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WIRE CHAMBER DEGRADATION AT THE ARGONNE ZGS§

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Abstract

Experience with multiwire proportional chambers at high rates at the Argonne Zero Gradient Synchrotron is described. A buildup of silicon on the sense wires was observed where the beam passed through the chamber. Analysis of the chamber gas indicated that the density of silicon was probably less than 10 ppm.

Introduction

A number of multiwire proportional chambers (MWPC's) were constructed at Argonne National Laboratory for use in πp and pp elastic scattering spin experiments at the Zero Gradient Synchrotron (ZGS). The first few of these chambers were built in 1971 and 1972, and the first major experiment to use them was in 1973.[1] Since that time, they have been used almost continuously in 17 different experiments at the ZGS and the Clinton P. Anderson Meson Physics Facility at Los Alamos (LAMPF), with only minor modifications in the chamber construction or the electronics. An upgrade to the electronic connectors and the electronics for these chambers is currently in progress in preparation for an upcoming experiment at Fermilab.

For most of the ZGS experiments and some of the LAMPF experiments, three 128 x 128 mm^2 MWPC's were located in the beam, a few meters upstream of the experimental target, to record the incident beam particle trajectories. Long run times were needed in order to collect sufficient elastic scattering events for the spin measurements. Typical beam intensities ranged from 10^4 to 10^6 per second, averaged over the accelerator cycle of several seconds. Instantaneous rates were up to about 5 x 10^6/sec. Experiments usually ran continuously for one to four months with interruptions for maintenance and repair of accelerator and experimental apparatus. Therefore, in a typical experiment, the total number of incident beam particles might be on the order of 10^{12} in an area of about 1-2 cm^2.

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The efficiency of the MWPC's in the ZGS beam was observed to decrease monotonically with time. Areas of the chambers that were not in the direct beam were found to have good efficiency, whereas in the center of the beam it could be 20% or less. When the chambers were disassembled, deposits were seen on both the sense wires and the high voltage (cathode) foils. This paper describes some of our tests to understand the cause of the deposits and our unsuccessful attempts to eliminate the problem. Ultimately, the chambers were moved relative to the beam a number of times, and the sense wires were changed at the end of the experiment in order to decrease the impact of these problems on the spin measurements.

Description of Detectors

The MWPC's located in the ZGS beam were all of identical construction. Each chamber contained both horizontal and vertical sense wires of 20 μm diameter gold-plated-tungsten with a spacing of 2.0 mm. Near each edge of the chamber, three additional wires of increasing diameter were located parallel to the sense wires to prevent electrical breakdown to the G10 frames. Initially, the wires were soldered and epoxied to printed circuit boards that were part of the chamber frames. Later, when the wires were replaced, they were soldered only. A standard lead-tin eutectic, resin-core flux solder was used. The active area of these chambers was 128 x 128 mm^2, and the total area was 140 x 140 mm^2.

The G10 chamber frames, and thus the gap spacing between the cathode plane and the anode sense wires, were 0.25" = 6.4 mm thick. The frames containing the wires consisted of a 1.6 mm thick printed circuit board of G10 epoxied to a 6.4 mm thick frame of G10; then it was machined to the proper thickness. The individual frames were bolted together with nylon threaded rod and nuts. The initial design called for O-rings to make the gas seal. Later, this seal was made with silicon-rubber glue (RTV) outside the O-ring groove.

The outer gas windows were 50 μm mylar covered with nontransparent mylar tape of about the same thickness. The cathode planes were initially aluminized mylar of thickness 50 μm. Early experience with these chambers in the beam showed that the aluminum was eventually etched away near the high voltage connection, presumably from the relatively high currents in these chambers due to the beam. The aluminum was also etched away in isolated spots, probably associated with "hot spots" or sparks. Additional problems were encountered in the area located in the direct beam, as described below. For these reasons, the cathode planes were changed to 50 μm aluminum foil for the beam chambers. NIM high voltage power supplies designed by T. Droege were used with series protection resistors of 9 KΩ on these MWPC's.

Various gases were tried with these chambers. Complexities of the gas mixing systems for the "magic gases" led to the adoption of argon-carbon dioxide mixtures. Based on the length of the high voltage plateau, a 65%-35% mix of Ar-CO_2 was chosen. Problems with chamber sparking and frequent breakage of the sense wires were solved with the addition of 0.4 - 0.5% Freon - 13 B1 ($CBrF_3$). Research grade gas was ordered in high pressure 1A gas cylinders from commercial vendors. The gas came premixed and chemically analyzed to verify its purity.

The chambers were operated at atmospheric pressure. A gas control panel, containing pressure regulators and flowmeters, was located near the gas bottles about 10m from the chambers. Polyflo tubing was used for most of the distance between the control panel and chambers, with a short (~ 10cm) length of tygon tubing at the chambers to reduce mechanical stresses. Similar tubing brought the exhaust gas back to the control panel, where it was bubbled through mineral oil before venting. Gas flowed to each chamber separately; they were not connected in series. The total gas volume of each chamber, exclusive of the tubing, was about 900 cc. The gas flow gave a change in this volume on the order of once a day.

The threshold on the electronics[2] for these chambers was equivalent to 1 mV across a 100 Ω input resistor. Allowing for the fact that the operating voltage was 100-200V above the knee in the plateau curve, the number of collected electrons per beam particle was roughly 10^6 -10^7. Estimating the number of primary electron-ion pairs (essentially all beam particles were close to minimum ionizing), then the total gain of the chambers per primary electron was approximately 10^4. The operating voltage was 4400V at the ZGS and 4200V at LAMPF (from the reduced atmospheric pressure). This gave electric fields of ~ 33 and 0.5 kV/mm at the sense wires and cathode planes, respectively.

Experimental Observations

Soon after the chambers were constructed and tested in the beam, problems were encountered with the efficiency, which decreased with time. When the chambers were disassembled, whitish deposits were observed on both the sense wires and the cathode aluminized mylar planes near the location where the beam had passed through the chamber. Chemical analyses of the wires showed a striking buildup of silicon. Several changes were made at that time. a) The fluid used in the bubbler was changed from a silicon-based oil to mineral oil (~ CH_2). b) The gas lines were changed from tygon to polyflo with a short length of tygon near the chamber. c) The aluminized mylar cathode planes were changed to aluminum foil planes. d) The wires with the deposits were replaced, although it appeared that the deposits could be removed mechanically. The deposits changed qualitatively, but the drops in efficiency persisted.

Tests were performed by operating two of the beam chambers with the standard gas (Ar-CO_2-Freon 13B1) and the third chamber with magic gas (68% Ar, 28.5% Isobutane, 3% Methylal, 0.5% Freon 13B1). Although detailed studies were not performed, the rate of drop in the efficiency was found to be about the same for the two gas mixtures. (The efficiency dropped about 10% for beam exposures of 10^{10} to 10^{11} particles/cm^2.) Thereafter, the standard mixture was used.

After these changes and tests, a chemical analysis of the chamber gas was performed with a mass spectrometer. Gas samples were taken, while the chambers were in operation, at five points in the gas system, both upstream and downstream of the chamber. No gross impurities (greater than ~ 100 ppm) were present in the mass range 12 to 250, except those that could be masked by Ar, CO_2 or Freon 13B1 ($CBrF_3$). The samples were also cooled to LN_2 temperature

and the argon pumped off. The resulting samples were tested again. Only CO_2 and $CBrF_3$ with a trace of H_2O were detected, suggesting that the impurities were probably less than 10 ppm initially. It is possible that ^{28}SiO was present at a low level in one or more of the gas samples, masked by the CO_2. However, the absence of signals from SiO_2 or Si or from ^{29}SiO and ^{30}SiO would limit the presence of SiO to a few hundred ppm.

The tungsten sense wires and the aluminum foil cathode planes were submitted to an ion microprobe mass analysis by D. V. Steidl of the Argonne Chemical Engineering Division. A beam of 20 KeV N_2^+ of diameter ~ 3μm was obtained from a duoplasmatron source and a mass spectrometer. This beam was used to sample the wires directly, and it was rastered over an area of 80 x 100 μm^2 on the foils. The resulting positive ions were measured with a secon mass spectrometer. The vacuum in the apparatus was about 10^{-9} Torr, so littl of the signal corresponds to beam - gas background. The results are given in Tables 1 and 2 and Fig. 1.

These results can be used to give rough comparisons of the surface compositions of the new and bombarded wires and foils for a given element. Comparisons between elements for a given sample do not give true abundances, since the sensitivity of the apparatus varies with the ion. Likewise, the io yields may be sensitive to surface topography; hence, the results are more reliable for the foils than for the wires. The changes indicated by these measurements are: a) There was a 2 to 3 order of magnitude increase in the silicon and a roughly one order of magnitude decrease in the sodium and potas sium for the bombarded wires compared to the unused wires, and b) there was considerable increase in the fluorine on the aluminum foils that were in the direct beam compared to new foils. The sensitivity to $^{19}F^+$ is quite low in this apparatus, so a substantial quantity of fluorine is indicated.

The source of the fluorine on the bombarded foils is probably the Freon 13B1 in the gas. However, silicon was not observed in the gas, although it was present in the chamber frames (G10 fiberglass-epoxy) and in the RTV used for the gas seal. Both of these materials are far from the primary beam. Various mechanisms to produce the observed silicon and fluorine were considered. However, none could explain the large amount of silicon observed. As a consequence, the chambers were moved relative to the beam several times during a single experiment when the beam intensity was high. Wires were also replaced between experiments (or during an experiment) when necessary.

Some Calculations

In this section, a number of very rough estimates are made for the buildup of silicon on the MWPC sense wires in the direct beam and on various possible mechanisms for the buildup. Similar estimates also hold for the fluorine deposited on the aluminum foils, but the presence of Freon 13B1 in the chamber gas can explain the source (but not necessarily the buildup mechanism) of the fluorine.

First, consider a lower limit to the amount of silicon deposited. The deposits were clearly visible and appeared to be continuous, even under a microscope. Therefore, their thickness must have been substantially larger

than the wavelength of light. In the absence of quantitative measurements, a lower limit of 10,000 A will be assumed. Also, from observations, the total length of coated sense wires was roughly 5 cm. Assuming a silicon spacing of 3 A, then the total silicon present was

$$\gtrsim 10^{17} \text{ silicon atoms deposited}$$

or

$$\gtrsim 2 \times 10^{16} \text{ silicon atoms/cm of wire.}$$

A similar value of the thickness and the number of silicon atoms can be obtained from a different estimate. In this case, the appreciable drop in efficiency is assumed to occur because the wire diameter is increased by the deposits to give a surface potential about 10% less than the chamber operating voltage. Furthermore, if the deposit is assumed to have a dielectric constant similar to glass (SiO_2, $\varepsilon \sim 3$-4), then the calculated thickness is somewhat larger than 10,000 A. On the other hand, the silicon spacing would be somewhat larger as well. In both estimates, the deposits were assumed to be continuous, without voids, which has not been demonstrated experimentally.

The material estimated above was deposited in roughly one month at a beam intensity of at least 2×10^6/pulse with a pulse every 3 seconds. As a result, a lower limit to the amount of silicon per incident proton was

$$\gtrsim 8 \times 10^4 \text{ silicon atoms deposited/incident proton.}$$

This is an enormous number! Even with the assumption of only a single, continuous layer of silicon (3 A instead of 10,000 A), the limit is roughly 25 silicon atoms deposited per incident proton. Clearly, the process that deposits the silicon is very efficient.

Such large numbers immediately rule out nuclear reactions of the protons with the gas or tungsten wire, since there is so little material present in the chamber. Nuclear reactions on the mylar ($C_5H_4O_2$) or CO_2 in the gas couldn't lead to silicon in any case. Likewise, sputtering of material from the G10 frames by particles in the beam halo is probably ruled out. With a beam spot size of 1-2 cm diameter, and a distance of greater than 6 cm to the frames, probably less than one part in 10^3 of the beam struck the frame. It seems implausible that on the average $\sim 10^8$ silicon atoms could be ejected from the frame for each particle in the halo that struck the frame.

With an assumed value of 10^7 electrons collected per incident beam particle, then the efficiency of depositing a silicon can also be expressed as

$$\gtrsim 0.008 \text{ silicon atoms deposited/collected electron.}$$

Silicon contamination of the chamber gas was measured to be orders of magnitude smaller than this, on the order of 100 ppm, or perhaps even 10 ppm or less. Furthermore, the ions formed near the anode wire should have a positive charge and thus be repelled. Clearly, chemical reactions are involved in some way with the depositing of the silicon.

Finally, it can be checked that the limits on the gas contamination do not exclude the gas as the source of the silicon. The precise gas flows were not recorded for the chambers. Taking a conservative value of 1 cc/min for the bubbling rate and a 10 ppm contamination of the gas by silicon, then 10^{17} silicon atoms would pass through each chamber in about seven hours. An allowance for the fact that not all the gas went near the beam would increase this estimate by about an order of magnitude to a few days. Therefore, if the gas contained silicon as a contaminant at a low level, whatever chemical processes taking place in the chambers would have to collect it efficiently.

Conclusions

Observations of MWPC's in multi-GeV beams of protons and pions at the ZGS indicated a drop in efficiency for exposures of about 10^{10} - 10^{11} beam particles/cm^2. Deposits on the sense wires (silicon) and the cathode planes (fluorine) were visible in the area of the chambers where the beam was present. The precise mechanisms for depositing the silicon and fluorine are not understood. The source of the fluorine was likely to be the Freon 13B1 ($CBrF_3$) in the chamber gas. The silicon was probably present as an impurity in the chamber gas at the level of 10 ppm or less. The source is not known, but may have been the G10 chamber frames, the RTV gas seal, or the commercial gas mixture. Many atoms of fluorine and silicon are deposited for each beam particle and the chemical processes responsible for depositing the silicon are reasonably efficient.

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REFERENCES

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2) K. Nield and R. Daly, Argonne National Laboratory Report ANL-HEP-PR-77-32 (1977), unpublished.

Table 1

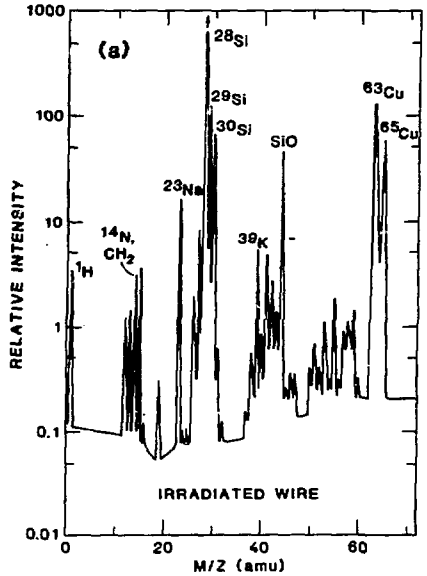
Ion Microprobe Analysis of Gold-Plated Tungsten Wires

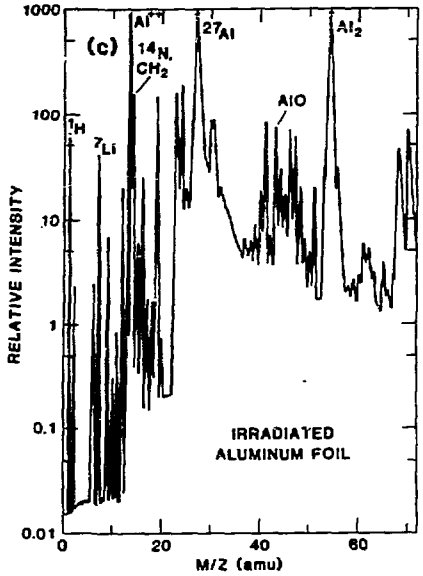
Ion	Relative Abundance on Irradiated Wire	Relative Abundance on New Wire
$^{1}H^{+}$	3.4	1.3
$^{7}Li^{+}$	---	0.2
$^{12}C^{+}$	1.2	0.2
$^{19}F^{+}$	0.25	< 0.1
$^{23}Na^{+}$	7.4	48
$^{27}Al^{+}$	8	1.2
$^{28}Si^{+}$	2200	5
$^{39}K^{+}$	5	54
$^{40}Ca^{+}$	< 0.7	< 4
$^{52}Cr^{+}$	0.6	0.15
$^{56}Fe^{+}$	< 1.7	0.4
$^{120}Sn^{+}$	0.3	< 0.1

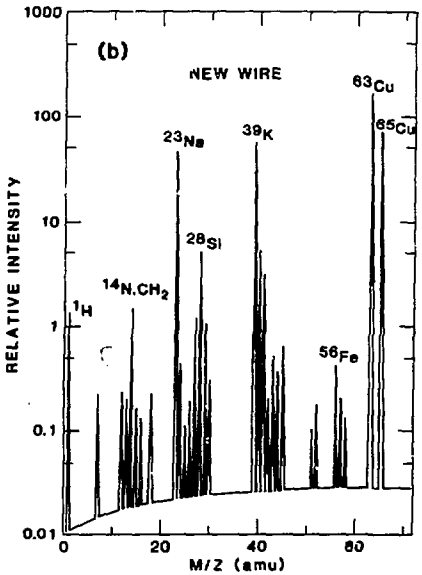
Table 2

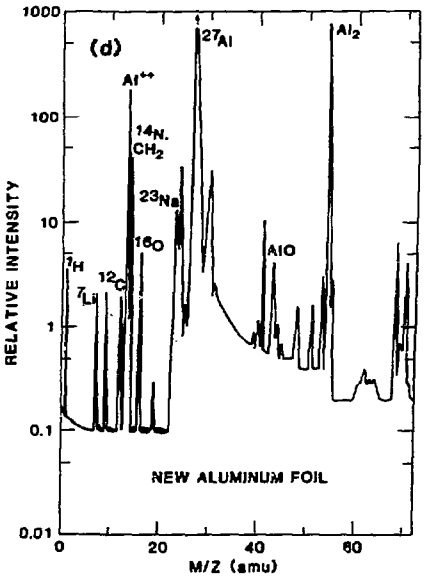
Ion Microprobe Analysis of Aluminum Foils

Ion	Relative Abundance on Irradiated Foil	Relative Abundance On New Foil
$^{1}H^{+}$	2.8	3.3
$^{7}Li^{+}$	3	1.9
$^{9}Be^{+}$	2.3	2.0
$^{12}C^{+}$	4	1.7
$^{19}F^{+}$	53	0.2
$^{23}Na^{+}$	53	15
$^{24}Mg^{+}$	63	30
$^{39}K^{+}$	3	0.9
$^{40}Ca^{+}$	4	1.2









Results from an ion microprobe mass analysis of tungsten anode wires and aluminum cathode foils from the MWPC's in the ZGS beam. The figures shown are a composite of several spectra with different sensitivities.
a) Irradiated wire. b) New wire. Signals were also seen at much higher masses corresponding to tungsten and gold. A copper holder for the wires was employed, which led to the copper signals. c) Irradiated foil.
d) New foil.

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