EXTENSION OF THE DYNAMIC RANGE FOR RECORDING IMAGES WITH MICROCHANNEL PLATES

A. F. Sorokin

UDC 539.1.074

The most promising devices employed in the amplification of weak fluxes of particles transferring an image are microchannel plates (MCP). Their advantages include insensitivity to visible-range quanta and electric and magnetic fields ($H < 1$ T) and a low dark-current level ($1 < 10^{-14}$ A) [1]. The use of assemblies consisting of several MCP enables obtaining gains which are comparable to those of the best photomultipliers ($K = 10^7$-10^8).

The standard MCP, however, are characterized by low values of the limiting admissible input-current densities ($j_{in} < 10^{-11}$ A/cm^2), which substantially limits their frequency range also. In this work we present the results of experiments on improving the temporal and spatial resolution of MCP as an image amplifier [2, 3].

The limitation of the input current for MCP is linked with the fact that the maximum output current of electrons in the MCP channel ($I_{out} = kI_{in}$) should not exceed some relative fraction ξ of the current over the volume of the MCP: $I \leqq \xi I_0 = \xi U/R$ (U is the voltage and R is the resistance of the MCP), since for large values of I_{out} the space charge of the electrons destroys the uniform distribution of the electric field along the channel, which lowers the gain of the MCP. At the same time, in order to ensure high-quality transmission of the image transported by the particle flow with a fixed spatial resolution C (the number of lines per unit area, resolved according to Rayleigh's criterion) the current density at the MCP input must be

$$j_{in} = I_{in}/S \geqslant CeN\beta/\Delta t,$$

where S is the area of the working surface and N is the number of particles in the flux recorded by the MCP [determined by the required value of the statistical error ε in transmitting the intensity of one line: $\varepsilon = (N)^{-1/2}$]; e is the electron charge; Δt is the resolving time required in this experiment; β is the efficiency with which the particles in the flow are recorded Therefore, the resolution time of the MCP

$$\Delta t \geqslant CekR\beta S/(\xi U\varepsilon^2) \qquad (1)$$

with fixed C, β, k, and ε is determined primarily by the values of the resistance of the MCP and the voltage supplied to it.

For standard microchannel plates $R \sim 10^{10}$-10^{11} Ω, $U \sim 10^3$ V, which is linked both with the electric properties of the materials used for their fabrication and the necessity for eliminating the effect of Joule heating on the characteristics of the MCP. For typical values $\varepsilon = 0.3$, $\xi = 0.05$ and relatively low spatial resolution $C = 10^2$ lines/cm^2 the time resolution of a single MCP $\Delta t > 5 \cdot 10^{-4}$ sec, and the time resolution of an assembly consisting of two MCP is $\Delta t > 0.5$ sec; the gains are equal to 10^4 and 10^7, respectively.

In many applications of the technology for visualizing images (study of flows from a plasma, discrimination of a signal from noise by the method of synchronous accumulation) much better spatial and temporal resolution are required.

It is especially important to increase the limiting admissible input currents for x-ray diffraction and mass-spectrometric measurements, characterized by large gradients of the intensity and small sizes of the images [4]. The required spatial resolution, for example when measuring the rocking curve $C = 10^8$ lines/cm^2 and, according to (1), the minimum exposure time for the parameters indicated above $\Delta t = 50$ sec nullify all the advantages of the MCP as ideal image amplifiers.

Astrakhan'. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 24-28, March-April, 1986. Original article submitted February 11, 1985.

0021-8944/86/2702-0174$12.50

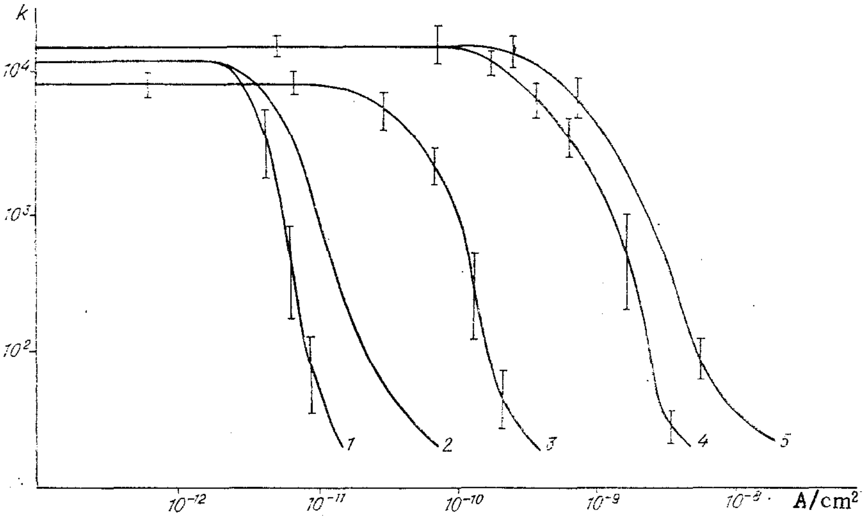

Fig. 1

It follows from formula (1) that the time resolution can be improved by reducing the resistivity of MCP and lowering the voltage supplied to it. Analysis of the technology for fabricating MCP showed that the resistivity can be reduced by

– increasing the number of channels per unit area of the microchannel plates and correspondingly decreasing the thickness of the plate d (in order to preserve the optimal values of ℓ/d);

– changing the conditions of saturation of the channel walls with hydrogen; and

– using highly conducting types of glasses, for example those used for fabricating channel electron multipliers.

Figure 1 shows the curves of the gain of the MCP versus the current density at the input for standard domestically produced MCP, standard Japanese MCP [5], and MCP with low resistance (channel diameter $d < 10^{-5}$ m, $R = 10^8$ Ω/cm²), and MCP made of high-capacity glass ($R = 3\cdot10^7$ Ω/cm²) (curves 1-4, the spread over the batches of 10-12 MCP is indicated).

To realize the possibilities of MCP operating in a state with high voltage supplied to the plate, we selected plates with a low coefficient of secondary electron emission (with a standard voltage supply $k < 10^3$). This selection is required because for $k > 10^4$ self-breakdown of MCP, associated with backward ion emission in the channels, occurs. To reduce the probability for malfunctioning of the plate as a result of Joule heating, the tests were performed with impulsive feeding of the plates. The experiments showed that increasing the voltage supply to the plate increases the optimal value of ℓ/d. Thus, for $U \sim (2\text{-}2.5)U_{st}$ the optimal value $\ell/d = 100$, which enabled increasing the thickness ℓ of the MCP while simultaneously reducing the diameter of the channel. Prolonged conditioning (~3 h) in the static state with gradual increase of the voltage supplied to the plate up to $1.5U_{st}$ while loading with the maximum input current enabled raising the voltage supplied by the pulse up to $2.8U_{st}$. This corresponds to increasing the limiting input current: for MCP with an elevated number of channels per unit area $I = 5\cdot10^{-10}$ A/cm², while for MCP consisting of high-capacity glass the current increases up to $I = 10^{-9}$ A/cm² ($3\cdot10^9$ particles/(sec·cm²)) (curve 5).

Thus the input current achieved in experiments $I/I_{stand} \sim 10^3$. The equivalent increase in the dynamic range enables using MCP to study processes with characteristic evolution times of $\Delta t > 5\cdot10^{-7}$ sec.

It should be noted that in [5] one other method is proposed for raising the maximum admissible current – development of MCP with nonlinear distribution of the resistivity along the channel. This enables increasing the maximum current by a factor of 2-3 which, in our opinion, does not justify the increased complexity of working with MCP.

The selection of MCP with small-diameter channels enables improving another characteristic which is important for visualizing images transported by particle fluxes and determining the dynamic range: the spatial resolution. As is well known [2], the spatial resolution in image transmission with optimized optics in the information-extraction system is equal

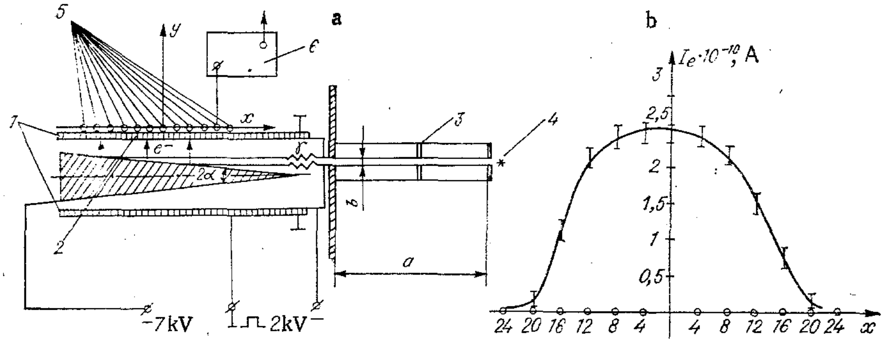

Fig. 2

TABLE 1

Nuclide	Energy of quanta, keV	Extraneous lines (energy, keV/ rel. intensity, %)	Recording coeffs., %		Nuclide	Energy of quanta, keV	Extraneous lines (energy, keV/ rel. intensity, %)	Recording coeffs., %	
			MCP	MCP with a converter				MCP	MCP with a converter
I^{125}	28,3	$\frac{35}{4}$	1,3	3,6	Co^{27}	122	$\frac{136}{11}$	1	3,3
Am^{241}	59,6	$\frac{26}{6}$	1,25	3,5	Ce^{139}	165,8	—	0,8	3,2
Tm^{170}	84	—	1,15	3,4	Hg^{203}	279	—	0,1	2,2

to $C = (1.2\text{-}1.5d)^{-2}$ lines/cm². For the MCP which we selected with $\ell/d = 100$ the lowest value $d \sim 8 \cdot 10^{-6}$ m provides a resolution of $C = 10^6$ lines/cm². For experiments in which one-dimensional images are being studied, the resolution along one of the coordinates can be substantially improved by using MCP with a converter, tilted at a small angle α to the plane of the plate. Figure 2 shows the arrangement of the experiment on determining the linear resolution in such a system recording an image transported by an x-ray flux [1, MCP (to increase the aperture two identical MCP are used); 2, secondary-emission converter; 3, collimator ($b/a = 10^{-5}$); 4, focal point of x-ray tube; 5, current extraction electrodes (gold-plated tungsten wire $2 \cdot 10^{-6}$ m in diameter); and, 6, amplifier].

In this scheme the image swept along the y axis is converted into an image swept along the x axis with a magnification numerically equal to $(\alpha)^{-1}$ rad^{-1}. The possibility of obtaining an enlarged image removes many technical difficulties and is especially important when recording on a photographic plate, since the presently achievable linear resolution is already limited by the grain size of the photosensitive material ($\sim 10^{-6}$ m).

Figure 2b shows the current distribution I(x) at the outlet of the MCP, arising when the converter is illuminated by x-ray quanta passing through the collimator, which consists of three sequential slits with $b = (0.8 \pm 0.05) \cdot 10^{-6}$ m (the equivalent width of a slit was determined from three peaks of the diffraction pattern appearing when the collimator is illuminated by an He–Ne laser). The converter consisted of a block of lead, cut at an angle of 0.03 rad, oxidized in oxygen (PbO is characterized by high secondary-emission properties with respect to x-ray radiation [4]).

It is evident from Fig. 2b that the linear resolution obtained in the experiment (the half-width at half height is 15 ± 2 μm), $C_\ell^{-1} = 0.5 \cdot 10^{-6}$ m/line is somewhat worse than expected, $C_\ell^{-1} = 1.5\alpha$, $d = 0.36 \cdot 10^{-6}$ m/line. This can be explained by the imperfection of the collimator and the fact that the line contour (determined by the convolution of the instrumental broadening functions with conversion on the converter and at the inlet to the channels) is broadened during the conversion of the fluxes.

The arrangement of the analog of an unsealed electrooptical converter, having a gain with respect to electrons of $k = 10^4$, an input window size of 1.2 × 4 cm, is shown in Fig. 2a. In the future development of this converter a photomatrix will be used for the information-extraction system.

To determine the absolute coefficients of recording of x-ray and gamma quanta by such a converter we calibrated the converter on standard gamma sources. The results of the calibration using the standard procedure are given in Table 1, where column 4 shows the coefficients of recording with direct irradiation of the surface of the MCP with x rays (normal incidence), while column 5 shows the recording coefficients for recording of x-ray quanta by the system Fig. 2a. The much higher recording coefficients can be explained by the much higher quantum yield of PbO than of $Si_2O_3(Pb)$ and the well-known fact that the quantum yield is higher for glancing incidence.

The experiments performed and the analysis of the possibilities for expanding the dynamic range for recording images show that it is possible to develop a compact image amplifier with high spatial and temporal resolution; such an image amplifier is being used in the development of an Auger spectrometer and multichannel analyzer of flows of atoms [6].

The author thanks G. P. Romanov for assistance in preparing the MCP.

LITERATURE CITED

1. V. Kh. Likhtenshtein and G. V. Alekseev, "Effect of a magnetic field on channel electronic multipliers and multichannel plates," Preprint IAÉ-3124, Moscow (1979).
2. A. F. Sorokin, "Strong-current microchannel plates for electrooptical conversion of the x-ray range," in: Abstracts of Reports at the All-Union Conference on Visualization of X-Ray Diffraction Images of Defects in Crystals, Erevan (1983).
3. A. F. Sorokin, "Measurement of recording characteristics of microchannel plates," in: Scientific-Technical Conference on NKI, Nikolaev (1982).
4. O. P. Oleshko-Ozhevskii and V. N. Rozhanskii, "Application of x-ray continuous observation vidicons for the study of phase transitions in ferroelectrics," in: Abstracts of Reports at the All-Union Conference on the Visualization of X-Ray Diffraction Images of Defects in Crystals, Erevan (1983).
5. S. Matsuura, S. S. Umebaushi, et al., "Current status of the microchannel plate," IEEE Trans., NS-31, No. 1 (1984).
6. A. F. Sorokin, "Construction of an analyzer for neutral atom flows," Bibliograficheskii Sb. VINITI, No. 2 (1981).

LIMITATION OF CUMULATIVE PROCESSES IN THE COLLAPSE OF A BUBBLE IN A LIQUID

V. V. Ermakov

UDC 532.59

The converging motion of an incompressible liquid is known to result in a local buildup of kinetic energy of the liquid. In such cumulative processes, at least theoretically [1], it is possible for energy to become concentrated in an infinitesimal volume and for infinitely large pressures and temperatures to develop. Obviously, such a cumulative process is always limited in practice by the nonideal nature of the liquid itself; viscosity, thermal conductivity, and compressibility must be taken into account [2, 3]. These effects do not alter the general behavior of the converging flow and play a major role in estimating the physically attainable limiting parameters of the cumulative process. A dimensional analysis shows [4] that such an important cumulative problem as the Rayleigh problem [5] admits the formulation of a cumulative-bounded solution if allowance is made for the thermodynamic properties of the residual gas in the bubble interior. The dynamic flow pattern in this case has been studied in detail in a number of papers [6, 7]. In the present study we discuss the analysis of flow stability in connection with the collapse of a gas bubble in a liquid.

It is usually attempted in the investigation of the motion of an energy-accumulating liquid to obtain a reliable picture of the pressure field inside the liquid [7]. For an in-

---

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 28-30, March-April, 1986. Original article submitted January 23, 1985.