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Nuclear Instruments and Methods in Physics Research A 419 (1998) 438–443

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Experimental results from a microdot detector overcoated with a semiconducting layer

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Abstract

A Microdot (MDOT) detector has been overcoated with a boron-doped amorphous silicon carbide semiconductive layer. The stable operation of the device in mixtures of argon, neon and helium with di-methyl ether (DME) at high gains and at high counting rates is shown. Radiation damage tests give a lifetime of over 120 mC/cm using a gas system with plastic gas pipes. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

Previously published results [1] from improved designs of microdot detectors, showed that it was possible to operate 100 μm pitch readout structures at high rates without substrate charging effects. This was achieved by using a standard boron ion implantation of the detector substrate to increase the surface insulator conductivity. However, 200 μm pitch structures displayed considerable charging effects because the increased anode cathode gap reduced the surface conduction below safe levels. Ion implantation using boron ions could typically achieve conductivity's of only 10^{15} Ω/square. A coating previously developed at the Lawrence Berkeley Laboratory [2] of boron-doped amorphous silicon carbide was applied to some of the detectors from Liverpool. The conductivity of the overcoating was about 10^{13} Ω/square and served also to make the detector operation independent of the backplane voltage.

Results are presented for the operation of the overcoated detectors in terms of gain as a function of applied voltage in binary mixtures of DME with various noble gases. The breakdown limit has also been measured in some of these gases and radiation damage tests have also been carried out. Accurate simulation of the results requires a field-dependent conductivity in the overcoating layer.

2. Results

The absolute gain of the detector was determined by two methods:

(1) the calibration of the electronics chain by the injection of a pulse of known amplitude, to the

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0168-9002/98/$19.00
PII: S0168-9002(98)00818-3

input calibration capacitor of an Ortec 142AH preamplifier and

(2) by monitoring the chamber current, performed using a Keithley 237 source measure unit (SMU) and the X-ray rate.

The agreement of the two methods, within the systematic error of 10%, gives confidence in this procedure. The presented results are obtained from the signal of 14 strings of anodes for the 200 μm pitch structures, and 22 strings of anodes for the 100 μm pitch structures, each of length 6 cm which are connected together and input to the preamplifier.

3. Gain measurements

Measurements were made of the gain as a function of surface cathode voltage for fixed drift voltages in binary mixtures of DME with the noble gases argon, neon and helium and are shown in Figs. 1–3 for 200 μm and Figs. 4–6 for 100 μm pitch detectors, respectively. The exact calibration of the gas mixing was assured by calibration of the gas mixer with a mercury sealed volume displacement meter to a precision of 1% in the mixing ratio. In order to obtain the gain, the number of initial electrons released in binary mixtures from ^{55}Fe X-rays is required. The number of electrons was calculated from electron molecule cross-sections and allowance was made for Penning effects [3]. The results of the calculations are shown in Table 1. The table shows that there is only a small

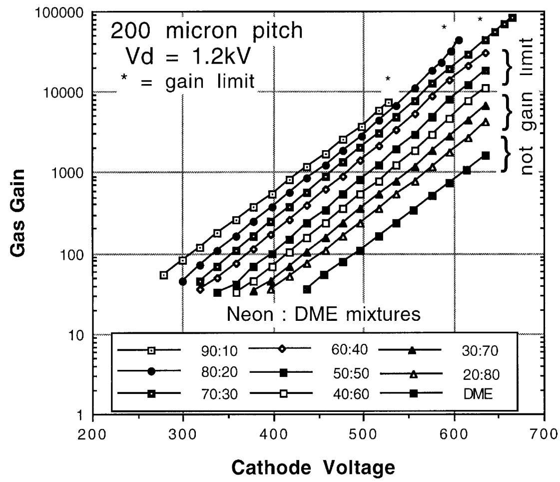

Fig. 2. Gain curves for 200 μm pitch overcoated microdot detector in Ne : DME mixtures.

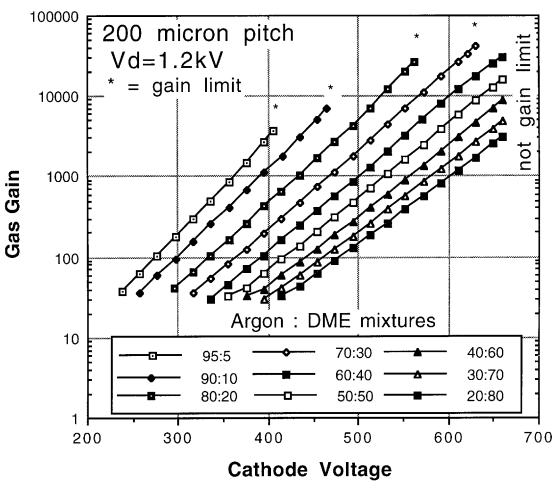

Fig. 1. Gain curves for 200 μm pitch overcoated microdot detector in Ar : DME mixtures.

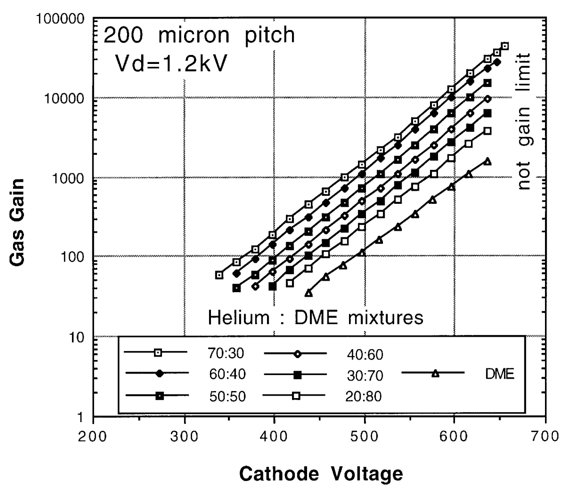

Fig. 3. Gain curves for 200 μm pitch overcoated microdot detector in He : DME mixtures.

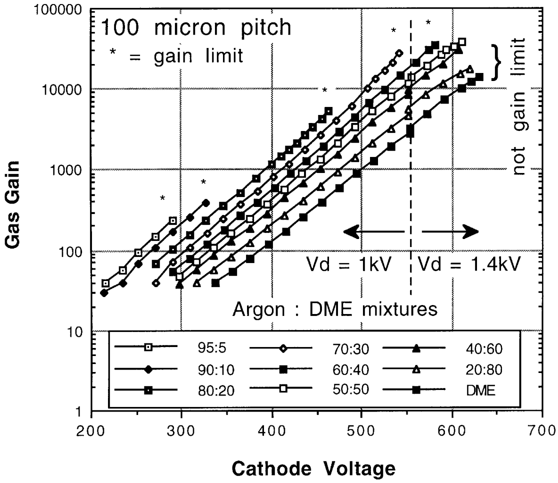

Fig. 4. Gain curves for 100 μm pitch overcoated microdot detector in Ar : DME mixtures.

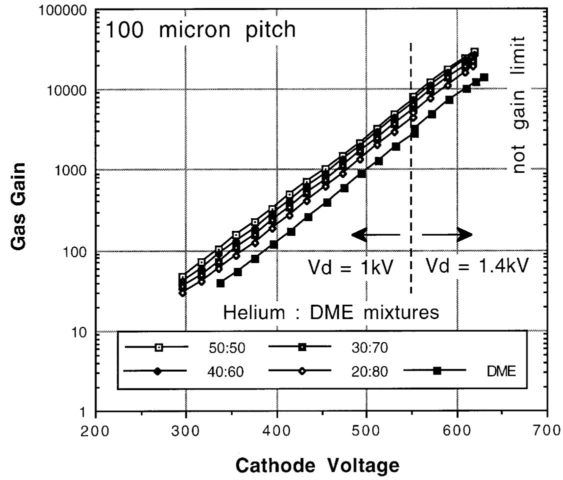

Fig. 6. Gain curves for 100 μm pitch overcoated microdot detector in He :DME mixtures.

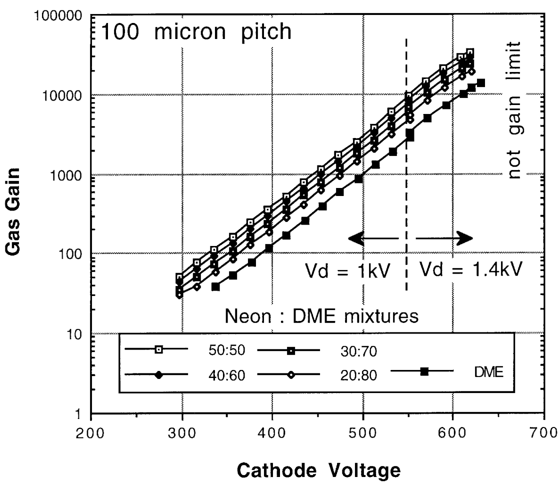

Fig. 5. Gain curves for 100 μm pitch overcoated microdot detector in Ne : DME mixtures.

Table 1
Calculated *W* and Fano factors for ^{55}Fe X-rays

Gas mixture	50:50	80:20	90:10
Ar:DME No. of electrons	247	249	251
Ar:DME Fano factors	0.244	0.202	0.177
Ne:DME No. of electrons	239	229	221
Ne:DME Fano factor	0.273	0.245	0.215
He:DME No. of electrons	239	226	213
He:DME Fano factor	0.289	0.297	0.294

difference in the number of electrons released for similar quencher fractions in the various noble gas mixtures. It has been conventional practice, unfortunately, to assume that the number of electrons released per unit X-ray energy loss, *W*, in neon mixtures is close to the *W* value of the pure gas. This has led in the past to overestimates of the gain in neon based mixtures by 45%. It is clear from the table that the effective *W* value varies in a small range and is close to the DME value in all cases.

The upper gain limit before discharge, was measured for gas mixtures with below 30% quencher concentrations in a low 6 keV X-ray flux of ~ 20 Hz/mm^2/s, and are shown with asterix in the Figs. 1, 2 and 4. For applications that require higher fluxes of highly ionising particles, such as with alpha particles, the gain limits should be reduced by a factor of 3. In conclusion the safe operation of the 200 μm pitch structures in an accelerator hadron beam should be between gains of 20 000 and 30 000 with a minimum quencher concentration of 30% DME. These safe limits can be compared with the 2000–3000 typically obtained for an MSGC-type structure.

4. Radiation damage

The application of these detectors to high-radiation environments requires that the gain and resolution do not change rapidly with accumulated avalanche charge. The primary source of damage in these detectors is due to surface polymer deposition from chemical reactions in the gas due to radical formation in the avalanches. Because of the low cathode field it is not expected that cathode glow discharge can lead to polymer creation, unlike in an MSGC. However, the more concentrated anode avalanche area may allow radicals to combine more frequently with other radicals and increase the polymer formation. Tests were therefore carried out with the overcoated detector using a high intensity 8 keV X-ray generator to irradiate a 200 μm pitch structure. The gas used was an Ar : DME 80 : 20 gas mixture and was taken from a clean gas supply into a standard CERN gas mixing rack. The connection to the detector, housed in a fibre glass box, was via 25 m of plastic polyurethane tubing. The results in Fig. 7, display the relative gain change with accumulated charge (we present the charge in the conventional manner of charge/distance since the detector is readout in bussed strings and therefore can be approximated to linear structures such as MSGCs) and the fractional resolution (FWHM of the 8 keV X-ray peak). The total charge was accumulated to over 120 mC/cm at a rate of 400 nA/mm^2/s.

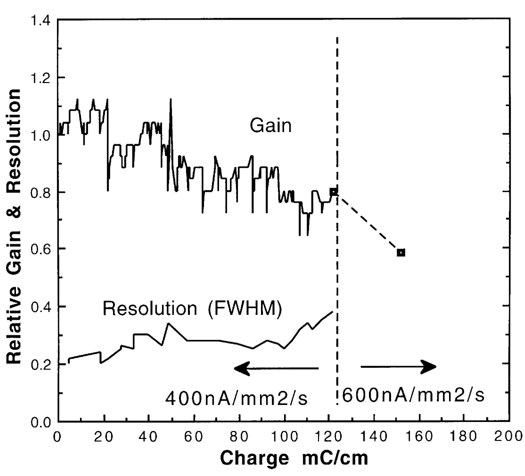

Fig. 7. Ageing curve for overcoated microdot detector.

At this point the gain had decreased to 80% of the initial value and the resolution had degraded to 36% FWHM. During the irradiation the accuracy of the measurement was checked by intermittently scanning the X-ray beam to an undamaged area 6 mm away from the irradiated spot in order to confirm the stability of the detector operation. The detector was then opened up for visual inspection. An OLYMPUS mask inspection microscope was used to search for damage to the surface in the area of the irradiated spot. No damage was observed at the spot to the underlying metal or the overcoating, but a light coloured deposit was observed over a region covering eight cells. The detector was then reassembled with a different drift cathode. The reason for this was that a hole had appeared in the aluminised mylar drift cathode due to ion bombardment. The new cathode was made of a fine mesh of stainless steel. The irradiation was then continued at a higher rate of 600 nA/mm^2/s in order to test a possible threshold effect in damage with intensity. It is clear from the figure that the loss of gain was accelerated at these higher rates and the irradiation was stopped after 160 mC/cm. On opening the detector, damage was observed to the underlying metal in the area of the beam spot due to sparking. This corroborated earlier measurements, which showed some surface damage to the overcoated detectors at these very high charge flow rates.

5. Detector simulation

The detector gain response was simulated using the MAXWELL field simulator [4] and the program MSGCSIM [5], which uses as input, the fields derived from MAXWELL and input gas properties derived from electron gas cross-sections. The gain values are particularly sensitive to the input Townsend coefficients used, and a new program was developed to calculate the Townsend coefficients with a numerical accuracy of better than 1%. The new program used monte carlo integration and the input of the experimental data of Opal et al. [6] on the energy splitting in ionising

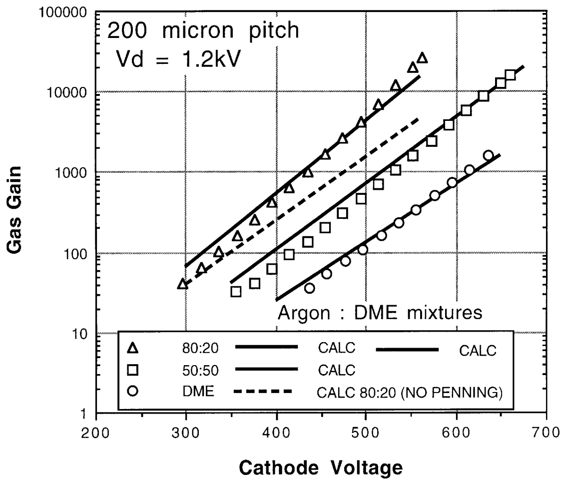

Fig. 8. Experimental and simulated gain curves for various gas mixtures.

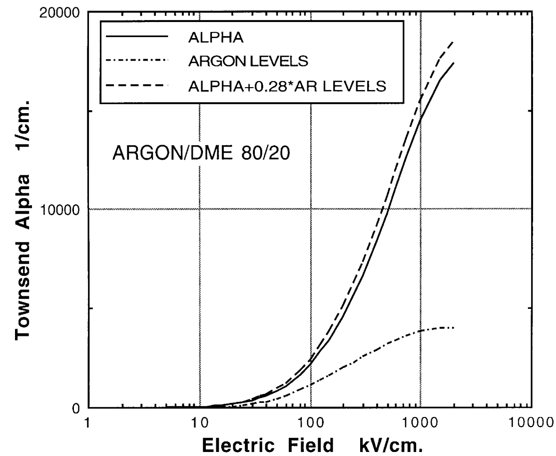

Fig. 9. Townsend coefficient with and without Penning effects in Ar : DME 80 : 20 mixture.

collisions combined with the MAGBOLTZ database electron scattering cross-sections [7]. The slope of the gain curves proved to be very dependent on the Penning effect, especially for the Ar:DME mixtures. Fig. 8 shows the calculated gain with and without the Penning effect for Ar:DME 80:20 and a fit to the slope gives a Penning effect of 28%. The 28% refers to the fraction of the argon excited levels, created in the avalanche, that ionise the DME molecules by energy transfer. The fractional Penning effect, 28%, was kept constant for the calculation in the Ar:DME mixtures 50:50, 80:20 and 90:10. The fits to the experimental gain curves are also shown in Fig. 8. The Penning effect in the neon and helium mixtures has a much-reduced effect compared to the argon mixtures and fits to the gain were only marginally improved by their inclusion in the calculation of the gain in these mixtures. The Townsend coefficients, with and without the Penning effect, in an Ar:DME 80:20 mixture are shown in Fig. 9 by the dashed and solid lines, respectively. Also shown in the figure, with dot-dash line, is the effective total excitation coefficient of the Argon excited states. The calculated Townsend coefficients were also used to model a MSGCs response, and the calculated gain in the MSGC geometry is in good agreement with the CERN measurements [8].

During the modelling of the MDOT detector response, it became clear that to achieve good agreement with experiment for the overcoated detectors, it was necessary to introduce a field dependent conductivity for the silicon carbide film. The net result of this is to increase the conductivity close to the anode spot thus reducing the anode field. The effect in terms of voltage is that for a film that does not have a field dependent term, the voltage steps would fall quadratically with distance from the anode. For the case with a field-dependent conductivity the voltage steps fall off with distance to the power of 1.5. This effect may also occur in MSGCs although here the effect will be smaller because of the almost constant surface electric field (in the case of coated detectors).

6. Conclusions

The overcoated microdot detector has been shown to operate at gains in excess of 20 000 in various noble gas mixtures. Radiation damage tests have shown that these devices are capable of operating to accumulated charges in excess of 100 mC/cm.

Simulation of the detector response has been developed and shows that Penning effects in the avalanche are necessary to describe MSGC and MDOT response. The simulation has also shown that field dependent conductivity changes in the coating material are necessary to describe the MDOT response.

Acknowledgements

We thank J. Kadyk, W.S. Hong and other members of the LBL microstrip group for kindly overcoating the microdot detectors used in this work.

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