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Section A

# On the high gain operation of low-pressure microdot gas avalanche chambers

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**Abstract**

Microdot avalanche chambers (MDOT) equipped with thin semitransparent Cr photocathodes, were characterized with UV photons at low gas pressure. Gains superior to $10^4$ were reached with gas multiplication at the dots. In a mode where preamplification in the gas volume precedes the additional dot multiplication, gains superior to $10^6$ were measured at 30–60 torr of propane. The fast amplification mechanism results in narrow high amplitude pulses with 2–3 ns rise time, visible with no further electronic amplification means. We present here our preliminary results and briefly discuss potential applications.

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## 1. Introduction

We report here our first observations of an interesting high gain fast amplification mode of microdot avalanche chambers, operated at low gas pressures.

In recent years there has been a tendency to replace amplification wires in gaseous avalanche detectors, by electrodes printed on solid substrates. This successful trend was motivated by the pioneering work of Oed [1] who proposed the microstrip gas chamber [MSGC]. It consists of thin parallel metal anode and cathode strips deposited on an insulating substrate. There has been major activity and progress in this field, as reviewed in [2, 3]. Other techniques have been derived from the MSGC; the microgap chamber (MGC) [4, 5] with anode strips placed on top of cathode strips through a thin insulator, the MICROMEGAS detector [6] with thin anode strips on an insulator with a cathode mesh placed at a short distance above, and the microdot avalanche chamber (MDOT) with 2D arrays of small dot-shaped anodes surrounded by cathode electrodes, as shown in Fig. 1 [7, 8].

In all these amplification structures, the small anode–cathode distance assures fast ion removal from the avalanche region, resulting in very high rate capability, superior to 1 MHz/mm$^2$ [9]. The rapid drift of ions in the vicinity of the anodes also results in the induction of fast pulses. Very good localization resolutions obtained in the above mentioned detectors are derived from the small anode pitch, reaching distances down to 100 μm with standard microelectronic procedures.

The gain limitations in these various devices are often related to surface discharges. The maximum practical numbers are from $10^3$–$10^4$ for MSGCs and MGCs, and $>10^4$ for MDOTs and for the MICROMEGAS. Higher gains may be obtained if the amplification on the surface electrode is preceded by volume amplification, in a so-called two-stage mode [10].

Interesting characteristics of MSGCs were found when operated at low gas pressures [11, 12]. It has been demonstrated that in this mode of operation the resulting high gain and fast response are due to an efficient two-stage multiplication, yielding amplification factors reaching values of $10^5$ for single UV-photons [11, 13]. It has also been found that only a small fraction of positive ions return to the drift cathode (photocathode), due to the electric field distribution [13]. This fact, and the observations that large fast signals are detectable already at moderate gains, are important for prolonging the photocathode (or other radiation convertor) life-time in gaseous detectors combining solid convertors with

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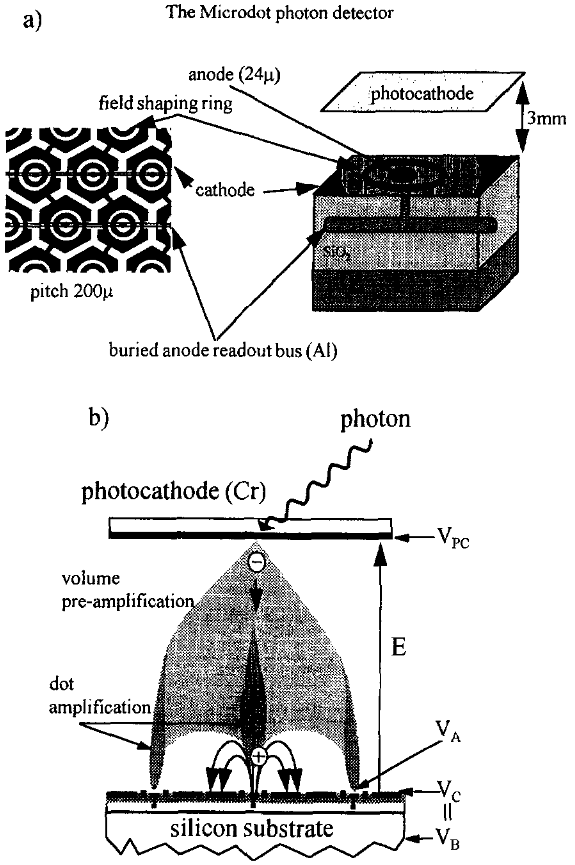

Fig. 1. (a) A Schematic drawing of the Microdot avalanche chamber and the electrode layout for the 200 μm pitch structure. The 100 μm pitch structure does not contain the extra field shaping rings and has circular cathodes. (b) is an artists view of the multiplication process, in which the photon is converted in the photocathode; the photoproduced electron is then pre-amplified in the gas volume (the parallel-plate stage); the avalanche electrons are focused on the dots where further amplification occurs. Positive ions drift towards the cathode rings and the photocathode, at a ratio depending on the electric field configuration.

electron multipliers [14]. The possible operation under lower gain is also beneficial for applications requiring higher rate capability.

Our recent investigations of the MDOT technique at low gas pressure have shown a superior behaviour of this multiplier in terms of gain, stability and time response as compared to the MSGC. Some of our results are presented in this work.

## 2. The microdot chamber

The MDOT electrodes (see Fig. 1(a)) were produced on a silicon wafer, using standard MOS technology [15]. The dots are interconnected in lines; the connecting buses are buried under a $SiO_2$ insulating film. The substrate was doped, so as to lower the surface resistivity in order to reduce possible upcharging effects and control the electric field gradient across the MDOT cell surface. To make this control more effective, additional floating metal rings were added within the cell, as shown in Fig. 1(a). A detailed description of the production technique and cell geometries is given elsewhere [8,16].

Two sets of MDOT electrode geometries (both on the same wafer) were investigated in this work:

(a) a 100 μm anode dot pitch with 10 μm dot diameter and 85 μm inner cathode diameter. The anode capacitance: is 0.02 pF/cell and the cathode capacitance is 0.045 pF/cell,

(b) a 200 μm anode dot pitch, with 24 μm dot diameter and 170 μm inner cathode diameter; there is a field shaping ring with an inner diameter of 110 μm. The anode capacitance is 0.05 pF/cell and the cathode capacitance is 0.14 pF/cell.

The total active area of the 100 μm pitch electrode is $6.5 \times 5.5\ \mathrm{mm}^2$ and that of the 200 μm pitch electrode is $52 \times 5\ \mathrm{mm}^2$. The wafer was attached to a printed circuit board into which anode and cathode electrode contacts were bonded. In each case all the cathodes were interconnected; the number of anode dots connected in our case to one readout channel was 1300 and 7000 for the 100 and 200 μm pitch electrodes, respectively. The backplane of the circuit was always kept at the cathode potential. The MDOT circuit was mounted at a 3 mm distance from a quartz plate coated with a 100 Å thick Cr film, playing the role of a photocathode. The detector was operated at low pressures of 30 and 60 torr inside a vacuum vessel, in a flow mode. The chamber was evacuated down to $10^{-5}$ torr before each introduction of gas. In this study we operated the detector with propane (99.99% purity); following our experience of low-pressure operation of MSGCs, we expect rather similar results with other gases like isobutane, ethane and DME.

The detector, shown in Fig. 1(b), was operated in three different modes. UV-induced photoelectrons emerging from the photocathode could be multiplied in a parallel-plate avalanche mode, when interconnecting the cathodes and dot anodes and keeping a high electric field across the gas gap. Reducing the field in this gap and setting high negative potentials on the MDOT cathodes, the detector was operated under microdot amplification only, in which photoelectrons drift towards the dots where multiplication occurs. Raising the field in the gas volume and adjusting the potentials between cathodes and dots the MDOT detector was operated in a two-stage (combined) mode, shown in Fig. 1(b). In this mode the photoelectrons are preamplified in the gas volume and further multiplied at the dot electrodes, yielding very high gains.

## 3. Experimental results

The detector was investigated with UV-photons, using a Hg(Ar) UV lamp (Oriel type 6035). Pulses were observed directly from the detector anode or through a fast (1 ns rise-time gain 200) amplifier. Gain curves were recorded by measuring DC photocurrent from the dot electrodes as function of potentials applied. Single electron pulse-height spectra were measured using charge amplifiers followed by integrating electronics.

Fig. 2 shows oscilloscope photographs of single electron pulses recorded at 60 torr directly and through fast amplifiers, with the 200 μm pitch geometry. It is a remarkable fact that single electron pulses can be observed, far above noise level, from a detector operating in a proportional mode without electronic amplification. The signals have rise times in the 2–3 ns range.

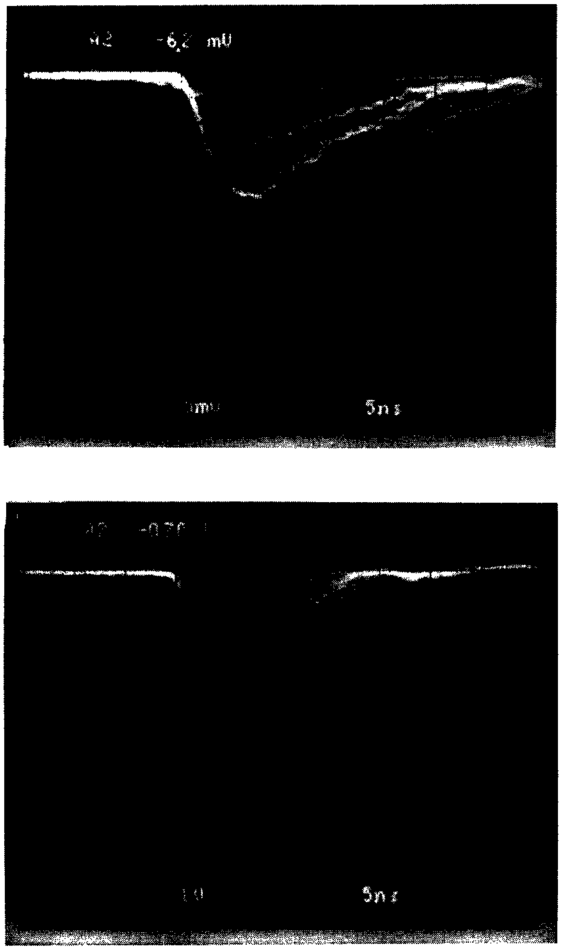

Fig. 2. Photographs of single electron pulses, recorded (*top*) directly from the anodes (a group of 7000 cells of 200 μm pitch) on a 50 Ω impedance, and (*bottom*) after a fast (1 ns rise time) amplifier, at 60 torr $C_3H_8$. The rise time here is ~ 3 ns in both cases. In these measurements $V_{PC}-V_C = -1594$ V; $V_C = -320$ V

Examples of typical single pulses recorded with a fast digitizer in a parallel-plate mode and in the high gain two-stage multiplication mode are shown in Fig. 3. One can make a few important observations. For similar gains, the signal pulse-height in the two-stage MDOT operation mode is about an order of magnitude larger and 2–3 times faster compared to that in the parallel-plate mode and is far above the noise level; the situation would further improve when reading out single or a few interconnected MDOT cells. Most interesting is the pulse shape recorded in the 100 μm cell MDOT geometry; here the narrow width of the pulse, due to the small cell dimension, could have important implications as discussed below.

The amplification curves of the detector are shown in Fig. 4, for three different modes of operation. In Fig. 4(a) the absolute gain of the MDOT electrode is shown. Here the electric field was maintained in such a way that multiplication of electrons, photoproduced at the photocathode, occurs at the vicinity of the dot electrode without amplification in the gas volume. Due to their considerable surface, and their photoemissive properties similar to that of Cr, the MDOT cathodes also act as photocathodes. By varying the electric field conditions, we could correct their contribution to the gain

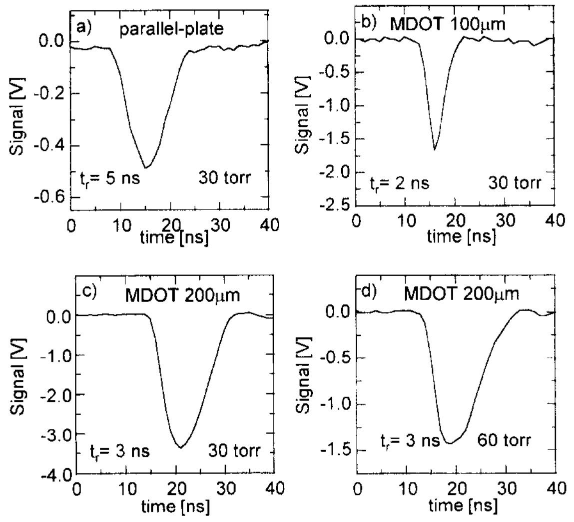

Fig. 3. Characteristic single electron pulses measured with a fast amplifier and recorded on a Tektronix digitizing oscilloscope (model TDS540) at a sampling rate of 1 Gs/s, in various modes of operation. (a) and (c) were both measured under the same gain and show the pulses for single stage parallel-plate and two-stage MDOT amplification modes, respectively, for the 200 μm pitch structure at 30 torr of $C_3H_8$. (b) shows the pulse obtained from the 100 μm pitch structure at 30 torr and (d) shows the pulse obtained from the 200 μm pitch structure at 60 torr.

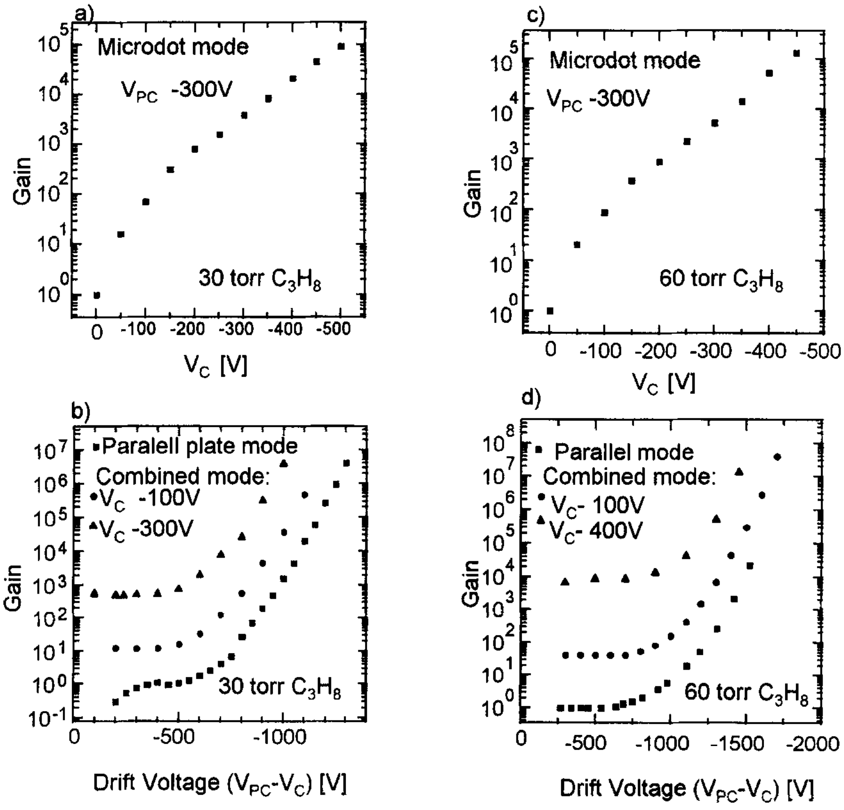

Fig. 4. The amplification curves measured for single electrons in the three operation modes of the detector for the 200 μm pitch structure. (a) and (c) show the gain curve for the Microdot mode for 30 and 60 torr of $C_3H_8$ respectively. (b) and (d) show the parallel-plate and two-stage combined mode amplification curves for 30 and 60 torr. Note that the total gain in the combined mode is just a multiplication of the gain in the parallel mode with the dot gain for the corresponding voltages. Note also, that in (d) we measured the parallel-plate mode curve only up to a gain of $10^5$; this was not due to instabilities and does not reflect any gain limitations.

measurements, which is of the order of 15%. The absolute gain of the MDOT reaches values of the order of $10^4$-$10^5$. Measurements were stopped at $10^5$ where some minor instabilities appeared. Fig. 4(b) shows the amplification curve of the detector operated in a parallel-plate multiplication mode (anode dots and cathodes kept at equal potential) and in a two-stage (combined) mode. Remarkably high gains were measured in the parallel-plate mode, suggesting that despite the equal potentials on anodes and cathodes, some enhanced field at the dot vicinity could have provided some gain increase. This point demands further investigation. The graphs of the two-stage amplification clearly indicate the dependence of the total gain on the microdot gain, namely on the cathode potential. Total gains reaching values of $10^6$–$10^7$ are possible, under stable operation conditions.

Fig. 5 shows the exponential behaviour of the single electron multiplication mechanism, at low and at high amplification conditions. Total average detected charges reach values of about 2 pC.

## 4. Summary

The microdot avalanche chamber, which is a true two-dimensional imaging device, presents very interesting characteristics when operated at low gas pressure in a proportional mode. Very large gas gains, superior to $10^6$ were obtained in an operation mode where single electrons are preamplified across the gas volume and further multiplied at the vicinity of the dot anodes. The gas gain in a mode where multiplication occurs only at the dot vicinity, reaches values close to $10^5$. The current pulses induced by single electron avalanches, on the MDOT anodes are very high. To the best of our knowledge, this is the first time where considerably large single electron pulses can be observed from a detector operating in a proportional mode without electronic amplification. The pulses are fast and narrow, in particular those recorded from a detector having the smaller 100 μm pitch cells; their FWHM reaches values as low as of 5 ns. We found the MDOT detectors to be very robust. We have

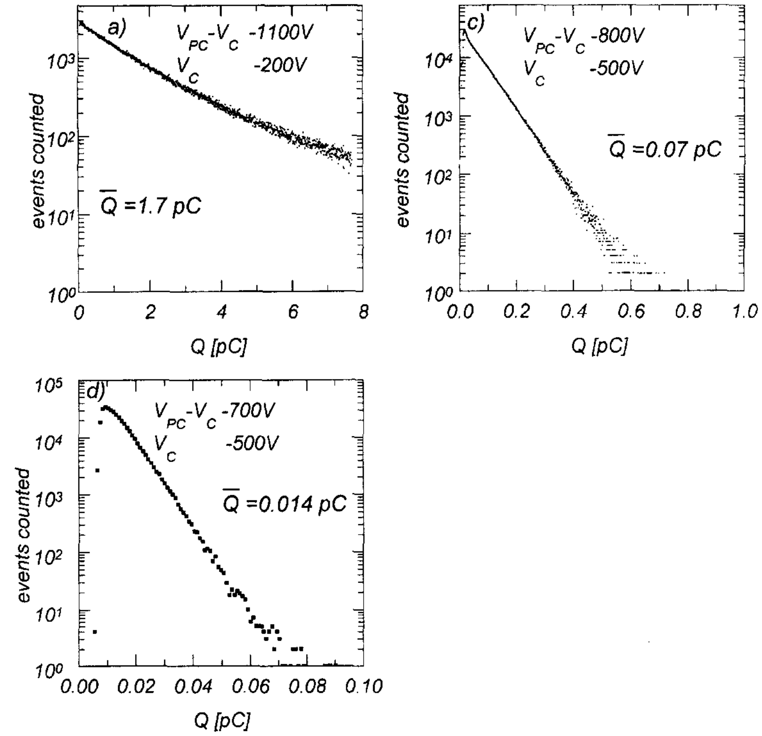

Fig. 5. The measured single photon pulse-height spectra, at 30 torr $C_3H_8$, with the 200 μm pitch structure for various amplifications. The spectra are exponential and non- saturated, for all of the operating voltages. At the highest gain shown here we can see an average charge of ~2 pC.

operated a single detector unit, at high gas gains, for long periods of time in a very stable way.

The interesting characteristics of the low-pressure MDOT detector could lead to numerous applications in radiation detection and imaging. Such devices would have the capability of operating at radiation flux superior to MHz/mm$^2$. They could provide high two-dimensional localization resolution in secondary emission imaging detectors combining solid radiation convertors and gaseous electron multipliers; such devices are currently being developed for imaging of UV and visible photons, X-rays and thermal neutrons [14]. The convertor could also be a gaseous or a solid scintillator. In the latter case, the scintillator could be coated with a photocathode, in contact with the gas. Photocathodes sensitive to visible light that can withstand operation under gas multiplication, are under intensive development [17–19].

The fast nature of the MDOT pulses and the high gain demonstrated in this work, suggest the use of such devices in detectors based on electron counting. In such detectors the information on the energy deposited by incident radiation is accurately derived from counting the number of the radiation-induced primary electrons [20]. In this case, the MDOT would enhance the electron counting efficiency of the technique, presently employed for basic ionization studies [21] and ultrasoft X-ray spectroscopy [22]. It will permit the measurement of larger deposited energy quanta, presently limited by pulse overlapping.

Finally, the high gain and fast timing properties of low-pressure MDOT detectors could suggest their use for localization and time-of-light measurements of heavy and light nuclei. With appropriate convertors, e.g., porous CsI [23–25] Cs-treated CVD diamond [26] or other highly emissive materials, one could expect time resolutions in the 100 ps range or below, also for relativistic particles.

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