Use of G10 near the Active Volume of an LArTPC

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Abstract

We consider the effect of an insulator (G10) in a Liquid Argon Time projection chamber (LArTPC) can have on the drift field. We find that conduction effects are likely negligible, but that further cold resistivity measurements will be needed to provide an adequate margin of safety. We also find that cosmic rays at the 800 ft depth will discharge any existing surface charge within about 20 minutes.

Introduction

Insulating structural materials are useful in large liquid Argon time projection chambers (LArTPC's). An example would be spacer bars between anode and cathode planes, assuring a correct and constant drift length.

Insulating materials can, however, hold surface charges and distort the drift field thus causing electron drift path deformations. It is desirable to have a system that will not create such unwanted surface charges, and which discharges them over time if they exist in the beginning.

Unwanted charge distributions will exist in slightly conducting insulators connected to potential differences if the material has non-uniform resistivity and/or if their shape is not carefully designed to provide the correct potential profile along the insulator. Remedies include the use of potential electrodes with appropriate voltage dividers.

There are two discharge mechanisms: use of slightly conductive Insulators, and natural discharge by electrons created by cosmic rays in the liquid Argon.

Slightly Conductive G10

We consider here only fiberglass –epoxy materials such as G10, since they are good construction materials that do not pollute the liquid Argon.

We have tested two samples of non-FR4 G10.

At room temperature, G10 has a well defined resistivity which depends steeply on the temperature.

We have measure two G10 samples at room temperature and at liquid nitrogen temperature (see LArTPC document # 587, specifically the sub-documents "Updated G10 Report" and "New test on G10 material, slim sandwiched plate.")

At room temperature the first sample (finger sample) had a volume resistivity of 1 Gigohm m. We also baked this sample for two days at 66 C to find out if the conductivity was due to its water content. The volume resistivity increased only slightly, to 1.5 Gigohm-m, indicating that the conductivity comes from native G10 properties. This is consistent with the literature which cites a complex conduction model using hopping of charge carriers.

The second sample (double clad sample) , a 0.28" thick double-copper clad sheet, had a room temperature volume resistivity of 36 Gigohm m. It came from a different source, thus can have different properties from the first sample.

At liquid nitrogen temperature we were not able to detect any current, hence we set lower limits on the volume resistivity based on our measurement sensitivity. The sensitivity was limited by a low frequency current noise.

For the first sample we determined that the cold volume resistivity was greater than 2 Tera-ohm m.

For the second sample we found the cold volume resistivity to be greater than 150 Tera-Ohm-m.

To convert that to currents in the TPC drift field we use these typical parameters:

Electric field strength 500 V/cm

Tubular strut with OD of 5 cm and wall of 2 mm

Current in the strut will be less than 8 pA (finger board data) or less than 0.1 pA (double-clad sample data).

Discharge by Cosmic Rays

Cosmic rays (CR) enter the TPC volume and ionize the Argon atoms. The resulting electrons and ions drift in the imposed TPC field. Any area that has free surface charges will preferentially attract electrons or ions until the charge has been neutralized.   We calculate the time it takes to discharge a patch of surface charges under the following assumptions

(see the Excel sheet below for full information):

Detector depth   800 ft

Detector size 60 m x 15 m x 14 m

Total CR rate into detector 240 muons per second

The rate of discharge depends on the liquid Argon column intercepted by the insulating patch. We assume a 5 cm wide patch.

LBNE at 800 ft depth:

Total CR rate	240	s^-1
Detector length	60	m
width	15	m
Depth	14	m
Surface area	900	m^2
Volume	12600	m^3
Ionisation pair density at 500 V/cm	5.50E+06	m^-1
Average track length	26	m
Total rate # of pairs	3.43E+10	electrons/s
rate density	1.32E+09	e / m^3 s
Assumed geometry:		
Column area	0.0005	m^2
Column length	1	m
Column electrons/s	6.60E+05	elec / s
Column current	1.06E-13	A
Patch Capacity	1E-13	F
Potential change rate	1.06E+00	V / s

We find that the patch discharges quickly, at 1 Volt/s.

If the initial charge was creating a field of 1000 volts, it takes only 20 minutes to discharge.

Combined effect of Conductive Current and Cosmic Ray Discharge

From the numbers quoted above we are confronting a cosmic ray discharge current of 0.1 pA with a conductive current upper limit of either 8 pA (finger sample limit) or 0.1 pA (double clad sample limit). Due to the current noise in the cold measurements we do not yet have a comfortable margin of safety against field distortions due to currents in cold G10 . While there is very little room for potential problems, it would be useful to improve the cold measurements, both in sensitivity and in looking at more samples from different batches and vendors. In particular, any material under active consideration will need to have its cold resistivity measured.

Behavior of a Perfect Insulator inside a liquid Argon Drift Volume

It is relevant (and amusing) to consider a perfect insulator immersed in a Liquid Argon volume with a drift field, in the presence of cosmic rays. Since no current can enter the insulator through its exposed surfaces, after sufficient time (20 minutes) all electric field components must end up parallel to the surface, since any normal field component would transfer charge to the surface. Any such charge would , after time, create its own electric field to cancel out the imposed external electric field.

If one was to calculate the electric field distribution, one would need to assign a dielectric constant of zero to the insulator. This could, by itself, introduce small corrections to the field distribution.