LABORATORY TESTS OF THIN-FILM DETECTORS OF SOLID MICROPARTICLES

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ABSTRACT

Results of laboratory tests of metal-dielectric-metal (MDM) structures used as detectors of solid microparticles in space researches are described. Tests were carried out on electrostatic accelerators with metal particles ~1-10 micrometers in diameter at velocities of 0.1-10 km/s. Polymer films with thin metal coatings deposited on both sides, as far as MDM structures on thick metal base were used as detectors. Thickness of MDM structures was 1-20 micrometers. Dependences of MDM-detector signal amplitudes on velocity and mass of the impact particles were obtained. Total charges of ions emitted from the particle impact area were measured.

1. INTRODUCTION

Thin-film metal-dielectric-metal structures (MDM) are used in space experiments for registration of micrometeoroids and space debris microparticles (Novikov L.S. et al., 1996; Novikov L.S., Voronov K.E. et al., 1997). In this connection, laboratory investigations of MDM-structures with the purpose to obtain a relation between amplitude of MDM-detector signal and velocity and mass of bombarding particles are actual. In the paper, results of test polymer films with metal coatings on both sides, and of MDM-structures on thick metal base are presented. Thickness of MDM-structures was 1-20 micrometers.

Tests were carried out on electrostatic accelerators. The MDM-structures were bombarded with Al, Fe, W, Mo particles of 1-10 micrometers in diameter and velocities 0.1-10 km/s. Dependences of MDM-detector signal amplitudes on velocity and mass of the impact particles were obtained for two operation modes: in absence of breakdown (mode of shock compression of dielectric) and in the case of breakdown.

Also, the total charge of the positive ions emitted from surface of the MDM-detector was measured. Device for registration of micrometeoroid particles and of space debris dust was developed on the basis of the test results. In the device, the MDM-detector matrix with collector of positive ions placed before it is used. The prototype of the device was tested.

2. TECHNIQUE OF EXPERIMENTS

Tests were done on three electrostatic accelerators of Skobeltsyn Institute of Nuclear Physics Moscow State University: 2 cascade generators with accelerating voltages U=0.2 MV and U =0.5 MV and Van de Graaff generator, U=4.0MV (Novikov L.S. et al., 1996). Before acceleration, the particles obtained positive charge in special particle source after contact to a needle having potential 10-20 kV. Velocity and charge of every accelerated particle were measured by means of contactless induction gauges. On the basis of these data, the mass of every particle was determined. It was possible to separate particles by their velocities and masses by means of the high-speed electrostatic gate.

As MDM-structures, polymer films of 2-20 micrometers thickness with metal coatings of 20-50 nanometers thickness deposited on both sides of films. MDM-structures less than 2 micrometers thickness were prepared by deposition of dielectric layer (polystyrene, PMMA) on thick metal base by method of polymerization in high-frequency discharge. Voltage of 100-200 V was applied to metal contacts of the MDM-detectors. Signals from the detectors arising as result of electric current pulse through the MDM-structure after impact of particle were registered. The shape of signals is shown in fig. 1.

On these oscillograms in both cases (a, b), the upper line is signal from contactless induction gauge which is proportional to the particle charge, and the lower line is signal from the MDM-detector. Fig. 1a shows a case of impact of slow particle with large mass, and fig. 1b corresponds to the case of impact of fast particle with small mass. It can be seen that the shape the MDM-detector signal is identical in both cases.

3. RESULTS AND DISCUSSION

The breakdown of thin films was observed visually by means of microscope. In fig. 2, the image of fragment of the thin-film MDM-structure with the holes formed by impacts of microparticles is shown.

In fig. 3, images of two separate craters obtained after bombardment of MDM-structure on the thick metal base are shown.

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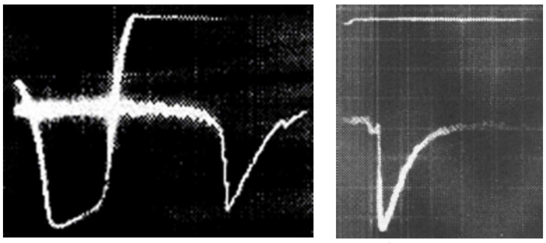


a *b*

Figure 1. Oscillograms of pulses: a – from large low velocity particle; b – from small velocity particle. Charge pulses from contactless gauge are shown on the upper lines on every oscillogram.

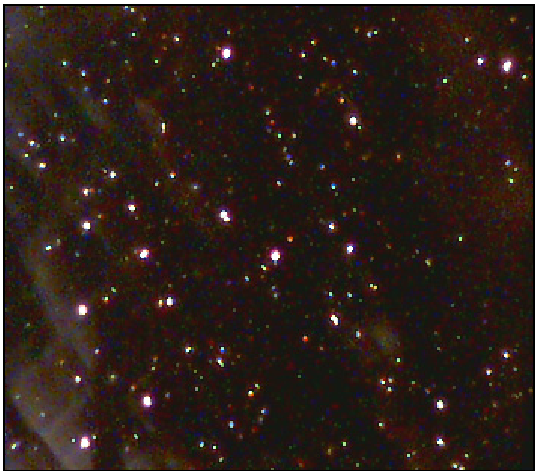
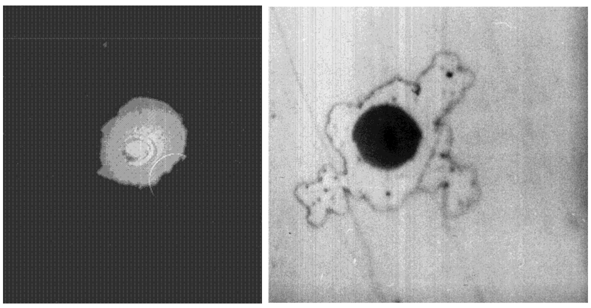


Figure 2. Fragment of the thin-film MDM-structure with the holes formed by impacts of Al microparticles: magnification 60x.

Fig. 3a corresponds to the case of impact of the fast particle. Here, the crater edges have regular enough shape due to melting of metal coating. Fig. 3b corresponds to the case of impact of the slow particle. Here edges of the crater have the irregular shape, and damages of the metal coating are visible. In similar cases, fragments of particles remain in the crater often.



a *b*

Figure 3. Images of craters in MDM-structure on the thick metal base: a – crater from the high velocity particle; b –- from the small velocity particle.

Visual observation of the breakdowns in the films was the one way to determine the detector operation mode. The other way to determine the mode was to calculate the threshold thickness of the film using the following expression:

$$h = k\,\rho^{0.418} m^{0.352} v^{0.875} \qquad (1)$$

where h – the film thickness, cm; v – particle velocity, km/s; m - particle mass, g; ρ - density of the particle material, g/cm^3; k – constant depending on the target material.

In fig. 4, results of experimental research of the breakdowns of the MDM-structure which was polymer film of 5 micrometers thickness with the thin metal coatings on both sides are shown in v–m coordinates. The film was impacted with Al particles. Here, dark circles show cases of the breakdowns, and light ones are cases of absence of the breakdowns. These data are in agreement with results of calculation using the equation formula (1) at v> 2-3 km/s, but deviate from computational results to large masses at v~0.1-2.0 km/s.

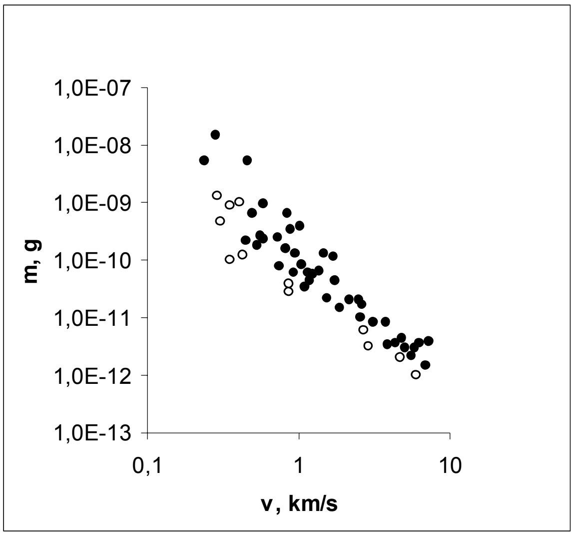


Figure. 4. A relation of velocities and masses of Al-particles in case of breakdown of the polymer film thickness 5 micrometers (black circles), and at absence of the breakdown (light circles).

Dependence of amplitude A of the signal of MDM-detector on mass m and velocity v of particle is featured by the following equation

$$A = c\ m^{\alpha}\ v^{\beta}\ , \qquad (2)$$

where c, α, β - constants.

Such dependences have been obtained experimentally for two operating modes (the breakdown mode and no breakdown mode) at thickness of MDM-structure h = 2 micrometers and h = 4 micrometers. On the basis of these data, values of α and β constants in equation (2) were determined.

For the no breakdown mode $\alpha = 0,28 \pm 0,1$; $\beta = 1,8 \pm 0,1$ (for h = 2 micrometers), and $\alpha = 0,65 \pm 0,1$; $\beta = 1,56 \pm 0,1$ (for h = 4 micrometers). For the breakdown mode $\alpha = 0,25 \pm 0,1$; $\beta = 0,92 \pm 0,1$ (for h = 2 micrometers), $\alpha = 0,65 \pm 0,1$; $\beta = 1,31 \pm 0,1$ (for h = 4 micrometers). The data above were obtained for particle masses m = 10^{-12} – 10^{-10} g, and particle velocities v = 0,3 – 7 km/s. These data are results of taking averages over many individual events.

For revealing the separate influence of the particle velocity and mass on amplitude of the MDM-detector signal, the signals were normalized by mass and velocity. In fig. 5, the ratio of the MDM-detector signal amplitude to particle mass is shown as function of the particle velocity. Lines 1, 3 were obtained at absence of the breakdown of the MDM-structure, and lines 2, 4 correspond to cases of breakdown. Here lines 1, 2 are plotted for MDM-detector with thickness h=2 micrometers at voltage of 100 V on metal contacts, and lines 3, 4 - for MDM-detector with thickness h=4 micrometers at voltage of 200 V. Increase of the voltage on MDM-detector contacts by 2 times at corresponding increase of the MDM-structure thickness was done with the purpose to create electric field intensity in dielectric equal for both cases.

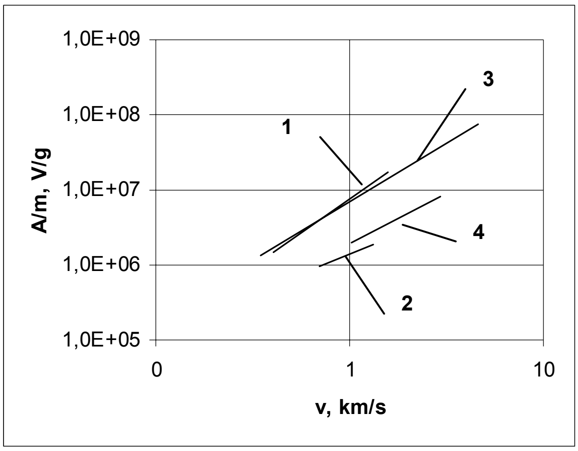


Figure 5. Ratio of the MDM-detector signal amplitude to particle mass as function of the particle velocity.

In fig. 6, ratio of the signal amplitude to the particle velocity as function of the particle mass is shown. Detector parameters and voltages on them are the same that in the previous case.

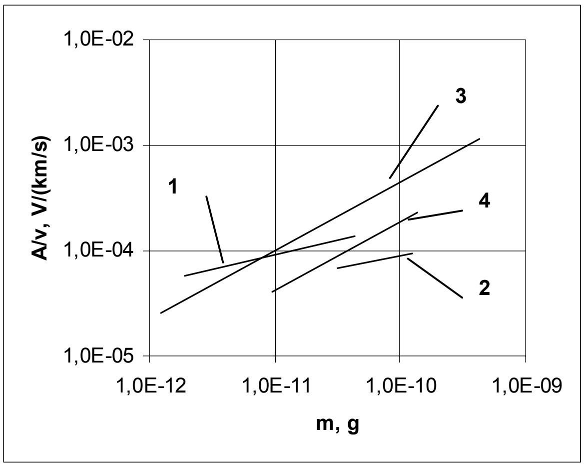


Figure 6. Ratio of the signal amplitude to the particle velocity as function of the particle mass.

Also, emission of positive ions from the area of particle impact was studied. Ions were trapped by meshy collector which was installed in distance of 15-20 mm from the MDM-structure surface. The total charge of emitted ions and velocity of ions were measured. The procedure of measuring of emitted charges is described in (Novikov L.S., Akishin A.I. et al., 1997).

In fig. 7, the total charge Q of the positive ions emitted from the area of the particle impact and flight time T of ions from the target to the collector are presented as functions of the impact particle velocity. Ion flight time from the target to the collector was determined by position of the current pulse maximum in the collector. In the considered case, the distance from the target to the collector was 10 cm. Maximum values of the ion velocities corresponding to data in fig. 5 were ~2 km/s.

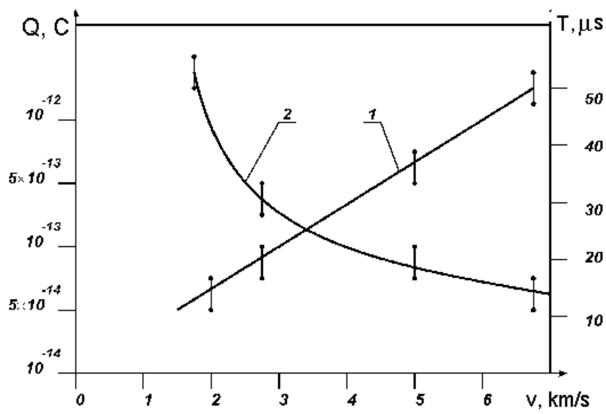


Figure 7. Experimentally determined total ion charge Q (1) and flight time T (2) as functions of the particle velocity.

Note that the data presented in figs. 5-7 are results of averaging over many individual events, too.

It is necessary to highlight especially the case of the MDM-structure breakdown at the increased voltage on metal contacts (U> 300 V). Here, electrostatic mechanism of the breakdown plays the important role in formation of the breakdown channel in dielectric. In this case, the relation of the emitted ions total charge value, and of the time of their motion up to the collector with the particle velocity presented in fig. 5 is violated: the charge increases by 2-3 orders, and the ion velocity in this case can reach 60-70 km/s.

On the basis of laboratory tests of the MDM-structures, the detector representing matrix of ~300 MDM-detectors of thickness h=1 micrometer obtained by means of the mentioned above technique deposition of dielectric on the metal base by the method of polymerization in high-frequency discharge has been designed. The total area of the detector is 400 cm^2.

As the detector above measures three parameters: A, Q and T, we may write system of three equations. It is known that the relation of the total full charge of the ions emitted from the target after the high velocity impact, to the particle mass and velocity is similar to relation (2), but constants have other values: c_1, α_1, β_1. These values are determined on the basis of experimental data. It was shown (Semkin N.D. et al., 1999) that the flight time of ions from the target to collector T depends on the ratio of the particle material density ρ_p to the target material density ρ_t. The relation is characterized by a factor k which is determined from experimental data also.

Taking into account the notes above, it is possible to write the mentioned system of the equations as follows:

$$\begin{cases} A = c\, m^{\alpha} \cdot v^{\beta} \\ Q = c_1 m^{\alpha 1} \cdot v^{\beta 1} \\ T = k\left(1 + \sqrt{\dfrac{\rho_p}{\rho_t}}\right) \end{cases} \quad (3)$$

Apparently, the above system of the equations allows to determine not only values of the registered particle mass and velocity, but the particles density, also. The last is very important because the particle density is criterion for reference of the particles to micrometeoroid particles, or to space debris.

If such device will be used in International space station or in spacecraft providing the return of the detector to the Earth, it is possible to make additional analysis of the remainder of the particle substance in craters by means of various laboratory methods.

4. CONCLUSION

1. Tests of MDM-detectors with thickness 1–20 micrometers aimed at registration of micrometeoroids and space debris microparticles were done on electrostatic accelerators.

2. Pulses from detectors were observed in two modes: at absence of the breakdown, and in the case of the breakdown.

3. Amplitudes of the detector signals as function of the particle mass and velocity were obtained.

4. It is shown that the total charge of the positive ions emitted from the area of the particle impact on the MDM-structure, and ion flight velocity are monotonous functions of the impact velocity. This relation is violated at high value of the electric field intensity in dielectric.

5. On the basis of laboratory research results, the device which operation is based both on registration of the MDM-detector signal, and on measurements of the total charge and velocity of the emitted positive ions was developed for use in space experiments.

5. REFERENCES

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