Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Development of a plasma panel muon detector

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ARTICLE INFO

Keywords:
Gaseous
Micro-pattern
Radiation
Detectors
Muon

ABSTRACT

A radiation detector technology based on plasma display panels (PDPs), the underlying engine of panel plasma television displays, is being investigated. Emerging from this well-established television technology is the Plasma Panel Sensor (PPS), a novel variant of the micro-pattern radiation detector. The PPS is fundamentally a fast, high-resolution detector comprised of an array of plasma discharge cells, operating in a hermetically sealed gas mixture. We report on the PPS development effort, including proof-of-principle results of laboratory signal observations.

0. Introduction

The detector performance requirements for high and super-high ($10^{34-35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) luminosities at the LHC and future facilities such as the International Linear Collider have motivated our investigations into a muon detector technology based on plasma display panels (PDPs). PDPs are the principal component of flat panel plasma television displays. Their design and production are supported by an industrial infrastructure with four decades of development. As televisions and displays, plasma panels have proven reliability, durability, very long lifetimes coupled with low costs with applications in both commercial and military sectors. Our objective is to develop from the PDP technology a novel micro-pattern radiation detector—herein referred to as Plasma Panel Sensors (PPSs) the fundamental concept of which was initially introduced earlier [1–4]. The PPS is intended to benefit from many of the key attributes of plasma panels.

The potential performance attributes, materials, fabrication techniques and some critical issues of the PPS are described in a recent paper [5]. This technology offers the potential of high gains, fast response times, a commensurate high data rate capability and extremely low power consumption. The RMS spatial resolution will be determined (and limited) by the dimensions, pitch and the uniformity of electrodes on the display glass substrate. Current manufacturing capability allows for electrodes with as little as 1–2 μm non-uniformity, well below the order of 100 μm pixel sizes intended for muon detectors. Here we provide an overview of the PPS concept and report on initial laboratory test result of signal observations.

1. Plasma Panel Sensors detector overview

The PPS is based on the Plasma Panel Display (PDP), which comprises millions of cells per square meter, each of which can, when provided with a signal pulse, initiate and sustain a plasma discharge. As a plasma panel detector, a PDP cell can be biased to discharge when a free electron is generated or injected into the gas. Therefore the PPS, as a redesigned PDP, functions as a highly integrated array of parallel pixel-sensor elements or cells, each independently capable of detecting single free electrons generated within the cell, either by incident ionizing radiation or by photoelectrons emitted by a cathode. While our current effort is motivated by minimum ionizing particle (MIP) radiation detection, the PPS with an appropriate front end might also be configured as a photodetector. The initial results reported here in fact derive from both photon and beta particle radiation.

The basic element of PDPs consists of orthogonal arrays of electrodes deposited onto glass substrates, separated by a gas discharge gap. PDPs have been manufactured as DC and AC units. Televisions employ the latter while some limited use displays, as with PPS units, use a DC mode. Fig. 1 illustrates the basic features of an AC-type PDP assembly. The pixel or cell contains a phosphor-coated wall structure enclosing a plasma discharge cell.

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doi:10.1016/j.nima.2010.07.076

The cells are quite small, on the order of 200 μm in each dimension for HDTV, although PDPs with cell dimensions on the order of 100 μm have been made for military applications. Because of the small electrode gaps, large electric fields arise with only a few hundred volts of bias. At least three cells, each associated to a specific color (e.g. RGB), comprise a pixel. The plasma discharges are usually made in Penning mixtures of noble gasses: typically Xe and Ne gas at about 500 Torr. It is important to note that the gas in a PDP is permanently and hermetically sealed in the panel's glass envelope. (The tests reported in this paper were conducted on a display panel that has been sealed for 7 years.) The discharge produces VUV photons that excite phosphors in the cells and produce the bright colors characteristic of plasma TV.

The PDP as a plasma panel detector is biased to discharge when a radiation-induced free electron is generated in the gas. Such electrons then undergo rapid electron multiplication, resulting in an avalanche and discharge that can be confined to the local pixel cell space. For PDP products, this process is self-limiting and self-contained by various means, one of them being a localized impedance at each cell. The technique of using a localized quench resistor is similar to that used in Resistive Plate Chambers (RPCs). The total charge available to produce a signal is that stored by the cell's internal capacitance and determines a maximum gain. Since the cell is operated above the proportional mode [6], in essence it may be considered to be a micro-Geiger counter. The signal pulse will be independent of the number of initiating free electrons, rendering therefore the PPS as intrinsically digital. The gain may be sufficiently large to produce signals with amplitudes of volts, and obviate signal amplification electronics. Discharge confinement and localization is achieved by various methods, such as a pattern of dielectric material deposited over the bare metal electrodes to establish regions where discharges can occur. The conceptual design suggested here uses truncated electrodes of limited lengths.

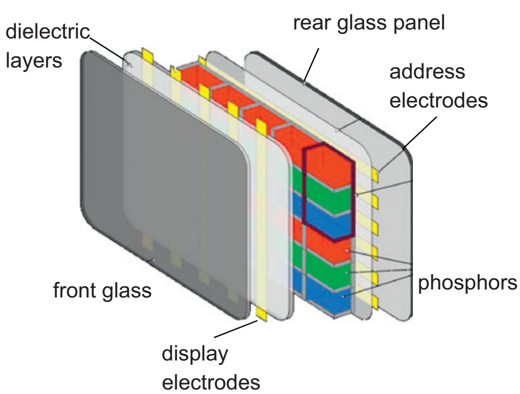

Fig. 1. Structure of an AC-type Plasma Display Panel, showing the basic elements. The plasma discharge region is defined by the front display electrodes. The gas mixture comprised of noble gasses is hermetically sealed in the glass envelope. In a PPS device, phosphors, address electrodes and dielectric layers over the display electrode are absent.

1.1. Cell geometry

The cell geometry includes the dimensions of the electrodes, their pitch and vertical spacing, and dimensions of cell walls. For MIP detection the electrode layout should have a "vertical" drift region on the order of 2–3 mm and a transverse electric field avalanche region of 50–100 μm. The drift region is required to ensure sufficient probability that a passing particle will produce at least one ion pair. Due to the large gain, a single ion pair can initiate a signal, suggesting that a drift region of ∼3 mm is sufficient to produce signals with very high efficiency [5].

1.2. Electrical characteristics

A conceptual representation of the cell configuration is shown in Ref. [5]. The cell is defined by a local electrode arrangement with an intrinsic capacitance and an embedded resistance in the high voltage feeds. The discharge gap is determined by the proximity of the two electrodes defining a capacitor, the high voltage (or discharge) side of each being fed by a resistance. The

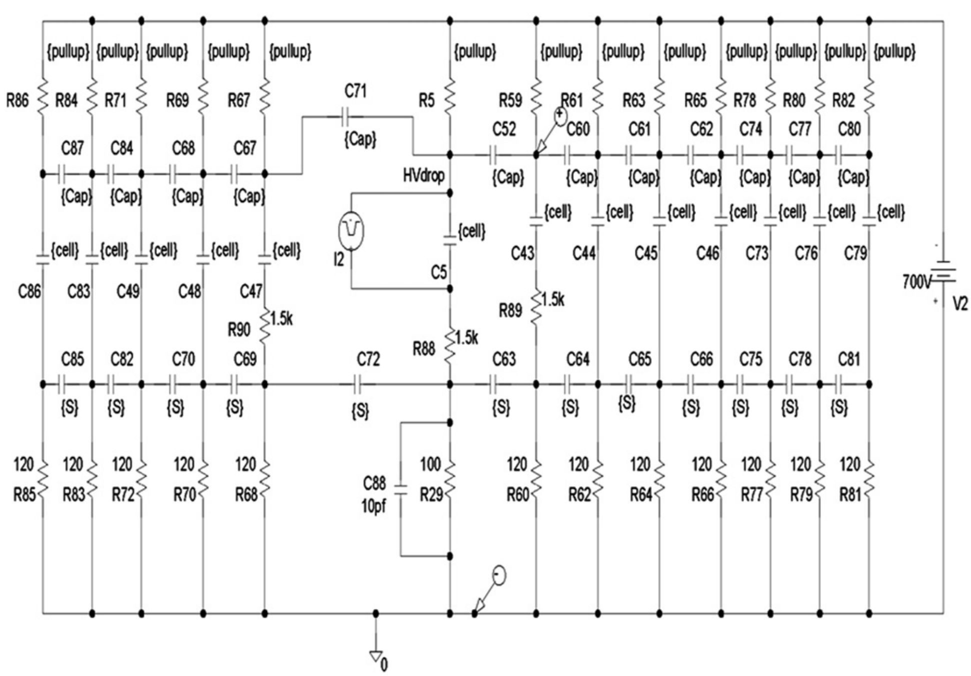

Fig. 2. Schematic of a pixel chain with discharge regions represented by capacitors isolated and quenched by embedded resistors.

resistance drops the high voltage at discharge and effectively terminates and localizes the discharge. The effectiveness of this resistance to electrically isolate the discharge is investigated with SPICE [7] simulations. A schematic of a chain of pixels, including resistances and stray capacitances, is shown in Fig. 2. Represented in this schematic are the embedded pixel resistances, the pixel capacitances, stray capacitances and the termination resistance. Also included is the discharge current source, which is assumed to be delta function like. The simulations in Ref. [5] indicated that the neighboring cells to the discharging cell experience no change in their bias; they remain charged independently ready to respond to incident radiation.

A design-goal representation of the PPS electrode layout is shown in Figs. 3 and 4. In this projected side view, the resistors are directly embedded in a thick-film process, and are represented by the solid green regions separating the high voltage bus from the discharge electrodes. The resistors do not occupy sensitive detection area on the substrate. Also shown (not to scale) is the 3 mm drift field. The electric field, where the electrodes are represented by wires, is shown in Fig. 5, computed with Garfield [8] and also with COMSOL [9]. While the dimensions shown are illustrative only, electrodes of the sizes indicated (25–75 μm) are easily within current low-cost manufacturing capability.

2. Proof-of-principle tests

An experimental program of proof-of-principle measurements has been initiated to establish the overall feasibility to induce self-limiting, large amplitude, plasma discharges and to extract initial measurements for well-defined geometries, gas mixtures and electric field configurations. The latter will provide a basis for comparison with the simulation effort underway. These first signal measurements were conducted using sealed, thin gap

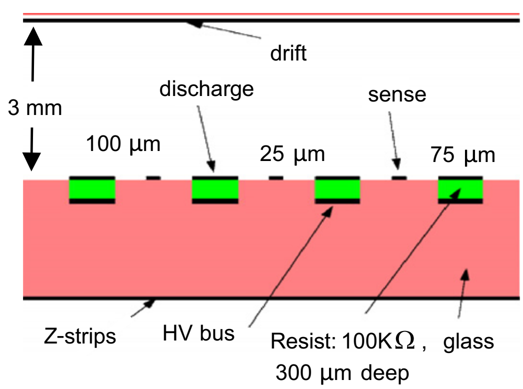

Fig. 3. 2D view of conceptual representation for test device substrate. Pixels formed by gap between HV (discharge) and sense lines. Quench resistances formed by resistive deposition. Signals form on sense electrodes.

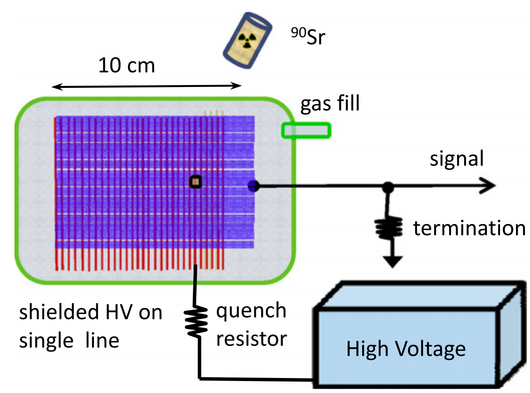

Fig. 5. Layout of proof-of-principle setup. Highlighted region at electrode junction is the instrumented pixel. Panel filled and sealed with 99% Xe and 1% O_2 in 2003.

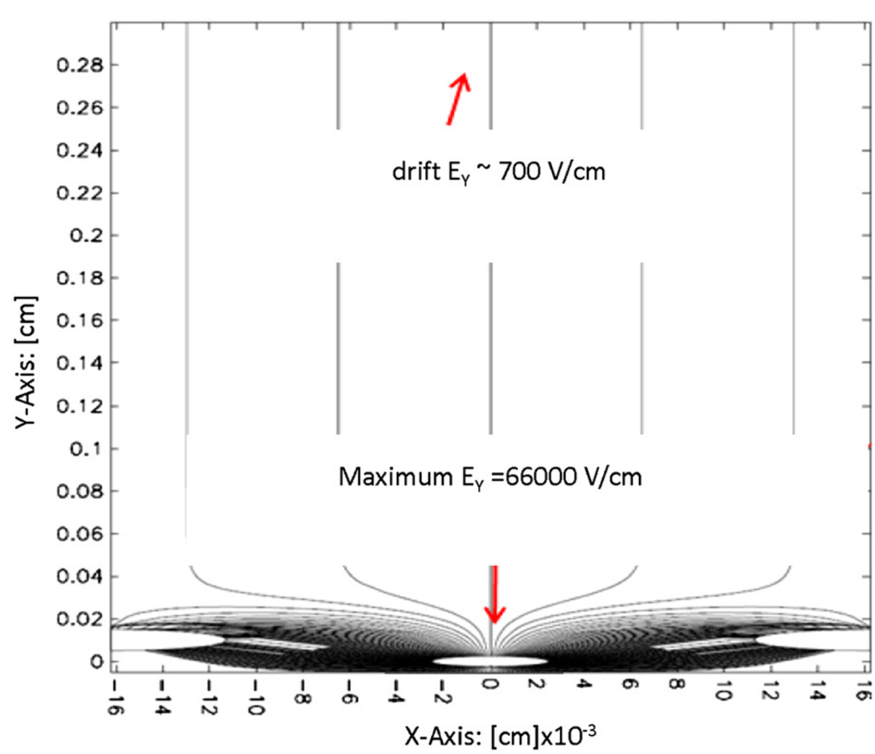

Fig. 4. Electric fields in the drift and avalanche directions for the rounded electrodes of the type of cell shown in Fig. 3. The field between avalanche and sense electrodes reaches a similar value as does the field from the drift region as it nears the sense electrode.

Please cite this article as: D.S. Levin, et al., Nucl. Instr. and Meth. A (2010), doi:10.1016/j.nima.2010.07.076

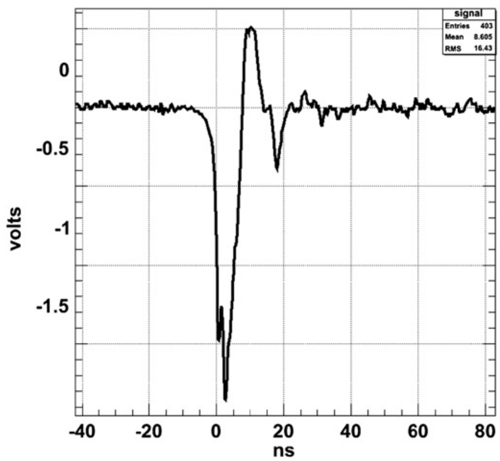

Fig. 6. Example of signal pulse obtained from proof-of-principle PPS tests. The rise time (20–80%) is ~1 ns, and reflects the combined time constants of the cell, stray capacitances and scope bandwidth. The volt scale amplitude is obtained without amplification.

envelope glass PDP panels, fabricated and gas filled in August 2003 [10] with a Penning mixture of 99% Xe, 1% O_2 to 650 Torr. These modules consist of two float glass 6×10 cm plates (1/8 in. thick) each with thin-film strips of metallic electrodes with approximately 1 mm pitch and oriented orthogonally. The plates are separated by a gas gap of approximately 220 μm. We emphasize that these units are designed as display panels, not as detectors. For the results reported here, signals are induced using a ^{90}Sr beta source.

Fig. 5 shows the basic configuration used to obtain the signals reported here. The intersection of the electrode comprises a columnar discharge region across the gas gap. The quench resistance is $10^5\ \Omega$ and the termination is approximately 50 Ω. Pulses could be induced by bringing a 3.7 mCi ^{90}Sr source to the panel, or alternatively by irradiation with a 366 nm UV source, which presumably ejects photoelectrons from the cathode. Further investigation of this result is ongoing. To obtain a signal, the bias voltage was ramped up to near the predicted breakdown voltage (600 V) based on the Paschen parameter for pure Xe [11] (about 13 Torr cm), then incremented slowly until pulses were observed. (The presence of O_2 in the mixture is presumed to be non-existent as it is readily adsorbed in the glass and by the thick-film Ni electrodes. Also, qualitatively the color of gas discharge looks exactly like that of pure Xe and not like that of the original 1% O_2 in Xe mixture.) The main features of this signal (Fig. 6) are its volt scale amplitude and fast rise time (20–80%) < 2 ns. The overshoot and ringing are presumed to result from residual impedance mismatches.

3. Summary

A program to develop plasma panel radiation detectors using plasma television display technology is underway. We have instrumented single pixels from small display units, filled with gas 7 years earlier. Fast signals, externally induced by a ^{90}Sr source, have been observed. These represent the first quantitative measurement of signals from a sealed plasma panel device. Detailed studies of the signal characteristics using circuit modeling and dynamic simulation codes are underway.

Acknowledgments

This work is sponsored by the Office of Nuclear Physics, U.S. Department of Energy and the US-Israel Binational Science Foundation.

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