Modeling and Development of BMCP Detector

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Abstract: In this research article, the micro-channel plate detector has been developed which can detect passage of high energy particles through thin film producing several secondary electrons. The micro-channel plate detectors are used in a time of flight-energy telescope for the mass identification of binary products of the nuclear reaction. The designed MCP detector is comprised of conversion foil, reflecting mirror, supporting screws, and a base. The passage of ions through conversion foil produces secondary electrons which are reflected down by the reflector before the detection. The working of BMCP designed at BARC is tested with Strontium-90 (β source). The best feature of Micro Channel Plate detectors is its low value of full time constant which is less than 2 nano-seconds.

Keywords-Micro-channel plates, Photo-multiplier tubes, Detectors, Accelerator driven systems, Heavy ions energy measurement.

I. INTRODUCTION

Scientist and researchers are eager to study the details of the exotic nuclei which have number of neutron to proton ratio higher than those situated on the stability line. Such studies can not only help us to understand novel nuclear properties and thus enrich our knowledge of atomic nuclei, but also reveal the origin of chemical elements in the nucleosynthesis processes. Several radioactive ion beam facilities being built to experimentally make accessible the more number of unstable exotic nuclei. The qualitative analysis of exotic nuclei requires the detailed knowledge of the masses, their production rate and beta decay characteristics. A novel time of flight spectrometer can be used for such as purposes. In mass spectroscopy, micro-channel plate detectors with electrostatic mirror are used.

The most important milestone in the development of the detectors is the photoelectric effect formulated by Einstein in 1905 [1]. Then period of more than 25 years was required for the development and commercialization of photomultiplier tube in RCA laboratories. Significant work in the development of solid state single photon detector was done in 1960 by McIntyre [2] and by Haiz [3].Gieger-mode avalanche diodes which are used to detect the photons has been described by Renkar [4], but these detectors suffer from dark count and after pulses. In photomultiplier tubes, photons are converted in electrons by photocathode and subsequently electrons are amplified. Some of following advantages of micro channel plate (MCP) detector over Silicon photomultipliers tube (Si-PM) compels users selection of MCP based detector.

First, they have small transit time for passage though micro channels (about few nano-seconds) with compare to 20-50 nano-seconds caused by photomultiplier tube (Fig.1). Second, the spread in time that determines the time resolution of the detector is very small (about 100 ps) which is faster by the factor 2-3 times required by photomultiplier tube. Recently, Roy et. Al have reported a time resolution of 188.8 picoseconds for SiPMs (silicon photomultipliers) [5]. For the same vacuum condition, PM tubes are susceptible to electromagnetic radiation and their gain is limited to 10^5 to 10^7 electrons, on contrary the gain offered by micro channel plates is unconstrained, as the gain depends on number of micro-channel plates cascaded together [6].

Fig.1 Schematic for a single channel inside micro channel plate

Several methods and techniques are used for identification and study of fission fragments in heavy ion induced nuclear reaction studies. One of the methods for measuring a mass of nuclear reaction product is using the conservation of momentum and energy, in which velocity and kinetic energy of both the reaction products are measured simultaneously to resolve fragment mass. This technique is also referred by “2V,2E” method [7].

In this work, we report the design, fabrication and initial test results of MCP based TOF spectrometer that can be used at Pelletron-LINAC facility for Heavy Ion fission reaction studies.

II. DESIGN OF MICRO-CHANNEL PLATE DETECTOR

A micro-channel plate is a thin slab manufactured with highly resistive material with a periodic array of micro tubes or slots (Micro-channels) extending from one face to the other face. This periodic array of micro tubes is densely spread over the whole surface of the micro-channel plate. Generally, the diameter of the micro-channels is 5-10 micrometers. Lower the diameter of channels, higher will be the resolution of MCP detector. All these channels are parallel to each other throughout the length and are separated apart by approximately 15 micrometers distance inside a microchannel plate. The shape of the micro-channel plate can be either in the form of circular disk (Fig. 2) or rectangular plate (Fig. 3).
In order to avoid the background noise radiation, BMCP make use of collimator in the front side of the detector. The MCPs are fitted below the foil-clad-glass cloth laminate triangular frame and above metalized anode. Three stainless steel metal screws are soldered at the corners of triangular frame. The threads of these screws have pitch of 0.5 mm. This winding which touches three screws, acts as ground plane for the electrostatic mirror. Another set of turns of copper beryllium wire is wound horizontally on the triangular structure to form upper face of the electrostatic mirror. The copper beryllium wire is wound with a pitch of 1 mm on the mirror. After passing through the collimator, the incoming particles fall on to the conversion foil where secondary electrons (SEs) are generated. A thin Carbon or Aluminum foil of thickness ~20μg/cm² can used for producing secondary electrons. These generated SEs are accelerated by the conversion foil in the forward direction by the electric field formed between the conversion foil and the ground plane (Fig. 4).

There are two micro channel plates placed in series to amplify the number of SEs. The total electron gain of the two micro-channel plates is 10⁷. The SEs which are released from conversion foil travel in straight path before hitting the electrostatic mirror which is inclined at 135° with respect to horizontal axis [8]. As SEs approach the electrostatic mirror, the vertical component of the field bends the electron beam downward at 90° before the detection. The bunch of electrons coming out from micro-channel plates are collected by metal anode. The Fig. 4 shows the schematic for BMCP detector and Fig. 5 shows the corresponding assembly.

III. EXPERIMENTAL SETUP

The external harp of electrostatic mirror is wound inside the groves of foil-clad glass-cloth laminate support plate in the form of triangular shape. The conversion foil and external harp of electrostatic mirror are at potential of V1 and V2 respectively [9]. The biasing circuitry for BMCP detector is shown in the Fig. 6. In Fig.6, D1, D2, D3 indicate micro-channel plates & metallic anode respectively. Each one of them are biased through power supply unit. The components C1-C7 form the biasing circuitry for BMCP detector. P1, P2, P3 are datum, accelerating and mirror potentials respectively. C4 is regulated power supply and C6 is the potentiometer to adjust the power supply voltages. The horizontal arrow represents the path of the secondary electrons.
A. Trajectory Traced by Secondary Electrons

Let \( r(t) \) be the position of secondary electron ejected out from accelerating foil in the detector.

\[
\frac{d^2r}{dt^2} = \frac{q}{m} F(x, y) \frac{\partial F}{\partial x} + \frac{q}{m} F(y, y) \frac{\partial F}{\partial y}
\]

where \( F(x, y) \) and \( F(y, y) \) are field components with respect to \( x \) and \( y \).

Lemma 1: Prove that the potential \( P(x, y) = \frac{4\pi \lambda (d_1 + y)}{c} + 4q \int_{0}^{\infty} \left[ \frac{\cos(2\pi x)}{c} \right] \left[ \sinh \left( \frac{2\pi(d_1 + y)}{c} \right) \right] dx \)

Proof:

Consider a drift chamber as shown in Fig. 7 in which single wire from the grid is placed at central position \((0, 0)\).

![Drift chamber diagram](image)

**Fig.7** Drift chamber to find potential field due to single wire with grounded conductors

The faces of this drift chambers along \( x \) direction are grounded electrodes where as faces along \( y \) direction are dielectrics; the field lines are parallel along the dielectric surfaces. Here \( d = d_1 + d_2 \), and \( q' \) is charge of the wire per unit length. The field lines are parallel to surfaces \( x = \pm c/2 \) \([10]\). On the left side of wire is region \( y < 0 \) and on the right side is the region \( y > 0 \).

Here, the boundary conditions are,

\[
P(x, d_1) = P(x, d_2) = 0 \quad \frac{\partial P(x, 0^+)}{\partial x} = \frac{\partial P(c/2, y)}{\partial x} = 0
\]

According to Gauss’s law,

\[
-\frac{\partial P(x, 0^+)}{\partial y} + \frac{\partial P(x, 0^-)}{\partial y} = 4\pi q' \delta(x)
\]

The Fourier series expansion for the potential satisfying the boundary conditions is

\[
P(x, y > 0) = A_0 d_1 (d_2 - y)
\]

\[
+ \sum_{i=1}^{\infty} A_n \cos \frac{2\pi x}{c} \frac{2\pi d_2}{c} \sinh \frac{2\pi d_1}{c} \sinh \frac{2\pi d_1}{c}
\]

\[
P(x, y < 0) = A_0 d_2 (d_1 + y)
\]

\[
+ \sum_{i=1}^{\infty} A_n \cos \frac{2\pi x}{c} \frac{2\pi d_1}{c} \sinh \frac{2\pi d_2}{c} \sinh \frac{2\pi d_2}{c}
\]

Using condition 7, the coefficient \( A_0 \) and \( A_n \) can be found out as,

\[
A_0 = \frac{4\pi \lambda}{cd} \quad A_n = \frac{2q'}{\sinh \left( \frac{2\pi d_1}{c} \right)}
\]

B. Simulation Results

Simulations for electron trajectories inside the focusing element have been performed and optimum voltage across the electrostatic mirror grids was decided accordingly. The effect of change in mirror potential was observed on the trajectory of charged particle. A charged particle is passed through electrostatic mirror operating at four different voltages \( V_{R1}, V_{R2}, V_{R3}, V_{R4} \) with ascending magnitude \( V_{R1} < V_{R2} < V_{R3} < V_{R4} \). As can be clearly seen, when mirror voltage increases, the angle of deflection increases in negative direction (Fig.8).
In second scenario (Fig. 9), at optimum value of the reflector voltage, three SEs with different initial velocities \( V_0(1 \pm \delta) \) are bent down at 90° [11], where \( \delta = 0.1V_0 \).

Several simulations were performed by applying different accelerating voltages. The propagation time taken by secondary electrons to travel from accelerating foil to micro-channel plate inside the detector against accelerating foil voltage is plotted in the Fig. 10.

IV. EXPERIMENTAL RESULTS

The MCP has been tested in vacuum with electrons from \(^{90}\text{Sr}\) \( \beta \)-source. The experiments were carried to test functionality of BMCP detector in two different scenarios. In the first scenario, the micro-channel plates were directly exposed to the \(^{90}\text{Sr}\) (\( \beta \) emitter). In this experiment, the output of the detector was directly connected to the digital oscilloscope. The response of the BMCP detector is quite fast. A typical MCP signal is shown in Fig. 11. Thus, the biasing circuitry along with micro-channel plates was checked.

Several simulations were performed by applying different accelerating voltages. The propagation time taken by secondary electrons to travel from accelerating foil to micro-channel plate inside the detector against accelerating foil voltage is plotted in the Fig. 10.

Fig. 10 Propagation delay for secondary electrons against accelerating foil voltage
V. CONCLUSIONS

A high accuracy and fast BMCP detector has been developed as well as tested at BARC. For heavy ions energy measurements, these detectors can be used in time of flight experiments. The functioning of the BMCP detectors was checked in two scenarios. In the first experiment, the detector was directly exposed to the Strontium (β source). The output of the detector was observed with few small amplitude ripples which can be eliminated by using preamplifier.

In second experiment, the Thorium source was used as Alpha emitter that knocked out secondary electrons from target Aluminium foil. The output signal of the detector has fall time constant less than 2 nano-seconds. Also, the propagation time for the SEs to travel from target foil to detector plates was analyzed through developed simulation code. It is found that the propagation time reduces exponentially when the accelerating foil voltage is increased linearly.

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