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APPLICATION OF MICROCHANNEL PLATES AT HIGH COUNT RATES

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The output parameters of microchannel chevron amplifiers built around microchannel plates with current variable along the channel length, i.e., variable resistivity, have been studied. The volume charge in such plates is not stored at channel outputs and this improves the output characteristics of the multipliers. The detector current gain is stable for a dynamic range of input flow rates of several orders of magnitude and the detector output parameters do not fail at count rates up to several megahertz. The detector's parameters are more stable in time at very high current rates.

Secondary-electron multipliers built around microchannel plates (MCP) are widely used in instruments designed to detect particle flows ranging from visible light to ions and neutral particles [1–4]. Presently MCPs are employed in various position-sensitive detectors of particles and photons [5–9].

A topic in the design of a detector based on an MCP is its dynamic sensitivity. An MCP gain drops with the intensity of the input particle flow [10], i.e., its gain depends on its workload (the intensity of the input signal).

Shutte et al. [11] were the first to demonstrate that the dynamic range and hence the detector's dead time after an output pulse of a microchannel detector built around two MCPs in the chevron configuration depended on the dimension of the exposed area. The dead time increased with the dimension of the exposed area, i.e., the dynamic range was wider when the detector's working area was smaller. In addition, the highest possible count rate was a function of the output current which could be generated at the MCP output. This conclusion was confirmed by Fraser et al. [12] and Cho and Morris [13] and it indicated that the highest possible ratio of the output current to the conduction current (I_{out}/I_c) depends on the dimension of the exposed area [11–13].

When designing and operating position-sensitive detectors built around chevron MCP structures, this fact is very important in correctly assessing their operation since in typical real conditions the exposure of the MCP input surface is fairly nonuniform.

When simulating the operation of a single MCP, it is traditionally modelled as a set of parallel independent channels, and its output current of secondary electrons is presumed to be less than 10–30% of its saturation current. If the output current is higher, the multiplication process is suppressed and the gain drops. In other words, the upper limit of an MCP's dynamic range (the ratio of the highest to the lowest output signal) is limited by the conduction current of the MCP channels [12–14].

Note that a correlation has been detected between a decrease in the dimension of the exposed MCP's input surface and the respective (proportional to the area) decrease in the absolute total output detector current, and, on the other hand, between the decrease in the dead time and an increase in the dynamic range of a chevron microchannel detector. This means that MCP channels cannot be independent in an analysis of the charge relaxation in them. This coupling between the local dead time of an MCP and the distribution of the incident flux intensity had been named the adjacency effect [15].

It follows from experimental data that when estimating the critical value of the ratio I_{out}/I_c the emission current I_{out} should be compared to the conduction current of all the MCP channels [11]. This

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means in turn that the real effect of the channels neighboring the exposed channels is essential. If this effect is not taken into account in an MCP in various devices (especially in position-sensitive detectors, electronic image converters, and optic devices), the output signals may be misinterpreted because they depend on the distribution of the incident flux intensity over the input MCP surface.

The existing models describing the basic MCP characteristics (the gain, amplitude resolution, and dead time) cannot yet account for the empirical functions for the output parameters of chevron detectors versus the dimension of the exposed area [11-13]. This effect, however, is essential in detecting, for example, flows of electrons and ions of cosmic plasma, whose intensity may vary by more than six orders of magnitude, depending on the parameters and condition of the environment.

Hence there is a need for a detector using two MCPs in the chevron configuration and capable of operating at a high count rate without any loss of sensitivity. The output count rate of this detector should be proportional to the incident flux as its intensity varies over a range of six orders of magnitude regardless of the flux distribution over the input surface of the upstream MCP.

The simplest way to increase the dynamic range and to improve the linearity of an MCP is to reduce the plate resistance [12, 16]. But these possibilities are rather limited. If the plate resistance is less than 30–40 MΩ, local heating will degrade the plate parameters, and it can only be continuously operated if there is forced cooling [17, 18]. For example, the highly conductive plates ($R = 500$ kΩ) produced by Galileo could be operated when cooled with running ethylene glycol [19, 20]. This mode of operating low-resistance plates in microchannel detectors evidently cannot be widely used in scientific and industrial facilities.

Since all the microchannels are connected in parallel by metal electrodes (films) deposited by vacuum evaporation on the plate surfaces, some researchers have attempted to reduce the resistance between channels by fabricating the contact electrodes from gold instead of chrome or nickel [12] in order to operate their plates at a high count rate. It was found, however, that both these methods, namely the reduction of the plate resistance and of the resistance between channels, are not very efficient and difficult in realization.

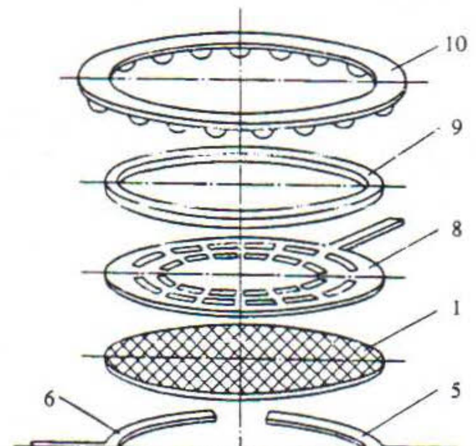

Fig. 1. Structure of a chevron MCP metal-ceramic detector: 1, 2) MCP; 3) sectional collector; 4, 5, 6) interelectrode pieces; 7) metal-ceramic body; 8) input mask; 9) supporting rings; 10) spring.

Note that experimental data indicate the importance of the conduction current I_c for MCP characteristics. First, the ratio of the output current to the conduction current, I_{out}/I_c, is the most important indicator of the detector stability against high current [11, 12]. Second, local variations in the conduction current control the cross-talk noise between MCP channels, i.e., determine variations in the output count rate as a function of the dimensions of the exposed area (or the number of actuated channels).

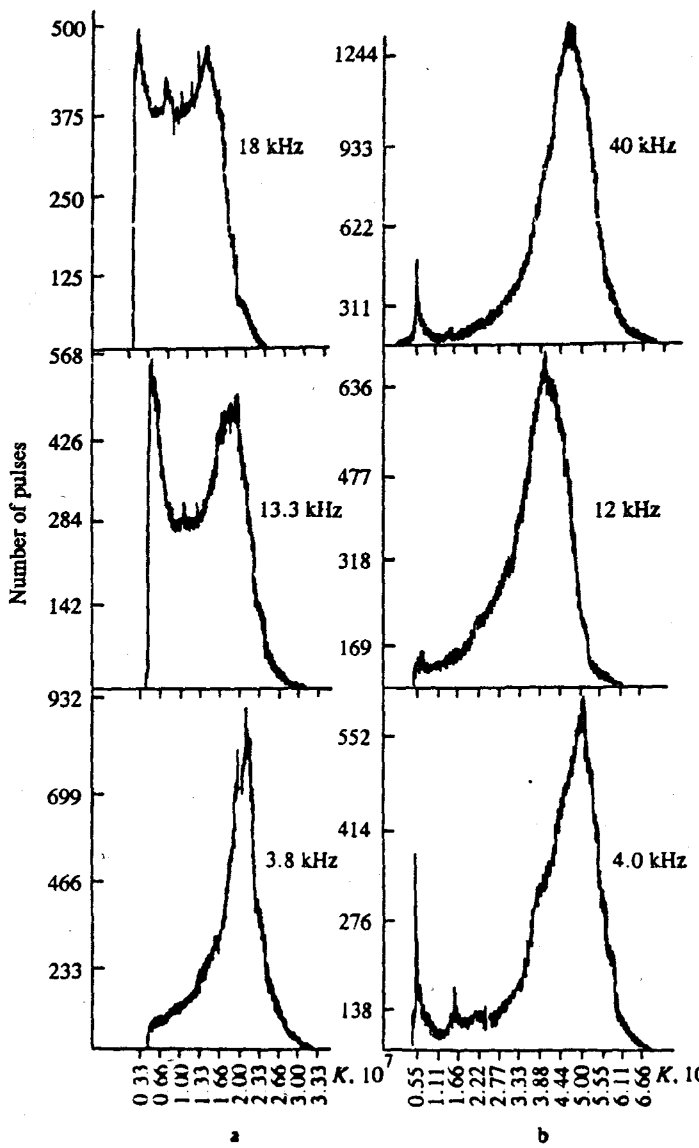

Fig. 2. Output pulse height distributions for (a) conventional 4MO and (b) new 14k detectors. The numbers at the curves indicate the output count rates in kHz.

It follows from an analysis of these factors that the problem can be solved by fabricating an MCP with a conduction current variable along the channel length. At the output end of the channel, where the emission current is maximum, the conductivity should be higher than at its input end. A similar condition can be achieved by fabricating an MCP whose input and output surfaces have different resistivities. In such plates the output emission current may be considerably higher, i.e., the stability against a high current may be improved.

In order to manufacture MCPs with a variable channel resistivity, a special technology using different regimes along the channel length to form the emitting layer has been developed. As a result, the thicknesses of the conducting layer on the input and output surfaces of plates differ by a factor of about ten [21].

The thicknesses of the conducting layer at the channel output and input are ~ 1150 Å and 100–150 Å, respectively. This means that the resistivity of the conducting layer at one end is nearly an order of magnitude lower than at the other end. Thus the plate with the resistivity variable over the channel length is fabricated. The resistivity of the channel surface changes gradually. It is evident that in such plates the conduction current at the output end is an

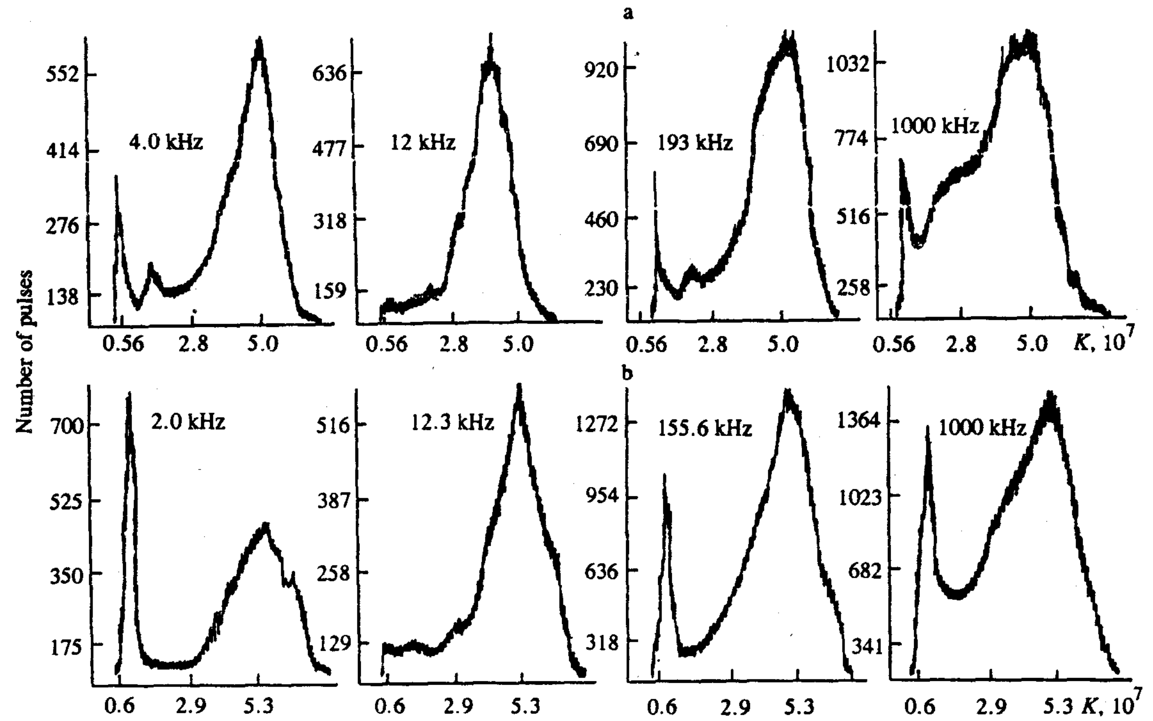

Fig. 3. Output pulse height distributions for (a) 14k and (b) 16k MCP detectors with variable channel resistivities at different count rates indicated by numbers at the curves.

order of magnitude higher than at the input end. As a result, the variation in I_{out}/I_c is lower although the output current increases with the incident flow intensity. Besides, plates with thicker conducting layers at the output end are more stable against a high current and operate more reliably under intense electron bombardment of this channel section.

It seems that this technology is the only way to manufacture plates that are stable against a high current. The operation of these plates is fairly easy and does not require cumbersome or expensive facilities for cooling etc.

Below we present the preliminary results of testing a microchannel detector built around two MCPs 56 mm in diameter (calibre 60) with a variable resistivity. The fabrication technology was developed as a result of a joint effort by workers at the Space Research Institute (Moscow), Gran factory (Vladikavkaz), and SNIIM (Saratov). A feature of the detector is its high stability against high current when the incident flux intensity varies by several orders of magnitude.

A structure (Fig. 1) built from two MCPs 1 and 2, a sectional collector 3, and interelectrode pieces 4-6 is housed in a complex metal-ceramic body 7 with an input mask 8. A two-ring sectional collector 3 with 24 decoupled outputs is placed downstream of the second plate 2. During tests various sections of the detector plates and, hence, various collector sections next to the inside and outside circles were exposed to electron beams.

Voltage is fed to the gap between the first and second plates via dedicated halves of a ring 5 and 6, and as a result, the gap between the plates is only 0.3 mm wide.

The input mask 8, whose slits mimic the shape of the collector sections, allowed us to channel the electron beam to collector sections and to determine the cross-talk noise between neighboring sections. The structure is supported by rings compressed against the MCP by a spring 10. All the components are soldered or welded together.

The device was tested in a vacuum chamber evacuated to $\sim 10^{-6}$ torr by titanium getter-ion pumps. The source of charged particles was an electron gun generating an electron beam with a flux density of 10^2 to 10^{11} $cm^{-2} \cdot sec^{-1}$ and an energy of several hundreds of electronvolts to several tens of kiloelectronvolts.

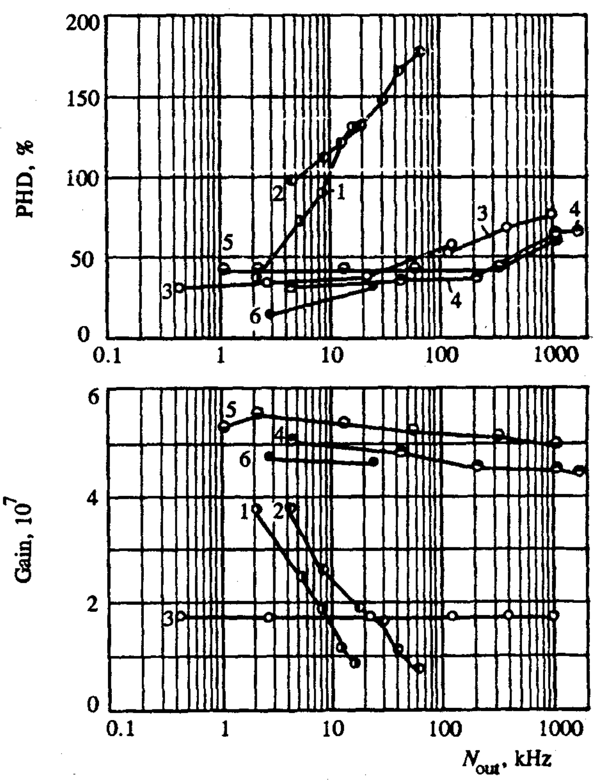

Fig. 4. Curves illustrating the dynamic range of detectors with variable resistivity and conventional MCP detectors with a plate diameter of 56 mm: 1) 1MO and 2) 15MO detectors with conventional plates; 3) 6k, 4) 14k, and 5) 16k detectors with variable plate resistivity; 6) 14k detector with an area exposed to an electron beam of ~ 0.2 cm².

The tested chevron MCP structure was powered from a conventional supply [11]. Output signals were detected by a dedicated shaping amplifier and processor of MCP signals, then they were recorded and statistically analyzed [22]. The computer-controlled hardware could analyze MCP pulses with an integrated current of $3 \cdot 10^{-13}$ C and a duration of 1.5–2 nsec at a repetition rate of up to 10 MHz.

During testing the detector stability against high current, attention was focused on studying the distribution of the pulse heights versus the output count rate N_{out} since this distribution is the most susceptible to variations in the output detector parameters at a high signal intensity.

Test experiments were performed with several chevron MCP detectors using both conventional MCPs (1MO, 4MO, 6MO, and 15MO detectors) and the new MCPs with variable resistivity (6k, 14k, and 16k detectors). They were exposed to electron beams with energies of 500–800 eV. Outlying sections of MCPs with equal areas were exposed. All data were recorded at equal supply voltages. Measurements are presented in Figs. 2–4.

Figure 2 compares output pulse height distributions (PHD) for the conventional 4MO and new 14k detectors at several count rates. The count rate is an order of magnitude (from 4 to 40 kHz) higher, and causes little change in the PHD and gain of the 14k detector. The four-fold increase in the count rate (from 4 to 18 kHz) radically degrades the output parameters of the 4MO detector. The frequency of low-amplitude pulses increases considerably, and the shape of the output PHD changes radically when the count rate rises from 3.8 to 18 kHz.

The upper count rate for the 4MO and 14k detectors is ~ 20 kHz and 1–2 MHz, respectively.

Figure 3 shows PHDs for the two new 14k and 16k detectors as the output count rate rises from 4 kHz to 1 MHz. The shapes of the curves are fundamentally the same, and there are no apparent signs of parameter degradation caused by the high count rate.

Figure 4 compares the gains and PHDs of conventional 1MO and 15MO detectors, and new 6k, 14k, and 16k detectors versus the count rate. These data indicate than not only the dynamic range of devices with variable-resistance MCPs is wider by two orders of magnitude, but their parameters remain practically unchanged at a high count rate. Note that the parameters of devices with conducting layers having a variable resistivity are constant despite the dimension of the exposed detector area, specifically when a small fraction of the MCP channels are used. Curve 6 in Fig. 4 is the characteristic of the 14k detector with an exposed area of ~ 0.2 cm². Since the device parameters are practically unchanged, this indicates that they are weakly dependent on area.

Our experiments lead us to the conclusion that detectors built around MCPs with variable resistivity are more stable against high current and can operate reliably at count rates up to several megahertz without any notable degradation in their parameters. Detectors using such plates operate stably at high count rates. Our measurements indicate that there is no buildup of volume charge at the channel outputs. Hence their output parameters are better and no special measures are needed to neutralize this charge at the maximum gain [23]. Therefore the application of these plates is promising both for devices detecting signals in a wide dynamic range, and for night-viewing and similar devices where the condition of the photocathode has to be constant for long periods of time.

Another positive feature of MCPs with variable resistivity is their high manufacturing reproducibility and the uniformity of their output parameters.

In order to understand the problem, we need a theoretical model which describes the generation, evolution, and propagation of charge along an MCP channel whose parameters are determined by both the characteristics of previous current pulses conducted through it, and by variations in the conduction current both in a quasi-steady state and under a variable total and local particle flow rate.

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