PARTICULAR QUALITIES OF THE MICROSPHERE PLATE SIMULATION

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Abstract. This paper is the description of the one electron forming processes of the microsphere plate output signal. The main tasks in that description can be detailed as physical representation of the device functioning, electrostatic field counting and simulation modeling of the secondary electron emission avalanche. The results of the modeling have shown the influence of the plate gain on the beads density, or porosity and the thickness of the plate.

1. Introduction

The microsphere plate (MSP) is the compact electron multiplier, which has form of thin (near one millimeter in thickness) porous plate of 20 - 100 mm in diameter. It consists of the large amount of tiny lead glass beads of 40 – 50 µkm in diameter fused together. The beads are almost uniform. The surfaces of them are covered with the semiconductive material. Both of the plate output sides have conductive layer. A voltage of 3 kV is applied to these sides. Investigated particle or radiation enters the input surface of the device and creates a secondary electron emission avalanche. This avalanche becomes larger and larger while moving in the paths between the beads under the applied voltage.

This novel electron multiplier has found its applications in vacuum system for detection of charged particles: particle-imaging, time-of-flight mass spectroscopy, particle counting, ion-beam monitoring, and electron microscopy; for UV and X-ray imaging and in the photomultipliers.

The forming processes of the output signals MSP represent themselves a very complicated system, while description of which it is necessary to take into account the interaction of a big amount of the factors. Firstly an incident particle comes to the entrance of the device, this particle has its own mass, energy, angle and trajectory of arrival. Then the system of the beads is very complicate. These beads consist of lead glass and covered by semiconductive layer, so the properties of them are between isolator and semiconductor. To describe the electrical field distribution inside of the system it is necessary to take into account this specific factor, so the isolator can influence the electrical field forces and hence an electron moving. Every secondary electron, which appears on the surface of a bead, has its own characteristics, such as a place, energy and an angle of its taking of the bead and the acceleration of its flight in the particular that part of the plate. While the secondary emission process is going on there are a lot of electrons with their many characteristics (time and three dimensional space coordinates) are in the system. More of that, if the collision of the first electron with a bead is on its top the new secondary electrons will never make the avalanche, because they cannot fly from the bead they were born so it is no need to count them but they are kept in the computer. But the computer memory is limited and the time, which needed to adapt all those characteristics, is very long. There are some publications devoted to that device, for example[1, 2], but there is no good description of its functioning. We think that is connected with all of those problems and this paper is the first part of our seeing and solving the question of that account. The first question is the description of the electrical field in the device with taking into consideration the isolator beads, which the system is consisted of. The next question to be solved is the number of the secondary electrons in the system with a big amount of their characteristics. We have algorithmically constructed the statistical tree and began its counting. The last question is the representation of the results of the modeling.

2. The electric field calculation

The calculation of the electrostatic potential and intensity for the arbitrary-shaped inhomogeneous dielectric medium with open boundary conditions was formulated in the integral form. Continuous distribution of the charge density on the dielectric border is replaced by the fictitious discrete charges that are placed inside the dielectric and the values and locations of them are chosen to satisfy boundary conditions. Denote E_i , ε_i and φ_i as the intensity, the dielectrically penetration and the potential of the electrical field accordingly (see .Fig.1).

The electric intensity value of material is inversely to the permittivity of that material. At the one-dimensional case for the normal component of the electric field the phase boundary with the total number i $(1 \le i \le \infty)$ looks like:

$$\frac{E_{i-1}}{E_{i+1}} = \frac{\varepsilon_{i+1}}{\varepsilon_{i-1}} \tag{1}$$

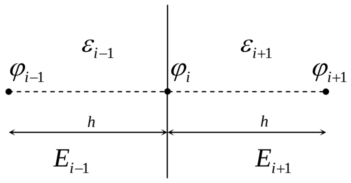

Fig.1. *Normal components of the electrical field on the phase interface for the one-dimensional case.*

So in the common form the electric field voltage and its intensity are equal as

$$E_{i-1} = \frac{\varphi_i - \varphi_{i-1}}{h}, \tag{2}$$

where h is the distance between φ_{i-1} и φ_i.

By substituting (1) into (2) we can get:

$$\frac{\varphi_i - \varphi_{i-1}}{\varphi_{i+1} - \varphi_i} = \frac{\varepsilon_{i+1}}{\varepsilon_{i-1}}, \tag{3}$$

or:

$$\varphi_i(\varepsilon_{i-1} + \varepsilon_{i+1}) - \varepsilon_{i-1}\varphi_{i-1} - \varepsilon_{i+1}\varphi_{i+1} = 0 \tag{4}$$

At one-dimensional case, when moving along the one axis the phase boundary always automatically crosses with the normal angle, hence (1) is always right, that is why (4) is right too. At the three-dimensional case with bricks space discrimination all the borders between two neighbor points cross with the normal angle. For the every point of the space the boundary condition for the normal component of the electrical field has the view of the linear equation system at the phase boundary:

$$\begin{cases} \varphi_{xyz}(\varepsilon_{x-1} + \varepsilon_{x+1}) - \varepsilon_{x-1}\varphi_{x-1} - \varepsilon_{x+1}\varphi_{x+1} = 0 \\ \varphi_{xyz}(\varepsilon_{y-1} + \varepsilon_{y+1}) - \varepsilon_{y-1}\varphi_{y-1} - \varepsilon_{y+1}\varphi_{y+1} = 0 \\ \varphi_{xyz}(\varepsilon_{z-1} + \varepsilon_{z+1}) - \varepsilon_{z-1}\varphi_{z-1} - \varepsilon_{z+1}\varphi_{z+1} = 0 \end{cases} \tag{5}$$

Since all three equations of the system (5) are independent and their right parties are equal to zero we can add them up:

$$\begin{aligned} &\varphi_{xyz}(\varepsilon_{x-1} + \varepsilon_{x+1}) - \varepsilon_{x-1}\varphi_{x-1} - \varepsilon_{x+1}\varphi_{x+1} + \\ &+ \varphi_{xyz}(\varepsilon_{y-1} + \varepsilon_{y+1}) - \varepsilon_{y-1}\varphi_{y-1} - \varepsilon_{y+1}\varphi_{y+1} + \\ &+ \varphi_{xyz}(\varepsilon_{z-1} + \varepsilon_{z+1}) - \varepsilon_{z-1}\varphi_{z-1} - \varepsilon_{z+1}\varphi_{z+1} = 0 \end{aligned} \tag{6}$$

From the last equation we can find φ_{xyz} and write down different scheme for electrostatic field counting:

$$\varphi_{xyz} = \frac{\varphi_{x-1}\varepsilon_{x-1} + \varphi_{x+1}\varepsilon_{x+1} + \varphi_{y-1}\varepsilon_{y-1} + \varphi_{y+1}\varepsilon_{y+1} + \varphi_{z-1}\varepsilon_{z-1} + \varphi_{z+1}\varepsilon_{z+1}}{\varepsilon_{x-1} + \varepsilon_{x+1} + \varepsilon_{y-1} + \varepsilon_{y+1} + \varepsilon_{z-1} + \varepsilon_{z+1}} \tag{7}$$

Binary-criteria task of the selection of the space discretization step, which satisfied accuracy and calculating speed requirements, was experimentally solved. This step was equal to the half of the radius minimum of the bead in compact packing and accuracy of the calculation had to be not more then 1e-5.

3. Avalanche counting of the secondary electron emission

The first electron, which appears on the surface of any bead, has an acceleration a_i of the applied electrical field. The step of time discretization dt is not constant and depends on the step of space discretization h, speed and acceleration of an electron:

$$dt = -\vec{\upsilon}_i + \frac{\sqrt{\vec{\upsilon}^2 + 2h\vec{a}_i}}{\vec{a}_i}, \tag{8}$$

where v_i is the initial velocity of the i-electron.

If we know the initial coordinates, speed and acceleration of an electron on i-iteration, we can calculate its position after time period dt:

$$\vec{r}_{i+1} = \vec{r}_i + \vec{\upsilon}_i t + \frac{\vec{a}_i dt^2}{2} \tag{9}$$

$$\vec{\upsilon}_{i+1} = \vec{\upsilon}_i + \vec{a}_i dt \tag{10}$$

So it is possible to calculate the motion of all electrons in the system. After every of that computation we are checking out whether the electron cross a new bead, or it get the end of it. If the crossing was out, so we calculate the next position of that electron. If the electron gets the end of packing, so we collect the statistics. When the electron arrives at the new bead we calculate the number of the secondaries, which our electron can beat out of that bead. The electron speed is the input parameter for the secondary emission yield calculation. After that calculation we suppose that this electron is not in the system. The result of that calculation is the number of new electrons, their coordinates and speeds. New electrons are added to the list, and then we calculate the coordinates and speed of the next electron from the list.

The number of the secondary emission yield was calculated as [1]:

$$\delta = \frac{E_f \times \tau}{E_g \times V \times dt \times n_{st}} \tag{11}$$

where n_{st} is the stationary leakage current, E_g is the band gap of the semiconductive layer of the beads, V – the bead's volume, which exited by the primary electron, τ – the life time of the electron-hole pare in the layer of the bead; E_f is the energy of the falling electron, which connect with the speed that the electron has in the field.

We suggested that the initial coordinates and the time of appearance on the surface of the bead for the secondary electron were just the same as ones for the primary electron disappeared. The direction of the initial electron was accidental with cosine distribution [1]. The average of that distribution is concurred with the perpendicular to the bead. The energy of the fly out electron E_{el} was distributed by the Reley partition law [**Ошибка! Закладка не определена.**]. The average of that distribution was the input parameter of the modelling program. The speed module calculates from that energy.

4. The list and the tree using

While program running the number of calculated electrons with their characteristics changes all the time and it is impossible to know the maximum of the electrons, which is necessary to keep in the operative memory of the computer. In that case it is very advantageous to construct the list instead of the simple data massive. It is well known that the constrained list is the set of the consistently organized data. When using it there is no need in the preliminary allocation of the computer memory [5]. This memory is added when the new electron is appeared and automatically cleared when the electron was deleted. The procedure of adding, deleting or reading out of the parameters of an electron is simple enough and not more complicate then all those processes for the data massive.

In the program it was implemented by us the two-forked list with two peaks. We have constructed the structures "TElectron" и "TElectronList". The fields of the "TElectron" – structure are: the time, three coordinates and three tangential speeds of the electron in the Deckart coordinate system, pointer to previous and following electron in the list. The structure "TElectonList" keeps the number of the electron in the list and the pointers to the beginning and the ending of the list.

We have algorithmically represented the electron avalanche in the system as a form of the tree. The root of that tree is the first electron, which appeared on the surface of the one of first beads and which is the beginning of the avalanche. The beginning of the branch is the electron born. The end of the branch is the electron crossing the new bead. The node of the branch is the falling electron energy transformation into the secondary emission yield. The node power is the secondary emission yield. The ending node (or the leaf) is the electron, which leaves the MSP. The tree is balanced because the highs of the all sub-trees statistically are equal (so called ALV-tree). The height of the tree H_{tree} is the mean distance between the root and the leaves.

If the electron is added to the list "TElectonList" in the only peak and the next in turn is taken for the counting from the other peak, so the tree are calculated by level to level. The tree are calculated by the height, if the electrons are added and taken for calculation from only one peak (the direct order of the tree treatment). The second case is hander for using in our case because we can quickly enough estimate the second emission coefficient distribution by the height of the tree and conclude the time uniformity of the existent processes. But in that case it is difficult to take into account the electron influence into the common electrostatic field and reconstruct the picture of the forming processes in the real time.

The retention all the data $Y\{y_1, y_2, y_3, \dots y_C\}$ in the computer memory is impossible because of the big amount of them, but it is possible to keep the data massive size of $L<C$. That is why we have suggested the algorithm of the resampling down of the incoming data and get the representative sampling $X\{x_1, x_2, x_3, \dots x_L\}$, without keeping the whole massive $Y\{y_1, y_2, y_3, \dots y_C\}$. The first L means y_i are consecutively noted into the massive $X\{x_1, x_2, x_3, \dots x_L\}$. After that every new incoming mean of y_i is written into the massive with the possibility of L/i by equiprobability replacing one of the relevant element. Resampling data X are physi-

cally and logically written in the memory location, which is used for the keeping of the non-resembling data *Y* [6].

5. The results of the modeling

The thickness of the plate was changed from 0,35 mm to 0,9625 mm with the step of 0,0875 mm and the applied voltage was changed too from 1,5 kV to 4,125 kV with the step of 0,375 kV, so that the initial plate intensity was constant. For every point there was taken 7 experiments and the results were averaged. From the picture it is possible to see that the gain of the plate is increasing with extension of thickness of the plate.

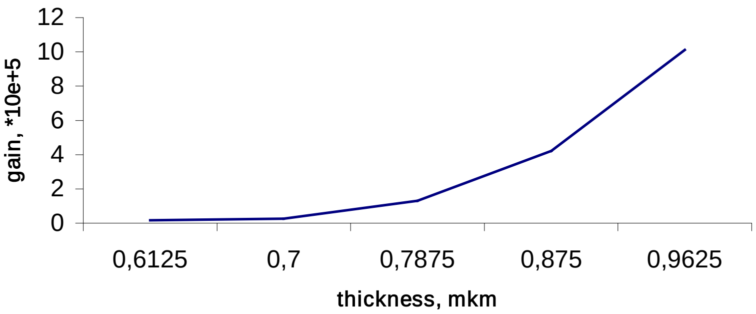

Fig.2. *The MSP gain dependence on the thickness of the plate*

The next experiments were taken with the purpose of the defining the gain dependence on the porosity. The results of these experiments are in the Fig.2. The porosity of the plate was changed from 0,75 до 0,4 with the step of 0,05. For the every point there were realized 7 experiments in the middle. The results of these experiments were averaged and the graphic of them is in the Fig.3.

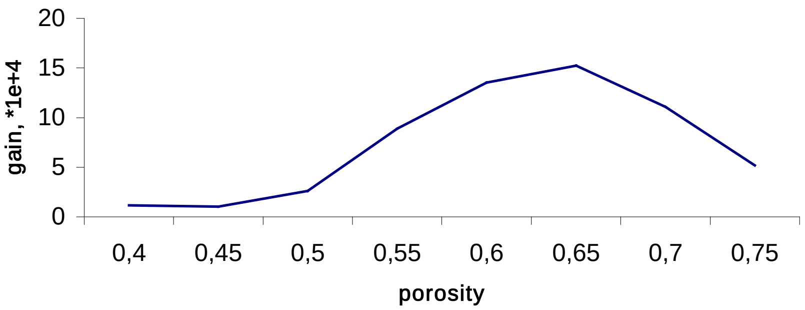

Fig.3. *The gain dependence on the porosity*

It is possible to see from the picture that the dependence of the gain has extreme. We can explain its appearance by interdependence of two factors. From the one side the length of the free electron running increases with the extending of the porosity and hence the energy of falling electron on the bead increases too so the number of the secondary electron enlarges also. From the other side, the number of the bead becomes less with the increasing of the porosity on the way of the electron avalanche. This leads to the decreasing of the collision acts number. The gain of the plate connects with the mean value of the secondary emission yield $\delta_{\exp}$ as:

$$K = \overline{\delta}_{\exp}{}^{H_{tree}}, \tag{12}$$

where H_{tree} is the height of the electrons tree.

6. Conclusion

This work is the first in our analysis of the microsphere plate functioning and its specifications. While modeling this device we saw a lot of problems. Some of them we have solved: a task of the electrostatistic field description, the secondary emission process and the beginning of the statistical tree account. In the closed future we are going to investigate the influence of the electron avalanche into the secondary emission process, the gain influence on the flaws in the bead structure, on the applied voltage, the output picture of the fly out electrons from the plate, etc.

7. References

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