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Nuclear Instruments and Methods in Physics Research A 361 (1995) 72–76

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

The microdot gas avalanche chamber: an investigation of new geometries

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Received 31 October 1994; revised form received 26 January 1995

Abstract

The gains of the microstrip and microgap gas avalanche chambers are limited to below gains of 5×10^3 by geometrical and gas properties. In order to increase the maximum gain to greater than 2×10^4 a new detector geometry, the microdot, is proposed that can be produced at a standard silicon MOS microfabrication facility at similar cost to present microstrip gas detectors. In addition to charged particle tracking, the new geometry is also well suited to imaging applications. The operating characteristics of the new device have been investigated using a numerical simulation and a comparison with conventional strip geometries is presented. These results show that the microdot geometry reaches higher gas gains than the strip-like geometries, for the same set of electrode potentials, with a reduced cathode electric field enhancing operational stability.

1. Introduction

Experiments at the LHC require detectors that can tolerate high rate and have low occupancy. Microstrip [1], MSGC, and microgap [2], MGAP, gas avalanche chambers can meet some of these requirements at low gas gain. However, these chambers are generally limited to avalanche gains of $< 5 \times 10^3$ by the onset of breakdown. Breakdown is observed at the ends of the anodes and cathodes, where the electric fields are much higher than in the main part of the detector. Normally, MSGCs are operated with some form of passivation technique (coating, electrode shape, extra electrodes) to inhibit breakdown at the electrode ends. However, such techniques do not alter the electric fields in the main part of the chamber, where the gain limitation is defined by the onset of cathode glow discharge. This gives rise to high currents and erosion of both the anode and cathode surface metalisation.

In this paper we propose a development of the MSGC, the microdot chamber, MDOT, and through numerical simulation, demonstrate that the new geometry offers several advantages over the conventional MSGC and MGAP geometries. Possible applications of this new device are also discussed.

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SSDI 0168-9002(95)00140-9

2. Microdot chamber geometry

Fig. 1a shows a single cell of a planar microdot geometry viewed in cross section through the substrate. The cell is rotationally symmetric about the anode axis and is formed from an anode of 20 μm diameter and a 40 μm wide cathode "ring" starting at a radius of 85 μm. The surface of the insulating substrate is doped to higher conductivity than the bulk oxide by ion implantation or phosphate glass deposition. The currents flowing in this higher conductivity surface layer control the field gradients in the chamber and reduce charge-up effects on the surface due to the deposition of electrons and positive ions from the avalanche. There are some obvious similarities between the rotational symmetry of this geometry and that of the pixel chamber [3,4]. However the microdot geometry defined here is a factor of 100 smaller in surface area than the pixel chamber and the doped surface leads to a better electric field configuration.

The microdot chamber substrate is patterned with cells using either a square or hexagonal close packed lattice. The cells can be read out either individually as pixels or as "strings". The strings are created by interconnecting the anodes of the cells using a buried metal bus. The strings can be in any topology: linear, circular or pads depending on the application.

The 125 μm radius cells can be placed on a 200 μm pitch linear bussed readout using hexagonal close packing.

The hexagonal close packing is preferred as it reduces the effect of low drift field regions, as can be found in a square lattice structure and is the type used in the following simulations. Another advantage is that it reduces the number of tracks firing a single bus strip and hence improves the spatial resolution when using analogue or digital interpolation between hit strips.

Fig. 1b shows an alternative non-planar microdot cell with the possibility of having the anodes and cathodes at different heights. This structure also requires that the top surface of the inter-metal oxide should be doped in order to provide a low cathode field. This structure is probably better suited to higher cell density at under 50 μm pitch.

In order to build the detectors only three mask steps are required. The first mask is used to pattern the anode readout bus structure (metal 1). The second mask is used to produce the via holes in the SiO_2 and the third to pattern the top metal surface (metal 2) with the anode and cathode structures. All masks have large feature sizes compared to standard MOS processing and because of the relatively simple nature of the processing a fully functional yield of > 99% of the area of a wafer scale detector can be anticipated. In the case of a pixel readout scheme, only the top two masks are required since the MOS pixel amplifier [5] already has readout pads that can be used for the anode connection.

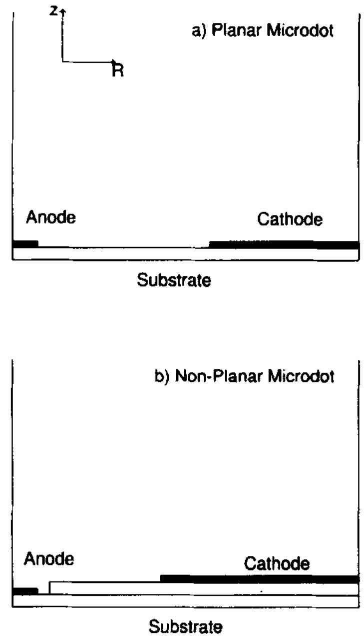

Fig. 1. Schematic of planar and non-planar microdot electrode geometries.

3. Comparison of MSGC, MGAP and MDOT geometries

3.1. General observations

For operation at high gas gains the MSGC requires that the electric field at the ends of the anode and cathode strips is reduced to avoid breakdown problems. This can be achieved by careful shaping of the electrodes and/or the application of a passivation layer of a suitable material. Both the above methods result in a reduction of the sensitive area and can also lead to a reduction in efficiency near the electrode ends. The MDOT geometry does not suffer from this problem since the cell is intrinsically circular and hence the full area of the substrate is active.

The buried nature of the anode bus limits the damage from spark breakdown to a single cell, leaving the remaining cells on the same bus intact. In the case of the MSGC or MGAP, a single spark can result in the creation of a break in the anode thus reducing the active area. A comparison of the MDOT and strip-like geometries shows that the loss in active area resulting from such damage in the MDOT is 0.3% that of the corresponding MSGC (or MGAP) for a 6 cm long detector.

In the bussed microdot detector both ends of the anode bus are available for wire bonding to charge sensitive microelectronic readout chips. This allows the possibility of obtaining a measure of the hit location along the anodes via charge division. Hence the bussed MDOT chamber can also give two dimensional information. Furthermore, problems associated with different voltage levels of pad and strip readout in the two dimensional MSGC and MGAP detectors are avoided.

The availability of cathode and anode bond pads at all edges of the detector also allows substrates to be butt-joined with cathode and anode connections being made by wire bonding. Hence a large area detector element can be made by tiling together several smaller (and cheaper) detectors.

3.2. Simulation procedure

The electric field in the MDOT chamber cell has been simulated and compared to those in the MSGC and MGAP chambers in order to characterise the performance of the new design in terms of gas gain for a given anode–cathode potential difference. As noted in [3,4] the electric potential near the dot or pixel falls off as $1/r$ whereas the field in the MSGC falls off like a wire as $\log(r/R)$. This statement is only approximately true if the electrodes are on an insulating substrate. However, if the substrate has a non-zero conductivity it tends to act as a potential divider across the gap between anode and cathode.

In the case of the MSGC there is a mis-match between the field driven by the electrode geometry and that of the linear potential divider. In the case of the MDOT geometry the field from the electrode geometry and that from the quadratic potential divider are better matched resulting in a tendency for fewer field lines to cross the gas–substrate

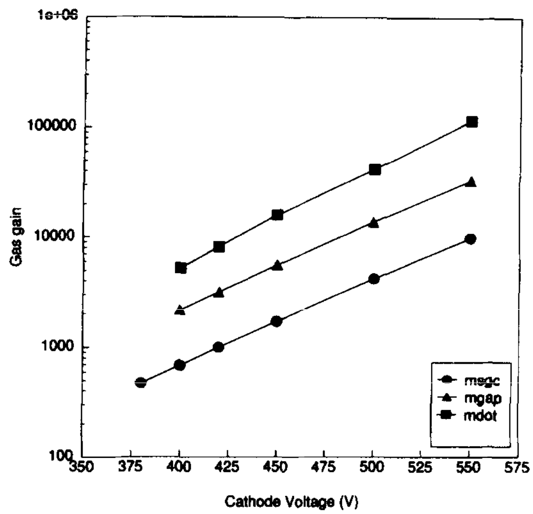

Fig. 2. Avalanche gain from drift region as a function of surface cathode voltage.

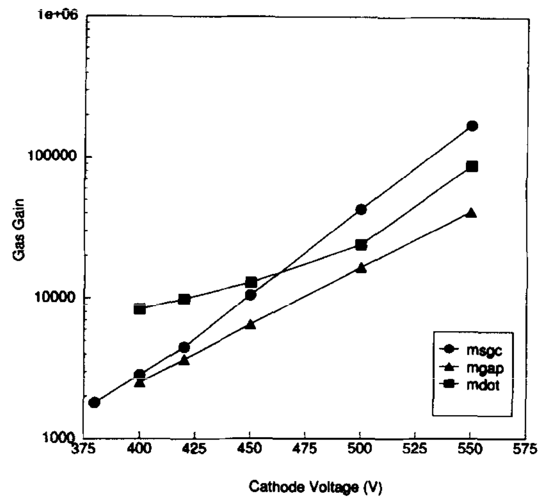

Fig. 3. Avalanche gain from near surface cathode as a function of surface cathode voltage.

interface. Hence we expect the electrostatic instabilities due the accumulation of electrons or ions on the substrate surface to be reduced compared to that normally associated with MSGCs.

The electric field for the different chamber geometries has been computed using the MAXWELL finite element analysis package [6] capable of solving both electrostatic and DC conduction problems in either x–y or R–z coordinate systems. The models consist of single cells containing the substrate and anode, cathode, back plane and drift electrodes. The substrate is subdivided into a thin conductive layer and a thicker, less conductive, bulk layer. In all cases the gas gap is 3 mm and the drift plane voltage is set to -2 kV. For each configuration the cell size corresponds to that of a readout pitch of 200 μm. The field map created by MAXWELL was used as input to the MSGC-SIM computer code [7]. This code simulates the response of the different detector structures to photo-electrons, X-rays and minimum ionizing particles.

4. Results of simulation

Fig. 2 shows the calculated gain for ionisations occurring in the drift region as a function of cathode voltage for an 80:20 Ar/DME gas mixture at atmospheric pressure. The figure clearly shows that the gas gain from the MDOT chamber is at least 10 times that from the MSGC, for the same cathode voltage, and three times greater than that of the MGAP detector.

This increase of gain is of no consequence unless it can be achieved without reducing the stability of the chamber to spark breakdown. At high gas gain the main source of breakdown is the large electric field in the vicinity of the cathode edge leading to cathode glow discharge which develops into streamer breakdown. Fig. 3 shows the avalanche gain for ionisations occurring in the region close to the surface cathode as a function of the cathode voltage. The behaviour of the gain in the MSGC shown in Fig. 2 and 3 clearly demonstrates the origin of the gain limitation in this type of chamber. At a gain of 1000 from the drift region, ($V_c = 420$ V), which is a relatively safe operating point, the gain from the cathode region is already 5×10^3. At a gain of 4×10^3 from the drift region ($V_c = 500$ V) the gain from the cathode increases to 4×10^4 due to the creation of a high gain region above the cathode.

Fig. 4 shows the maximum cathode electric field strength for the three chamber geometries. The locations of

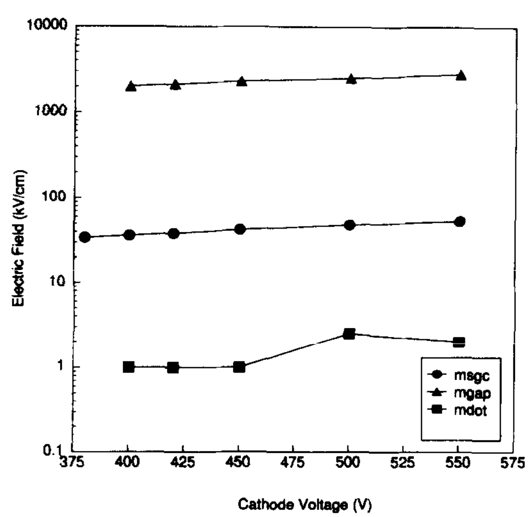

Fig. 4. Maximum surface cathode electric field strength as a function of surface cathode voltage.

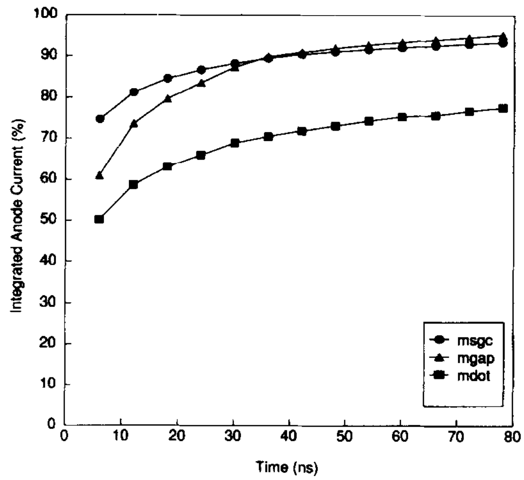

Fig. 5. Integrated anode current as a function of time for pulses originating from ionisation in the drift region.

the maximum field correspond to the cathode edge in the MSGC and MDOT and the oxide–cathode edge in the case of the MGAP. The cathode field at the safe MSGC operating point ($V_c = 420$ V) is typically 30 kV cm^{-1}. However, at an applied voltage of 500 V the cathode field increases to 60 kV cm^{-1} which exceeds the ionisation threshold for this gas mixture. In the MGAP chamber the close proximity of the surface cathode to the anode limits the integral of the Townsend coefficient along the short drift path allowing the large cathode field of 2,000 kV cm^{-1} to be sustained. The operational limit for the MGAP comes from UV photon emission in the avalanche. These photons can easily reach the cathode removing electrons and thus limiting the gain to $\sim 5 \times 10^3$. As shown in Figs. 2 and 3, only the MDOT simulation predicts a cathode gain less than or equal to that from the drift region. The reason for this is that the MDOT cathode field is typically less than ~ 2 kV cm^{-1}, see Fig. 4, well below ionisation thresholds, except in the small regions above the anode readout bus where it may be 10% greater than at other points on the cathode edge.

For a 200 μm readout pitch, the anode–cathode gap in the MDOT geometry is 85 μm which can be compared to 60 μm for the MSGC. This larger gap should allow a proportionally larger cathode voltage to be applied. The choice of $V_c = 500$ V should offer a very safe operating point with a gas gain of 4×10^4 compared to the MSGC (~ 1000 at $V_c = 420$ V).

The integrated current pulses induced by the electron and ion motions on the anode are shown in Fig. 5 for pulses caused by ionisations in the drift region. Similarly Fig. 6 shows integrated current pulses for ionisations near the adjacent cathode. The anode signal development in the MDOT is slower than both the MSGC and MGAP although this is not significant for practical purposes.

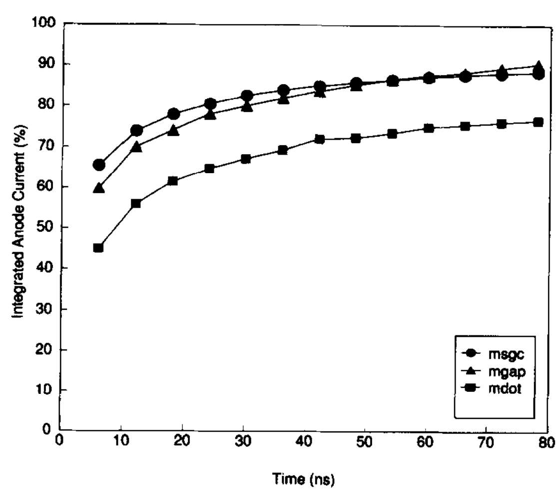

Fig. 6. Integrated anode current as a function of time for pulses originating from ionisation near the surface cathode.

5. Possible applications

The enhanced gas gain and reduced cathode field of the MDOT offer the possibility of stable operation at gas gains of $> 10^4$. If such gas gains can be achieved in practice the signal from single-electron avalanches would be sufficient to define a hit. This would enable the drift gap to be reduced to ~ 1 mm, equivalent to < 20 ns maximum drift time, allowing single-bunch tagging at LHC whilst retaining full hit efficiency.

The operation of MSGCs at low pressure with photosensitive drift cathodes has already been demonstrated [8]. The combination of this type of operation with an integrated MDOT pixel-type readout would allow an imaging device of unmatched time and space resolution to be developed. Preliminary studies of single electron avalanches induced by photons incident on a photosensitive drift cathode at low pressure have been performed. The results indicate that a detector with MDOT cells of 125 μm outer radius would have a time resolution of a few ns and a spatial resolution of 20 to 30 μm with a two photon separation of 500 μm. Applications of such a device include miniature RICH counters and pulsar imaging.

6. Conclusions

A new geometry, the microdot chamber, has been proposed and investigated by numerical simulation. A comparison of the electric field in the MSGC, MGAP and MDOT geometries shows that the new chamber offers enhanced gas gains with added operational safety margins due to a reduction in the field at the side cathodes over the conventional strip geometries. The electrode geometry of the MDOT offers several advantages over the MSGC and MGAP in terms of breakdown resistance, readout topology and the possibility of second coordinate readout via charge division as opposed to capacitive pickup. Furthermore, the integration of CMOS pixel amplifiers with the MDOT geometry during fabrication would allow the development of high performance imaging devices without the interconnect problems inherent in silicon-based devices.

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