ELECTRODELESS DRIFT CHAMBERS WITH 50-CM DRIFT DISTANCE

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Summary

The electrodeless drift-chamber technique is potentially very useful in applications requiring the drifting of ionization in gas over long distances in narrow channels. Chamber construction is simple and cheap; the technique is well suited to very large detectors operating in low-rate environments. Prototype tests on planar chambers reveal excellent drifting characteristics after the initial charging, but show a substantial degradation of pulse height from cosmic rays over a two-week period. The loss of efficiency appears to be caused by excess charge buildup on the dielectric surfaces of the chamber. Several solutions are suggested.

Introduction

One of the most intriguing developments in drift-chamber technology in the last few years has been the discovery that a nearly ideal drift-field configuration can be produced automatically by the buildup of positive ions on the insulating inner surfaces of a chamber, eliminating the need for multiple electrodes to shape the field. A group from the University of Manchester[1] observed that the muon chambers in the JADE detector not only violated the traditional taboo against dielectric surfaces inside drift chambers, but that the electrostatic charging of these surfaces was in fact essential to the operation of the chambers. The difference between the JADE chambers and more conventional designs was in the direction of the electric field in the insulator: in the JADE chambers, this field was such as to attract positive ions, which are copiously produced at the anode wire, to the dielectric surfaces. A logical extension of this idea led to the construction and successful operation of laboratory prototype chambers which had no field-shaping electrodes at all, and where the drift field was established entirely by static charges built up on the dielectric surfaces inside the chamber.

Chamber Operation

The charging process in an electrodeless chamber is shown schematically in Fig. 1. (Drift chambers with the geometry shown are being developed at Argonne for use in the proposed Soudan 2 tracking-calorimeter proton-decay detector.[2,3]) The anode wire is at one end of the 50-cm long drift volume, which is 1-cm thick by 25 cm along the anode-wire direction. The only conductors inside the chamber are the anode wire and the drift electrode, at opposite ends of the chamber. The outside surface of the chamber is covered with conductor, which establishes the field in the dielectric (G-10 fiberglass epoxy) which surrounds most of the drift volume.

Figure 1(a) shows the field configuration just after the high voltage is switched on: nearly all the field lines terminate on the dielectric surfaces, and drifting efficiency is very poor even for short drifts. The positive ions generated by avalanches (and discharges) at the (+10 kV) anode wire will, however, follow the field lines shown and attach themselves to the dielectric walls of the chamber. This process will continue until the state shown in

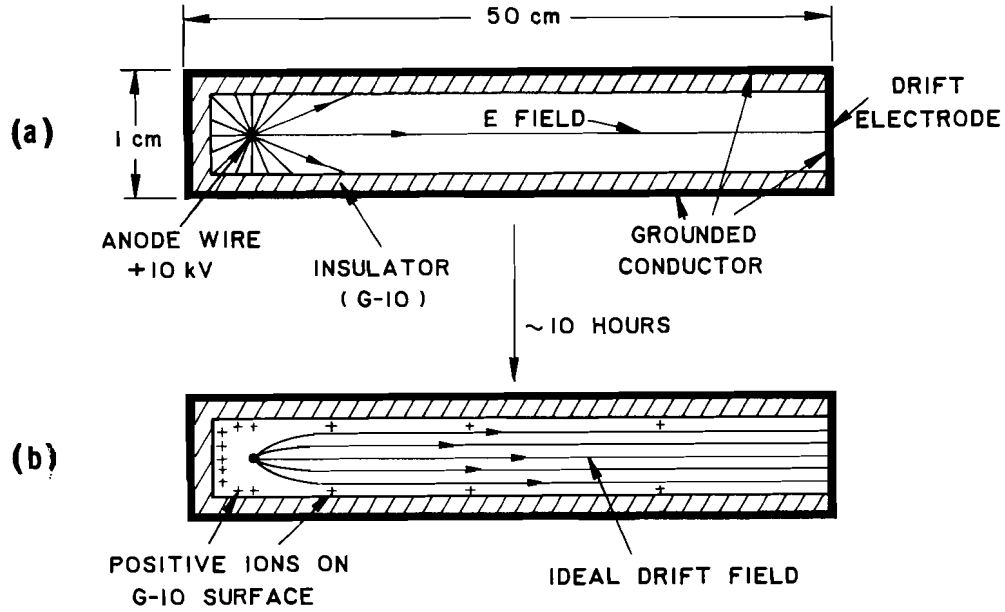

Fig. 1. Schematic representation of the structure and the initial charging of a prototype electrodeless drift chamber built and operated at Argonne. (a) Initial field configuration, before any accumulation of positive-ion surface charge. (b) Fully charged state of the chamber, reached ~10 hours after the high voltage is turned on. The chamber uses 90% argon, 10% CO_2 gas with an oxygen contamination of less than 10 ppm.

Fig. 1(b) is reached, where no field lines terminate on the dielectric, but instead all lines go from the anode wire to the drift electrode at the far end of the chamber. The resulting field configuration is in principle ideal: ionization electrons deposited anywhere in the chamber will follow the field lines to the anode wire, and no electrons will be led into the walls of the chamber. As the surface charge leaks away with time, it is replenished by positive ions from the anode wire, which otherwise are collected by the drift electrode. Attenuation of the drifting electrons will then be produced only by electron capture by electronegative impurities in the chamber gas, and by the diffusion of electrons which causes them to wander into the walls.

There are two obvious shortcomings of this simple chamber design. One is that the anode-wire gain cannot be adjusted independently of the drift field. In fact, the chamber shown in Fig. 1 will not amplify satisfactorily[4] unless wire voltages much higher than 10 kV are used, or alternatively, the gap is increased from 1 cm to ~3 cm. This shortcoming can be easily rectified by installing a cathode which surrounds the anode wire on three sides, and which is held at an appropriate fixed potential ($\lesssim$2 kV) relative to the anode.

A second limitation to the chamber shown in Fig. 1 is that the drift-field shape is predetermined, and in particular, that a focussing field configuration[3] cannot be used. This can be rectified by installing more electrodes inside the "electrodeless" chamber: in this case, widely spaced conducting lines on the insulating surface, parallel to the anode wire. These field-shaping electrodes can be connected to a resistive divider chain to give any desired drift-field shape, for example an exponential potential to force ionization electrons drifting near the walls back toward the midplane of the chamber.[3]

Prototype Chamber Tests

With these changes, the "electrodeless" chamber is nearly identical in structure to the resistive-ink chamber[2,3] initially proposed for Soudan 2, except that the interpolation of the wall potential between field-shaping electrodes is now done by the positive-ion surface charges, instead of by the resistive ink covering the inside of the chamber. We have compared the attenuations of a resistive-ink chamber (using a constant drift field) and a geometrically-similar "electrodeless" chamber, modified as described above, and have found their performances to be very similar. This comparison is shown in Fig. 2.

Figure 2 emphasizes one of the major differences between our requirements and those of other tests[1,5] of electrodeless chambers reported in the literature: the Soudan 2 application demands dE/dx ionization information in addition to the spatial measurement derived from the drift time. It is therefore essential that the attenuation be well known and constant in time: Fig. 2 shows a ~30% loss of pulse height for ionization drifting over 50 cm. This loss is consistent with that expected from diffusion in the 90% argon, 10% CO_2 gas, which causes the drifting ionization electrons to wander into the walls of the chamber. The loss is reduced from 30% to 12% by use of an exponential, focussing drift-field in the resistive-ink chamber.[2]

Results

Because we were concerned about the time stability of the drift field in the electrodeless chamber, we monitored the ionization pulse height, with a 50 cm drift, for several weeks while the chamber was exposed only to cosmic rays. The results are shown schematically in Fig. 3, and indicate a slow increase in attenuation after the initial charging of the chamber. Detailed attenuation curves are shown for two diferent times in Fig. 4. We believe that the deterioration with time is due to the overcharging of the dielectric surfaces inside the chamber, caused by diffusion of positive ions into the walls, as they travel from the anode to the drift electrode. The time constant (~10 days) for the increased attenuation is comparable to that observed when the chamber is purposefully overcharged, either by reducing the drift voltage after the initial charging, or by exposing the chamber to a strong radioactive source. In both cases, the chamber recovers very much more slowly than the initial charging time, indicating that the charge bleedoff rate is very slow compared to the positive ion buildup rate.

Discussion

If this explanation of the increasing attenuation is correct, several possible cures can be contemplated:

(1) Replace the G-10 dielectric with a poorer insulator, allowing a faster bleedoff of surface charge;
(2) Periodically neutralize excess positive surface charge by switching on an electron source inside the chamber;
(3) Control the steady-state positive-ion flux from the anode wire using a gated grid between the anode wire and the drift volume.

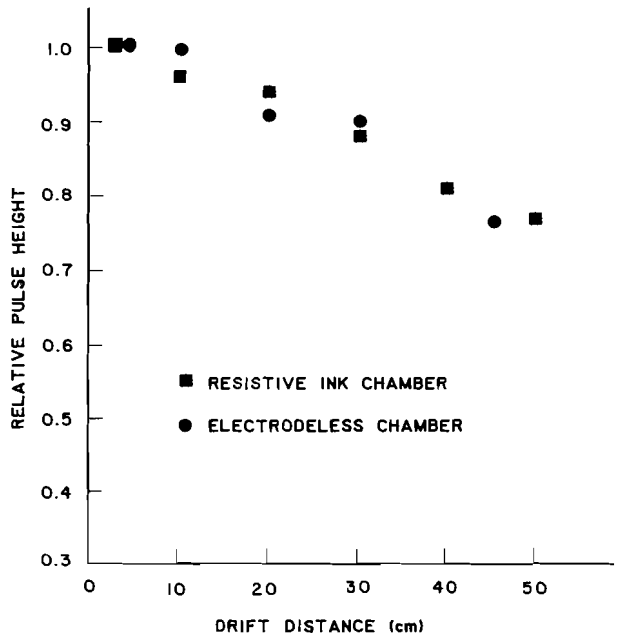

Fig. 2. Comparison of pulse-height attenuation in resistive-ink and "electrodeless" chambers. The measurements were made using a low-intensity radioactive beta source. The electrodeless chamber was similar to that shown in Fig. 1 except that it had a three-sided cathode surrounding the anode wire and linear drift electrodes on the G-10 surfaces, parallel to the anode wire, mounted one centimeter apart and held at the desired potentials by an external resistive divider chain. A linear potential gradient was used to produce a constant drift field in both chambers.

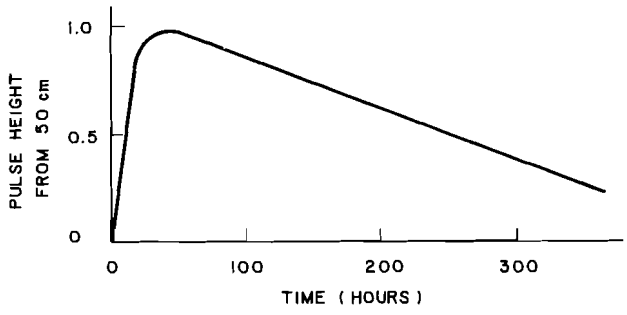

Fig. 3. Schematic representation of the signal amplitude from the anode wire of an electrodeless chamber during the initial charging and subsequent operation. The chamber was exposed only to cosmic rays (at sea level) and was kept well away from radioactive sources during the entire test.

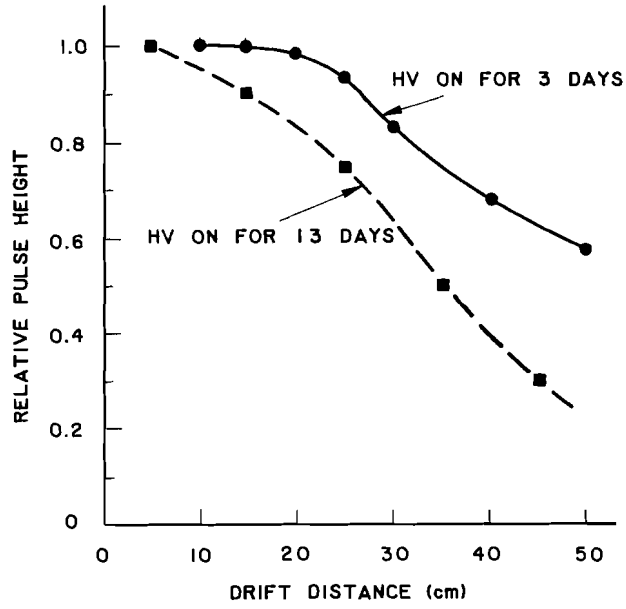

Fig. 4. Comparison of the attenuation in an electrodeless drift chamber at 3 days and at 13 days after the high voltage was switched on.

Similar slow degradation of drifting performance has been observed in electrodeless chambers built at Oxford[6] and Rutherford[7] but has not so far been seen by other groups developing this technique.[1,5,8-10] This could be due to the shorter drift distances employed in some cases,[1,5,8,9] to higher drift fields,[1,5] to the measurement only of chamber counting efficiency and not of pulse height,[1,5,9,10] or to the short time period covered by single laboratory tests. It is likely that the pulse height indicated in Fig. 3 will come to equilibrium at some nonzero value, after sufficient surface charge has built up to inhibit further collection of positive ions. We have not observed evidence of such an effect, however, and the asymptotic attenuation is probably quite high in our chambers. It is also obvious that, in chambers where pulse-height information is not measured, or with drift distances shorter than our 50 cm, the effects described here will have less serious consequences than in our case.

Conclusions

The electrodeless drift-chamber technique is potentially very useful where ionization must be drifted in narrow channels over long distances. In principle, geometries more complex than our planar one can be easily implemented[3-6] allowing ionization to be extracted from inacessible regions of a detector. Chamber construction is potentially very simple and cheap; the technique is thus well suited to very large detectors operating in low-rate environments: for example, nucleon decay searches, e^+e^- colliders, and neutrino experiments. Despite the problems with time stability of the drift field which we have described here, there are several possible solutions which could be implemented without losing the main advantages of this very promising technique. Unfortunately, it may be difficult to obtain sufficient time stability of the drift field for applications requiring accurate dE/dx information. In order to obtain reproducible drifting of the high quality required for Soudan 2 and similar applications, it will probably be necessary to achieve a more fundamental understanding of the behavior of dielectric materials than has so far been brought to bear on the problem.

The material presented here reflects the insights of our colleagues W. Allison and J. Cobb, whom we thank for several enlightening discussions. I. Ambats, J. Dawson, R. St. Denis, J. Kim, and N. Solomey performed much of the experimental work which we have described.

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