Aging in large CDF tracking chambers

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Abstract

The experience of the Collider Detector at Fermilab (CDF) with aging in the large axial drift chamber responsible for tracking in the central region is presented. Premature aging in the Run 1 chamber was observed after only 0.02 C/cm. After cleaning much of the gas system and making modifications to reduce aerosols from the alcohol bubbler, the observed aging rate fell dramatically in test chambers. Considerable effort has been made to better understand the factors that affect aging since the replacement chamber for Run 2 will accumulate about 1.0 C/cm. Current test chambers using the full CDF gas system show aging rates of less than 5%/C/cm.

1. Introduction

CDF is a large magnetic detector built to study 2 TeV PbarP collisions at the Fermilab Collider. At its center is a large cylindrical tracking chamber coaxial with the beam. This chamber is inside a large solenoidal magnet with a 1.4 Tesla field.

In section 2, both versions of the central drift chamber will be described. In section 3, the aging experience with the Run 1 chamber (CTC)[i] will be detailed. In section 4, the response to the unexpectedly large aging rate measured in Run 1 will be described. This includes the results from aging studies in test chambers. In section 5, the analysis of the deposits on the chamber wires will be discussed. In section 6, the monitoring for the Run 2 chamber (COT)[ii] will be discussed.

2. Chamber specifications

The chamber is roughly 3 meters long by 3 meters in diameter and filled with a 50/50 mix of argon/ethane with a small admixture of alcohol

(roughly 1%)[iii] to reduce aging. In the future when the beam crossing time is decreased, a component of CF_4 will be added to the gas in order to increase the electron drift velocity. The sense wires are 40 micron gold-plated tungsten.

The Run 1 chamber (CTC) had over 6000 sense wires distributed over 9 superlayers (5 axial and 4 stereo) in a jet cell configuration. The drift distance was about 5 cm, the cathode was a wire plane, and there were potential wires between sense wires to shape the electric field. The potential and cathode wires were ≥ 140 micron 304 stainless steel. Ethanol was the additive.

The Run 2 chamber (COT) has over 30,000 sense wires distributed over 8 super-layers (4 axial and 4 stereo). The drift distance is about 1 cm and the cathodes are 35 nm of gold, vapor-deposited on a mylar sheet. Both the sense and potential wires are 40 micron gold-plated tungsten. Isopropanol is the additive.

3. Aging experience with the CTC

Prior to Run 1, tests on prototype chambers indicated aging rates of < 10%/Coulomb/cm using gas from the CDF gas system. Near the end of Run 1 (early 1995), much larger aging effects were noticed in the CTC. This large rate started in early 1994 coinciding with two unrelated occurrences: 1) There was a change in ethane supply. The ethane came from a new well that had a much larger component of ethylene than the previous source. 2) There was a
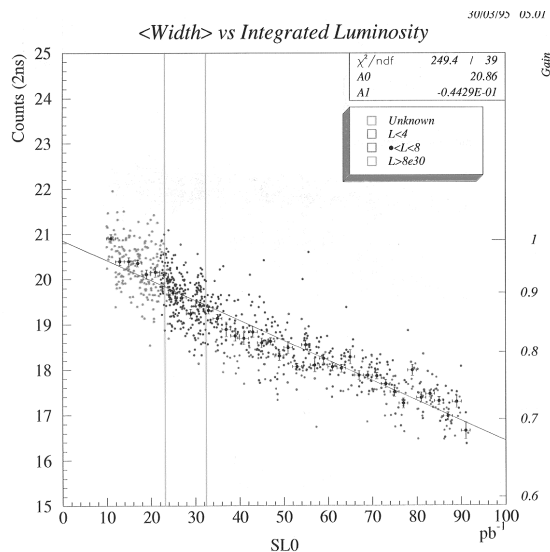
Figure 1: Pulse width and gain vs. integrated luminosity.

significant increase in the interaction rate (luminosity) seen by the chamber.
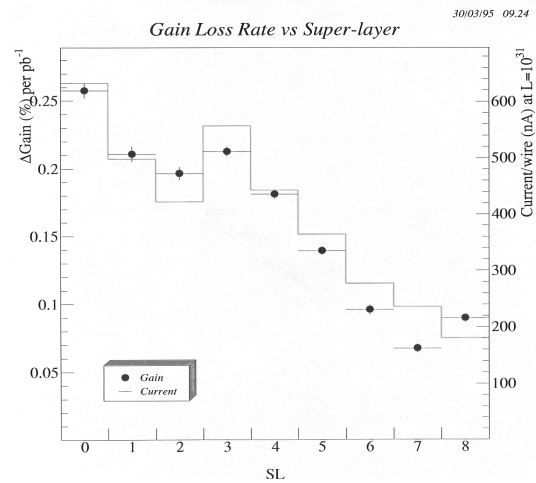
Figure 2. Average gain loss and current per superlayer.

Before the change of ethane supply, the effect of ethylene on the aging rate was measured in test chambers. Without an admixture of alcohol it was about 80%/Coulomb/cm (%/C/cm) and with alcohol it was about 5%/C/cm. The lower aging rate with alcohol was obtained with either ethanol or isopropanol.

The aging rate in the CTC was measured using the physics data by monitoring the average width of the discriminated pulses from the chamber. Longer pulses correspond to larger pulse height and higher gain. By quantifying this relationship, the gain of the chamber could be determined as a function of time. Figure 1 shows the average width of pulses associated with good tracks and the corresponding gain for wires in the innermost superlayer as a function of integrated luminosity.

Figure 2 compares the average loss of gain for each superlayer relative to the current drawn. The correlation between the two is quite good. The gain loss observed corresponds to about 1000%/C/cm or 200% per fb^{-1} of integrated luminosity.

4. Response to the measured CTC aging rate

During March-April 1995 parts of the gas system were cleaned. The mineral oil inlet pressure valve

was replaced by a mechanical valve. The alcohol bubbler was cleaned and refilled. The alcohol and bubbler looked clean to the eye, but traces of silicon and glycol were found in the evaporated residue using Fourier Transform Infrared Spectroscopy (FTIR). The molecular sieve absorber for the ethane was found to be contaminated with vacuum pump oil; it was cleaned and precautions were taken to prevent a reoccurrence. Gas monitor chambers were inserted into the CTC gas system in strategic places to measure changes in aging rates. [90]Sr sources were used to produce aging in these chambers and [55]Fe sources were used to measure the change in gain.

The chronology of the subsequent events is summarized as follows:

- April: The aging rate was measured directly after the alcohol bubbler to be ~100,000 %/C/cm.

- April-May: After cleaning many valves, aging rate still was ~100,000 %/C/cm.

- May-June: Aging measured at the CTC input (50 meters from the bubbler) was ~15,000 %/C/cm.

- July: It is suspected that aerosols from the alcohol bubbler are contributing to the large aging rates. A filter canister with a single copper wool pad is placed after the bubbler. Aging before the copper wool was ~100,000 %/C/cm and after the copper wool ~50,000 %/C/cm.

- August: A second copper wool pad is added to the filter canister and it is heated to ~ 50 $^{\circ}$C. The aging rates were (17,000±4,000) %/C/cm directly after the filter canister; (3,000±2,000) %/C/cm at the CTC input; and (400±200) %/C/cm at the CTC exhaust.

- November-February: A second heated filter canister with two copper wool pads was added after the alcohol bubbler. In order to reduce turbulence in the bubbler, 80% of the argon/ethane flow was bypassed and the alcohol temperature was increased by the amount necessary to maintain the same alcohol content in the total flow. The aging rates were now measured to be (50±30) %/C/cm directly after the two filter canisters; (10±30) %/C/cm at the CTC input; and (80±20) %/C/cm at the CTC exhaust.
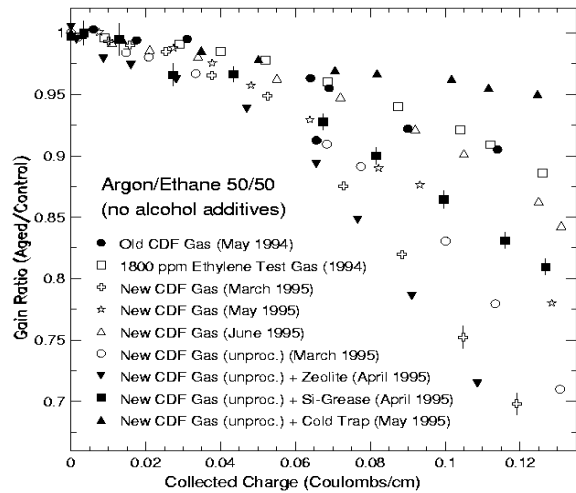

Figure 3. Summary of the effect of contaminants on aging in bench tests using argon/ethane with no alcohol admixture.

In addition, bench test aging measurements were made to determine the effects of several contaminants for the standard CTC gas. These tests were all done without alcohol in order to enhance the effects of the contaminants. In general, the aging rate due to most contaminants was found to be reduced by about an order of magnitude by the addition of alcohol.

Figure 3 summarizes these bench test measurements. The "Old CDF Gas" points used ethane from the original vendor. The "1800 ppm Ethylene Test Gas" was a special test gas which was prepared with 1800 ppm of ethylene; other identified impurities were measured to be less than 200 ppm. The "New CDF Gas (unprocessed)" was from a batch of ethane from the new vendor that had not been processed with hydrogen to reduce the ethylene content. This gas had approximately 1400 ppm ethylene, 600 ppm propane, and 1100 ppm propylene. The "New CDF Gas" was actual gas used by CDF from the new vendor that had been "processed" to remove the ethylene.

In general, the gas from the new vendor showed larger aging rates than the one set of measurements for the old gas. There was little difference between the new gas and the unprocessed gas. The most striking feature of this figure is that the lowest aging rate was obtained using a cold trap. Because of this, a cold trap was added to the gas system for Run 2.

5. Analysis of aged wires

To help interpret the aging results, sample wires were scanned using electron microscopes. Energy and Wave Dispersive Spectroscopy (EDS and WDS) gave a spatial resolution of a few nanometers and good automated elemental spectroscopy. Additional FTIR gave the capability of measuring molecular bonds.

Wires from bench test chambers without alcohol (used for the aging measurements shown in figure 3) had deposits dominated by silicon and oxygen in the form of amorphous silicon oxide. Pictures of a wire aged with the unprocessed gas from the new vendor showed a landscape of thin fibers that resemble a dense, burnt out forest as shown in figure 4 These pictures are consistent with the chemically active nature of silicon.
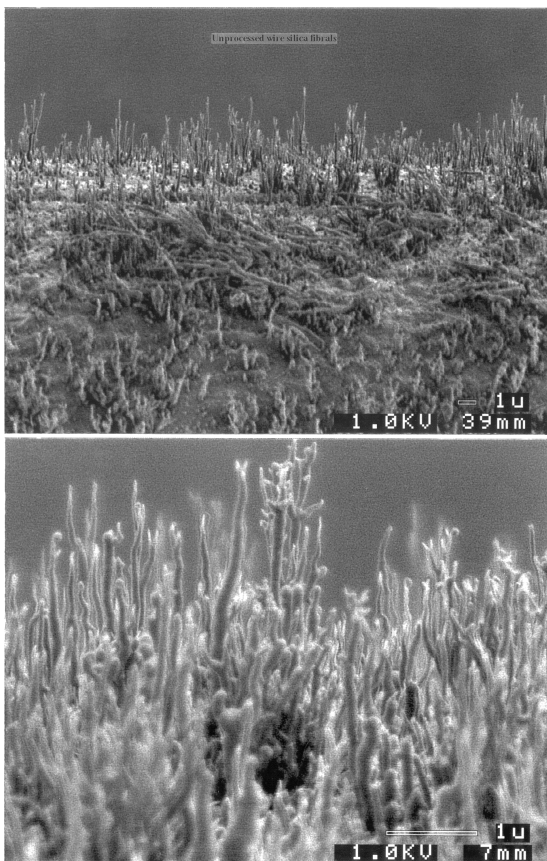

Figure 4. Pictures of silicon growths on a wire aged to 30% gain loss in unprocessed gas from the new vendor. The lower picture is with higher magnification.
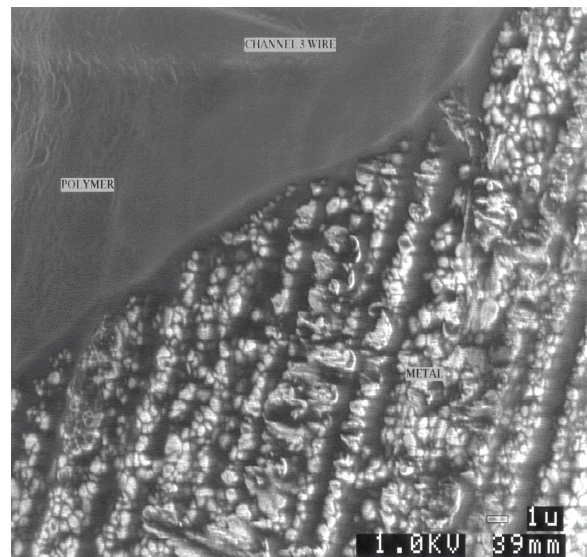

Figure 5. Picture of wire aged in a test chamber directly after the alcohol bubbler. The smooth dark polymer coating is seen in the upper left and the bare wire is seen on the lower right.

A wire from a gas monitor chamber inserted into the CTC gas flow just after the bubbler (before measures to reduce aerosols were implemented) had a smoother film-like polymer coating. The coating was mostly long-chain hydrocarbon polymers with only traces of silicone and O-H bonds. A lower magnification picture is shown in figure 5 of this wire which had aged at a rate of about 100,000 %/C/cm.

At the same time, wires in a test chamber at the CTC input (50 meters downstream from the alcohol bubbler) developed a coating that was dark to the naked eye. They had been aged at a rate of about 15,000 %/C/cm with a total gain drop of 50-60%. Electron microscope spectroscopy measured mostly carbon, some oxygen, sodium, and a little silicon. FTIR analysis picked up a long aliphatic hydrocarbon polymer (at least 10 carbon atoms long), a likely mixture of a free organic acid (possibly oleic acid or stearic acid) and an organic-acid salt, and silicone. Under magnification the coating appeared smooth with occasional nodules as shown in figure 6.

Sample sense wires from the CTC itself had a similar appearance to figure 6, but with a lower density of nodules. A sample near the west endplate (gas input) had elemental percentages of 23% carbon, 8% oxygen, and 1.2% silicon (with the rest being gold and tungsten from the wire). A sample near the

east endplate (gas output) had 20% carbon, 15% oxygen, and 3% silicon. This is in contrast to the wires from the bench test chambers without alcohol that had mostly silicon and oxygen.
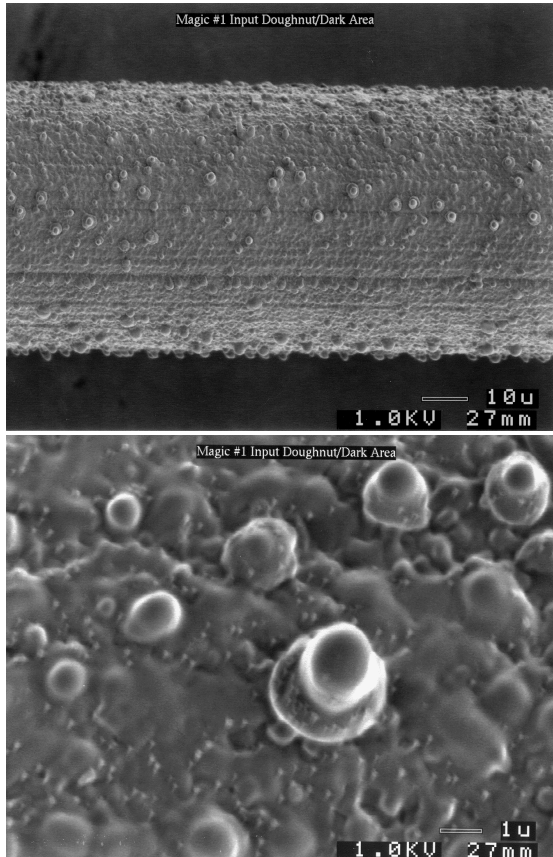

Figure 6. Wires from test chambers just in front of the CTC input before measures to reduce aerosols were taken.

6. Gas monitoring for Run 2

For Run 2 an integrated luminosity of 15 fb^{-1} is expected corresponding to about 1.0 Coulomb per centimeter of accumulated charge in the worst case. Therefore, several steps have been taken to ensure that the aging rate is small. A cold trap running at about $-70\,^{\circ}C$ and two activated charcoal filters have been inserted into the gas flow before the alcohol bubbler. The procedures to reduce aerosols have been

kept and gas monitor chambers of a new design have been installed at strategic points in the gas system.

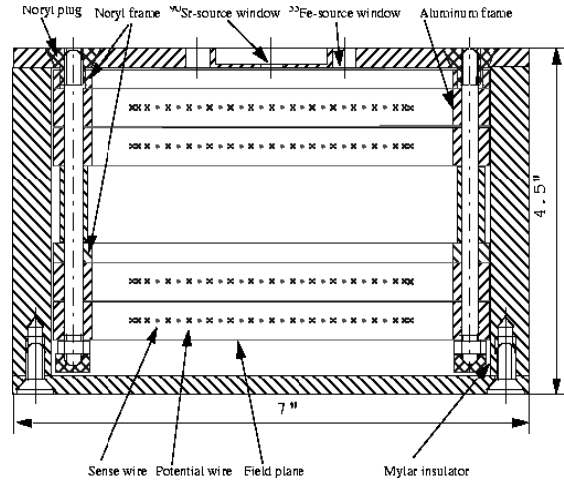Figure 7 shows the cross-section of the new gas monitor chamber. Each chamber consist of four wire

Figure 7. Cross-section of the gas monitor chamber used to measure aging for Run 2.

planes, each a different distance from a ^{90}Sr source. The source current that ages the wires is used also to measure the gain. By looking at the ratio of the currents in two planes as a function of time, a measure of aging is obtained. The actual amount of charge collected per plane does not vary much because all planes see most of the radiation. However, the effective length of wire collecting charge in each plane differs significantly with distance from the source. The collected charge per cm and the resultant aging varies by a factor of 8 between planes 1 and 4, the two farthest apart. The ^{55}Fe window was used to study chamber systematics.

The most sensitive measure of aging is the ratio of the currents in planes 1 and 4 as a function of time. In general, the effects of temperature and pressure cancel out in the ratio of the currents. However, the ionization rates are large enough that a correction must be made because the variation in space charge effects as a function of gain is different for the two planes. Figure 8 shows how the current ratio I_1/I_4 varies as a function of I_4 (i.e. gain) due to space charge effects. Variations in I_4 were obtained by making small changes to the high voltage.

Figure 9 shows the results of one aging study. The horizontal axis is time in hours. The top curve is

the temperature in degrees Celsius. The second curve is the pressure in torr. The third curve is the current I_4 in plane 4 which reflects the gain of the chamber. The gain is proportional to the temperature and the inverse of the pressure and changes by about 25%.
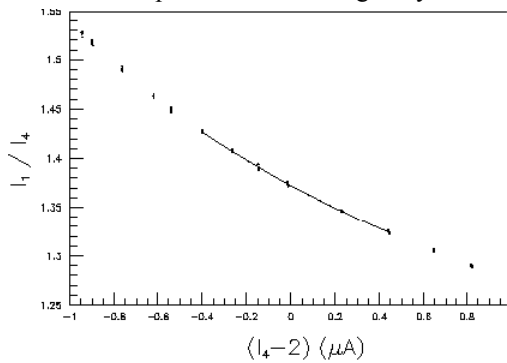

Figure 8. The current ratio between wire planes giving a measure of the space charge correction.

The fourth curve is the ratio I_1/I_4; its variation is of order 2%. The bottom curve is I_1/I_4 corrected for the space charge dependence on gain using the quadratic fit to the central region shown in figure 8. It is a measure of aging and varies by less than 1%. The approximations in the space charge correction cause some structure; the two larger glitches are coincident with large temperature excursions.

Currently, gas monitor chambers are located after the alcohol bubbler, at the COT input, and at the COT exhaust. After taking into account systematic uncertainties, the measured aging rate has always been < 5%/C/cm. This will be an acceptable aging rate for Run 2 if it can be maintained.

7. Conclusions.

Near the end of Run 1, an unexpectedly large aging rate in the CTC of 1000 %/C/cm was observed using the physics data. Gas monitor chambers were inserted at important points in the gas system and they also exhibited large aging rates. The reasons for this accelerated aging are not completely understood; however, cleaning parts of the gas system and implementing procedures to reduce aerosols from the alcohol bubbler restored the aging rate to the expected levels in the gas monitor chambers. The nature of the deposits on the wires of the gas monitor
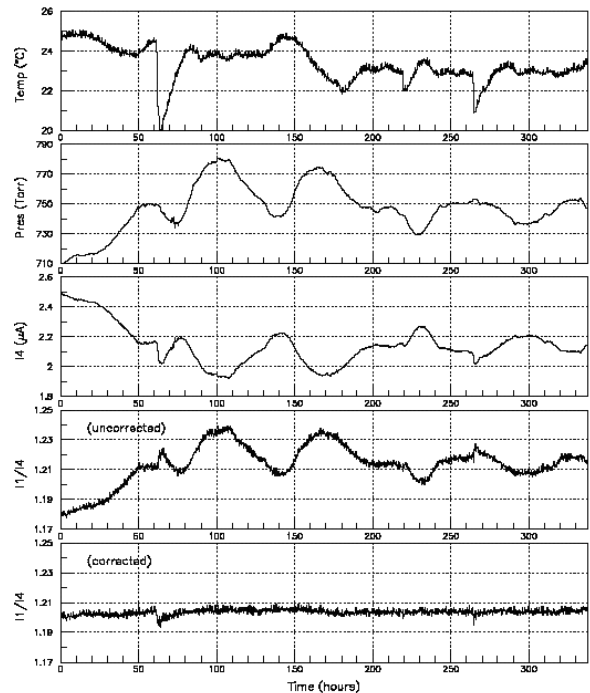

Figure 9. Curves from a typical aging study. The corrected ratio of currents in the bottom curve reflects the aging rate.

chambers and on wires from the CTC itself was different from deposits on wires aged without an alcohol bubbler.

For Run 2, the gas system for the COT is cleaner, a cold trap and activated charcoal filters have been added, and the procedures for reducing aerosols from the alcohol bubbler have been retained. New multilayer gas monitor chambers have been built which measure aging by looking at the ratio of currents in the different layers. To date, the aging in these chambers is < 5 %/C/cm after including systematic uncertainties. This should allow the COT to operate for the full 15 fb^{-1} of integrated luminosity expected in Run 2.

[i] F. Bedeschi, et al., Nucl. Instr. and Meth. A 268 (1988) 50.
[ii] K. T. Pitts, Nucl. Phys. B 61 (1998) 235.

[iii] M. Atac, et al., Nucl. Instr. and Meth. A 249 (1986) 265.