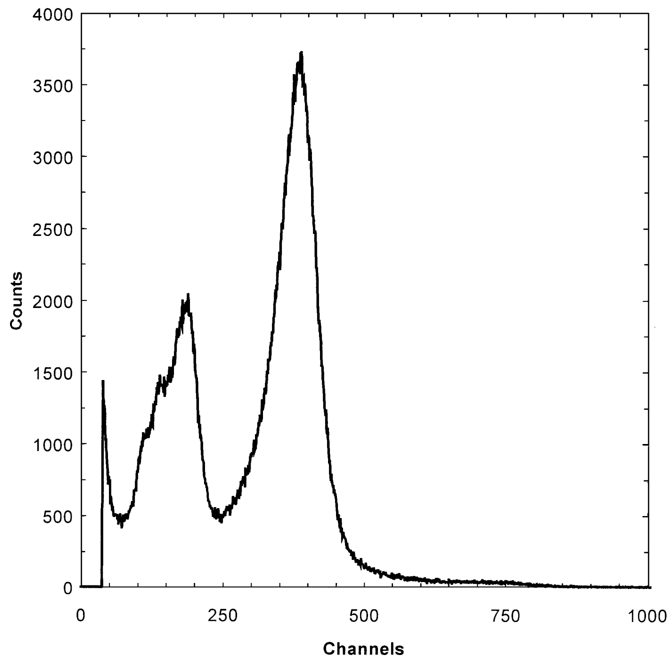

Fig. 3. Spectrum of $^{241}\mathrm{Am}$ measured in 20 bar Xe.

the spectrometric performance of ionization detectors can be eliminated in EL detectors. The EL process is linear, in contrast to the exponential behavior of electron multiplication. Due to this circumstance, EL benefits from lower fluctuations and may support better energy resolution than the gas gain amplification process. Advantages of EL detectors in getting good energy resolution in particularly at 9–20 bar pressures have been already demonstrated [4], [5]. The goal of this work is to show that ELD are relatively insensitive to vibrations.

II. Methods

A schematic design of the EL detector used in this paper is presented in Fig. 2. The cathode (2), drift electrodes (3), and the grid (4) define a sensitive volume having dimensions of $\varnothing 5\ \mathrm{cm} \times 5\ \mathrm{cm}$. Parallel-plate photolithography-made grid electrodes (4, 5) are used to generate EL that is detected by a photomultiplier (9) optically coupled to a window placed behind the grounded grid. A 0.5-$\mathrm{mg/cm}^2$ layer of p-terphenyl $(\mathrm{C}_{14}\mathrm{H}_{18})$, serving as a wavelength shifter, is vacuum-deposited on the inner surface of the optical window enabling the photomultiplier to "see" the 170-nm UV light generated during the EL process. The quantum efficiency of the p-terphenyl wave shifter has been measured to be >90% in pressurized xenon [5]. The emission spectrum of p-terphenyl has two peaks: one at 350 and another at 450 nm. An important property of this well-known scintillating dye is that it does not contaminate xenon. High-voltage feedthroughs (8) are installed in the flange (7) to supply voltage to the electrodes. The flange is equipped with a knife-edge groove for 2–3/4″ CF gaskets, which were used for installation of 10-mm-thick UV-grade optical window (KU-8). A blue-sensitive EMI THORN 9125B photomultiplier with 30-mm diameter input window was optically coupled to the external face of the window.

Before assembly, all metal and ceramic-made detector parts were baked at 200 °C under a vacuum of $< 10^{-6}$ torr. The assembled detector was pumped down to 10^{-8} torr for a week before filling with xenon. We used pure Xe or $\mathrm{Xe} + 0.2\%\mathrm{H}_2$ gas mixture to fill the detector. A spark purification technique [7] has been used to remove electronegative impurities from the gas. The ultimate purity of used gases corresponded to several milliseconds of electron lifetime.

In this project, we have used standard NIM electronics and a desktop computer with an APTEC-NRC 5016 MCA card providing data acquisition, display, peak search, and analysis. A high-voltage potential of up to 30 kV, filtered with a custom-made HV filter, was applied to the anode of the detector. A cathode bias of up to 20 kV was supplied using a separate HV power supply. The system includes a LeCroy LT346L Waverunner digital scope for data recording and pulse shape analysis.

The detector operates in the following manner. Ionization radiation absorbed in the sensitive volume generates electrons, which drift into the EL region and generate an EL flash. UV light is shifted into the 350–450 nm range by p-terphenyl deposited on the inside surface of the window. The PMT detects the 350–450 nm photons.

III. Results

The EL detector was tested with pure Xe and $\mathrm{Xe} + 0.2\%\mathrm{H}_2$ gas mixture pressurized up to 31 bar. The best energy resolution has been achieved at pressures of about 20 bar. In Fig. 3, there is shown a pulse height spectrum measured with $^{241}\mathrm{Am}$ gamma

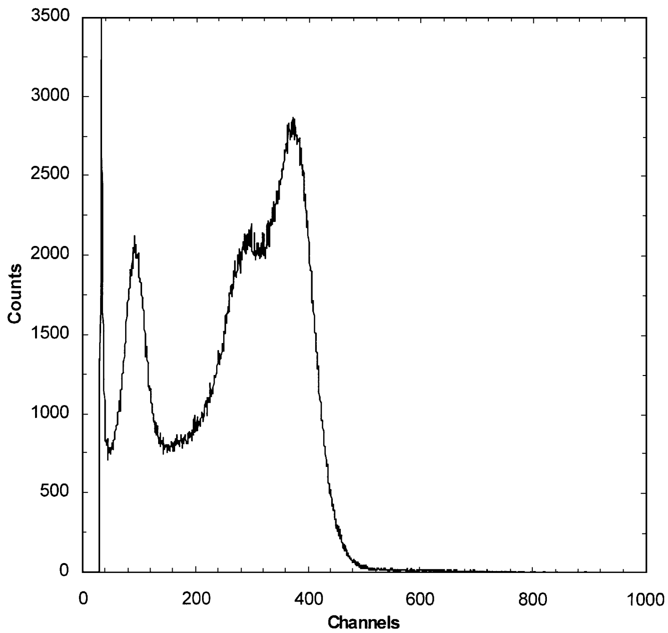

Fig. 4. Spectrum of ^{57}Co measured in 21 bar $Xe + 0.2\% H_2$.

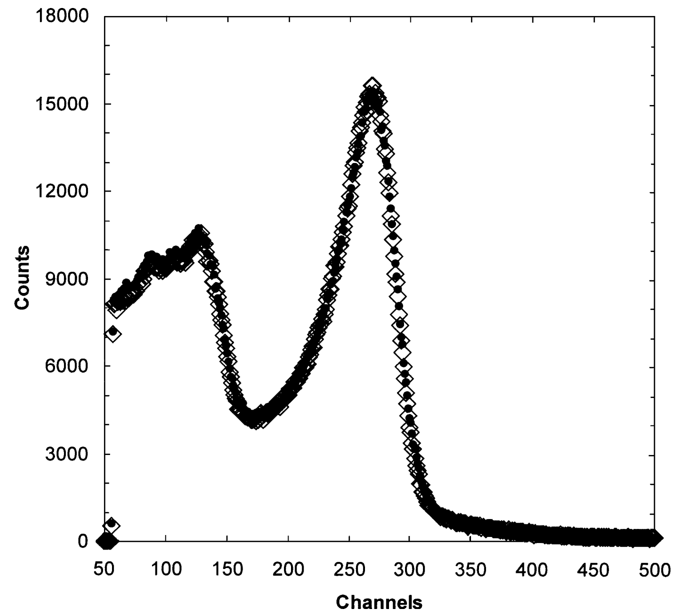

Fig. 5. Spectra of ^{241}Am gamma ray source measured in absence (open diamonds) and presence (closed circles) of mechanical vibrations generated by an electric engraver. The detector is filled with 20 bar Xe.

source installed in the center of the cathode (2, Fig. 1). The highest peak represents photoabsorption of 59.6 keV gamma rays in the sensitive volume of the detector. The next on the left peak is a superposition of the escape peak and photoabsorption of fluorescence photons (29.7 keV and 33.8 keV). In Fig. 4, there is shown a pulse height spectrum measured with ^{57}Co gamma source placed outside the detector. The highest double peak represents photoabsorption of 122 keV gamma rays and escape peak ($\sim$92 keV). The next on the left peak represents photoabsorption of the fluorescence photons.

In order to prove the statement about vibration insensitivity of the ELD, we used an electric engraver (10 W, 60 Hz) to disturb the ELD. The writing pin of the engraver was installed onto the flange of the ELD. Pulse height spectra of ^{241}Am gamma source were taken for the same acquisition time while the engraver was working and when it was turned off. No significant difference between spectra in the range $>$10 keV is found (Fig. 5). We tried to repeat the test with a few available cylindrical HPXe ionization chambers [8], [9] and found that the working engraver generated enormous noise signals exceeding the ionization signals from the gamma sources by two orders of magnitude. The microphonic effect prohibits any spectral measurements with ionization chambers under these conditions and introduces the risk of damage to the preamplifiers.

IV. Conclusion and Discussion

The experiment confirmed that vibrations do not affect the performance of an ELD with parallel-A electric field. This property is unique among HPXe detectors and allows the consideration of ELDs for use under very challenging conditions. We plan to improve performance of the ELD by replacing the relatively fragile optical window and PMT with a large avalanche photodiode.

The limiting factor of the ELD is that it requires extremely high voltages for generation of EL signals at high xenon densities. Technically, an ELD is most suitable for work below 30-bar pressure or 0.2 g/cm^3 xenon density, limiting their application for detection of relatively soft gamma radiation. We believe that EL detectors may find use in oil-well logging and in nuclear material monitoring systems.

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