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Development of a plasma panel radiation detector

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ABSTRACT

This article reports on the development and experimental results of commercial plasma display panels adapted for their potential use as micropattern gas radiation detectors. The plasma panel sensor (PPS) design and materials include glass substrates, metal electrodes and inert gas mixtures which provide a physically robust, hermetically sealed device. Plasma display panels used as detectors were tested with cosmic ray muons, beta rays and gamma rays, protons, and thermal neutrons. The results demonstrated rise times and time resolution of a few nanoseconds, as well as sub-millimeter spatial resolution compatible with the pixel pitch.

1. Introduction

This article reports on the development and testing of commercial plasma display panels adapted for use as a novel type of micropattern gas radiation detector. Plasma display panels (PDP) are commonly used in televisions and graphical display devices. Their design and production is supported by an extensive and experienced industrial base with four decades of development. The application of PDPs as particle detectors is referred to as a plasma panel sensor (PPS) [1–6]. The primary motivation underlying the PPS concept is to use well established manufacturing processes of PDPs to develop scalable, inexpensive and hermetically sealed gaseous detectors with the potential for a broad range of commercial and research applications.

A commercial PDP consists of millions of cells per square meter, each of which can initiate and sustain a plasma discharge when addressed by a bias-voltage signal [7]. A PDP, in the simplest matrix configuration, consists of an envelope of two flat, parallel, glass plates with line electrodes deposited on the internal surfaces. The plates are sealed together at the edges with the top and bottom electrodes aligned perpendicularly. The gap separating the two plates is between 200 and 400 μm and is filled with a Penning gas mixture of mostly Xe, Ar or Ne, typically at pressures of about one-half atmosphere. In such a structure, a pixel is made of an electrode intersection and gas gap.

A PPS incorporates the general structure of a PDP, but instead of actively inducing a plasma discharge with an applied voltage delivered to an addressed pixel, the plasma discharge is caused by ionizing radiation entering a PPS cell biased with a constant DC voltage above the Paschen potential. Results reported in this article were produced with commercial PDPs modified in specific ways to allow them to be used as particle detectors. They operated with DC bias voltages, had no dielectric barriers to isolate individual cells and had no phosphors in the cells. These panels were a simple matrix of anodes and cathodes with a gas filled gap of a few hundred micrometers. An example of a test device is shown in Fig. 1. The modifications made to the panels were

- Panels were normally fabricated with a hermetically sealed glass port. This was replaced with a stainless steel valve assembly that connects the panel to a gas mixing and vacuum pump system.
- The original Ne based panel gas was replaced with a test gas.
- The electrodes in the commercial panels were made from both Ni and SnO_2:F. A selection of the tested PPS panels used all Ni electrodes. The Ni was found to be much more resistant than the SnO_2:F to sputtering degradation.

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Fig. 1. A modified commercial PDP (type VPA in Table 1).

Table 1
PDP manufacturer's specifications. The packing fraction is the ratio between the active pixel area and total area. The electrode length includes only the section inside the gas volume. HV = high voltage, RO = readout. The dielectric mesh defines the pixel perimeter but does not act as a barrier between pixels. The panel type name is an internal identifier without global significance.

	Panel type VPA	Panel type MP
HV electrodes material	Ni	Ni
HV electrodes width (mm)	1.40	0.44
HV electrodes length (mm)	81	65
RO electrodes material	Ni	SnO_2:F
RO electrodes width (mm)	1.27	0.71
RO electrodes length (mm)	325	131
Electrodes pitch (mm)	2.54	1.02
Active pixel area (mm^2)	1.50	0.22
Packing fraction	23.5%	22.0%
Gas gap (mm)	0.38	0.29
Glass thickness (mm)	2.23	2.23
Electrodes thickness (mm)	0.02	0.02
Dielectric mesh thickness (mm)	0.02	0.02
VISHAY product number	PD-128G032-1	PD-128G064-1

- The electronics required for panel display operation was replaced with signal extraction circuitry on the readout anode electrodes.
- The high voltage bias was routed through quench resistors connected to each cathode electrode.

The above modifications allowed these commercial units to serve as a useful test bench for the PPS concept. The modified commercial panels served as prototypes for investigations and the results obtained from them have informed the next generation of PPS panels, the subject of a future paper. Commercial PDPs are sealed devices designed to work for 10^5 h. One panel filled with a Xe-based gas mixture at 600 Torr and hermetically sealed in 2003 produced signals when operated as a PPS 7 years later, clearly demonstrating the long term stability of the materials and gas mixture.

The panels evaluated in this report differed from each other in the electrode material, pixel density and size, and gas gap, that is separation of the anodes and cathodes. For the hit position studies, a type MP plasma panel was employed with a pixel pitch/granularity of 1.02 mm. For the investigation of panel timing, efficiency and response to various particle types a larger VPA panel was used with a pixel pitch/granularity of 2.54 mm. The specifications of these two different types of panels are summarized in Table 1.

Signals were investigated from panels filled with different gas mixtures at various pressures, exposed to radiation from radioisotope sources, particle beams and cosmic rays. The various mixtures were either commercially obtained or produced in our gas mixing system.

2. Operational principles

The use of PDPs as particle detectors requires that a charged particle will generate enough ion-pairs to initiate an avalanche leading to a discharge. This operational mode must be beyond the proportional region in the Geiger region [8] of gas ionization to achieve the desired fast, high gain response. This mode of operation of a cell can yield copious photons, photoelectrons and metastable atoms which could, due to the lack of physical barrier between the pixels, propagate and spread the discharge to other pixels.

Various mechanisms mitigate discharge regeneration in a PPS. Small amounts of gases such as CO_2 or CF_4 are added to the primary gas to absorb the photons through non-radiative vibrational and rotational excitations. Penning type mixtures [9] may also be used wherein the dopant gas has a first ionization energy level lower than the host gas excited states, e.g., CO_2 or CF_4 in Ar. The Penning transfer process allows for collisional de-excitation of the long-lived, metastable states. Finally, the discharge is externally quenched with a large resistor connected in series to each pixel or chain of pixels on the high voltage (HV) electrode. The pixels are then allowed to recover on a time scale determined by the RC time constant, where C is the effective pixel capacitance, effectively dominated by the choice of the quench resistor. This time constant should be commensurate with the time required for positive ions to neutralize and gas metastable species to decay [10].

The detailed mechanism for the discharge process is uncertain. A classic Townsend gas avalanche is limited by space charge buildup that negates the applied electric field, known as the Raether limit [11,12]. The gas discharges that occurred in PPS pixels produced charge in excess of the Raether limit. This is shown in the next section where the signal is described by a simple capacitive discharge model. This model is valid after the discharge has fully evolved between the pixel electrodes. We do not yet have the complete description of the progression from avalanche to full discharge that is required to accurately predict the gas dependent signal evolution.

2.1. Signal model

An idealized model for one pixel in the PPS detector is shown in the equivalent circuit model in Fig. 2, where R_q is the quench resistor (~ 100 MΩ), C is the pixel total *effective* capacitance and R_t is the 50 Ω termination resistor over which the signal is read.

The effective pixel capacitance includes the capacitance presented by the crossing of two orthogonal electrode lines and that from stray or parasitic couplings with all the other electrodes in the panel. This effective pixel capacitance in a type VPA panel was modeled using the COMSOL [13] package which uses the finite element method to solve the Poisson equation. This three dimensional model simulates the entire volume of the detector and specifies the electrode dimensions, pitch, gap and number of electrodes in an orthogonal square array. The model did not account for the dielectric glass substrates, nor the thin dielectric mesh overlaid on the electrodes at the cell perimeter. The computation was run for a series of increasing array sizes up to 15×15 at which point further increases became computationally impractical. The simulated capacitance versus number of pixels, shown in Fig. 3, was fit and extrapolated to the VPA panel array size of 32 pixels $\times$ 128 pixels. The extrapolated result was 1.9 ± 0.15 pF, where the uncertainty was determined from the fit

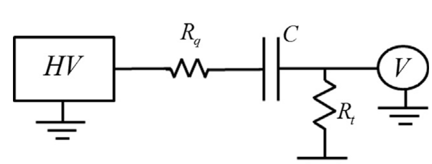

Fig. 2. Idealized schematic view of a single pixel.