

Polymer growth rate in a wire chamber with oxygen, water, or alcohol gas additives*

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Abstract-- The rate of polymer growth on wires was measured in a wire chamber while the chamber was aged initially with helium-isobutane (80:20) gas, and then with either oxygen, water, or alcohol added to the gas. At the completion of the aging process for each gas mixture, the carbon content on the wires was measured in a SEM/EDX instrument. The same physical wires were used in all the gas mixtures, allowing measurement of polymer build up or polymer depletion by each gas additive. It is found that the rate of polymer growth is not changed by the presence of oxygen, water or alcohol. Conjecture that oxygen reduces breakdown by removing polymer deposits on field wires is negated by these measurements. Instead, it appears that the reduced breakdown is due to lower resistance in the polymer from oxygen ions being transported into the polymer. It is also observed that field wires bombarded by the electrons in the SEM and then placed back into the chamber show an abundance of single electrons being emitted, indicating that electron charge is stored in the polymer layer and that a high electric field is necessary to remove the charge.

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I. INTRODUCTION

Drift chambers that operate in a high ionization environment with a gas containing hydrocarbons such as ethane or isobutane soon show signs of increased chamber current and eventual breakdown. This aging process is due to the build up of a polymer film on the field wires (cathode) from the collection of positively charged ions in the chamber gas. As this insulating polymer layer grows in thickness, it becomes increasingly difficult for the collecting ionic charge to discharge through the polymer layer, producing a large electric field in the polymer that leads to breakdown. It is well known that adding water or alcohol to the chamber gas prevents this breakdown. In previous work [1] it was shown that oxygen also suppresses breakdown, and it even appears to reverse the aging process in that an aged

Another case in which oxygen played a beneficial role is the CDF chamber [2] where a loss of gain was restored by operating the chamber with an oxygen additive in the gas. Deposits on the sense wire (anode) were examined, and it was found that operating with oxygen removed deposits from the sense wire.

The mechanism for polymer build up on wires is not well understood. The high electric field near the wire surface can lead to energetic ions that form plasma in this region. Yasuda [3] has tried to apply the competitive ablation and polymerization (CAP) principle from plasma chemistry to explain the polymer build up on wires. Polymer growth and ablation compete in this turbulent region, and the addition of elements like O₂ can turn the net effect from one in which polymer growth dominates to one in which ablation dominates. But O₂ could also change the polymer properties by chemically

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combining with the polymer or by trapping mobile oxygen ions in the polymer. If the change results in a lower resistance, then charge build up would be reduced and breakdown would be suppressed. It remains a question whether oxygen improves the chamber by chemically removing some of the polymer film from the wires or by reducing the resistance of the polymer film.

This article addresses the latter question by presenting measurements of polymer growth rate on the sense and field wires in a test chamber operated with oxygen, water, alcohol, or no additives in a helium isobutane (80:20) gas mixture.

A short chamber was built that could fit into a scanning electron microscope (SEM) without having to remove the wires from the frame. Energy Dispersive X-rays (EDX) in the SEM measured the amount of carbon and oxygen deposits on the wires. The short chamber allowed the same wires to be used throughout all the various gas mixtures, and in particular it allowed direct observation of any polymer reduction by an oxygen additive. Since polymers consist mostly of carbon and hydrogen, the carbon content gives a measure of the amount of polymer on the wire surface.

II. APPARATUS

A short, one-cell test chamber was built with a hexagonal wire pattern shown in Figure 1. The chamber has one sense wire (+) surrounded by 6 field wires (filled circles) surrounded in turn by 6 bias wires (open circles) having diameters 20, 120, and 120 microns and voltages +2055, 0, and +1880 volts respectively, giving surface fields of 2.4×10^7 V/m on the gold coated tungsten sense wire and 1.9×10^6 V/m on the gold coated aluminum field wires. Wires are spaced 1.0 cm apart and are 9.0 cm long.

The wires are held by feedthroughs in a wire cage consisting of the end plates and the two walls on either side. The cage is inserted into a bigger gas-tight box containing top and bottom covers with the ^{55}Fe source and the outside signal connections. The top and bottom covers provide the other two walls for the chamber. The chamber walls have a rectangular cross section in order to provide the same electric field on all field wires having a hexagonal pattern in the four walled geometry.

The wire cage could be removed from the gas box, taken to the SEM/EDX instrument, and then re-inserted into the gas box with the same

wires intact. In order for the SEM to view the aged portion of the top field wire, the wire cage is split horizontally and the upper part of the cage is flipped up side down for the SEM to view the aged field wire region without obstruction by other wires. Similarly, the bottom part of the cage provides an unobstructed view of the sense wire.

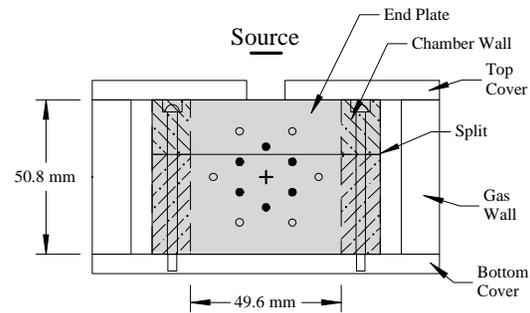


Figure 1 Cross section of the wire chamber. The wires are held by a wire cage that is inserted into a gas containing box. The cage is split to allow the top field wire to be mounted with its aged surface facing the SEM.

A difficulty was encountered with the short chamber from the non uniform electric field near the end plates. Ideally, the potential profile on the end plate should be the same as that between the wires away from the end plate, and the need for long feed through insulators projecting into the chamber would be avoided. Conducting metal end plates can not have such a potential, and insulating end plates behave erratically because of time dependent charge build up on the insulating surface. However, an insulating end plate coated with conducting paint having a surface resistance of approximately 10^9 Ohms per square can solve this problem. The ^{55}Fe peak is then seen to match the spectrum from a long-wire chamber with no end effect problems.

End plates were made from 12.5 mm thick black polycarbonate material with 30% glass. Both the sense wire and field wire feed through pins were pressed directly into holes in the end plate (no plastic) with the pin ends protruding into the chamber by only $\frac{1}{2}$ mm, almost flush with the polycarbonate surface. The surface facing the inside of the chamber was then coated with a thin layer of conducting paint (Ceramabond 668 from Aremco Products), making sure the paint touched the pins. The

potential profile on the paint surface then approximately matches that in the cell.

III. EDX MEASUREMENTS

An initial test run was made with the helium-isobutane(80:20) gas with no additives for an integrated charge of 80 mC/cm on the sense wire. The carbon content on the field wire was measured by EDX spectra taken every 2 mm along the field wire. A typical EDX spectrum is shown in the bottom of Figure 2. The carbon peak is at the left end of the spectrum, while the large gold peak is off-scale at the middle of the spectrum.

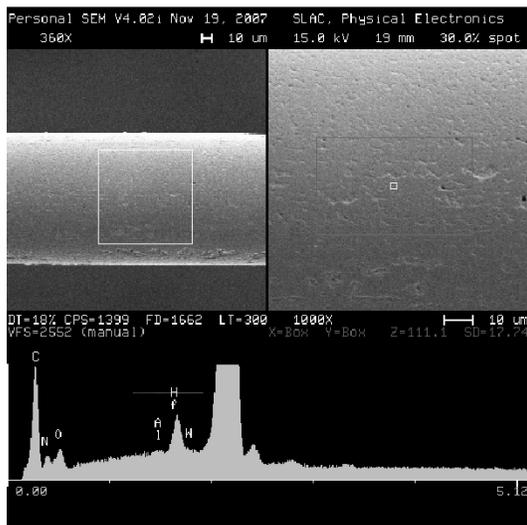


Figure 2 A typical SEM/EDX picture. The field wire surface is shown at 300X (top left) and 1000X (top right) magnification. A large, faint rectangle in the top right view depicts the region used for the EDX spectrum. The spectrum is shown at the bottom. The tall peak at the left is from carbon and the large off scale peak is from the gold coating on the wire.

Figure 3 shows the carbon peak heights along the wire length. The carbon content is approximately constant near each wire end where there is no radiation because the X-rays from the source are masked out by the source window. The carbon content increases at the middle of the wire where the radiation is at a maximum. This profile agrees well with a MonteCarlo simulation (dashed curve) of the ion flux in the cell from the ^{55}Fe X-ray conversions in the gas. The simulation used the actual geometry of the source and the collimating window for the 6 keV X-ray flux, as well as the absorption lengths in air, window, and chamber

gas. The MonteCarlo rate and base line were adjusted to match the EDX data.

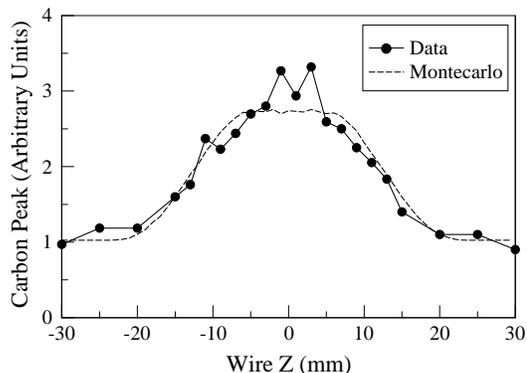


Figure 3 Measured carbon deposit along the wire length. The dashed line is a MonteCarlo simulation of the ion flux on the wire.

The chamber was re-strung with new wires for the final set of aging measurements. The first aging run used the base helium-isobutane (80:20) mixture with the maximum ^{55}Fe source strength, giving a pulse rate of approximately 6 kHz per centimeter at the central region of the sense wire. This aging run continued until the single electron rate seen in the ^{55}Fe spectrum reached a level that indicated breakdown was imminent. The run was stopped at an integrated charge of 63 mC/cm on the sense wire, and the wire cage was then taken to the SEM for the EDX spectra. The next aging run had an additive of 500 ppm oxygen that ran for 20 mC/cm of integrated charge. EDX spectra were again taken. The above two runs were then repeated to better detect any depletion of polymer by the oxygen runs. Finally, aging runs with 3500 ppm water vapor and 1% alcohol were also made with EDX spectra after each run. Table 1 shows the total integrated charge at the end of each run.

Table 1 Gas mixtures used in the aging runs, showing the integrated charge at the end of each run. The base gas is helium-isobutane (80:20).

Integrated Charge (mC/cm)	Gas Additive
63	None
83	Oxygen 500 ppm
102	None
133	Oxygen 500 ppm
163	Water 3500 ppm
193	Alcohol 1%

Each time the wire cage was mounted in the SEM, it was necessary to locate the center of the wire ($Z=0$) in the SEM coordinate system so that the same wire regions could be used for all the runs. This was done by attaching a cross wire to the wire cage at the mid-length of the wires and focusing on this with the SEM for the zero point. The cross wire location was reproducible to approximately 0.5 mm, giving a location error of this amount for the locations of the EDX spectra. The setting error of the SEM stage was much smaller than this, approximately 0.001 mm. Measurements were made at $Z=-3, -1, 1, \text{ and } 3$ mm along the mid-length portion of the wire and [25], [27], and [30] mm locations at either end of each wire. EDX measurements were made for both the field and sense wires. The cross wire used was actually an aged field wire that provided a constant calibration peak from carbon to check the stability of the EDX spectra over the half year duration it took to make these measurements.

A ruler was used to measure the heights of the carbon and oxygen peaks in the spectra. The association of the peak height of an element to the quantity of the element present was not made, so this peak height gives only a relative measurement for the element's abundance, not the absolute amount. Hence an arbitrary unit is used in the plots that follow, but the unit is consistent over all the plots.

Averaged peak values were made both at the aged and the non-aged regions of the wire. For the aged region, only the two most central points at $Z=1$ mm and $Z=-1$ mm were used to assure that the points were well within the plateau of maximum ionization. For the non-aged region, the peak average was made from six points (three at each wire end).

The errors in the peak heights could be estimated from the reading error on the ruler and the statistical error of the counts in the peak channel. However these error estimates were too small by a factor of approximately two compared to the rms spread of all peak heights in the non-aged regions on the wire. The larger error is most likely due to a non reproducible EDX scanning area used for the spectrum, due to the positioning error in Z described previously and the EDX sampling rectangle which is selected manually with a mouse pointer on a computer screen for each EDX spectrum.

The measured deposits on the field wire as a function of integrated charge in the chamber are shown in Figure 4. Carbon is the top plot, oxygen the middle plot, and the gas additives

used during the aging process are shown in the bottom section.

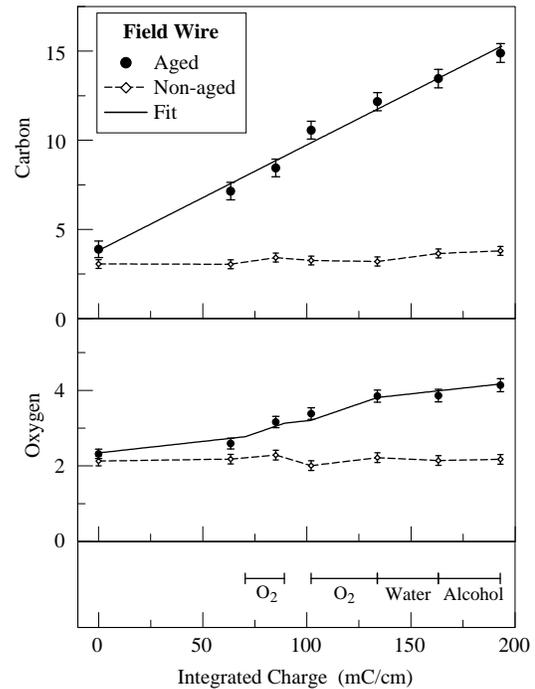


Figure 4 Carbon and oxygen deposits on the field wire as a function of integrated charge on the sense wire. The vertical scale is in arbitrary units. The carbon content on the aged and non-aged regions on the wire is shown in the top plot, while the middle plot shows the same for oxygen. The gas additives used during the aging process are indicated at the bottom.

The error bars for the non-aged region are the rms of the 7 points in the plot, since these points do not collect ions and should remain constant over the aging runs. In order to do a fit of the aged data, the errors have to be adjusted for the growth in the peak height with integrated charge. This was done by adding a term proportional to the square root of the integrated charge in quadrature to the non-aged error. The coefficient of this term was chosen to provide a 50% Chi-square probability for 5 degrees of freedom. This linear fit for carbon is shown by the solid line.

The carbon deposit on the aged field wire grows linearly with the integrated charge on the sense wire. No carbon growth is seen at the wire ends in the non-aged region.

None of the oxygen, water, or alcohol additives prevent the build up of carbon on the field wires. No decrease of carbon is ever seen. Oxygen does not show any cleansing or

depleting action of the carbon deposit, ruling out conjectures that oxygen removes polymer deposits from the field wires.

Oxygen deposits on the field wire in the aged region also grow with integrated charge, but to a lesser extent as shown in the middle plot in the Figure 4. The oxygen deposit grows faster when oxygen is present in the gas. A fit with two aging rates - a higher rate when the oxygen additive is present in the gas and a lower rate otherwise gives a better fit than a fit with only a single rate. This two-rate fit is shown by the dashed line in the plot.

Water and alcohol do not show any increased oxygen growth on the field wire, even though these molecules contain oxygen.

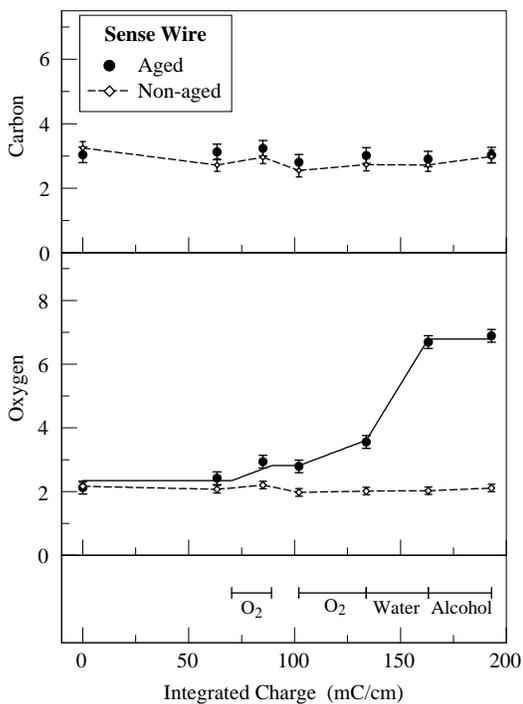


Figure 5 Carbon and oxygen deposits on the sense wire, as described in Figure 4. No carbon is seen, the aged and non-aged points lie almost on top of each other. Oxygen deposits are seen with oxygen or water in the gas. The solid line is a fit with separate slopes for oxygen and water additives.

The carbon and oxygen content on the sense wire is similarly shown in Figure 5. There is no evidence of carbon deposit on the sense wire during any of the aging runs. The aged and non-aged carbon points lie almost on top of each other.

The oxygen deposit, however, is seen to grow slowly with integrated charge when 500 ppm oxygen is present in the gas, and grows more

rapidly when 3500 ppm water is present. The solid line is a fit with separate slopes for the oxygen and the water additive. The growth rate with water is 4 times the growth rate with oxygen, which is approximately the same as the 3.5 ratio of oxygen atoms in 3500 ppm water to oxygen atoms in 500 ppm O_2 .

It is known that water can be absorbed in metals, and this might explain the oxygen growth with the water additive, but after drying out the chamber for over a month followed by four days in the SEM vacuum, the oxygen peak did not show any reduction. It appears that oxygen from the water molecule, or from the oxygen gas, is somehow permanently bound to the gold coated tungsten sense wire.

There is little or no oxygen growth seen on the sense wire with alcohol in the gas. It is interesting to note that oxygen atoms from O_2 or H_2O are equally adept at contributing oxygen on the sense wire, but the oxygen atoms in alcohol contribute nothing.

IV. SEM CHARGE

When the SEM bombards the field wire surface with 15 keV electrons, and the wires are then put into the wire chamber with the high voltage and source on, an abundance of single electrons is seen in the pulse height spectrum. From this it is clear that the SEM imbeds electrons into the polymer, and these electrons are then extracted by the high electric field in the polymer when the chamber is turned on. But the most interesting feature is that these single electrons are seen for a long time, taking several hours to a day for the stored charge to disappear as shown in the curve labeled "After SEM" in Figure 6.

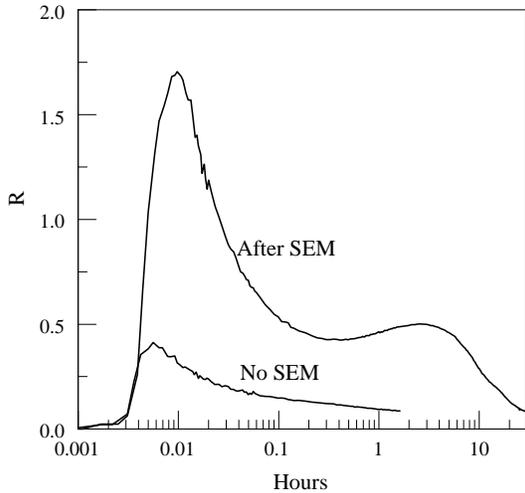


Figure 6 The number of single electrons per ^{55}Fe gamma conversion (R) after turning on the source. The top curve shows the large single electron rate after the field wire was exposed to an SEM electron flux, while the bottom curve shows the normal rate without the SEM exposure.

The second peak at 4 hours is likely from a higher density of stored electrons deepest in the polymer (near the cathode metal) that takes the longest time to be transported out of the film. The bottom curve in Figure 6 shows the corresponding single electron rate when no SEM charge is present.

This stored charge does not readily discharge by itself when the chamber high voltage is off. In one case there was a delay of three days between the SEM exposure and the chamber on time, and single electrons from the stored charge were still seen. The stored electrons appear to be tightly bound in the polymer and require a high field (as produced by the accumulating ionization charge at the polymer) in order to be transported out of the polymer. This could be explained by mobility transport of electrons in the polymer with a small mobility constant.

This behavior has similarities to the models of charge transport through insulators [4], where an effective mobility for free electrons and free holes in the insulator together with charge stored in trapping centers in the insulator are used to explain the transport of charge through thin films of polyethylene in the presence of high electric fields. The trapping centers are thought to be due to topological disorder (e.g. micro-voids [5]) or chemical disorder in the polymer.

V. OXYGEN BEHAVIOR

After the first run with the oxygen additive (83 mC/cm), the chamber could operate with the base 80:20 gas at the maximum source strength, but not for long. After a few hours the chamber showed signs of break down, and the source had to be reduced by a factor of two or more in order to complete the run to the 102 mC/cm exposure. These measurements show that an oxygen additive does not provide a long term cure for breakdown once the oxygen is removed.

The effects from oxygen have a delayed nature. When oxygen is added to the gas it takes time before breakdown is suppressed [1], and when oxygen is then removed it takes time for breakdown to reappear. Also, high ionization in the chamber is required to see these changes take place, which implies that high electric fields are required in the polymer.

This is indicative that oxygen ions are transported by mobility into the polymer film when oxygen is first introduced in the gas and transported slowly out of the polymer when the oxygen additive is removed from the gas. Because a high electric field is required to see these changes, diffusion is ruled out as the transport mechanism. It appears that while oxygen ions are in the polymer, the polymer resistance is reduced and this prevents the large build up of charge that triggers breakdown. This has similarities to semiconductors, where the addition of doping centers in an insulating material can change the resistance of the material.

VI. CONCLUSION

These measurements show that an oxygen additive in the gas of a wire chamber does not clean or remove polymer deposits on aged field wires in the chamber. Instead the polymer builds up with integrated charge at the same rate as for the base gas with no additive. Water and alcohol additives also do not prevent or accelerate the polymer build up on the field wires. Within the errors of measurement, there is no change in the rate of polymer growth between the base gas and a gas containing an oxygen, water, or alcohol additive.

The likely scenario for chamber improvement from the oxygen additive is transport of oxygen ions by mobility into the polymer film that makes the material more conductive and prevents breakdown. A low mobility constant can explain why it takes time to see improvement in an aged chamber when oxygen

is first introduced in the gas and also why a chamber remains improved for a long time after the oxygen is removed from the gas.

No carbon deposit is seen on the sense wire for all additives. However, oxygen deposits are seen to grow on the sense wire when either the oxygen or the water additive is present in the gas. The oxygen deposit grows most rapidly with the water additive, and this oxygen deposit is not removed by drying out the chamber. It is not clear how oxygen manages to adhere to the gold coated tungsten sense wire.

Electron bombardment of field wires by the SEM results in stored charge in the polymer film that takes approximately a day to discharge (longer if the chamber is turned off). Numerical models [4] of charge transport through insulators that use electron mobility and stored charge within trapping sites in the polymer might also explain the charge behavior seen here.

Acknowledgments

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