BNL E-787 Technical Note 293
UTC Foil Fabrication

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1 Introduction

The primary design goal of the recently installed Ultra Thin Chamber (UTC) was to present particles with the lowest possible number of radiation lengths while still maintaining good track resolution.[1] An essential element of the UTC's design was the use of metal plated foils to separate the chamber into discrete gas volumes and provide the position of the track on the axis parallel to the wires (figure 1). This technote gives detailed information on how the foils were manufactured as well as techniques which may be helpful to anyone attempting a similar project.

2 Foil Description

The foils used in the UTC perform three discrete functions, all of which help reduce the total mass of the chamber. Monte Carlo studies of the original E787 drift chamber showed that its momentum resolution was being limited by multiple Coulomb scattering in the Ar/ethane gas mixture and the Be-Cu cathode wires. By separating the volume of the new chamber into concentric active and non-active regions it is possible to fill the non-active regions with a lighter gas, ideally He, and reduce the scattering cross section. By using the foil as a ground plane it is possible to eliminate one row of cathode wires that would otherwise be needed to provide the correct electric field geometry around the layer of anode wires closest to the foil. Finally by etching a helical strip pattern onto the foil (figure 2) and reading out the

[1] See technote 182 for mechanical details of the UTC

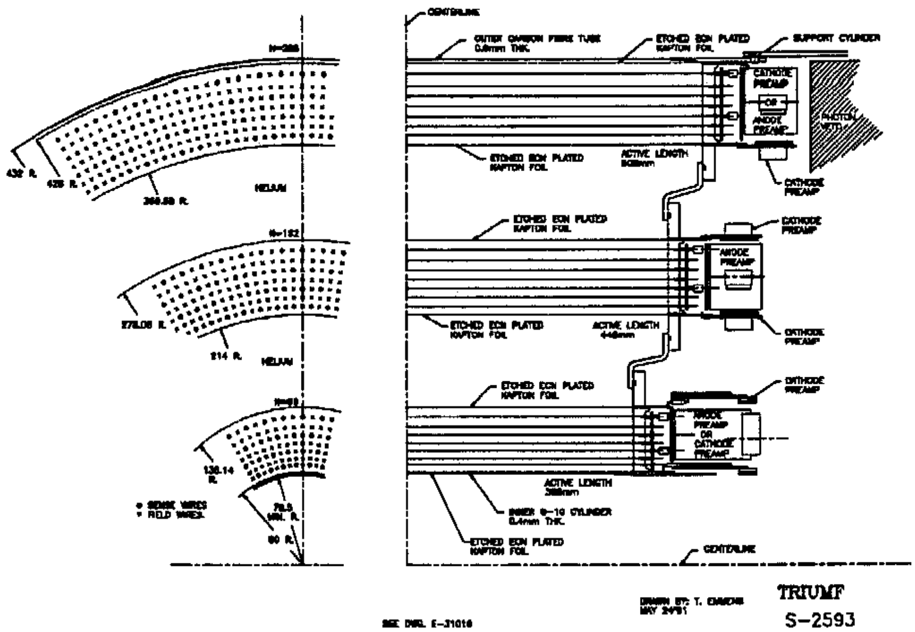

Figure 1: Sectional view of UTC structure

charge induced on the strips by an avalanche on the adjacent anode wires it is possible to readout the Z position of the track without the need of stereo wire layers. This Z measurement also has the benefit of being independent of the XY measurement other than needing to know which wires were hit.

The foil used was 25μm Upilex (equivalent to Kapton) with 1200Å of Cu and 300Å of Ni vacuum deposited onto it.[2] A Ni outer coating was chosen after earlier tests found that Cu corroded quickly in air and aged fairly rapidly in a chamber environment. A Kapton-like base plastic is excellent for this type of chamber application, it is radiation and heat resistant and stretches very little when placed under tension.[3] The metalization was found to be fairly resistant to bending or creasing of the foil, but if mishandled minute breaks would appear in the metal surface resulting in a high impedance path. Tests were done on aluminized mylar, which has an even lower cross section and a more flexible metal coating. However, several problems exist with aluminized mylar. Aluminum has a non-conductive oxide layer and

[2] Courtaulds Performance Films, 21034 Osborne Street, Canoga Park, California 91304

[3] However, because Kapton will not stretch to compensate for misalignments, the mechanical tolerances of the chamber have to be very high to avoid wrinkles in the foil

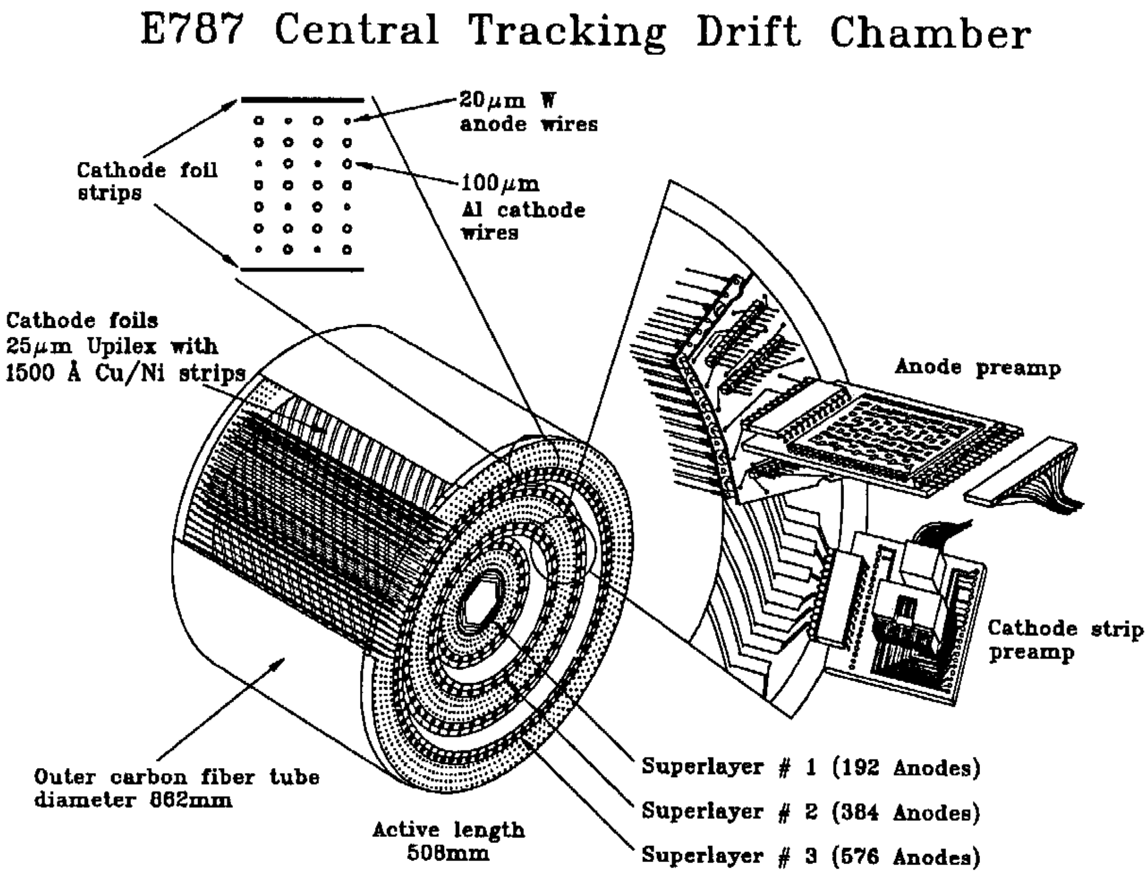

Figure 2: Cut-away view of the UTC

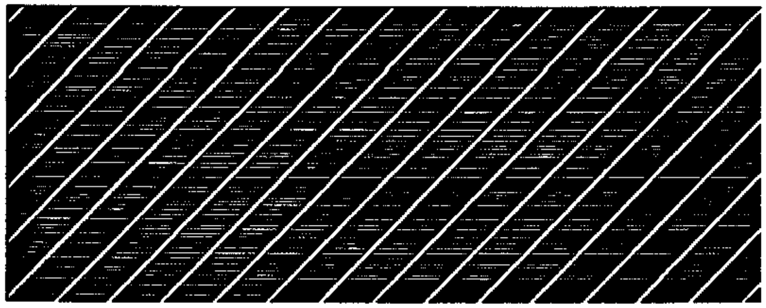

Figure 3: Foil strip pattern (any horizontal lines are a printing artifact)

in drift chambers tends to form a dielectric surface film both of which can lead to the Malter effect, in which positive ions collect near the surface of the metal and promote electrons out of the aluminum into the active volume of the chamber. A photoelectric effect has also been seen on aluminum foils, where after exposure to high rates the foil is light sensitive for up to an hour.[4] More importantly, after initial trials with aluminized mylar and more extensive testing by Peter Vincent, no reliable method has been found to etch patterns on Al foil using photoresists that are hydroxide soluble. This would require going to a solvent based negative photoresist, which for UTC sized foils, would produce large volumes of difficult to dispose of toxic waste and pose a serious health risk to the people doing the processing. [5]

The pattern that was etched onto the foil was parallel strips 7mm wide at an angle of roughly 45 degrees to the straight edge of the foil with a gap of 1mm between strips (figure 3). The installed circumference of the foils varied from 48cm to 2.7m. When unwrapped the largest foil required etching of 216 strips onto a rectangular section of foil 75x385cm. To maximize yield all foils were made to this size then cut to shorter lengths for the inner foils.

3 Processing Techniques

A photographic technique was used to transfer the desired image from a mask onto each treated foil. The mask was produced using a large 'flatbed'

[4] Robert Oppenshaw: private communication

[5] There has recently been some success laminating a photoresist film to aluminized mylar and processing with a sodium carbonate based developer. However, pattern quality is still not comparable to copper foil and the largest commercially available photoresist laminate is only 60cm wide.

plotter[6], a negative image of the pattern was drawn onto drafting quality white mylar using the most opaque black ink available[7]. This type of mylar is translucent but does not have a high enough contrast between the white mylar and the black ink to make it usable directly as a mask. Instead the mylar was transfered to a 4 foot by 13 foot table, surfaced in a single sheet of arborite to ensure a smooth surface, and vacuumed down onto a sheet of ultraviolet sensitive contact film[8]. One hundred micron thick film was used to ensure dimensional stability during processing and UV sensitive film allowed handling under white light. The best result was obtained if the side of the mylar with the drawing faced the emulsion side of the film. After exposure using banks of UV fluorescent tubes, the film was rolled up and sent to a commercial lab to be developed. The resulting positive image could be easily touched up using standard photographic ink and a light table. The same method was repeated twice more using the last touched up image as a mask to produce the next image. Because the film was lithographic, and could be touched up at each iteration, a better contrast image was obtained after each contact print. The final result was a high quality positive of the strip pattern, with no loss of resolution visible as long as there were no air pockets between the mask and film during exposure. In this and later exposure steps, a vacuum of 15-20 inHg was maintained on the mask and any wrinkles or air bubbles were worked out by hand.

To prepare the foil itself a 3 foot by 12 foot section of foil had to be painted with positive photoresist and, once dry, exposed on the vacuum table in the same manner as the above film. A thin film of water was first applied over a sheet of Plexiglas large enough to hold the foil. Adhesion would firmly hold the foil onto this wet surface, but wearing cotton gloves it was still possible to push any air pockets or wrinkles to the edge of the foil using moderate pressure. As long as care was taken not to get any water or dust on the gloves it was found that this did not scratch the metal surface. Once the foil was flat, it was painted in a dust free room using foam brushes with a mixture of 150ml positive photoresist and 150ml thinner[9]. After drying for at least 24 hours the foil was lifted away from the Plexiglas sheet and any water on its lower surface removed. The foil was placed under the mask on the vacuum table, vacuumed down and exposed to UV for 17 minutes. It was found that the exposure time varied with different

[6]Xynetics 1201 Automated Drafting System, Xynetics Inc. Santa Clara, California

[7]3084-F Rapidraw, Koh-I-Noor Inc. Bloomsbury, New Jersey

[8]Fujilith Contact Film, KU-S100

[9]MG Chemicals positive photoresist 416 and resist thinner 417

lots of photoresist, but in all cases it was better to overexpose the foil than underexpose it. Once this was finished the foil was affixed to a Plexiglas carrier sheet using small pieces of double sided tape. In all future steps the Plexiglas prevented the foil from bending at sharp angles, which might crack the resist coating, and provided a way to hold the foil rigid while it was immersed in solutions.

The photoresist was processed in the conventional manner using a tray containing 60 litres of developer[10]. Much to the surprise of the photoresist manufacturer, long immersion in the developer did not seem to affect the unexposed resist. Typical developing times were 2-10 minutes, but in one case up to 40 minutes was used. Gentle rubbing of the surface would generally remove any exposed resist that wasn't dissolving into the solution. Once the foil was rinsed with water and allowed to dry any small holes in the remaining unexposed resist could be touched up using straight photoresist on a fine paint brush. Excess resist could also be removed from areas to be etched, but the resist would tend to flake off often damaging the strip edges and even a nearly invisible layer of resist would still interfere with etching. Because of this, it was best to push the UV exposure and developing times as much as possible, as long as the edges of the remaining 7mm wide stripes of resist weren't damaged. This was not true if very fine details were to be produced. If the sections of unexposed resist were very thin then they became susceptible to partial exposure from light scattering under the edges of the mask pattern and lacked the mechanical strength to withstand abrasion during long developing times. However, tests on small patterns showed that features down to 50μm could be easily produced in the photoresist. Etching proved to be the greatest problem with both fine and course patterns.

A great deal of time was spent trying to perfect the etching solution. The copper layer had a much higher reactivity than the nickel outer coating and would tend to dissolve first. This undercut the Ni and caused the metal surface to come away in flakes. The result was ragged edges on the strips. A variety of different acid mixtures were attempted, including the use of Cu salts to moderate the rate at which the Cu was attacked. In all cases the metal would come away from the plastic in flakes but the finest grain size was obtained with a solution of 20 parts water and 1 part concentrated nitric acid. At room temperature this gave an etching time of about 3 minutes, which was enough to check that all 30 square feet of foil were etching uniformly. Any areas that were slow could be lightly rubbed just

[10] MG Chemicals positive photoresist developer 418 mixed 1 part to 8 parts water

as in developing. Because of the difficulty of removing excess metal after etching, it was again desirable to extend the etching time as much as possible without undercutting the pattern. For the fine test designs mentioned above, it was not possible to consistently produce metal strips of less then $100 - 150\mu m$ width. Anything thinner than this would be undercut from both sides, leaving gaps or completely removing the metal. This was largely due to a lack of mechanical strength in the photoresist covering such narrow strips. On wider sections of resist the resolution was considerably better.

After etching there were often small sections of unetched metal between the strips. These resulted from spots where the photoresist was too thick to be completely exposed, where there was a dark spot on the mask during exposure or where dust or debris had settled onto the foil during painting. Removing this metal was fairly time consuming but could be done quite effectively by applying a small amount of acid solution to the area then scraping lightly at the unetched spot with a sharp object. The small amount of acid present would require one or two minutes to undercut the adjacent strips as long as their photoresist layer was undamaged, but would quickly attack the section being scraped. The Upilex under this section would not be damaged if a soft object, such as a sharpened piece of wood, was used to do the abrasion.

The final production step was to expose the remaining photoresist to UV then strip it using a 0.25 molar NaOH solution. After all the resist was removed (5-10 minutes) the foil was rinsed with tap water, then distilled water and allowed to dry before being rolled up for storage. When rolling the foil it was essential to make sure both front and back surfaces were completely dry. Even distilled water, if left on the surface, would eventually etch a hole in the metal film.

4 Application Notes

When the foil was actually to be used, it was cleaned using acetone on a lint free, non-abrasive wiper (normal Kimwipes would leave scratches on the nickel). In some cases the acetone would react with any remaining photoresist to leave a white residue and an additional cleaning with semiconductor grade isopropyl alcohol was needed. The end-to-end resistance of each strip was tested and any high impedance sections identified. Typically less then 5% of the strips would display higher than nominal resistance and almost none of them would be complete breaks. Close examination would normally reveal a very fine scratch crossing the strip which could be repaired using a thin coating of silver paint [11]. To make the electrical connection between the foil and the readout electronics silver epoxy[12] gave the best result. It was possible to solder to this type of foil using a cool soldering iron (486-515 °F) but it was found that silver epoxy gave a more flexible and reliable contact. Solder joints would often break if the foil was even slightly flexed and if the surface was overheated during soldering the Cu/Ni layer would dissolve into the solder leaving a bare patch of plastic. As long as the surface was cleaned with acetone immediately before applying the silver epoxy, the epoxy-metal contact would have less then 2Ω resistance and be immune to any minor flexing of the epoxy joint.

5 The Final Result

Before installation the end-to-end resistance of each strip was measured. The values on all but a small percentage of the strips were within 10% of the mean resistance.[13] The few remaining high impedance sections were easily repaired using a small amount of silver paint.[14]

Quality checks on the final foils show a remarkably good spatial resolution. Using a microscope attached to a milling machine, the center-to-center spacing of the strips was accurate to within 50 microns, which was approximately the same as the measurement uncertainty. The strips were found to be parallel and straight to the same level of accuracy. Using a profile viewer, the edges of the strips were somewhat jagged, but the edge features were only on the order of $20 - 40\mu$m in size. The edges also showed long undulations, with amplitudes of up to 40 microns, which resulted from variations in how the plotter pen layed down ink on the original drawing.

The initial success rate for manufacturing and installing foils was quite low, with several hundred feet of foil being needed before the six foils were finally installed. However, by the end of the project almost 100% of the foils etched were completely usable.

[11] Electrodag 415-SS, Acheson Colloids Company, Port Huron, Michigan

[12] TRA-DUCT BA-2902, TRA-CON 55 North Street, Medford Mass. 02155

[13] The resistance varied depending on the foil size, but was typically in the 50-60Ω range.

[14] Once the foils were installed and both ends were no longer accessible it was still possible to check for breaks by measuring the capacitance between adjacent strips. Typical numbers were 20-40pF.

6 Acknowledgments

Construction of the UTC foils would not have been possible without the help of two TRIUMF technicians. Peter Vincent who helped develop and perfect the fabrication techniques at great personal risk of being dissolved in one of the processing vats. And Chapman Lim whose mechanical abilities and insights made it possible to actually assemble the foils into something resembling a drift chamber.