Micro Strip Gas Chamber (MSGC)

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A position-sensitive detector of a new type has been developed. A microstrip anode replaces wires generally used for electron multiplication in gases. In contrast to wires in the gas, microstrips are fixed on a glass substrate. The microstrip detector offers improved counting rate and position resolution.

Figure 1: Electric field and equipotentials in the multiwire proportional chamber

1 Introduction

The microstrip (MS) detector is based on principles of the multiwire proportional counter (MWPC), which was coinceived almost twenty years ago. MWPC consists of a large number of thin anode wires assembled in a plane and mounted between two cathode plates. In most of the gas volume of MWPC, the electric field (figure 1) merely produces a drift of charges: of electrons to the anodes, and of positive ions to the cathodes. However in the immediate surrounding of an anode wire, the sharp (1/r) increase of the field strength delivers enough energy to electrons to allow inelastic collisions with gas molecules, causing both excitations and ionizations. Exications are often followed by a photon emission as an atom returns to the ground state. The creation of electron-ion pairs in the collision is at the origin of avalanche multiplication, and is exploited for signal amplification.

The achievable position resolution is directly determined by the wire spancing. A smaller wire spacing, however, causes a decrease of the field strenght at the wire [1]. In order to compensate this loss, higher voltage has to be applied. But with wire spacing getting smaller and smaller, voltage has to be so high, that a mechanical instability can occur, therefore this is not the way to increase significantly the position resolution.

The microstrip detector has no wires at all, but very narrowly spaced conductor strips. The field strength necessay to produce gas amplification is generated between neighbouring strips, which are at alternating potential and not by voltage difference between the strips and the detector cathode which can be at a long distance. As the spacing between the strips is much smaller than the smallest wire spacing in an MWPC, it is possible to reach higher position resolution, higher counting rate and a very good energy resolution.

Figure 2: Tipical dimensions of MS-plate. The chromium layer on the glass substrate is 300nm in thickness

2 The microstrip anode as gas amplifier

A field strenght at least as high as the field strenght near a single wire in Geiger-Muller counter can be reached by means of a thin (some μm) conductor strip. If one reduces the distance of the thin anode strip to neighbouring cathode strips (figure 2) to only few multiples of its width, gas amplification can take place at low potential difference [3]. If an entire plane is to be covered with a large number of such amplifier strips, the neighbouring cathode strips have to be correspondingly narrow. The construction of such a structure, with its strips being on alternating potentials, is possible only if the strips are fixed on an isolating substrate. This can be done by means of photolithography, a procedure used to fabricate integrated circuits. The separation between two amplifier (anode) strips is usually more than five times smaller than the wire spacing in MWPC.

. An electron produced anywhere in the gas volume which reaches the electric field between the strips of MS-plate will drift along the field lines towards the positive strip where it will experience avalanche multiplication. Approaching the anode strip, electrons multiply in cascade, leaving behind an exponentially increasing number of positive ions. The whole process of multiplication which begins a few strip widths from the anode, is over in a fraction of a nanosecond, leaving the cloud of positive ions receding from the anode. The motion of positive ions is responsible for the largest fraction of charge signals detected on the anode induced by the avalanche.

The geometry of the electric field is different of that of MWPC. In an MS plate

Figure 3: a.) Calculated equipotential lines (continous line) and electric field lines of the MS-plate (dashed line). The rear layer of the plate is at half the potential of the 10 μm strips. b.) Field lines calculated for the chamber realized on thin plastic support, for optimized potentials

ions are sucked off into the nearby microstrip at negative potential and not into the far-off detetor cathode as in a MWPC, where the dirft velocity rapidly decreases as a consequence of the decrease in electric field strenght. The relation between drift velocity and field strength is given by

$$\vec{v} = \mu \frac{\vec{E}}{p} \qquad , \tag{1}$$

where the gas preasure is denoted by p and the mobility of ions by μ. The electric field in MS detector is very loosely similar to dipolar [3] (figure 3) and therefore the electric field strength and the drift velocity does not decrease so drasticly along the ions way to the cathode strip. Because the distance between two neighbouring strips is small, ions are collected very fast compared to the collection time in a MWPC, where the wire is screened by the ion cloud for a relatively long time. This space charge effect can alter the electric field in the detector and by that reduce the energy resolution and counting rate.

If ions from the charge cloud reach the surface of the substrate, they will practically be fixed there because of their extremely reduced mobility on insulators. The charge accumulated on the substrate would give a contribution to the electric field in the gas. That would cause a time variation of the amplification factor, as a consequence of the time variation of the electric field. The siplest estimate of the time

Figure 4: Shematic setup of MS-detector

constant is obtained from the relation [8] $\tau = \varrho \varepsilon_r \varepsilon_0$, where ϱ is the bulk resistivity of the material and ε_r is its dielectric constant. This gives times around 100 s. It is therefore absolutely necessary to prevent positive gas ions from accumulating on the surface of the insulator. This can be achieved by installing a conductor strip with positive potential at the rear of the MS-plate (figure 3a). Such a potential produces a repulsive field for the ions. It emerges through those parts of the plate surface which are not covered with metal and thus protects the surface from ion accumulation. Ideally, no field line should intersect the glass substrate surface as can be seen on figure 3b.

The general set-up of a MS detector is shown in figure 4 [3] and corresponds with the arrangment of an axial ionization chamber with the electric field parallel to the direction of incident radiation. The anode, which in an ionization chamber is just a simple metal sheet is replaced by the MS-plate.

The cathode of the detector is held at a negative high potential, the electrons produced in the gas volume thus drift towards the MS-anode. The cathode strips are held at ground potential or at negative potential, whereas the anode strips are at a positive potential.

3 Properties of MS detector

For a better position and energy resolution it is important to reduce the particle range, so that a large majority of electrons produced by ionization of gas molecules in the gas volume experience avalanche multiplication. The path length of a particle can be derived from the equation

$$R = \int_{E_0}^{0} \frac{dE}{|\frac{dE}{dx}|} \qquad , \tag{2}$$

where $|\frac{dE}{dx}|$ is the specific ionization energy loss of the particle in the gas estimated by Born's formula

$$|\frac{dE}{dx}| = \frac{z^2\, e^4\, n}{4\,\pi\,\varepsilon_0\, M\, v^2} \ln(\frac{M\, v^2}{\bar{I}\,(1-\beta^2)}). \tag{3}$$

The average ionization energy is denoted by $\bar{I}$, the mass of the particle by M, its velocity by v, its charge by z, and density of electrons bounded to molecules in the gas by n. If we apply (3) to calculate the loss, we will obtain the path length

$$R = \frac{M}{z^2\, n}\, f(v)\, , \tag{4}$$

where the function $f(v)$ is the same for a specified substance for all particles. These equations are valid for heavy charged particles and qualitatively also for electrons. For a more precise calculation Born's formula can be replaced with the Bethe-Bloch formula [4].

We can see that by increasing n the path becomes shorter. A short path can be achieved through using gases with a high molecular mass. Any gas with a high molecular mass which is composed of atoms of a high atomic number, however, has a high probability for excitatiton followed by emission of an ultra-violet or a visible photon [5]. Under proper circumstances this de-excitation photon could create additional ionization through interaction with less tightly bound electrons in the wall of the detector or in the gas fill. Because of that, gases have to be composed of molecules with a large number of atoms of low atomic number. Such a gas with high stopping power is hexafluoroethane. It is interesting, however, that this gas does not perform so well in MWPC. Its performance is worse than with classic gases such as a mixture of methane(10%) or isobuthane and argon(90%). The reason is in the different field geometry. In MWPC, the wire is screened by the ion cloud for a relatively long time. This screening seems to reduce the electron drift velocity in hexafluoroethane quite substantially. In contrast to this behaviour in wire counters, in MS detector hexafluoroethane has a better characteristic due to its larger stopping power than in the case of isobuthane. The sreening of anode strips is negligible, because of smaller separations and higher field strength (figure

Figure 5:

5). This means that many more counting gases can be used in the MS-detector than in any kind of wire detector.

The energy resolution $\frac{\sigma_E}{E}$ is proportional to $\frac{\sigma_U}{U}$, where U is a signal from the detector and is given by

$$(\frac{\sigma_U}{U})^2 = \frac{F}{n_0} + \frac{b}{n_0} = \frac{C}{n_0} \qquad , \qquad n_0 = \frac{E}{\bar{I}} \qquad . \tag{5}$$

where n_0 is a number of primarily created pairs. So called Fano factor F derives from the fact that the creation of an electron-ion pair is not an ordinary Poisson process. If the entire particle energy is always converted into ion pairs, there will be no fluctuations and F will be zero. The factor F therefore represents the fraction of energy of the particle converted into ion pairs within the detector and depends on the dimensions of the detector. The second term in (4) comes from the fluctuations in the multiplication factor for every avalache. The factor b is the measure of homogenity of the multplication over the entire plate and varies with the voltage. The value of sum C is around 0.2 [6], which is lower than in a MWPC (0.5) and does not depend so sharply on the multiplification factor.

To determine the gas amplification as a function of the voltage applied to the anode strips, alpha-particles are chosen for the reason that their signals are considerably higher even at mere charge collection without gas amplification than the noise level of the amplifier. Thus a precise determination of the amplication factor is ensured. The measured amplification factors are on an average 30 times higher at the same potential difference than in any other wire detector. However, there is one major limitation of the MS-detector. The avalanche amplification gain is not likely to exceed 10^4 [5], because of spark breakdown through the dielectric support. The limiting voltages are now around 1000V.

An advantage of an MS-plate is also the homogenity of amplification over the entire surface. It has been checked by means of the neutron reaction (figure 5) with ^{3}He [3]. In this reaction, one proton and one triton are emitted with a total energy of 770 keV. The measured line width was 11 keV only. Such a narrow line proves the uniform amplification over the entire MS-plate. Even with a silicon detector device such an energy resolution can only be realised under favourable condititons.

One of the most important features of the MS-detector is its high counting rate capability. It comes partly from its small separation between the strips, so that an event can be localized and therefore more than one can be detected at the same time, and partly to the very short collection time. The short collection time reduces the space-charge buildup and results in fast signal development. Recent measurements have given counting rates more than 10^6 s^{-1} mm^{-2}, but an unexplained phenomena was observed in counting x-rays. The amplification factor decreased with increasing counting rate. The decrease of the amplification factor (ΔG) is linearly dependent [6] on the counting rate (R).

$$\frac{\Delta G}{G_0} = C_G R \quad \text{with} \quad C_G \approx 10^{-7} \mathrm{s\,mm}^2 \tag{6}$$

4 MS photodetector

The MS-plate can also operate without any further elctrodes on the working table with air. The signals can be detected, if the radiation source is brought within the distance that coresponds to particle range in air. As there is no cathode, only those charge pairs produced immediately in the field range of MS-plate contribute to the signal. As air is not an ideal counting gas, the pulse height spectrum is of course very wide and not well resolved. Instead of air a better counting gas can be used, but with the detector cathode being grounded (figure 6).

This measurement leads to an entirely new mode of operating an MS-detector which cannot be realized with the MWPC. If the conductor strips consist of a material which emits ionized particles or electrons into the gas volume after a reaction with the incoming radiation or particle beam, so that the charge pairs deposited in the field range produced between the microstrips cannot escape. The electrons drift towards the positive conductor layers, where they experience multiplication.

Not too long ago, gas-filled phototubes were widely used light sensors; because of the ion bonbardment of the photocathode, however, these tubes could only operate with low gas amplification factors. With a phototube consisting of MS-plate

Figure 6:

and a separate photocathode, the limitation caused by the ion current through the cathode is no longer important. Most of the ions produced by gas amplification drift towards the close conductor strips and not to the photocathode and therefore the gas amplification factor and sensitivity can be higher.

5 Position determination

An important advantage of the MS-detector is that the distance between electrodes can be matched to the desired position resolution. To determine a precise position of the reaction, the track length of the charged particles has to be as short as possible. But even if the produced ion-electron pairs merge in one point, the thermal motion of the electrons will make them drift apart on their way. Therefore signals appear on several strips. For a precise localization it is necessary to determine the centre of gravity of the signals (figure 7).

$$\bar{y} = \frac{\sum Y_i\, y_i}{\sum Y_i} \tag{7}$$

where Y_i is the measured charge on the strip of central coordinate y_i and $\bar{y}$ is the average position of the avalanche along the direction y. There are two ways to determine the charge Y_i collected by the anodes. The charge can be collected on

Figure 7: Shematic setup of a two-dimensional MS-plate. The second coordinate is detected on the rear conductor strips

an individual strip ('digital readout') or can be derived by connecting the anode strips to a common resistive stripline deposited on the MS plate. Localization is then achieved using conventional charge division.

So far the determination of the cooordinate perpendicular to the anode strips has been considered. With an MS-plate, the second coordinate is obtained by the induced charges of the ion cloud. Across the uncovered surface of the substrate, the ions induce a signal on the rear layer of the plate. If this coating is divided into strips which are perpendicular to the conductor strips of the surface, the second coordinate can be determined in the same way as the first. With increasing thickness of the substrate plate, the induced signal will be reduced by the screening of the microstrips. In order to achieve a good signal-to-noise ratio, the substrate plate should be as thin as possible [7]. The signal from the rear layer is usually a decade weaker than than the signal from anode strips. Lately the position resolution of 10μm in the direction parallel to the microstrips has been achieved.

6 Future

The MS-detector has proven to be a mojor step forward in gas-detector technology. Almost all the characteristics of the detector such as: position resolution, energy resolution, rate capability are significantly improved over those of the standard MWPC. MS detectors are now being developed for use in a wide range of fields: Neutron diffraction, x-ray astronomy, and high energy physics, where MS detectors will be applied at the Large Hadron Collider. Among all other advantages of MS-detector to MWPC are also low cost and long term stability. It is believed that such a detector can operate for several years without degradation of its performance.

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