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OPERATION OF MICRO-STRIP GAS CHAMBERS MANUFACTURED ON GLASS COATED WITH HIGH RESISTIVITY DIAMOND-LIKE LAYERS

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ABSTRACT

We describe recent observations and measurements realized with micro-strip gas chambers (MSGCs) manufactured on boro-silicate glass coated with a thin layer of diamond-like carbon (DLC) having a surface resistivity around $4\cdot10^{16}\Omega/$❐. The role of the back-plane electrode configuration and potential in the detector performance has been studied. Even for this very high resistivity of the coatings, MSGCs operate differently from those manufactured on bare boro-silicate glass; the charge gain increases with the radiation flux for counting rates above 10^3 Hz/mm^2, reaching a value 60% higher for 10^5 Hz/mm^2. This behavior does not depend on the presence and potential of the back plane electrode; however, both maximum gain and rate capability are influenced by the drift field. From this study, compared with measurements realized previously with other detectors, we deduce that for stable high rate operation of MSGCs the resistivity of the coating should not exceed ~10^{15} $\Omega/$❐.

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1. **INTRODUCTION**

The influence on long-term stability and rate capability of the back-plane electrode on the operation of Microstrip Gas Chambers (MSGCs) manufactured on boro-silicate glass substrates has been reported in previous works [1-5]; it has been observed that when a potential, positive in respect to the anodes, is applied to the back-plane, the charge gain is reduced and rate capability improved.

The present study aims at clarifying the role of the back electrode configuration on the operation characteristics of MSGCs manufactured on glass coated with a high resistivity (~10^{16} Ω/❐) diamond-like carbon (DLC) layer; it is reasonable to expect indeed that the influence of the back-plane on the coated detector, if any, should be enhanced at a higher resistivity of the coating.

2. EXPERIMENTAL SET-UP

The MSGC structure used for the measurements is shown schematically in Fig. 1: a standard geometry has been used, with cathode and anode strips 100 and 7 μm wide, respectively, at a pitch (anode to cathode centers) of 100 μm. The chromium strip structure is engraved[1] with an active area of 100x100 mm^2 on 300 μm thick boro-silicate glass substrate[2] coated with a 50 nm thick DLC layer having an initial resistivity close to 10^{14} Ω/❐[3]. A short review of the coating techniques is given in Ref. [6]. After manufacturing, the plate was baked at 250 °C during 4 hours, following the procedure described in Ref. [7], and resulting in an increase of surface resistivity to $4\cdot10^{16}$ Ω/❐ (measured at a cathode-anode voltage of 500 V).

A rectangular polymer frame, 2 mm wide and 3 mm thick, is glued onto the micro-strip plate, adding on the top a 300 μm glass plate, made conductive on the inner side by vacuum evaporation of gold, and constituting the drift electrode [8]. The chamber is mounted on a thick fiberglass support plate, with openings corresponding to the active area of the detector. For measurements requiring a back-plane electrode, a thin copper foil, glued to a Rohacell support, could be mounted in contact to the outer surface of the micro-strip plate and connected to the power supply.

Cathode strips, in groups of 20, are connected through 500 kΩ resistors to the common high voltage line, and to the (negative) power supply with a 10 MΩ protection resistor; anode strips are read out individually or in groups. A negative voltage is applied to the drift electrode. The detector was operated in a mixture in equal proportions of argon and dimethylether (DME) at atmospheric pressure.

As radiation source for the measurements we have used an X-ray generator with iron target, providing a main fluorescence line at ~6 keV. Three adjacent groups of anodes, 16 strips wide each, were connected: the side groups to ground, and the central to a charge sensitive amplifier followed by readout electronics (ADC, discriminator and scaler). The total avalanche current, corresponding to avalanches on three groups (9.6 mm width), was measured on cathodes and on the drift electrode. The pulse height as well as the counting rate was recorded on

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[1] Produced by IMT Masken und Teilungen AG, Greifensee (Switzerland).

[2] DESAG D-263, produced by Deutsche Spetialglass AG, Grüneplan (Germany).

[3] Produced by SURMET Corp., Burlington, MA (USA).

the central group of anodes. The length of the irradiated area was set to 16 mm by using a diaphragm. The irradiation rate was uniform within 20% on the active area of about 1.6 cm^2. Further details on the set up can be found in Ref. [9].

The detector has been tested in several configurations for the back electrode:

- -3000 V on the back-plane;
- +2500 V on the back-plane;
- grounded back-plane;
- back-plane removed.

Relatively high voltages have been chosen for the back-plane in order to enhance the possible influence of electric field in the glass on detector operation; no breakdown problems in the glass have been encountered for potentials up to 4.5 kV.

3. EXPERIMENTAL RESULTS

3.1 Gain dependence from the back-plane configuration

The MSGC manufactured on DLC coated glass and without back plane exhibits very good stability of operation when exposed to a high radiation flux at moderate gains (~1000), see Fig. 2. We have not observed the initial gain drop at power on, typically occurring on MSGCs made on uncoated D-263 supports, with a time constant of about one hour [5]. This is presumably a consequence of the effective screening by the resistive coating from the polarization properties of the substrate.

It should be noted that specific resistivity of D-263 is about $3\cdot10^{15}$ Ωcm, whereas DLC layer ($4\cdot10^{16}$ $\Omega/\square$ for 500 Å thick layer) has specific resistivity about $2\cdot10^{11}$ Ωcm, significantly lower.

On the detector with back plane present, the measurements show the charge gain is independent from the potential applied to the back electrode. This implies that the thin film of high surface resistivity deposited on the boro-silicate glass substrate effectively screens the field in the gas from the one in the bulk. At high radiation fluxes (10^3 Hz/mm^2) a maximum gain of 10^4 can be reached both for positive and negative potentials on the back electrode (Fig. 3). In absence of radiation, however, the maximum voltage that can be applied to the cathodes is about 40 V higher for a negative than for positive back plane; an intermediate voltage limit is found for grounded back plane.

We have also observed that for a negative back plane voltage the leakage current is stable and increases almost linearly with the cathode voltage, whereas for positive values current spikes are detected even at moderate cathode voltages. These micro-discharges are probably related to the migration of ions in the support [10]; a positive potential applied to the back electrode causes an accumulation of ions in the vicinity of the cathode strips, thus creating high electric field that may provoke electric breakdown across the thin DLC film. A small decrease of surface resistivity (to $2.5\cdot10^{16}$ $\Omega/\square$) after measurements with positive back plane polarity has also been observed, that could be due to migration of ions from the support bulk into the surface layer, a process accelerated by the back plane potential.

3.2 Charge gain and avalanche currents as a function of drift field

The charge gain of the MSGC depends on the drift field strength (Fig. 4), as already known from previous works [11]; for a given cathode potential, the charge gain is about two times higher for a drift voltages of -3 kV (E_D~ 10 kV/cm) than at -1.5 kV. The gain increase at large drift fields is understood to be due to the strengthening of the electric field in the vicinity of the anodes.

Fig. 5 shows the signal currents, independently measured on the cathodes and on the drift electrode, as a function of drift voltage; their ratio corresponds to the fraction of ions reaching the respective electrodes, and the total equals the anodic current and represents the absolute charge gain. For drift fields close to 10 kV/cm, about 75% of ion current flows to the drift electrode. These results are consistent with those obtained for the DLC over-coated detectors [9].

The maximum cathode voltage that can be reached before discharges at high radiation fluxes does not appear to depend on the drift field strength; increasing the drift field allows therefore to achieve higher gains before breakdown.

3.3 Rate capability

The rate capability of the undercoated MSGC has been studied as a function of the back electrode configuration. In all measurements, the potential applied to the drift electrode was -3 kV and the cathode set at -500 V, resulting in a charge gain at low rates of ~1300. The detector response was measured up to rates of $8 \cdot 10^4$ Hz/mm^2.

As shown in Fig. 6, the gain increases with the flux of radiation for all back plane configurations, i.e. negative, positive, grounded or absent; small discrepancies are within the statistical errors at low rates. At 10^5 Hz/mm^2 the charge gain is about 60% higher than at 10^3 Hz/mm^2; a similar behavior was measured previously with MSGCs manufactured on D-263 glass, and over-coated with a DLC layer having a surface resistivity of $2.2 \cdot 10^{16}$ Ω/❐ [7, 9].

A measurement of the rate dependence of gain for various drift voltages reveals that the detailed shape of the gain increase depends on the drift field. In Fig. 7 the rate dependence of gain for grounded back plane is given: for high drift fields, the relative charge gain increases linearly, while for lower fields after an initial increase the charge gain saturates and even decreases above 10^4 Hz/mm^2. A similar behavior has been observed for other back plane configurations.

This behavior is different from the one observed for MSGCs on bare borosilicate glass for which the rate capability depends strongly on the back-plane potential and on the drift field [2, 5]; the gain decreases quickly at a rate of $2 \cdot 10^3$ Hz/mm^2 for low drift fields (~ 1.5 kV/cm), whereas at higher fields (~6 kV/cm) the charge gain increases with rate, reaching a maximum around 10^4 Hz/mm^2 before a rapid decrease.

3.4 Ion current as a function of rate for different back electrode configurations

At fixed drift field, the fraction of ion current flowing to the cathodes increases with the avalanche rate for all configurations of the back electrode (see Fig. 8) and at 10^5 Hz/mm^2 it is about 50% higher than at $6 \cdot 10^2$ Hz/mm^2. Taking into account the increase of gain with the rate (Fig. 6), the avalanche charge towards the cathode strips doubles at high rates. The rate dependence of the current sharing between cathodes and drift electrode suggests dynamic changes of the gas amplification process: the avalanche charge modifies the electric field in the vicinity of the strips, set initially by potentials on the electrodes, affecting the process of charge multiplication.

The present results differ qualitatively from those obtained with uncoated MSGCs made on boro-silicate glass [2]; those measurements show a decrease of the cathode current with avalanche rate in the range from $3\cdot10^2$ to $5\cdot10^4$ Hz/mm^2.

4. DISCUSSION OF THE RESULTS AND CONCLUSIONS

Micro-strip detectors manufactured on boro-silicate supports having a high resistivity DLC surface coating behave quite differently from those made on bare glass. The maximum charge gain that can be reached at radiation rates of 10^3 Hz/mm^2 does not depend on the level and polarity of the potential applied to the back electrode. However, the maximum cathode voltage in absence of radiation depends on the polarity of the potential on the back-plane.

For a positive potential on the back electrode we have observed instabilities of the leakage current, even at low cathode voltages. This effect is probably due to the migration of ions in the support to the vicinity of the DLC layer; there are indications that use of a support with reduced ionic conductivity (e.g. alkali free AF-45 glass) for the coated MSGC is a better choice for long-term stable operation. Surface charging-up was not observed during medium-term irradiation; the detector becomes operational immediately after powering.

The rate dependence of gain is in first approximation insensitive to the configuration of the back electrode for coated MSGC supports; however, the gain increases with rate, by about 60%, between 10^3 and 10^5 Hz/mm^2. The increase is slightly reduced at low drift fields. This may be a serious problem in a high rate environment; the gain has tendency to diverge at higher rates, therefore decreasing the maximum safe cathode voltage. From this point of view chambers made on bare boro-silicate glass, suffering a gain decrease at high rates, would be safer to operate, at the cost of a reduction in efficiency.

For high resistivity coatings, the repartition of avalanche currents to the cathodes and to the drift electrode depends on rate; this tendency is opposite to the one observed for MSGC made on bare boro-silicate substrates. Understanding the correlation between current sharing and rate dependence of gain may help explaining the basic phenomena governing the operation of the detector.

For drift fields close to 10 kV/cm, the majority of ions from the avalanches is collected on the drift electrode; MSGCs operated in these conditions should suffer less from ageing processes, if due to the damage of the electrode surface by ions or to polymerization processes.

For the reasons indicated, the use of coatings with resistivity close to or larger than 10^{16} Ω/❐ is not recommended for MSGCs designed for operation at high rates; it is suggested that the surface resistivity should not exceed ~ 10^{15} Ω/❐ [7,9]).

REFERENCES

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F.D. van den Berg et al, “Gas gain stability of MSGCs on boro-silicate glass”, NIKHEF PREPRINT 95-069.

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[4] J.J. Florent et al, "The electrostatic field in micro-strip chambers and its influence on detector performance", Nucl. Instr. Methods A329 (1993) 125.

[5] R. Bouclier et al, "Development of micro-strip gas chambers for high rate operation" Nucl. Instr. Methods A367 (1995) 168.

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[7] B. Boimska et al, “Progress with diamond over-coated Microstrip Gas Chambers”, CERN-PPE/97- in preparation.

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[9] A. Barr et al, “Diamond over-coated Microstrip Gas Chambers for high rate operation”, CERN-PPE/97-21, presented at 5th International Conference on Advanced Technology and Particle Physics, Como, 7-11 October, 1996.

[10] G. Cicognani et al, “Stability of different microstrip plates on ionic and electronic conducting glass”, Proc. Int. Workshop on Microstrip Gas Chambers, Lyon Nov. 30, 1995, p. 235.

[11] T. Beckers et al, Nucl. Instr. Methods A346 (1994) 95-101.

FIGURE CAPTIONS

Fig. 1: Schematic cross-section of a micro-strip Gas Chamber.
Fig. 2: Medium-term charge gain stability of the MSGC under continuous irradiation.
Fig. 3: Gain as a function of cathode voltage for different potentials on the back-plane; the limits without irradiation for different potentials on the back-plane are marked.
Fig. 4: Charge gain as a function of cathode voltage measured for two values of the drift voltage: -3000 V and -1500 V.
Fig. 5: Cathode, drift and total avalanche currents as a function of the drift potential across the 3 mm gap (no back plane electrode).
Fig. 6: Rate dependence of gain for several configurations of the back plane electrode; drift voltage -3 kV.
Fig. 7: Rate dependence of gain for several values of drift potential (grounded back-plane).
Fig. 8: Current sharing between cathodes and drift electrode as a function of rate for positive and negative back-plane potentials (drift voltage -3 kV).

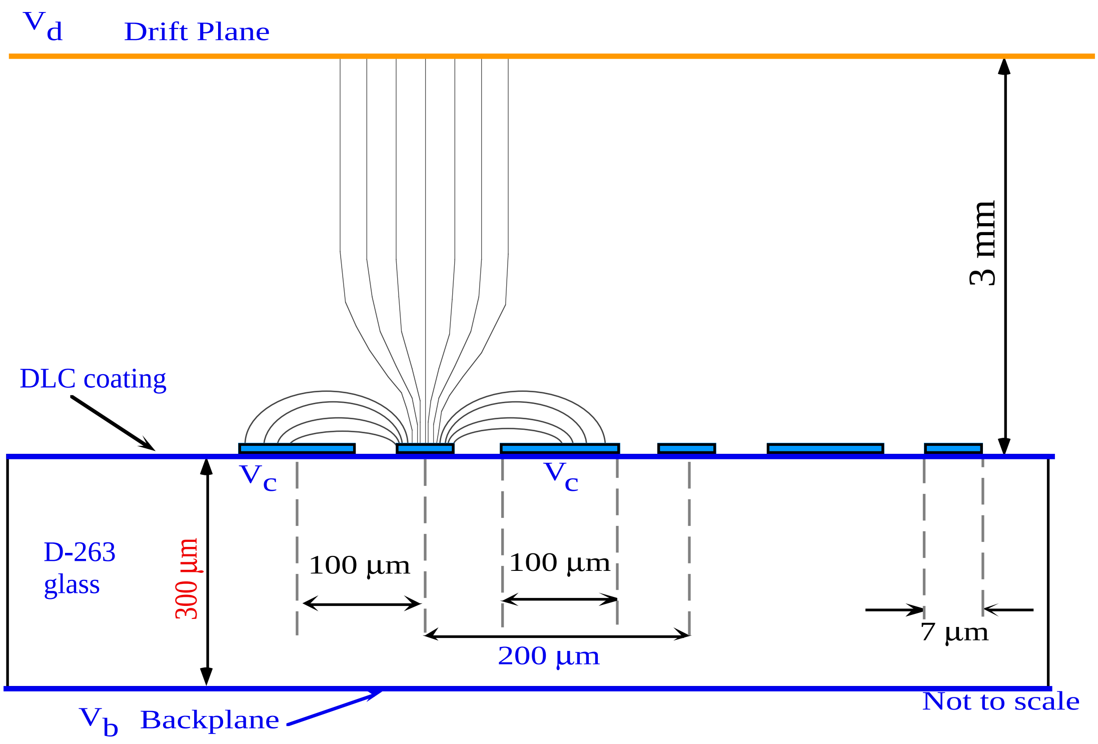

V_d
Drift Plane
3 mm
DLC coating
V_c
V_c
D-263
glass
300 μm
100 μm
100 μm
200 μm
7 μm
V_b Backplane
Not to scale

Fig. 1

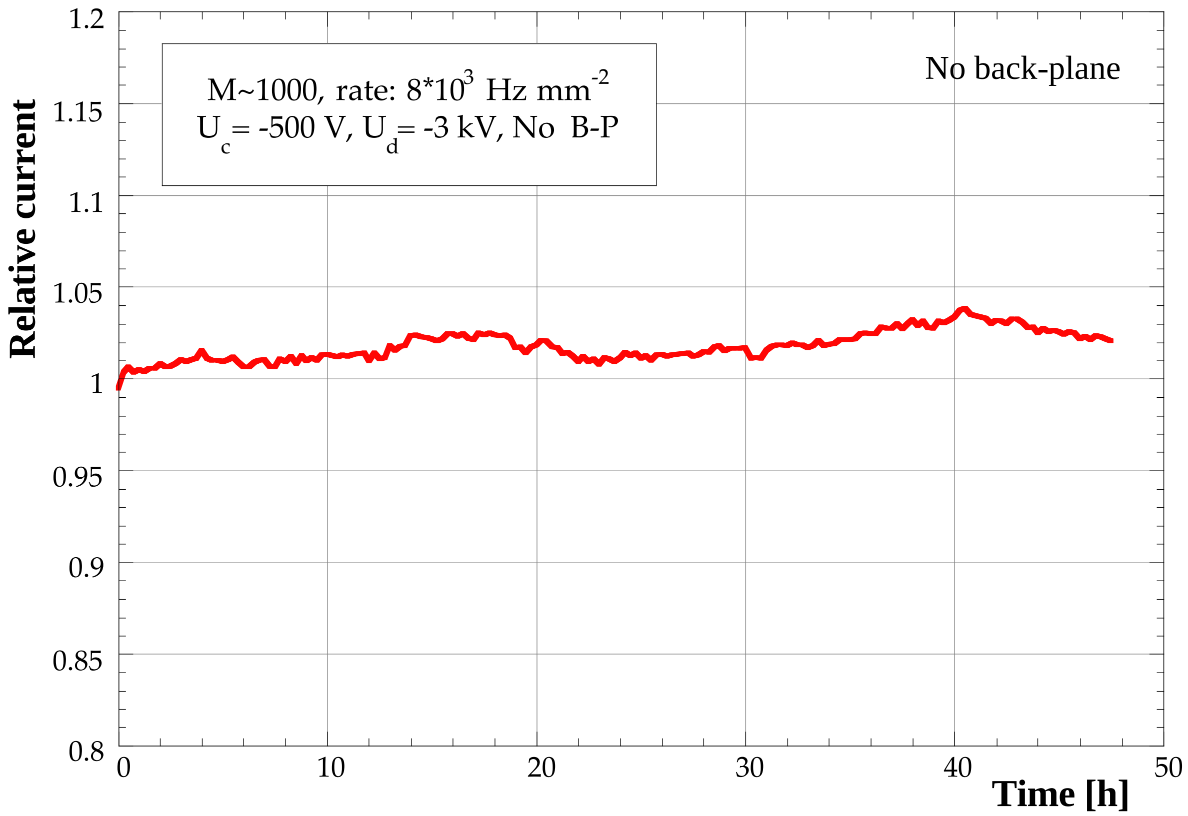

M~1000, rate: 8*10^3 Hz mm^-2
U_c = -500 V, U_d = -3 kV, No B-P
No back-plane
Relative current
Time [h]
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0
10
20
30
40
50

Fig. 2

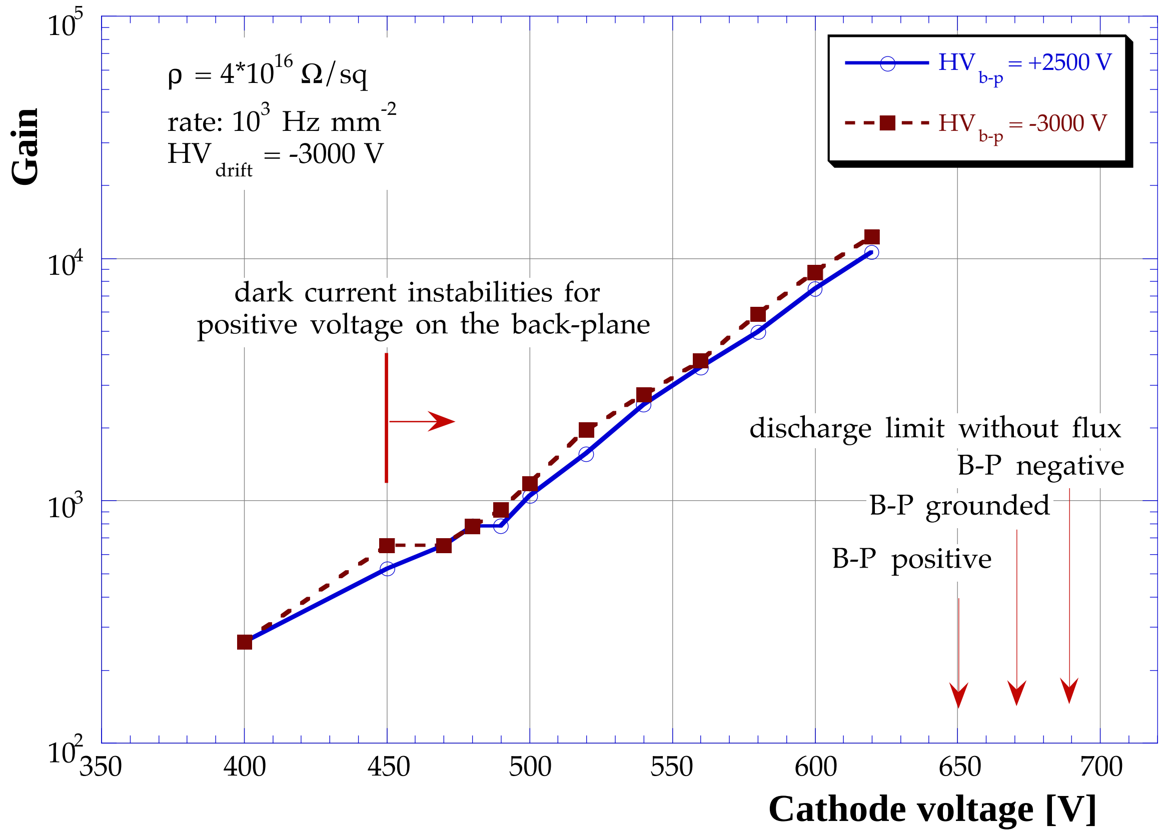

Gain
10^5
10^4
10^3
10^2
350
400
450
500
550
600
650
700
Cathode voltage [V]
$\rho = 4*10^{16}\ \Omega/\mathrm{sq}$
rate: 10^3 Hz mm^{-2}
HV_{drift} = -3000 V
$HV_{b\text{-}p}$ = +2500 V
$HV_{b\text{-}p}$ = -3000 V
dark current instabilities for
positive voltage on the back-plane
discharge limit without flux
B-P negative
B-P grounded
B-P positive

Fig. 3

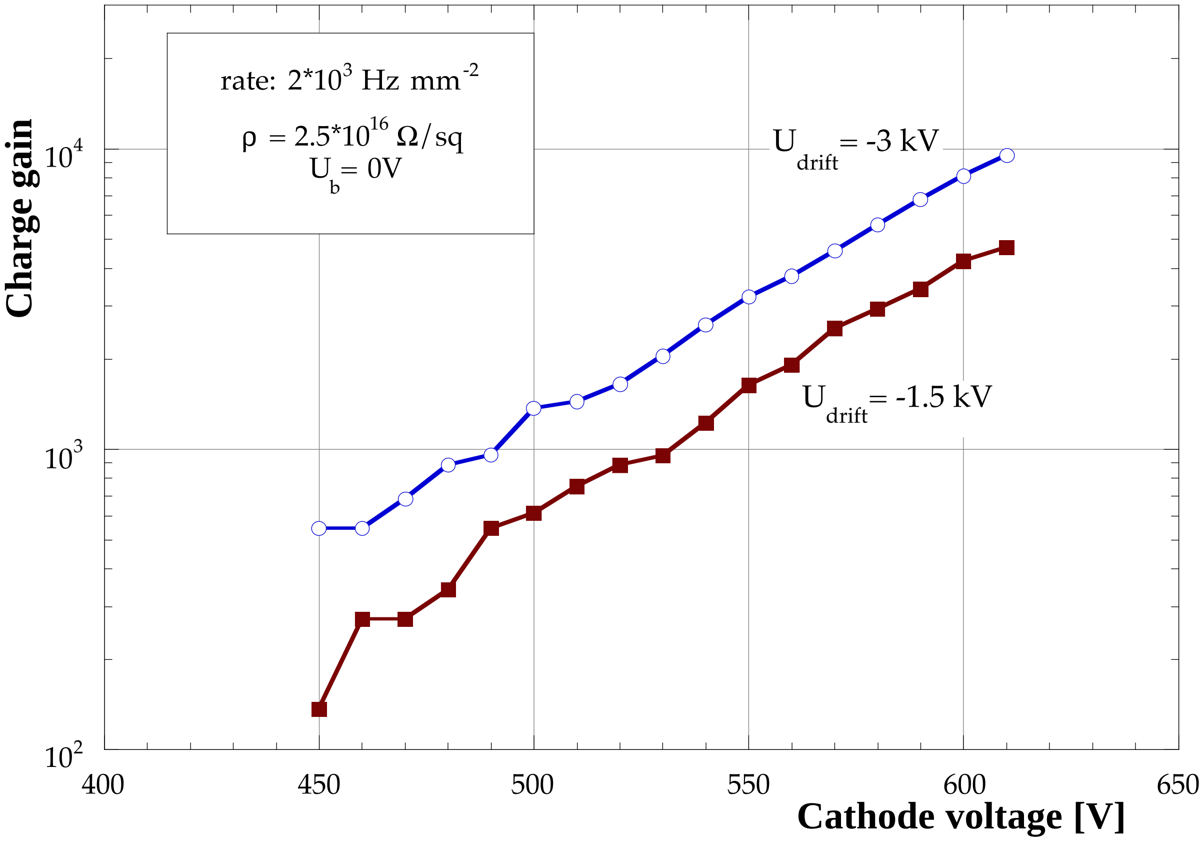
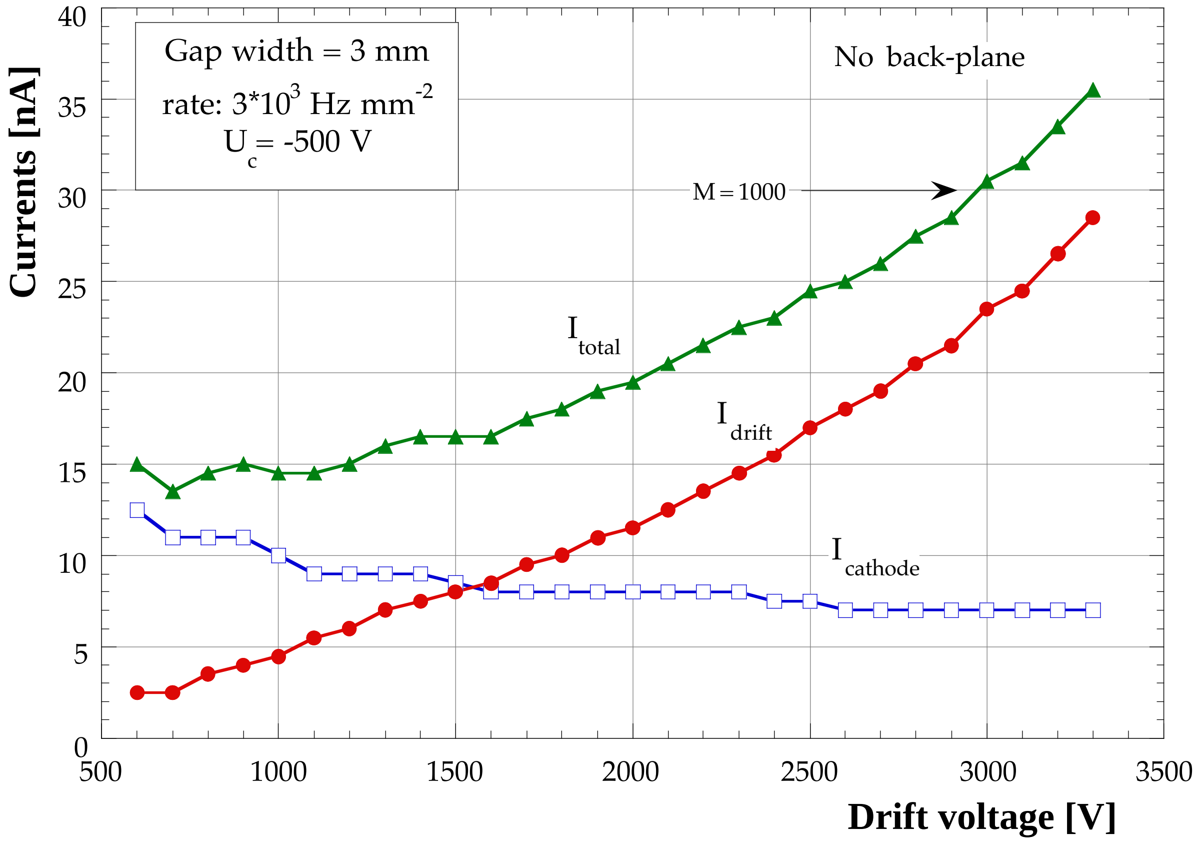
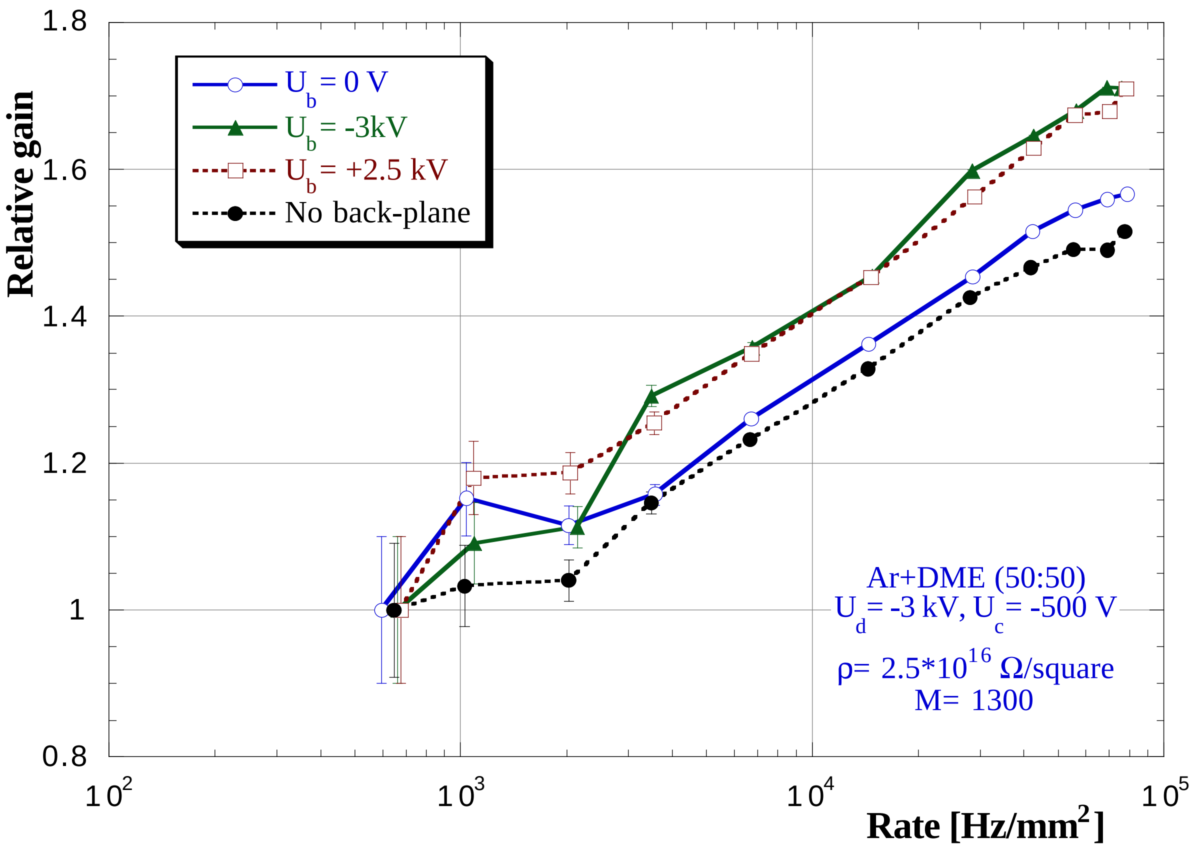

Charge gain
10^4
10^3
10^2
400
450
500
550
600
650
Cathode voltage [V]
rate: $2*10^3$ Hz mm^{-2}
$\rho = 2.5*10^{16}\ \Omega/\mathrm{sq}$
U_b= 0V
U_{drift} = -3 kV
U_{drift} = -1.5 kV

Fig. 4



Gap width = 3 mm
rate: $3*10^3$ Hz mm^{-2}
U_c = -500 V
No back-plane
M = 1000
I_{total}
I_{drift}
$I_{cathode}$
Currents [nA]
Drift voltage [V]
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500

Fig. 5



U_b = 0 V
U_b = -3kV
U_b = +2.5 kV
No back-plane
Ar+DME (50:50)
U_d = -3 kV, U_c = -500 V
ρ= $2.5*10^{16}$ Ω/square
M= 1300
Relative gain
Rate [Hz/mm^2]
0.8
1
1.2
1.4
1.6
1.8
10^2
10^3
10^4
10^5

Fig. 6

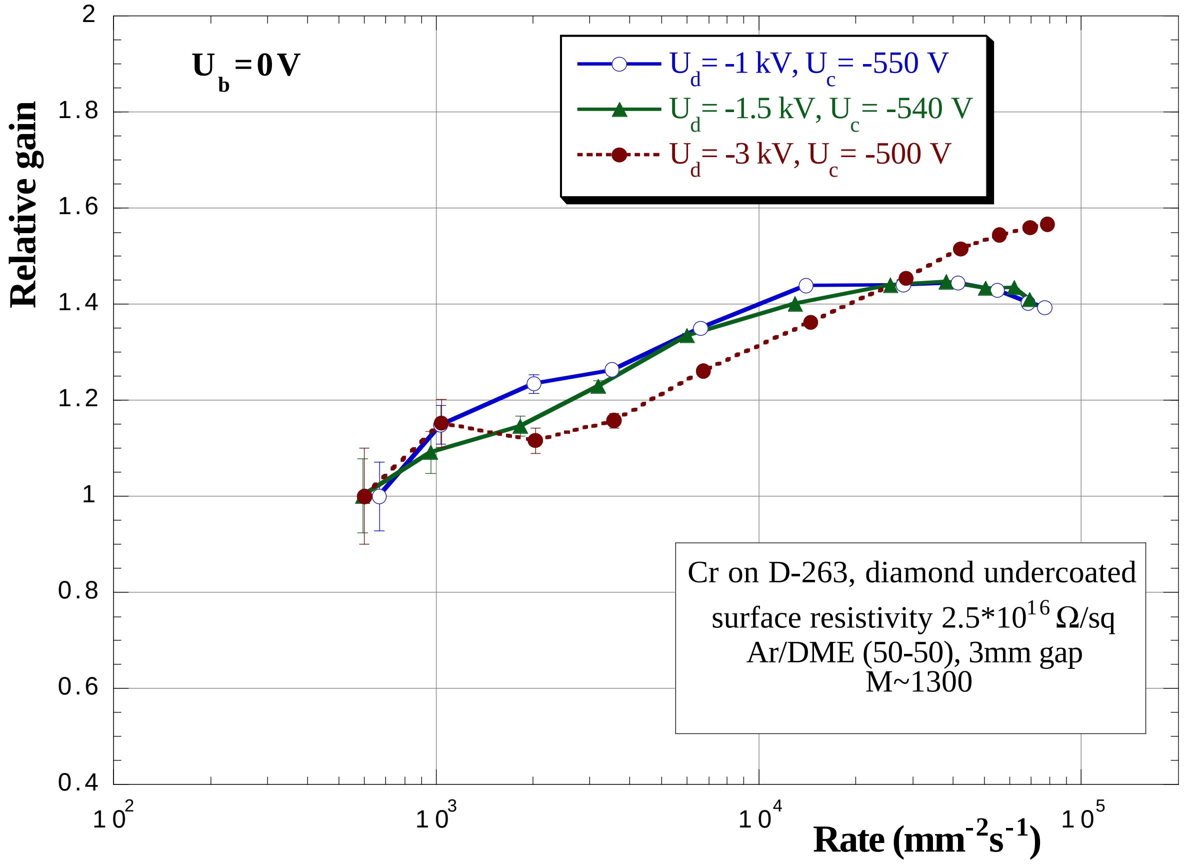

$U_b = 0V$
U_d = -1 kV, U_c = -550 V
U_d = -1.5 kV, U_c = -540 V
U_d = -3 kV, U_c = -500 V
Cr on D-263, diamond undercoated
surface resistivity 2.5*10^{16} Ω/sq
Ar/DME (50-50), 3mm gap
M~1300
Relative gain
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
10^2
10^3
10^4
10^5
Rate ($mm^{-2}s^{-1}$)

Fig. 7

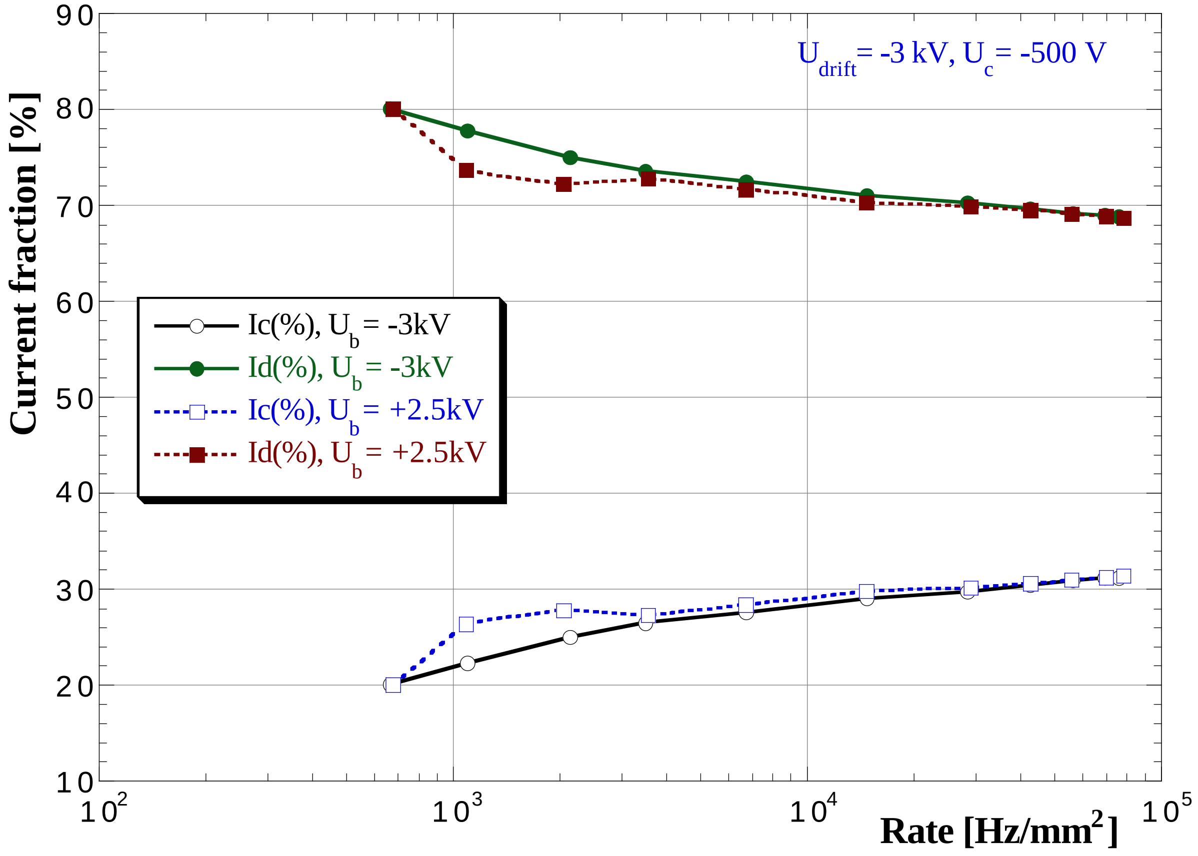

U_{drift} = -3 kV, U_c = -500 V
Ic(%), U_b = -3kV
Id(%), U_b = -3kV
Ic(%), U_b = +2.5kV
Id(%), U_b = +2.5kV
Current fraction [%]
90
80
70
60
50
40
30
20
10
10^2
10^3
10^4
10^5
Rate [Hz/mm^2]

Fig. 8