ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
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INFLUENCE OF THE BULK RESISTIVITY OF CLASS WITH ELECTRONIC CONDUCTIVITY ON THE PERFORMANCE OF MICROSTRIP GAS CHAMBER

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НОВОСИБИРСК

Influence of the Bulk Resistivity of Glass with Electronic Conductivity on the Performance of Microstrip Gas Chamber

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ABSTRACT

The optimization of parameters of Microstrip Gas Chambers (MSGC) on glass substrata with electronic conductivity is presented. It was shown experimentally that a discharge voltage between anode and cathode strips did not change practically with a decrease of anode width from 13 μm to 5 μm, while at the same time the gain maximum increased from 1000 to 4800. The change of a conducting pattern thickness from 0.5 μm to 1.5 μm improved the gain maximum by 30%.

The measurements were made of the rate capability of MSGC depending on the glass resistivity going in the range from $0.9\cdot 10^9\,\Omega\cdot$ cm to $2\cdot 10^{12}\,\Omega\cdot$ cm. At higher resistivity the rate capability was limited by the modification of electric field by current flowing along the resistive surface, and therefore the rate capability increased when decreasing the resistivity of the support. At the glass resistivity of about $10^{11}\,\Omega\cdot$ cm the rate capability came to plateau, which was the result of the influence of space charge in gas on an electric field. The rate capability on the plateau depended on a gas mixture and a chamber gain, and the value of 10^7 Hz/mm^2 was obtained for an Ar+20%CO$_2$ gas mixture and a gain of 400 for 8 keV X-rays.

1. Introduction

Fast progress in the development of Microstrip Gas Chambers (MSGC) has shown clearly very promising features of this device intrinsically capable of overcoming some limitations of existing wire chambers, particularly limited spatial resolution and rate capability. Significant improvements in these areas could be made through a dramatic reduction of the spacing of amplifying electrodes in a gas chamber. This is done with the help of precise microelectronic technology, photolithography or electron-beam lithography by producing a metal strip structure on top of the insulating substrata (Fig.1).

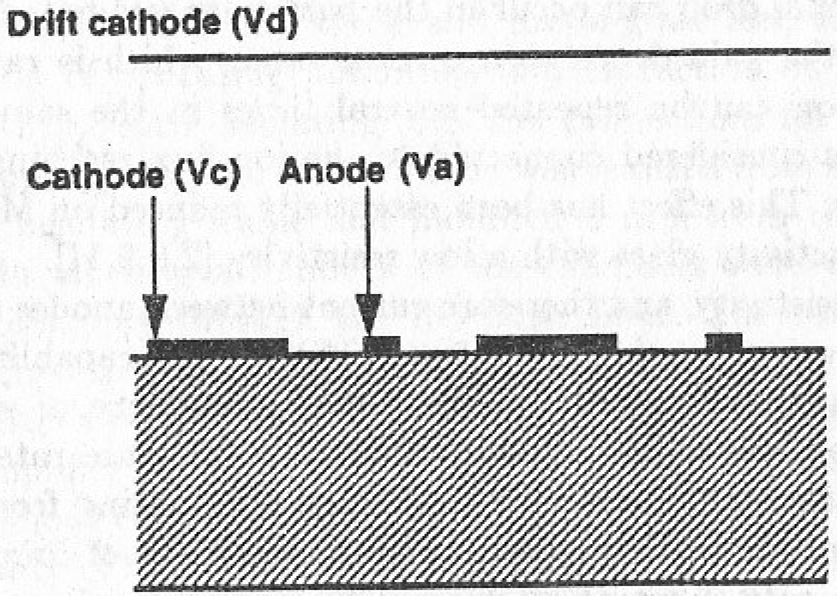

Fig.1

Cross-section of a Microstrip Gas Chamber.

The results reported by various groups are very encouraging. A position accuracy obtained for minimum ionizing particles is $\sim 30\ \mu m$ [1], which is much better than in drift chambers and already close to that of silicon microstrip detectors. A rate capability up to $\sim 10^6$ Hz/mm^2 [2] is better than in any other type of proportional gas chambers. An energy resolution of 11% for Fe^{55} X-rays has been achieved [3] at a proportional gain up to 10^4. These properties make MSGC very attractive as intermediate tracking device in the detectors for the LHC and the SSC [4–7].

However, recent observations have shown certain kind of instabilities in the performance of MSGC. The chambers produced on relatively high resistive supports, such as Hoya SL or Tampax glass [2,8,9], and different plastic foils [2,10] showed modifications of gain in measurements at relatively moderate or high fluxes. More systematic study of these phenomena [2,9] shows that they can be divided into short-term reproducible changes of gain and long-term modifications, which, as a rule, lead to a non-reversible changes of signals in the irradiated region. This degradation of gain is often accompanied by a visible change of microstrip structure, which appears as a deposit and/or damage to strips.

Short-term effects, which look like a relatively fast (seconds or minutes) drop of gain after the beginning of the measurements, can be divided in turn into global and local phenomena [9,10]. After turning on high voltage the gain can drop all over the chamber independently of the irradiation rate. This drop is usually measured by a short probing of the signal by low irradiation rate. An additional drop can occur in the particular irradiated spot. During the irradiation the gain drops to a certain value, which is rate dependent. This phenomenon can be repeated several times in the same or different regions and it is considered connected to the ion flux reaching the support from avalanches. This effect has been essentially reduced on MSGC made of electronic conductivity glass with a low resistivity [2,8,9,11].

A support resistivity, and therefore current between anodes and cathodes, determines the important characteristics of MSGC: rate capability, shot noise, dissipating heat, and probably ageing. The dependence of some of these characteristics on resistivity is quite different: to increase rate capability it is necessary to decrease resistivity, but noise and heating from current get worse at the same time. This paper presents the results of comparative tests of the chambers with different electronically conductive glass supports with the aim of making a choice of the optimal resistivity. In the measurements performed we distinguished only short-term reversible modifications of gain and carried out the optimization of the resistivity on this effect. We have also made measurements of the performance of MSGC with different geometrical parameters (widths of anodes and thickness of a pattern layer) and we present the comparative results in this paper.

2. Chambers and experimental set-up

For the measurements described in this paper we have used several chambers built on electronically conductive glass substrata with different bulk resistivity in the range of $0.9 \cdot 10^9 \Omega\cdot$ cm to $2 \cdot 10^{12} \Omega\cdot$ cm [12]. The strip structure was produced for us [13] using photolithography on two successive vacuum evaporated layers of titanium and nickel. A gold layer, galvanically grown on these underlayers, was then etched by a combination of wet and plasma processing. All the chambers had similar geometry, the anode and cathode strips being alternated on the substratum with a distance of 100 μm between centres and a width of 10 μm and 80 μm respectively. The thickness of a metal pattern was 0.5 μm. A schematic cross-section of the chamber is shown in Fig.1. One MSGC on a support with a resistivity of $0.9 \cdot 10^9 \Omega\cdot$ cm was produced with a thickness of pattern of 1.5 μm with all other parameters similar to other detectors. We also used one more glass plate with a different geometry of the strip structure to investigate the dependence of performance of the chamber on the anode width. This plate contained 4 structures with an anode-cathode pitch of 100 μm, 60 μm cathode width, and anode widths from 5 μm to 13 μm and a metal pattern thickness of 0.5 μm.

The experimental set-up for the measurements is shown schematically in Fig.2. Each individual chamber was mounted in a stainless-steel box with a beryllium window 0.2 mm thick and metal-glass feed-through, allowing the application of operating potentials and extraction of the signals. The chamber was fixed with insulating rods and connections for providing anode and cathode potentials. The drift cathode was realized from aluminized mylar stretched on insulating frame and mounted 6 mm from the surface of the plate itself. In all tests all anodes of the chambers were connected to the anode voltage supply through the RC noise filter. The cathodes were of 6 groups 25 strips each connected to a $150 k\Omega$ resistor so that it was possible to measure either pulse height with a charge sensitive amplifier coupled to a shaping amplifier and ADC, or voltage drop on the resistor, which gives information about current flowing through the chamber. For investigation of the performance of the chambers at fluxes higher than 10^4 Hz/mm^2 we have made measurements in d.c. mode, measuring current through the chamber rather than individual pulses from photons, thus avoiding pile-up problems. These measurements have been done with a sampling ADC in CAMAC, connected to one of cathode sections.

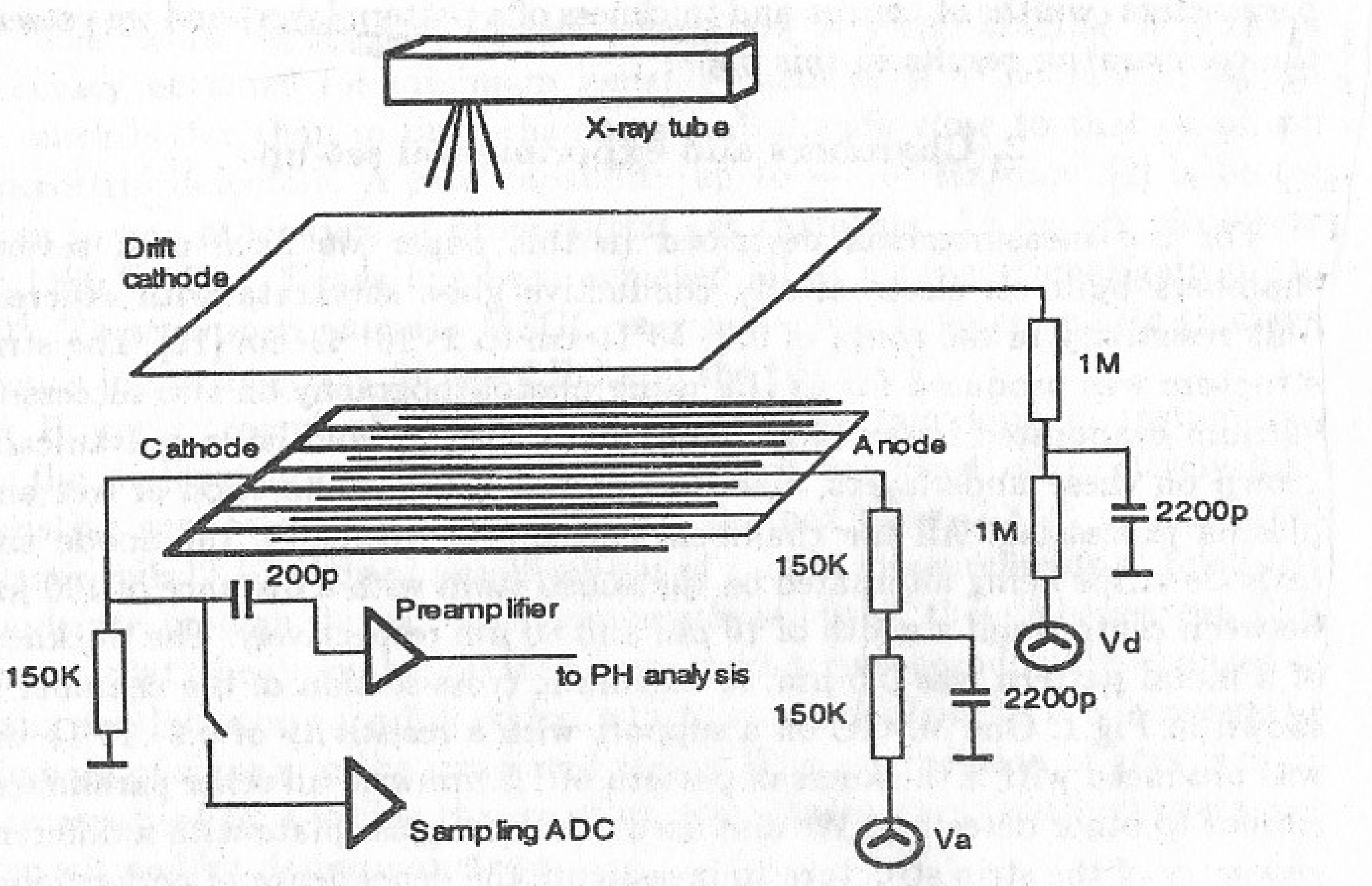

Fig.2

Experimental set-up for the high-rate measurements.

Electrical connections to the chamber have been made with conductive glue. The edges of anode and cathode strips have been covered with epoxy to avoid discharges due to higher field strength. The measurements were done with two gas mixtures: Xe+10%CH_4 and Ar+20%CO_2. We employed data obtained using these mixtures with different ion mobility to distinguish between the effects induced by space charge in gas and by surface charge on the support. The test box was mounted in front of the X-ray tube with a copper target at a distance of about 10 cm. With this geometry the tube provided a maximum detected flux of about 10^7 Hz/mm^2 with an energy spectrum of around 8 keV.

3. Measurements and experimental results

Using Cd^{109} X-ray source at low rate, we have measured the pulse-height spectrum and dependencies of the gain on anode voltage for the chambers with different anode widths. A typical example of a pulse-height spectrum of

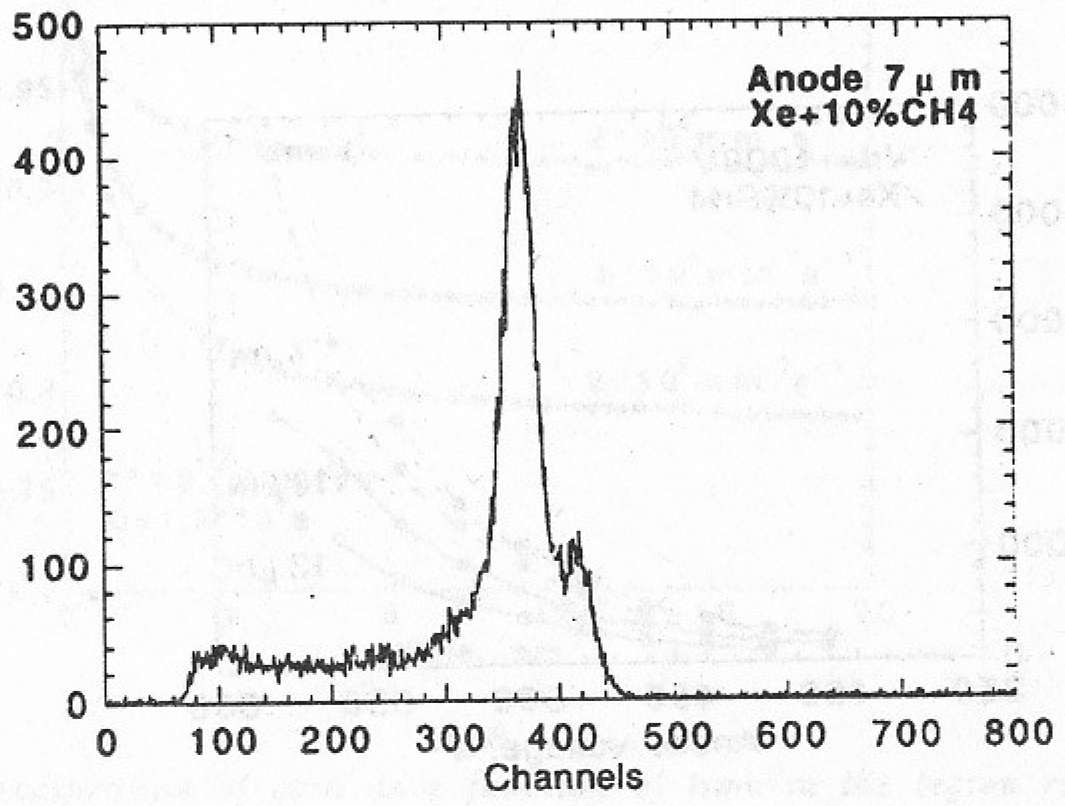

Fig.3

Pulse height spectrum for 22 keV *X-rays (*Cd^{109}*) measured with the low resistivity chamber* ($10^9\Omega\cdot$cm) *and 7* μm *anode width.*

22 keV X-rays from the source obtained on the chamber with 7 μm anodes is shown in Fig.3. Each measurement of gain-voltage dependence was finished after a discharge occured between anode and cathode strips. The anode high-voltage supply had current protection which turned off the voltage at ~ 80 μA. The detector could work for continuous periods of time having a number of discharges without substantial changing of its characteristics. The dependences of gain on anode voltage for four different anode widths are shown in Fig. 4.

The same measurements have been made on the chambers with two different thicknesses of the metal pattern: of 0.5 μm and 1.5 μm. Other parameters were 13 μm anodes, 80 μm cathodes, and 200 μm anode-anode pitch. The interruption of these measurements occurred at the same condition as the previous ones. The results are shown in Fig.5.

As mentioned in the Introduction, a change of gain after application of voltage has been observed on most microstrip structures manufactured on insulating supports. However, this kind of instability is absent in MSGC

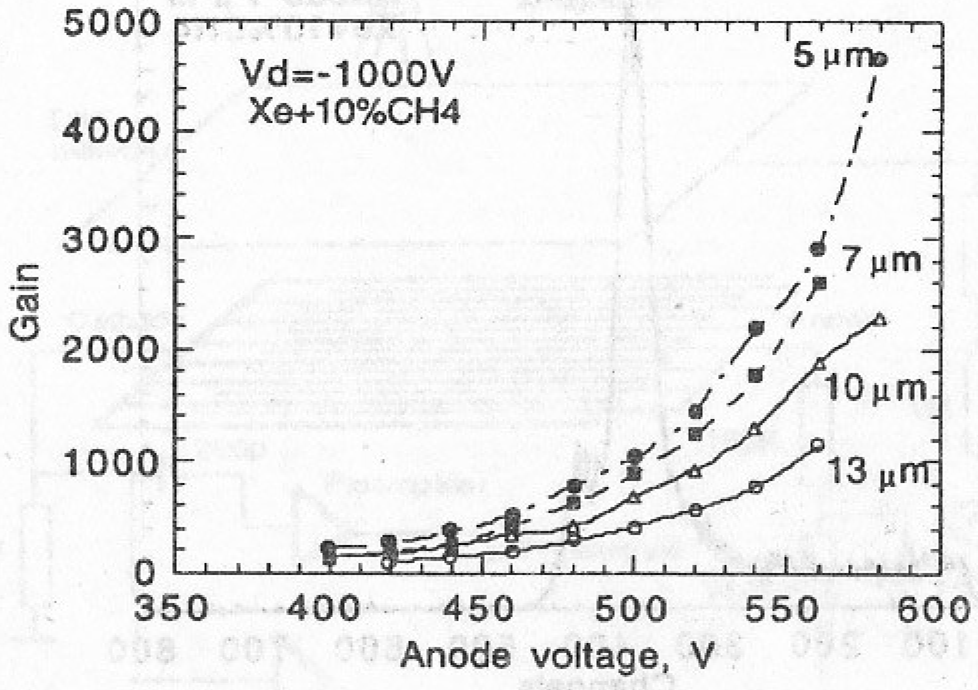

Fig.4

Dependence of gain on anode voltage for the chambers with a different width of anode strips.

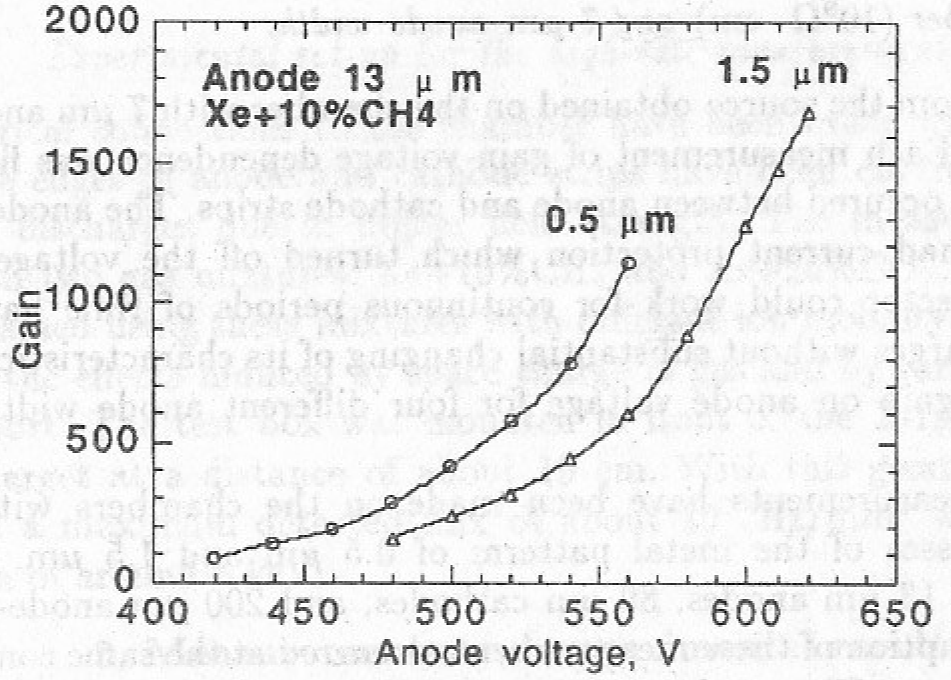

Fig.5

Dependence of gain on anode voltage for the chambers with a different thickness of conducting patterns. Anode width—13 μm.

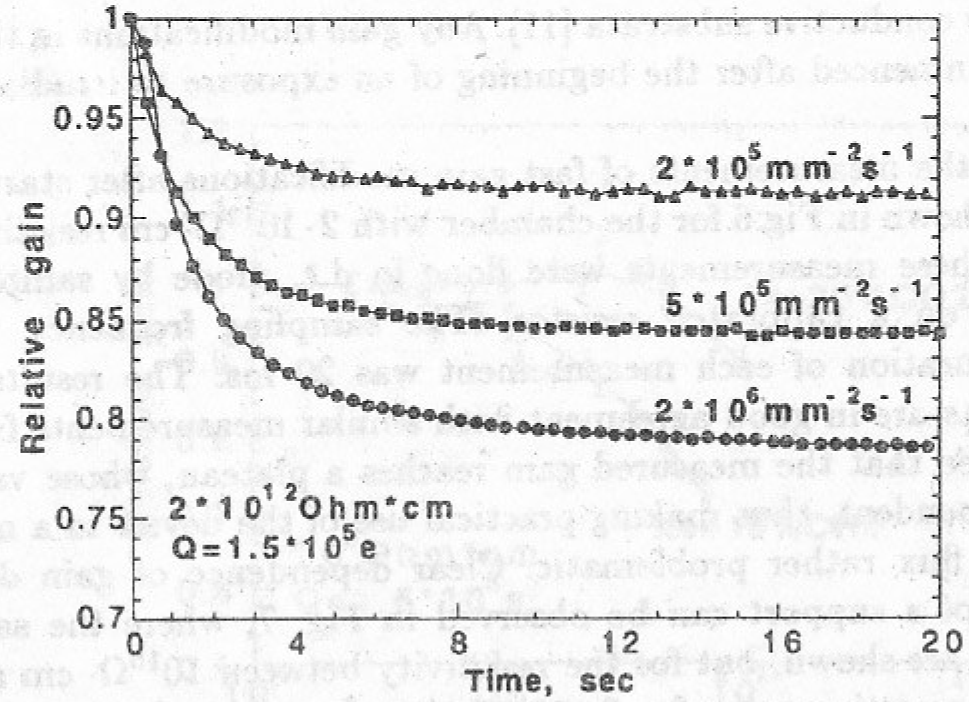

Fig.6

Local modification of gain as a function of time in the region exposed to radiation, measured with the high resistivity chamber ($2 \cdot 10^{12}\Omega \cdot$ cm) at different rates.

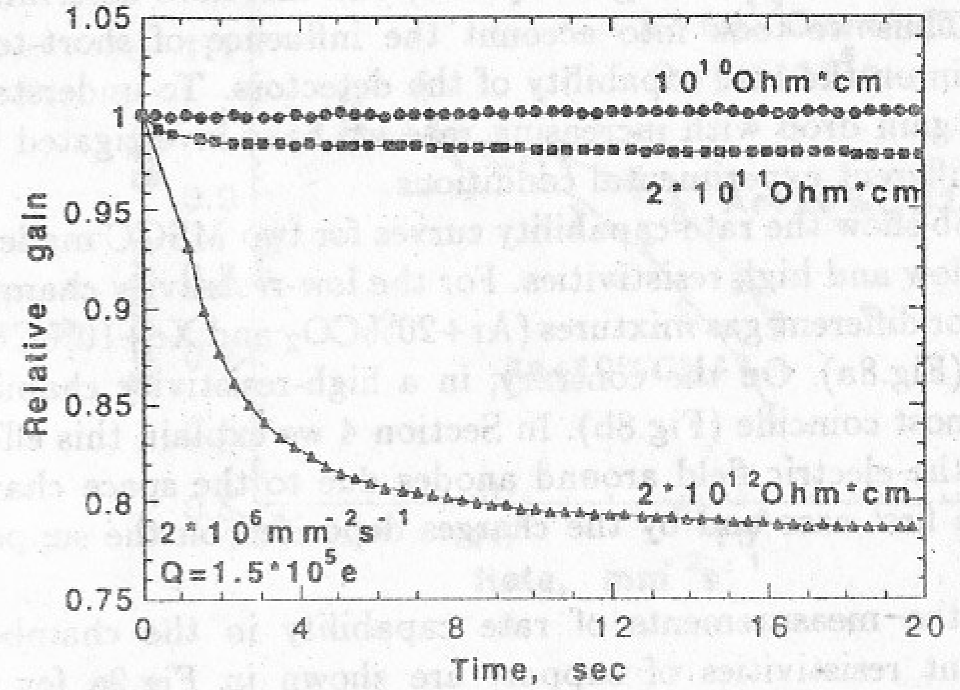

Fig.7

Local modification of gain as a function of time in the region exposed to radiation, measured at a rate near 10^6Hz/mm^2 with the chambers realized on a support with a different resistivity.

with electronically conductive substrata [11]. Any gain modifications in these chambers have commenced after the beginning of an exposure to irradiation flux.

The results of the measurements of fast gain modifications after starting the exposure are shown in Fig.6 for the chamber with $2 \cdot 10^{12}\Omega\cdot$ cm resistivity of the support. These measurements were done in d.c. mode by sampling the voltage drop on a calibrated resistor. The sampling frequency was about 2Hz; the duration of each measurement was 20 ms. The results of these measurements are in good agreement with similar measurements from Ref.[11]. We can see that the measured gain reaches a plateau, whose value is however rate dependent, thus making practical use of the device in a non-uniform radiation flux rather problematic. Clear dependence of gain drop on the resistivity of a support can be observed in Fig. 7, where the same curves as in Fig. 6 are shown, but for the resistivity between $10^{10}\Omega\cdot$ cm and $2 \cdot 10^{12}\Omega\cdot$ cm for a counting rate of $\sim 2 \cdot 10^6$ Hz/mm^2.

To obtain the rate capability of the MSGC (i.e. the dependence of relative gain on the detected counting rate) we measured the X-ray tube current and read out the current through the chamber in 10 s after each increase of X-ray flux. Then we normalized the chamber current by a tube current (which is proportional to the incoming X-ray flux) and therefore determined the relative gain. Thus we took into account the influence of short-term modifications of gain on the rate capability of the detectors. To understand physical reasons of gain drop with increasing rate we have investigated the rate capability at different experimental conditions.

Figures 8a and 8b show the rate-capability curves for two MSGC made on a support with the low and high resistivities. For the low-resistivity chamber the characteristics for different gas mixtures (Ar+20%CO_2 and Xe+10%CH_4) are quite different (Fig.8a). On the contrary, in a high-resistivity chamber these curves are almost coincide (Fig.8b). In Section 4 we explain this effect by modification of the electric field around anodes due to the space charge of avalanches in the first case and by the charges deposited on the support in the second.

The results of the measurements of rate capability in the chambers with several different resistivities of support are shown in Fig.9a for an Ar+20%CO_2 gas mixture and in Fig.9b for a Xe+10%CH_4 gas mixture. The decrease of rate capability could be observed clearly with increase of support resistivity above a certain level in both mixtures. This fact can also be explained by two different reasons of gain drop in low- and high-resistivity regions.

In order to achieve clearer data representation we plotted in Fig.10

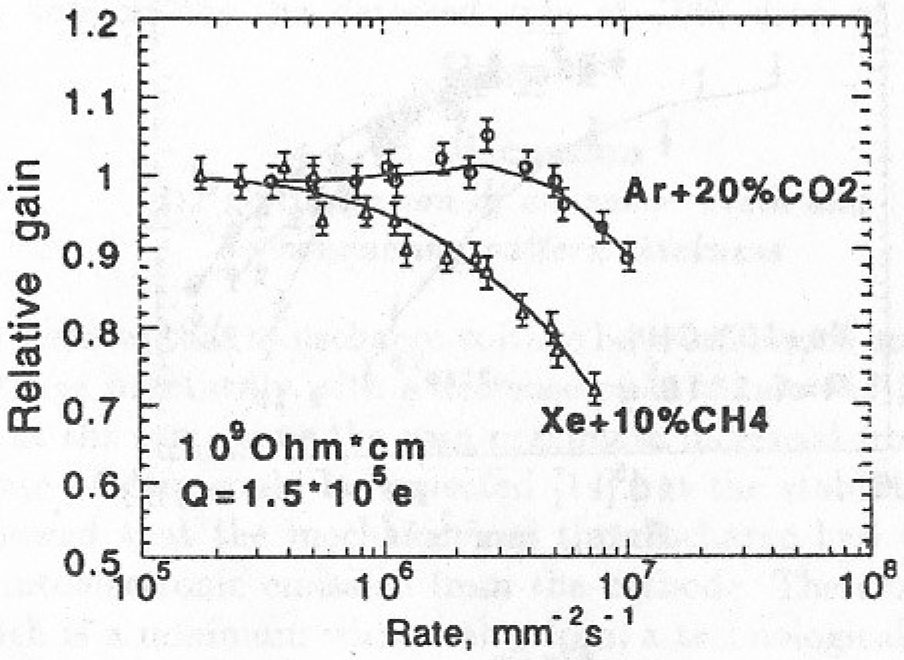

Fig.8a

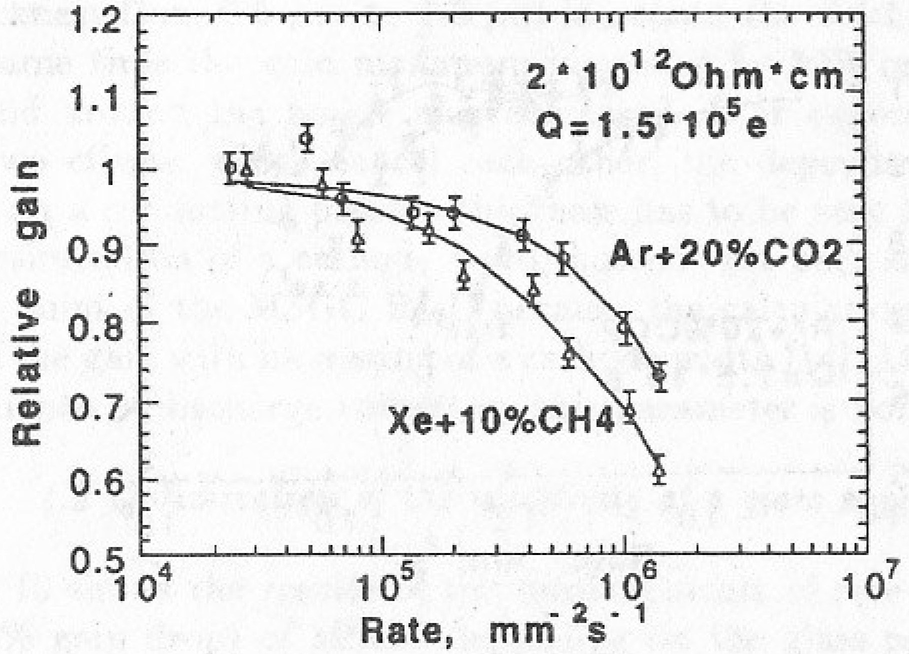

Fig.8b

Gain as function of rate at the gas mixtures based on argon and xenon with a) the low-resistivity chamber ($10^9\Omega\cdot$cm) *and b) the high-resistivity chamber* ($2 \times 10^{12}\Omega\cdot$cm).

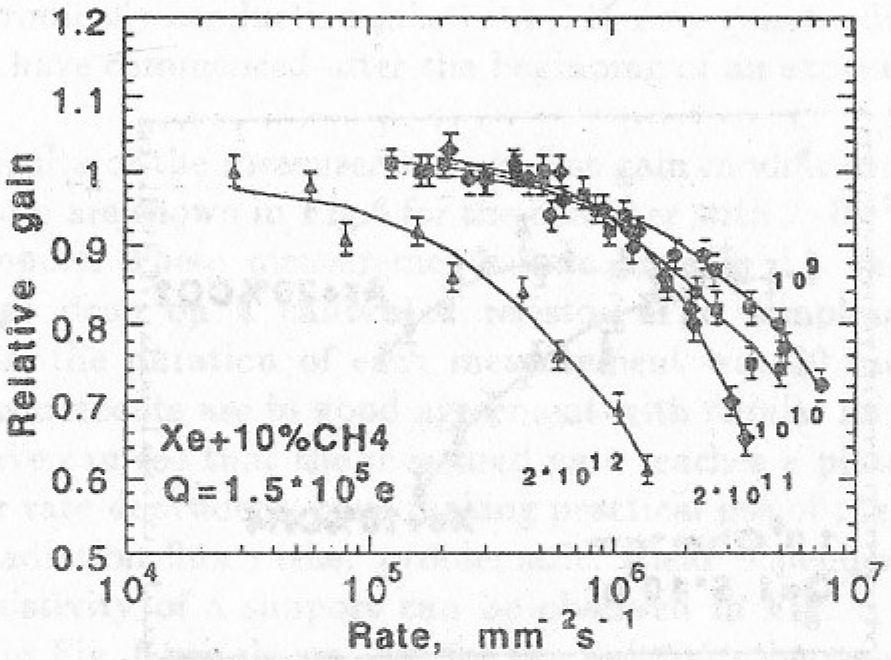

Fig.9a

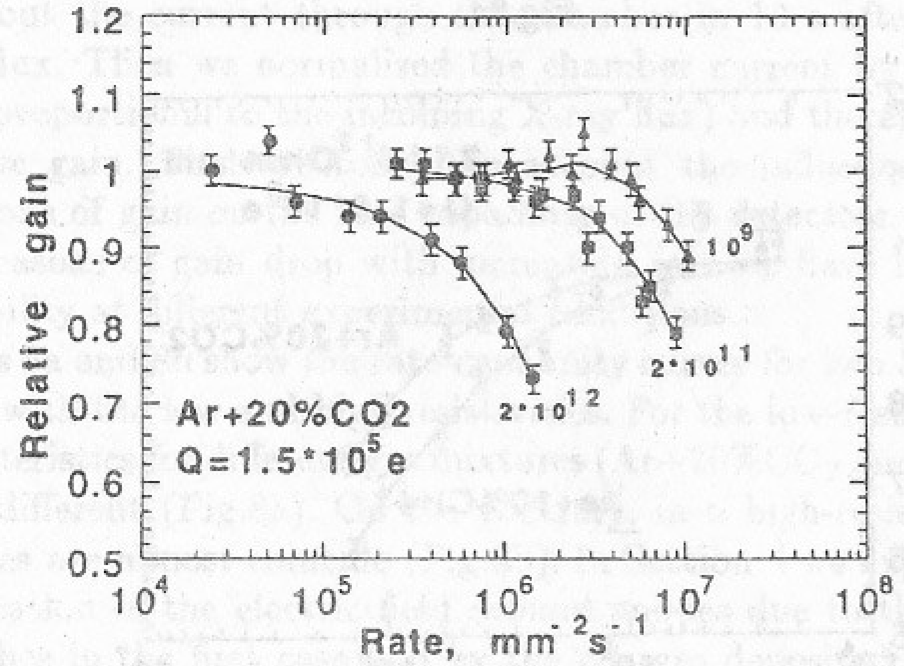

Fig.9b

Gain as function of rate with the chambers having a different resistivity of a support at the gas mixture based on a) xenon and b) argon.

the dependence of rate capability on the resistivity of the support. Rate capability here means the detected rate at 10% drop of the gain in the chamber.

4. Discussion

4.1 Optimization of an anode width and a conducting pattern thickness

Figure 4 shows that a discharge voltage between anode and cathode strips did not change practically with a decrease of an anode width from 13 μm to 5 μm and at the same time the gain maximum increased from 1000 to 4800. The increase of gain could be expected [14] but the stability of a discharge voltage showed that the mechanism of the discharge had to be connected with the autoelectronic emission from the cathode. Therefore the optimum anode width is a minimum width value from a technological point of view.

The assumption about the autoelectronic mechanism of the discharge between anode and cathode was confirmed by measurements with the chambers having different thicknesses of a conducting pattern (Fig.5). Change of the thickness from 0.5 μm to 1.5 μm increased the discharge voltage by 10%. At same time the gain maximum improved by 30% only because the electric field around the anode also decreased. It is expected that owing to these two effects, which cancel each other, the dependence of the gain maximum on a conducting pattern thickness has to be very flat.

The optimization of a cathode width has not yet been done. This is an important point of the MSGC R&D because the calculations predicted the increase of the gain with increasing of a cathode width [14]. At the same time, the dependence of discharge voltage on this parameter is not so obvious.

4.2 Optimization of the resistivity of a glass support

Figure 10 shows the results of the measurements of rate capability (the rate at 10% gain drop) of MSGC depending on the glass resistivity in the range from $0.9 \cdot 10^9\Omega\cdot$cm to $2 \cdot 10^{12}\Omega\cdot$cm. At higher resistivity the rate capability was limited by the modification of electric field by current flowing along the resistive surface, and therefore the rate capability increased when decreasing the resistivity of the support. The experimental data for the higher glass resistivity can be approximated by an inclined straight line, which corresponds to the reversed proportional dependence of rate capability on resistivity. The inclined lines for two different gas mixtures were normalized in Fig.10 at the points with highest resistivity.

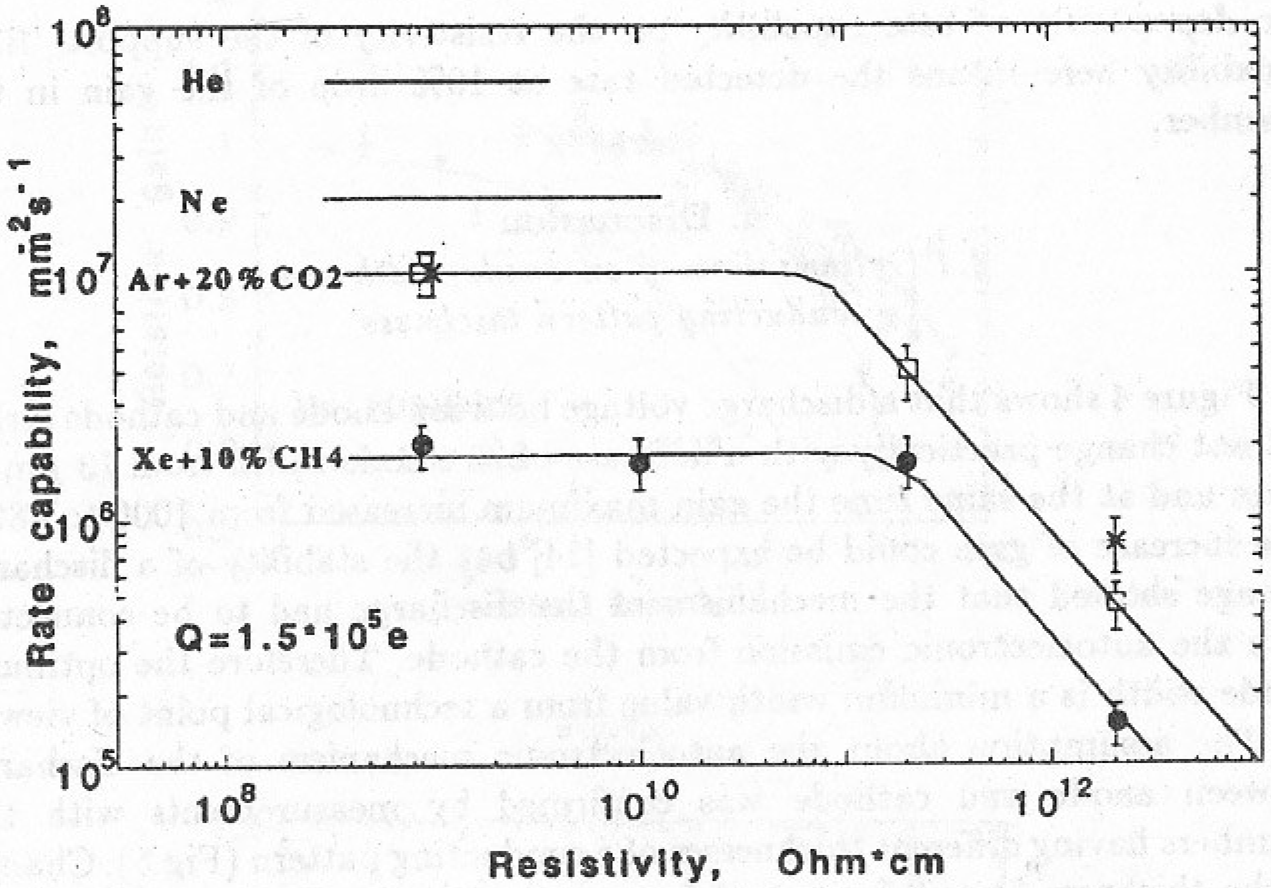

Fig.10

Dependence of rate capability (the rate at 10% gain drop) on resistivity of a support at the gas mixtures based on argon (open squares) and xenon (triangles). Points (asterisks) are from Ref. [11].

When glass resistivity was close to $10^{11}\Omega\cdot$cm the experimental values of the rate were coming to a plateau as a result of the influence of the space charge in gas on an electric field. The experimental value of the rate capability on the plateau depends on a gas mixture due to different ion mobility. According to Ref. [15] the gas mixture based on argon is faster compared to the gas mixture based on xenon, which coincides with the experimental data presented. The use of a gas mixture based on neon and helium could give even higher rate capability of MSGC. In Fig.10 the predicted plateau values for gas mixtures based on neon and helium are shown by the horizontal lines. We have normalized the new plateau values to the measured data for the Ar+20%CO_2 gas mixture, assuming mobility of ions of gas mixtures based on argon, neon, and helium, corresponding to a mobility of these noble gases [16]. However we have to take into account that the ionized state is quickly transferred to the molecules with the lowest ionization potential in the mixture, and therefore actual ions could be different from the main component, especially for light noble gases.

In order to verify the consistency of present measurements with earlier results we also put on the graph (Fig.10) two points from our previous work [11]. Those measurements were done at a gain of ~ 1000 whilst present results were obtained at ~ 400. After multiplication of the old results by a factor of 2.5 (assuming the reversed proportionality of rate capability to gain) we have obtained a good agreement between old (asterisks) and present (open squares) experimental data.

The resistivity of support defines the important characteristics of MSGC. The dependence of some characteristics on resistivity is quite different: in order to decrease noise and heating from current between anodes and cathodes the resistivity has to be decreased, but the rate capability gets worse at the the same time. To optimize the rate capability we can use any support resistivity value on the plateau of Fig.10. To obtain at the same time, low current noise and heating it is necessary to choose the maximum value of resistivity on the plateau. This optimal resistivity value depends on a gas mixture and gain and is equal to about $10^{11}\Omega\cdot$ cm.

5. Summary

In our first systematic study of the behavior of several MSGC detectors on glass substrata with electronic conductivity [11] it was shown that a chamber made of low resistive glass with electronic conductivity had very high rate capability and radiation hardness. In the present paper we have started to optimize parameters of MSGC made of glass with electronic conductivity. Some general dependences of MSGC performance on various geometrical parameters were investigated as well as the effect of support resistivity on the rate capability of the chamber.

It was found that the maximum gain increased very fast with the decreasing of an anode width and hence the optimal value of this parameter is defined by a technology. The choice of the thickness of the metal pattern is not critical from the point of view of maximum gain, but still about 30% can be gained by increasing the thickness from 0.5 μm to 1.5 μm. The optimization of a cathode width has not yet been done. We consider this optimization important, because it can affect maximum gain as much as anode width but it is easier from a technological point of view.

The measurements of MSGC rate capability at different resistivity of support allow us to find the optimal value of this parameter depending on gain, shot noise (dark current), and gas mixture. For two particular gas mixtures Ar+20%CO_2 and Xe+10%CH_4 and a gas gain of 400 this optimization has been carried out in the present paper. It was found that at lower resistivity the rate capability is limited by only space charge effects in gas, but above a certain threshold of resistivity it drops owing to the change of field near the anodes by the charges deposited on the substrate. The rough estimation of this threshold value is about $10^{11}\,\Omega\cdot$cm. The rate capability of 10^7 Hz/mm^2 was obtained for the chambers with support resistivity lower than this threshold value with an Ar+20%CO_2 gas mixture and a gain of 400 for 8keV X-rays.

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Влияние удельного сопротивления стеклянной подложки с электронной проводимостью на характеристики микростриповой газовой камеры

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