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Abstract

A drift chamber type radiation detector is being used to examine design criteria for a new type of detector called a micro Time Projection Chamber (micro TPC) which is being proposed for use in high energy nuclear physics experiments. The main advantage of the micro TPC detector is its very low radiation thickness compared to its silicon counterpart. The micro TPC is a charged-particle detector which will be optimized for good two track resolution which is needed in a high track density environment. Such performance requires low electron diffusion and high resolution readout. The diffusion will be reduced by limiting the drift distance to 15 cm and by using a low diffusion gas such as dimethyl ether. High resolution will be obtained by using a new readout technology called microstrips. Microstrips are a recent development using photolithography techniques that allow the creation of anodes a few microns in width with submicron precision. The main purpose of this test chamber is to demonstrate the feasibility of a micro TPC design using a low diffusion gas and to insure the sufficient signal remains after electron attenuation. The drift chamber design and the proposed testing procedures are described.

Introduction

In high energy nuclear physics experiments, such as those proposed for the Relativistic Heavy Ion Collider (RHIC), high particle density puts an extra demand on a detector's ability to distinguish between close pairs of tracks. A new type of detector has been proposed (Wieman, 1994) which will be optimized for low mass and good two-track resolution. This detector, known as a micro Time Projection Chamber (micro TPC), will utilize microstrip anodes for readout.

A time projection chamber works on the principle that radiation passing through a gas ionizes molecules in its path and leaves a trail of electrons along the way. The electrons are forced by means of an electric field to drift towards anode wires at one end of the chamber. As the electrons approach a distance of a few times the wire radius r, the electric field felt by the electrons increases as 1/r. In this high potential region electrons accelerate enough to ionize molecules with the new electrons in turn accelerating and ionizing more molecules until an avalanche forms. This avalanche is known as the amplification or the gas gain and insures that a sufficient number of electrons are produced to obtain a detectable signal.

Traditionally, the anodes were thin wires capacitively coupled to readout pads. Recently, however, a new technology known as the microstrip detector (Oed, 1988; Angelini et al., 1991, 1992) has been developed which can be used in a micro TPC as an alternative readout technique. These microstrip detectors use thin metal electrodes on an insulating substrate which, by using precise photolithography techniques, can be spaced accurately on the order of a few microns. This distance is significantly smaller than what one is able to accomplish with conventional readouts and the position and two-track resolution are correspondingly improved. For this project, microstrip detectors have been fabricated at the Berkeley Micro-Fabrication Laboratory (Gong et al., 1994).

Dimethyl ether (DME) has been chosen as a promising candidate for the drift gas of the chamber. The limits of position resolution and two-track resolution in the micro TPC design are set by the diffusion of the drift gas and DME has been shown to have a very low diffusion constant (Villa, 1983). In addition, limiting the drift length of the chamber to 15 cm will help keep the diffusion low.

One of the main concerns of using DME in the micro TPC design is the electron attenuation due to electron attachment coupled to the relatively slow drift velocity, resulting in a loss of part of the signal. The number of electrons lost increases exponentially with the drift length and the concentration of elector-negative epollutants (Sauli, 1977). Since the proposed drift length is relatively long, the purity must remain exceptionally high for proper functioning of the detector. Thus, the primary purpose of this test chamber is to measure the electron attenuation to insure that a sufficient number of electrons reach the microstrip anodes. Also, if necessary, purification methods will be studied to determine how to best minimize pollutants that cause electron attenuation.

Materials and Methods

Chamber construction.--The test chamber consists of an aluminum cylinder 18 cm in height and 21 cm in diameter (see Fig. 1). It has quartz windows on one side for the purpose of shining a laser into the gas chamber. The laser will act as an electron point source by ionizing gas molecules. The quartz windows are attached with high vacuum quality flanges. The other side has two thin aluminum windows to allow the passage of X-rays from an ^{55}Fe source. Also, the top of the chamber has a quartz window to allow a laser to shine in from the top. The position of this laser will be varied with a translation stage for the purpose of measuring the diffusion width of the electron cluster.

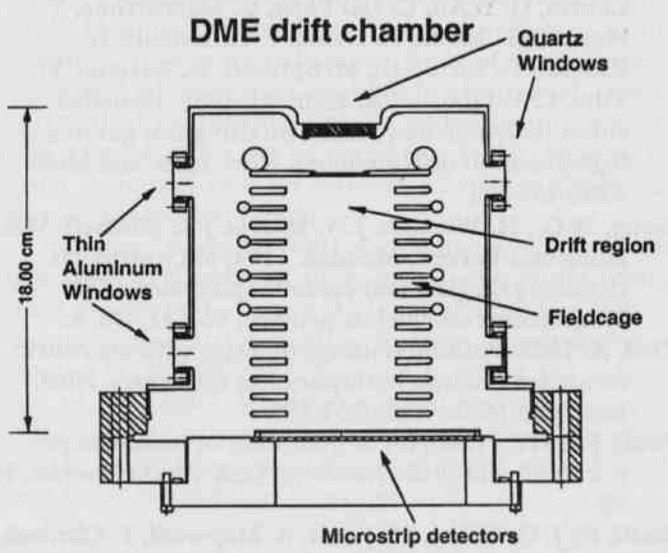

Fig. 1. A schematic of the 18 cm chamber used to test dimethyl ether as the drift gas for use with micro strip detectors. (This Fig. is provided as a courtesy by Mr. Russ Wells of Lawrence Berkeley Laboratory.)

Inside the chamber is a field cage structure consisting of a stack of 15 annular disks spaced 1 cm apart. This field cage creates an electric field region for the drifting electrons. A resistor chain connecting the plates maintains a uniform potential gradient down the stack.

As mentioned, microstrip detectors have been fabricated and successfully tested in the lab. The microstrip detector currently being used consists of 100 pairs of alternating anode and cathode strips laid out on a glass substrate. The anodes are 10 microns wide, the cathodes are 90 microns wide and there is a 50 micron spacing between each anode and cathode. 16 channels (anodes) of the detector will be bonded to a preamplifier/shaper chip. The detector and preamplifier chip will be attached to a ceramic board which will sit at the bottom of the chamber and define the end of the drift region. It is necessary to make the PC board of ceramic material to help preserve the purity of DME.

The DME gas flows through the chamber at a rate of 0.05 liters/minute. A NanoChem filter is used in line to take out the majority of elector-negative impurities. Also, a hygrometer and oxygen analyzer will be used in line to monitor the has. DME is an excellent solvent of many common construction materials, including several that are often used as o-rings in gas valves (Sauli et al., 1989). Therefore, wherever possible, all metal seals were used in components such as valves and regulators.

Testing Procedures.--Two difference methods are employed to test DME using this chamber. The first method uses the 5.9 keV X-rays emitted from ^{55}Fe. These X-rays pass into the chamber through thin aluminum windows set in the side of the chamber at different heights. The second method utilizes an ultra-violet laser to directly ionize the gas molecules. This laser shines ultra-violet light into the chamber via quartz windows set in the sides and top of the chamber.

The position resolution measured using this chamber is strongly dependent on the diffusion of the drift gas (Basile et al., 1985). As mentioned, DME was chosen because it is a low diffusion gas. The diffusion is measured by reading the signal height on several adjacent anodes. The resulting shape is an approximate gaussian distribution. The width of the gaussian is a measure of the diffusion.

Various properties of DME have previously been measured for small drift distances, but only up to 3 cm (Basile et al., 1985). It is fully expected that the drift velocity and diffusion will scale in a predictable manner for the 15 cm drift distance. Electron attenuation, however, is not expected to behave in a simple manner for the 15 cm distance. The attenuation is highly dependent on elector-negative impurities and will thus depend on the chamber being "clean." Attenuation in the ionization-electron signal is measured using the UV laser to produce ionization electrons at various heights within the chamber. Depending on their different drift distances, more or less of the electrons reach the anodes to be collected. Since the UV laser produces the same number of ionization electrons, within a statistical variation of roughly 10%, the difference in collected signal directly measures electron attenuation versus drift distance.

The length of the anodes to be used is relatively short. Short anode length is a requirement for adequate two-track resolution. The trade off is between electron signal attenuation and anode length. Electron attenuation is more of a problem with short anodes because fewer electrons reach each anode. Only about 180 electrons/cm will be ionized by X-rays coming from ^{55}Fe. Therefore, for a 3 mm anode length, only about 60 electrons would reach the anode. In addition, electron attenuation will decrease this number even further. The number of electrons will then be boosted by the gas gain; however, one of the goals for this detector is to operate at as low a gain as possible since low gain operation is more stable and has smaller space charge effects (Gong et al., 1994). Thus, once the extent of attenuation is known, an optimization of the anode length can be made to maximize two-track resolution while maintaining a sufficient signal.

Results and Discussion

In summary, a new type of detector, called a micro TPC, has been proposed. This detector would help meet the needs of high energy nuclear physics experiments to track charged particles in high track density environments. The performance of the micro TPC will require a low diffusion drift gas combined with high resolution readout. DME has been chosen initially for the drift gas. The test chamber described above is needed to demonstrate the feasibility of a micro TPC design and to test the performance of DME as a drift gas.

A simulation has been done showing the dependence of the performance of the micro TPC on various parameters such as geometry, multiplicity of particles and the measured value of the DME diffusion constant (Wieman et al., 1995). Unlike other properties of DME, however, the value of electron attenuation at a drift length of 15 cm is very uncertain and must be measured. In addition, measurements of the other properties of DME are being made to confirm earlier reported measurements of its properties. This chamber will allow the testing of different cleaning strategies for DME in order to minimize the attenuation of ionization-electrons within the DME. Also, once the extent of this minimized attenuation has been established as a function of drift length, this data will be used in a simulation for optimizing of the exact length of anode in order to maximize two-track resolution while maintaining a sufficient signal.

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