Experience in computer design of microchannel amplifiers

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Abstract

The experience of computer-aided design of microchannel amplifiers as fast photo detectors of modern charged particle accelerators is generalized. All aspects of the design of devices from the photocathode to the collector are considered, including the issues of thermal stability, the influence of noise, saturation effects, edge fields, dark currents and the operation of amplifiers in strong magnetic fields. A review is given of modern analytical, numerical and mixed mathematical models used in modeling amplifiers that detects signals in a wide range of radiation - from infrared to x-ray. Comparison of simulation results with experimental data for four major Russian and foreign projects presented in monographs [1-2].

Introduction

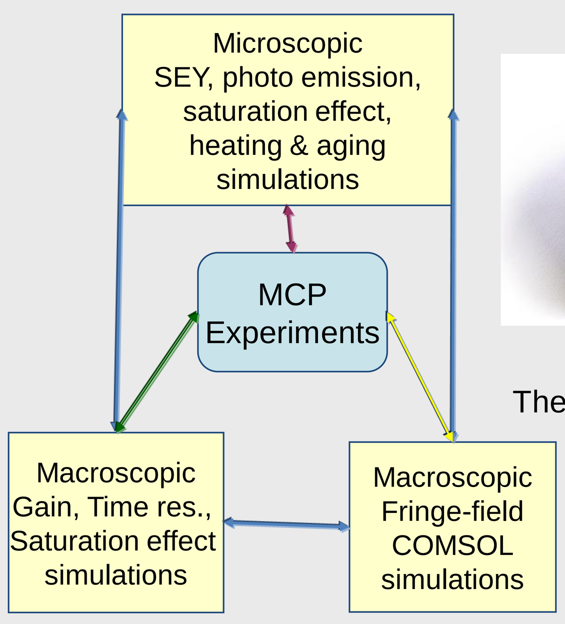
Theoretical studies of secondary electron emission yields (SEY) are necessary as a preliminary step of the development of new emissive materials for MCP-based particle detectors in high-energy physics, such as Cherenkov, neutrino, and astro-particle detectors. Secondary electrons also play a significant role in the development of new scanning electron microscopes and night vision devices.

The goal of the computer design is to develop a parameterized set of the SEY dependencies in two variables, the energy of the primary electron and the angle of incident electrons for lead glass. This parameterization can be done by using results obtained from Monte Carlo calculations with the original code MSC3D.

End-to-end MCP amplifier design should include the influence of many important physical effects:

- •Photo emission;
- •Secondary electron emission;
- •Cold emission
- •Saturation effect;
- •Thermal stability;
- •Ion background;
- •Space charge effects;
- •Fringe field effects;
- •Dark current effects;
- •Thermal, shot and flicker noise;
- •Strong external magnetic field;
- •Inter channels effects.

The common way to get the data on the material emission properties is computer simulation based on Monte-Carlo algorithms for numerical models of molecular dynamics using the code "CASINO"



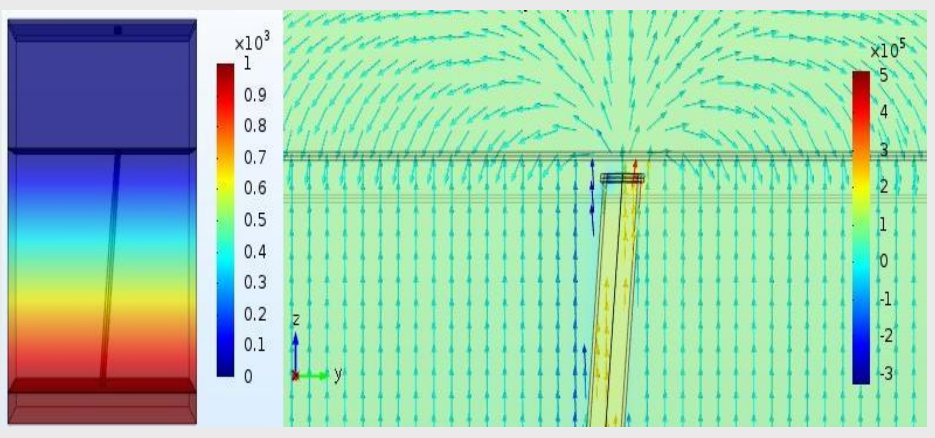
Simulation work chart

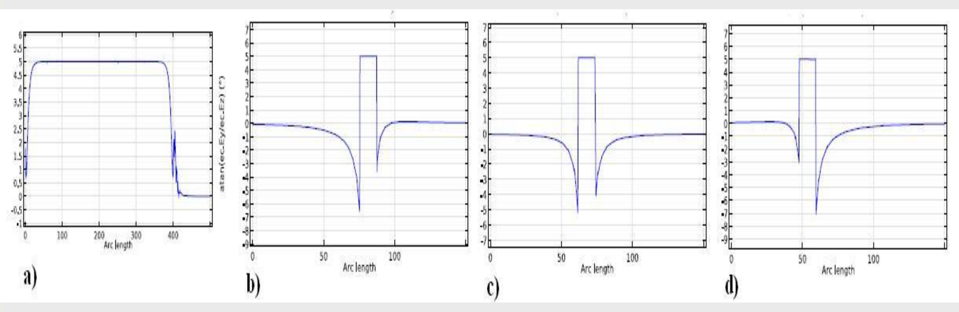

The assembly of the MCP amplifier.

Fringe fields simulations in 3D

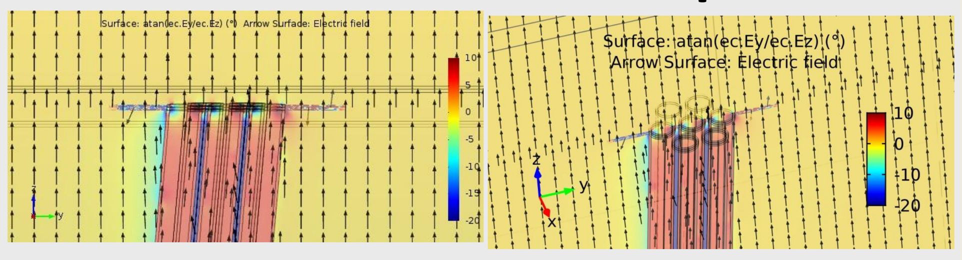
The electric field inside the MCP pores was simulated using the multi-physic COMSOL to study the photoelectron collection efficiency. The simulations show that in a highly-conductive environment, the electric field in the pore is directed axially inside the pore, having a gradual turn from the value in the resistive layer near the surface.

One-pore modeling

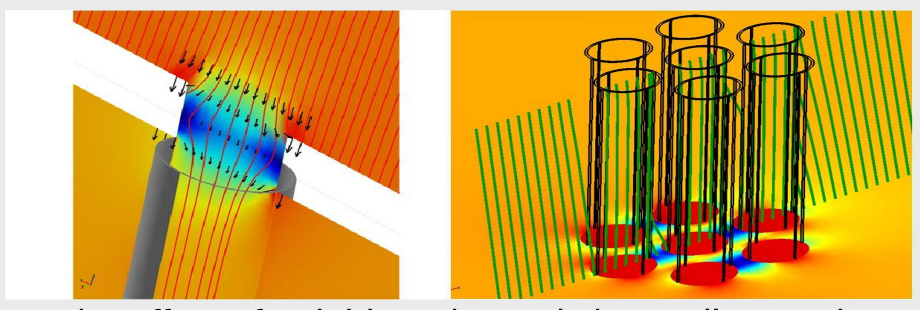

Potential distribution (left) and the electric field stream-lines in the gap, in MCP body and in in the pore.


Edge effect for the electric field: a) on the pore axis; b) in upper cross-section; c) in the middle cross-section; d) in the bottom cross-section

Electric field inside 7 pores

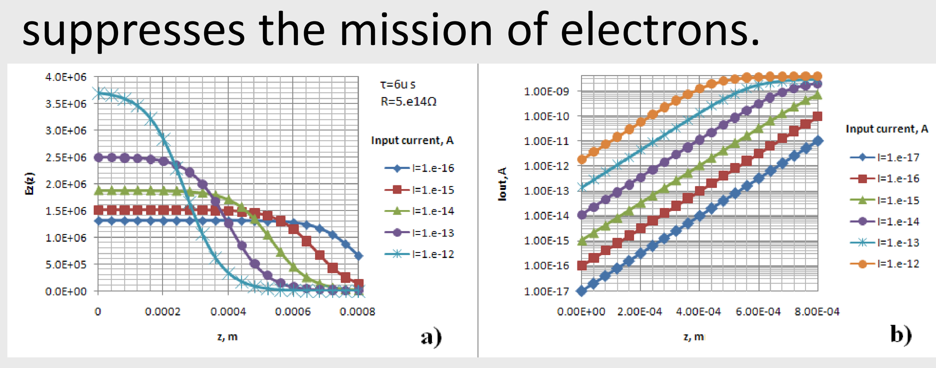

Vector field in a cross-section

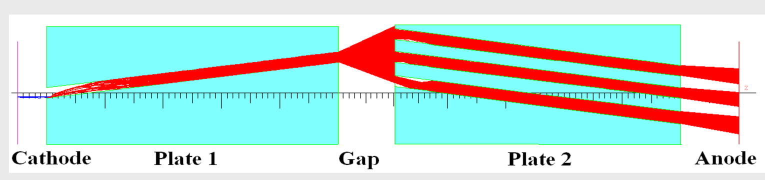
Vector field in a bunch of seven channels


The effect of neighbor channels is small enough

Saturation effect

When the pulse signal is amplified for large gain factors, the so-called "saturation effect" takes place. The essence of this effect is that the cascade multiplication of secondary electrons increases exponentially along the channel; therefore, for a short input signal, a dense electron cloud breaks out from the channel exit, and since the channel resistance is quite high, then for some the time τ in this region is formed by an induced positive charge, which suppresses the mission of electrons.

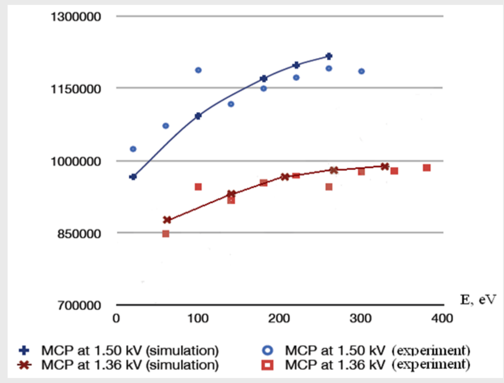

(a) Distribution of the field in the channel for different values of the current at the input; (b) Output current profile in the channel for different values of the input current.

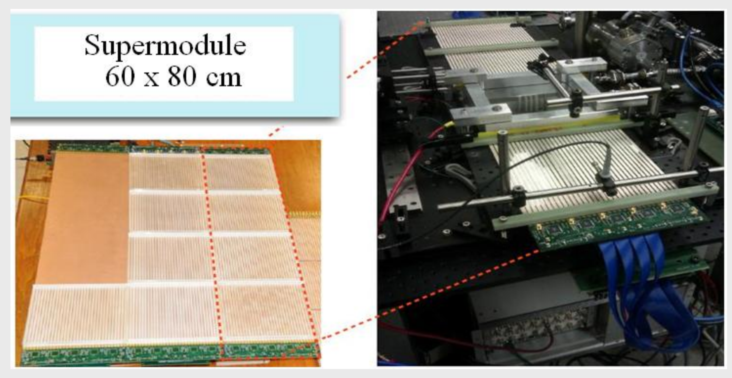


Charge relaxation time v s. the Gain M. $M = 3.4E^6$ for $\tau = 1$ μsec, and $M = 1.13E^6$ for $\tau = 1$ msec. Large inter plate gap redistributes the secondary electron flow in between the neighbor channels.

Large-area Pico second Photo Detector Project

In 2009 the US developed a project to create a large-area photo detector of picosecond time resolution and sub millimeter spatial resolution. The aim of the project was to create a prototype of an universal module based on MCP of large area (20 x 20 cm) with a gain factor of about 10^7, with a temporal resolution of less than 10 psec and a spatial resolution of less than a mm, which can easily be integrated into super modules of an arbitrary size.

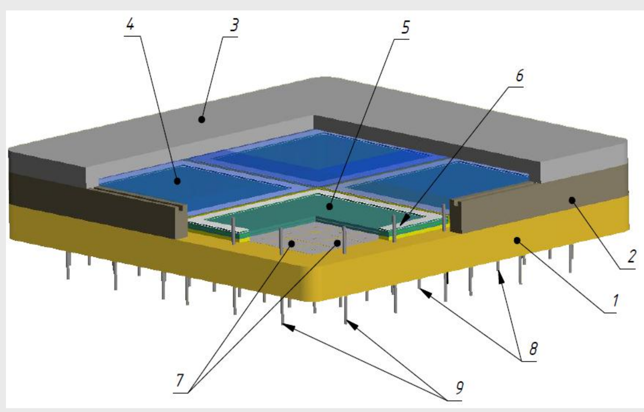

Numerical (solid lines) and experimental (circles and squares) results for the averaged gain at 1.5 kV (blue) and 1.36 kV (red color) of applied voltage on the MCP vs. the first strike energy *E*.



The configuration of the supermodule of 12 modules (on the left) and the universal module of 20 x 20 cm (right).

Finally, the use of photo detectors of the picosecond range began to expand with growing interest in many scientific and commercial applications. The use of measuring the coordinates of arrival of photons or charged particles both in time and space was investigated in water Cherenkov counters, medical imaging, neutrino and beta decay studies. In Fermi Lab, the ANNIE experiment was created to conduct the tests of the use of LAPPD™ modules [3-4].

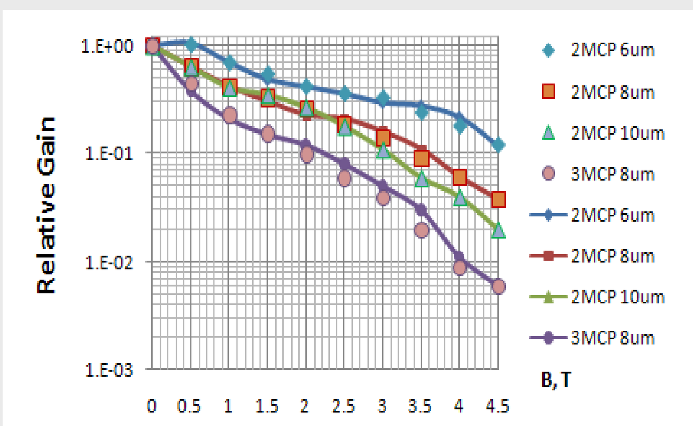
The Photo Detector Project of BINP SB RAS

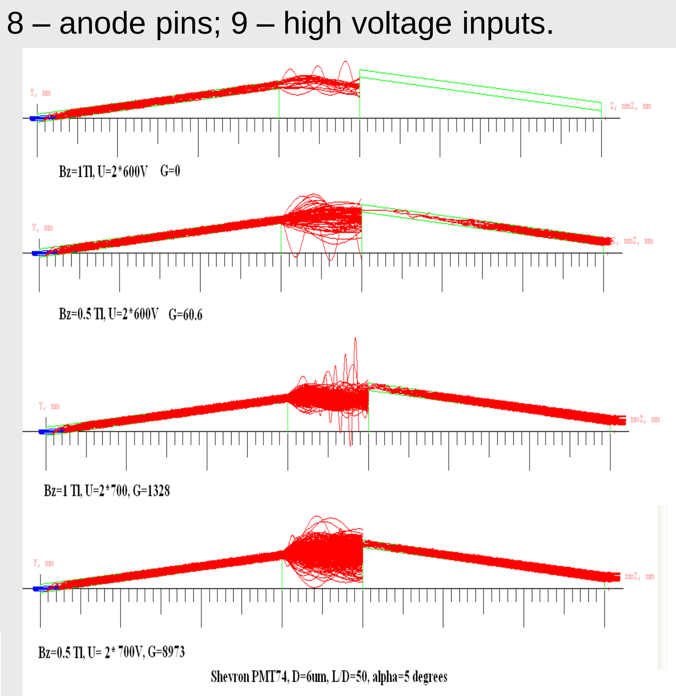


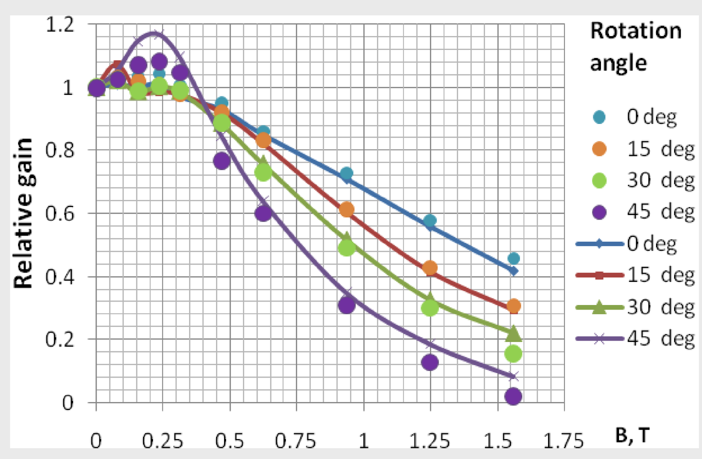
Type	Name	Channel diam. D, μm	Caliber L/D	Bias angle, °
Single	89664	12.5	160	5
Chevron pair	74	6	50	5
Chevron pair	88353	7	40	13
Chevron pair	82015	10	40	5
Z-stack	418	7.5	43	5

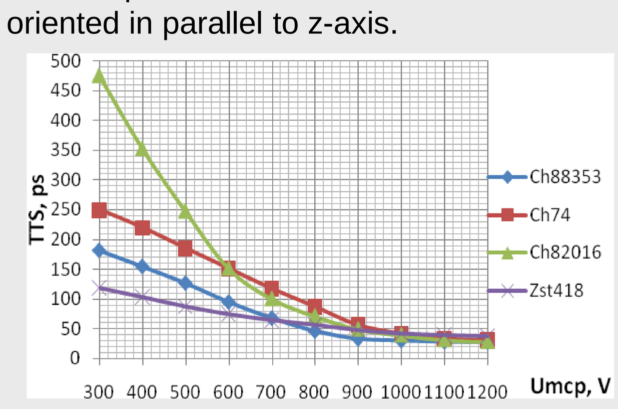
Parameters of the examined MCP assemblies

Lay-out of the 130x130 mm detector: 1 – ceramic frame; 2 – metallic wall; 3 – metallic cover; 4 – Cherenkov radiator with sputtered CsI photocathode; 5 – 2x2 matrix of the MCP chevron pairs; 6 – ceramic spacer; 7 – anode platforms; 8 – anode pins; 9 – high voltage inputs.


Dependence of the relative gain on the magnetic field. Solid lines - experiment, markers - numerical calculations.


Trajectories shape variations for the chevron 74. Umcp =1200 -1400 V, B= 0.5 - 1 T oriented in parallel to z-axis.


Angular dependence of the relative gain on the magnitude of the magnetic field for z-stack MCP. Experiment - solid lines, numeric data - circles


Dependence of the time-of-flight spread on the voltage applied to each plate.

Computer code "Monte Carlo Simulator 3D" under Linux and Windows platforms

The code MCS is full 3D simulator with friendly user's interface and graphical post-processor. Numerical models include the angular, energy and spatial distributions for photo- and secondary emitters. They include also the fringe fields, saturation effects and other features representing different multi-layer materials. The code can provide the end-to-end numerical design in order to evaluate all needed parameters of realistic MCP devices: gain, transit time spread, angular, energy and spatial distributions of photo- and secondary electrons in pre defined cross-sections. Typical CPU-time for simulation of 1 million particles is 1 to 10 minutes at desktop or laptop computer with 1.8GHz CPU. The massive computations of. statistical properties of amplifiers demand parallel computations at super computers or PC-clusters.

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[3] M.Wetstein, B.Adams, M.Chhollet et al. Systems-Level Characterization of Microchannel Plate Detector Assemblies, Using a Pulsed sub-Picosecond Laser. Physics Procedia 00 (2012) 1–9.
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[6] A. Barnyakov, M. Barnyakolv, V. Blinov et al., Development of a picoseconds MCP particle detector, NIM A, 952 (2020) 161831.