1 First results with a microcavity plasma panel detector

2 R. Ball^a, M. Ben-Moshe^c, Y. Benhammou^c, R. Bensimon^c,
3 J. W. Chapman^a, M. Davies^c, E. Etzion^c, C. Ferretti^a, P. S. Friedman^d,
4 D. S. Levin^a, Y. Silver^c, R. L. Varner^b, C. Weaverdyck^a, B. Zhou^a

5 ^a *University of Michigan, Department of Physics, Ann Arbor, Michigan, 48109, USA.*

6 ^b *Oak Ridge National Laboratory, Physics Division, Oak Ridge, Tennessee, 37831, USA.*

7 ^c *Tel Aviv University, School of Physics and Astronomy, Tel Aviv, Israel.*

8 ^d *Integrated Sensors, LLC, Ottawa Hills, Ohio, 43606, USA.*

9 Abstract

A new type of gaseous micropattern particle detector based on a closed-cell microcavity plasma panel sensor is reported. The first device was fabricated with $1 \times 1 \times 2$ mm cells. It has shown very clean signals of 0.6 to 2.5 volt amplitude, fast rise time of approximately 2 ns and FWHM of about 2 ns with very uniform signal shapes across all pixels. From initial measurements with beta particles from a radioactive source, a maximum pixel efficiency of greater than 95% is calculated, for operation of the detector over a 100V wide span of high voltages (HV). Over this same HV range, the background rate per pixel was measured to be 3 to 4 orders of magnitude lower than the rate with the cell illuminated by the beta source. Pixel-to-pixel count rate uniformity is within 3% and stable within 3% for many days. The time resolution is 2.4 ns, and a very low cell-to-cell crosstalk has been measured between cells separated by 2 mm.

10 *Keywords:* micropattern gas detector; particle detector; plasma panel sensor.

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1. Introduction

Plasma panel sensors (PPS) with *open*-cell structures as particle radiation detectors have been investigated by our group for several years [1]. The first results for a new radiation detector based on a *closed*-cell microcavity-PPS structure are here described. This research aims at developing scalable, inexpensive, low mass, long life and hermetically sealed gaseous detectors for both scientific and commercial applications.

The panel acts as an array of independent closed gas pixels/cells biased to discharge when free-electrons or ions are generated in the gas by ionizing radiation. The electron avalanche is self-contained by the walls that define the cell itself and suppressed using Penning mixtures [2] with quenching gases and a localized resistance at each pixel. The HV applied to each pixel is chosen such that the mode of operation is in the Geiger region [3], and rendering this device intrinsically digital. The cell capacitance, which was measured to be 0.3 ± 0.1 pF, stores the total charge available for a pulse.

Figure 1: Concept side view of a microcavity-PPS panel.

26 The detector consists of two substrates (see Fig. 1) sealed together. The
 27 top supports the anode in each cell, which is connected by a metal via to a
 28 readout (RO) or sense line on the outside. The bottom hosts the metalized
 29 cavities, each one with a metal via connecting the cathode to the HV distri-
 30 bution by means of an external quench resistor. In this first prototype, cells
 31 of $1 \times 1 \times 2$ mm were arranged with a low packing fraction of 18% as shown
 32 in Fig. 2. Smaller cells with much higher packing fractions are planned for
 33 the next generation of detectors.

Figure 2: Photograph of part of a microcavity-PPS bottom substrate with $1 \times 1 \times 2$ mm metalized microcavity array. Three thin gas lines (vertical) are visible, each servicing two columns of cavity pixels.

34 **2. Experimental Results**

35 *2.1. Setup and DAQ*

36 The gas used for the experiments described here was 1 atm of Argon-Neon
 37 Penning mixture with CF_4 added to improve the response with and without a
 38 radioactive source. Each pixel was instrumented with a $1\text{G}\Omega$ quench resistor.
 39 The response was investigated with a ^{106}Ru β -emitter source.

40 In most of the tests the readout signals were first discriminated before
41 being sent to a Wiener NIMbox, configured as a 20 channels scaler using
42 customized firmware, readout by locally developed LabVIEW code.

43 For efficiency and time resolution measurements, the coincidence of an
44 external pair of scintillator detectors was used to generate a trigger for the
45 readout, using 20 ns wide, NIM logic signals. The coincidence window of the
46 panel and trigger was 2 μ s.

47 In order to acquire the signal time spectrum, a portable version of the
48 LHC ATLAS precision muon chambers readout system called MiniDAQ [4]
49 is used. This system is capable of recording integrated charge and times
50 relative to the trigger with 0.78 ns precision.

51 2.2. Signal response

52 The signal produced by a discharge is very clean ($S/N > 20$), has a
53 range of amplitudes from 600 mV (at HV=800V) to 2.5 V (at HV=1200V)
54 requiring no amplification electronics, and has rise times of about 2 ns and
55 FWHM of between 2 to 3 ns, as shown in Fig. 3.

Figure 3: Example of microcavity-PPS pulse operating at 1150V.

Fig. 4 shows the hit rate of a single pixel, exposed to the collimated source, as a function of the applied high voltage. A plateau between 1090V and 1190V is clearly visible. Over the whole range of HV tested, less than 0.01 Hz of background per pixel were measured whereas with the source, a count rate of 2 to 3 orders of magnitude higher was observed. Data taken with an uncollimated source shows that a single pixel can count at rates up to 400 Hz or more (at higher voltages) maintaining a very low background with a 3 to 4 orders of magnitude source to background ratio.

Figure 4: Single microcavity-PPS pixel rate response to ^{106}Ru at different HV.

2.3. Pixel uniformity

The response rates of different pixels was measured to determine the quality of the parts and their assembly. Fig. 5 shows a histogram of the rate at fixed voltage of pixels illuminated by the collimated ^{106}Ru source. The distribution has a variance of about 12% over 52 pixels tested (see Fig. 5).

A more precise measurement of the pixel response uniformity was obtained by exposing the detector to a source placed at a distance far away enough to produce an approximate uniform flux of radiation over the whole

Figure 5: Histogram of microcavity-PPS single cell response rates to a collimated ^{106}Ru source at 1050V for 52 pixels. The distribution is fitted with a Gaussian function.

72 panel. The rate measured on each readout line was proportional to the num-
 73 ber of pixels instrumented on that line (Fig. 6). The RMS variation was
 74 about 3%, smaller than the variance determined from Fig. 5. The difference
 75 is largely due to alignment errors in placing the collimator on each pixel.

Figure 6: Microcavity-PPS response rate exposed to an uncollimated ^{106}Ru source 13 cm above the panel. The RMS on the Y-axis is 3%.

76 2.4. Pixel isolation

77 The pixel isolation was directly confirmed by the result shown in Fig. 7.
 78 This plot displays the hit map associated with the collimated ^{106}Ru source
 79 placed over a single pixel in readout (RO) line #6, in a configuration that

80 had 21 other active cells nearby.

Figure 7: Hit map of the microcavity-PPS with 22 active pixels (not all the lines have the same number of pixels) and where a ^{106}Ru source was collimated over a pixel on RO #6.

81 The measured rate on the illuminated line was significantly larger than
 82 the one on the other lines which remained very close to the background level,
 83 confirming that a pixel discharge on one line does not affect the others. The
 84 slightly higher observed rate on the two lines adjacent to the illuminated is
 85 due to the collimator diameter being slightly larger than the cell, which leads
 86 to a small collateral leakage contribution to the neighbors.

87 2.5. Time stability

88 Fig. 8 exhibits the stability of the pixel response rate in time: the plot
 89 is the average hourly count rate under the uncollimated ^{106}Ru source placed
 90 15 cm above the panel. The first 18-20 hours show a fast change in response
 91 rate due to the individual gas components still mixing (i.e., the DAQ was
 92 started immediately after filling the panel one gas component at the time).
 93 After this period, the RMS variation was $\sim 3\%$ over the next 9 days.

Figure 8: Microcavity-PPS single pixel response as a function of time at 1000V.

94 2.6. Efficiency

95 The pixel efficiency is defined as the ratio of the number of events with a
 96 coincidence between a pulse in the microcavity pixel and a trigger, divided by
 97 the total number of triggers. The calculation of the efficiency was corrected
 98 using GEANT4 [5] mainly because of two effects that increased the number
 99 of triggers: 1) the collimator diameter was larger than 1 mm, causing a
 100 fraction of the source β 's to trigger an event even when not passing through
 101 the pixel. 2) triggers due to secondary electrons from X-rays produced by
 102 the ^{106}Ru β 's interacting either in the panel substrates or in the scintillators.
 103 The trigger rate was also measured with a plate identical to the collimator
 104 but without the hole: roughly one third of the triggers are recorded in this
 105 configuration. This data driven method of subtracting the fraction of triggers
 106 coming from the source and not going through the pixel active area reduced
 107 the dependence of the result on simulation.

108 Fig. 9 shows the pixel efficiency measured as a function of the applied
 109 HV for two pixels. The fit lines, based on a Fermi-Dirac function, each show

110 a plateau, one at $\varepsilon \sim 95\%$ and another at $\varepsilon \sim 100\%$. The total systematic
 111 error was estimated to be about 10%, and was due to a misalignment between
 112 the collimated source and the pixel, and the pixel relative to the trigger.

Figure 9: Microcavity-PPS pixel efficiency as a function HV measured for two pixels.

113 2.7. Time resolution

114 The response time of single pixel hits from the collimated ^{106}Ru source
 115 is shown in Fig. 10, where the number of hits is plotted as a function of the
 116 pulse arrival time after subtraction (event by event) of the trigger time.

Figure 10: Distribution of the microcavity-PPS single cell arrival time at 1530V.

117 The experimental points were fitted with a Crystal Ball function, a convo-
 118 lution of a Gaussian with a power law accounting for an asymmetric tail [6].

119 The Gaussian part of the distribution reflects the stochastic nature in which
 120 the avalanche leads to the discharge, while the tail represents the longer drift
 121 times of electrons arriving from regions with lower field and farther away
 122 from the anode. The time resolution, defined as the dispersion in the time
 123 difference between the pixel signal threshold crossing and the trigger time,
 124 shown by the Gaussian sigma of the fit is ~ 2.8 ns. This width includes
 125 the trigger jitter, measured at 1.5 ns. The approximate procedure of the
 126 subtraction in quadrature of the trigger component yields a Gaussian time
 127 resolution of 2.4 ns. The distribution's negative mean was due to a lack of
 128 correction for the trigger delay with respect to the pulse (e.g. extra cables,
 129 electronics, etc.).

130 **3. Summary**

131 The microcavity-PPS detector prototype showed very promising results
 132 in terms of pixel-to-pixel uniformity and time-stability of both signal shape
 133 and rates. The prototype has also demonstrated very low background over a
 134 wide range of applied high voltages, excellent pixel response isolation, time
 135 resolutions of a few nanoseconds, and efficiencies above 95% over a 100 volt
 136 range for beta particles emitted by a ^{106}Ru radioactive source.

137 The geometrical parameters of the panel microcavity cell design can be
 138 tuned for specific applications including smaller cells and much higher pack-
 139 ing fractions. These changes, together with the optimization of the gas mix-
 140 ture and reduced quench resistances, could increase the maximum response

141 rate, improve both the spatial and time resolution, and increase the overall
142 efficiency. Based on these initial results, the development of this technology
143 should provide a promising alternative for particle detection.

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