A Comparative Study of GEM Foils from Different Manufacturers

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Introduction

The purpose of this study was to test certain performance characteristics of a triple GEM detector constructed from different sets of GEM foils produced by three different manufacturers: CERN[1], 3M[2] and Tech Etch[3]. Measurements were made on the gain characteristics and gain stability for an identical detector consisting of three foils from each of the manufacturers. The characteristics that were measured were the gain as a function of voltage potential across each foil, the gain drift with time, and the energy resolution for an ^{55}Fe source. Every attempt was made to maintain constant conditions during each test, so that any difference in behavior could be attributed exclusively to the foils. Also, before each of the measurements were carried out, the impedance and leakage current across each foil was measured, and only foils with an impedance greater than 10 GΩ (typically 50-100 GΩ) and a leakage current of < 1 nA at their operating voltage were used in the detectors that were tested.

Method

The overall experimental apparatus is illustrated below in Figure 1 and depicts a set of foils assembled into a triple GEM stack, mounted within a small, gas tight stainless steal vessel with a volume of ~ ¼ L. In addition to the three GEM foils, the detector structure also consists of a mesh above the upper-most GEM foil, which establishes a uniform electric field to collect the charge within the drift gap. A printed circuit board was also mounted below the lower-most GEM foil, and was comprised of an array of 12 pads (~1x10 mm each), covering an active area of ~ 1x1.5 cm over the center of the board. Every effort was made to insure the experimental method and the conditions for testing each set of foils was as consistent as possible.

The hole size and pattern for the foils from the three different manufacturers is as follows: (*pitch/outer hole diameter/inner hole diameter [μm]*)

- CERN: 140/80/70
- 3M: 140/70/40
- Tech Etch 140/74/33

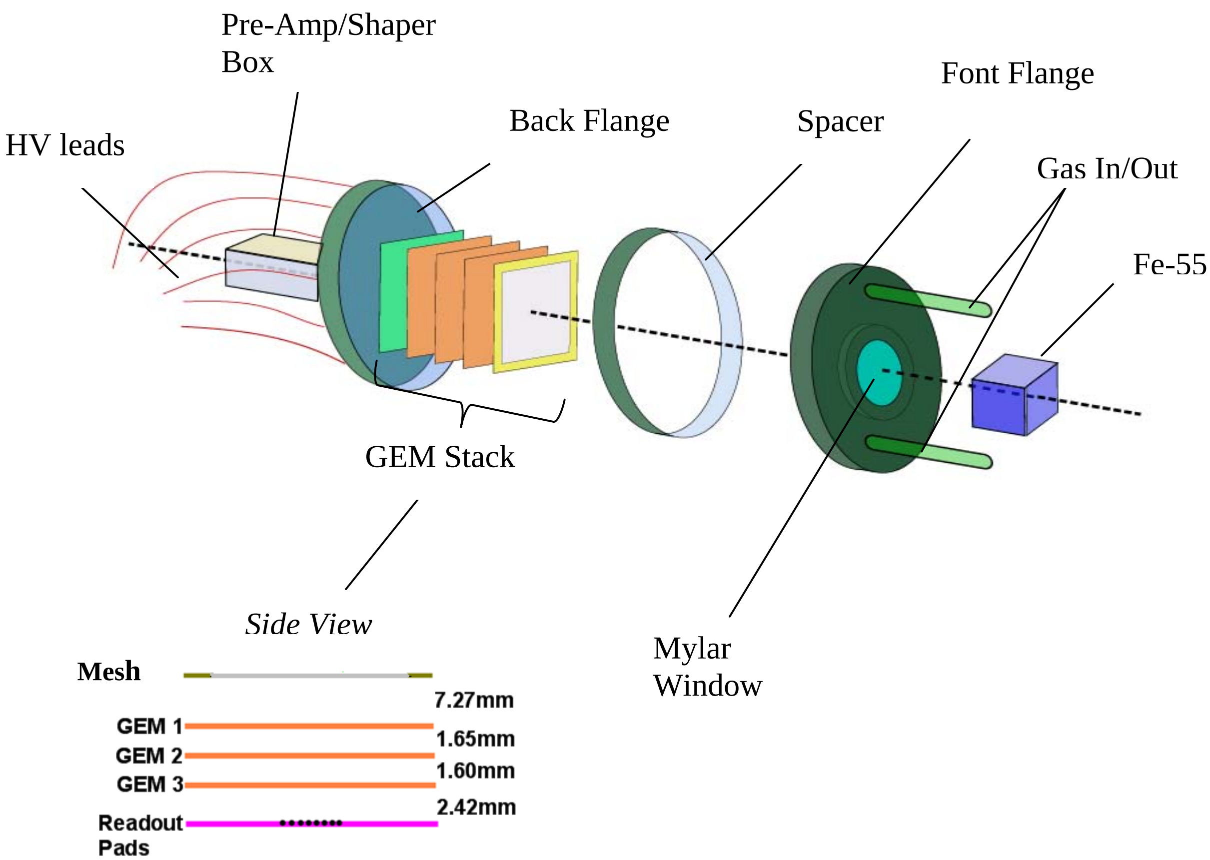

Figure 1: Schematic of the GEM detector and apparatus used for these tests.

The method consisted of illuminating the detector structure with a semi-collimated beam of 5.9 keV X-rays from an ^{55}Fe source. As illustrated above, the X-ray source is aligned with the pad array, and mounted externally to the detector volume. The emitted X-rays ionize the gas after penetrating a thin mylar window and produce the primary charge cluster within the drift gap. Transfer fields applied within the successive gaps of the GEM stack then transfer the charge from one stage of GEM to the next. The magnitude of the fields applied are as follows: Drift Gap: 0.4kV/cm, Transfer Gap 1: 2.5kV/cm, Transfer Gap 2: 3.0kV/cm, and Induction Gap: 3.5kV/cm. Although the potential across each of the foils may have been varied to produce a gain curve, the field configuration within the gaps was kept constant throughout all the tests. The total charge output from the triple GEM was collected on the pad array and read out as a single signal into a charge sensitive ADC (LeCroy 2249). The pulse height spectrum was recorded and the gain was calculated knowing the primary charge and the charge calibration of the ADC. The number of electrons within each primary charge cluster produced by the X-ray was taken to be 212 for the 70/30 Ar/CO_2 gas mixture.

The working gas used for all tests was premixed Ar/CO_2 (70/30 mixture, 99.990 purity). After each set of foils was mounted, the vessel was purged at a relatively high flow rate for one day before any tests were started, and continued to flow during all the measurements in order to insure good gas quality.

In total, the detector structure was comprised of seven electrodes, each of which is powered by a dedicated HV supply with current monitoring capabilities (LeCroy 1458 HV mainframe). With the use of a computer interface, several free parameters could be set which enabled the HV to be applied to the GEM's in a very controlled and consistent manner. Specifically, the ramp-up speed was the same each time the GEM's were powered up, which was important for the time dependant measurements, and allowed for a well defined time reference. Each gain measurement within the gain stability plots below is taken with respect to the exact time after the HV had completed ramping up. The time of the measurement was defined as the time immediately after the DAQ accumulates roughly 5K events. Since the detected rate of the source was constant (~100Hz), this method insures a uniform and accurate time basis. In order to factor out the observed time-dependence of the gain, the gain curves were generated only after the HV has been on for a full day, well beyond the time it took for the foils to stabilize onto a plateau. Throughout the course of each measurement, none of the GEM foils ever tripped even after 5-7 days of continual operation, and each maintained sub-nA leakage currents. For all three sets of foils, the gain was observed to fluctuate by roughly +/- 10% after the detector had reached its operating plateau.

Results

Figure 2 shows the gain curves for the triple GEM detector for the three types of foils. Again, the gain curves were measured one day after the high voltage was first applied to allow the gain to stabilize. For a given voltage, the 3M foils produced much higher gain, approximately an order of magnitude higher than the CERN foils. The Tech Etch foils showed a gain in between the CERN foils and the 3M foils. The two sets of Tech Etch foils also differed in gain by about a factor of two. The slopes are all very similar, although the slope for the 3M foils is slightly steeper. It was possible to reach a gain of $\sim 10^4$ for all three sets of foils without discharging. However, it was also possible to achieve higher gains for all three sets of foils. The maximum voltage achievable without discharging was typically greater than 550 V for the CERN foils, and ~500 V for the 3M foils, and ~450 V for the Tech Etch foils.

Figures 3 and 4 shows the change in gain with respect to time for the three types of foils. Both the 3M foils and the Tech Etch foils show a significant increase in gain during the first four hours. It is difficult to quantify the factor by which the gain increases from time the high voltage is first applied, since it takes a finite amount of time to measure the gain, and the initial value is not well defined. However, one can see that the 3M foils show a sharp increase during the first hour, and reach a plateau after approximately four hours. The Tech Etch foils show a much more gradual increase in gain over the same four hour period, with some indication that the gain continues to increase even after this time. The CERN foils, on the other hand, show a very slight increase in gain during the first 20-30 minutes, and then reach a stable plateau. This same behavior for the CERN foils was observed at two different voltages.

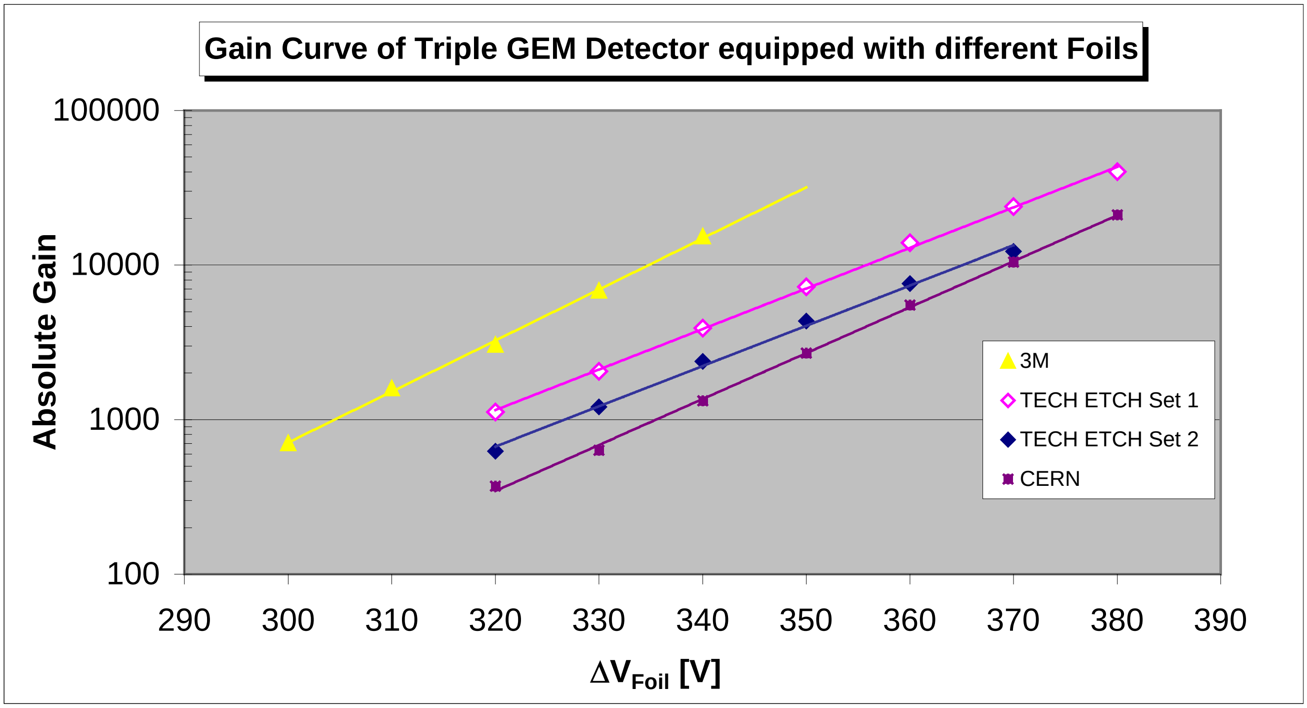

Figure 2: Absolute Gain vs. Potential Across the Foils (potential across all three foils were equal, and the field within the transfer and induction gaps were held constant).

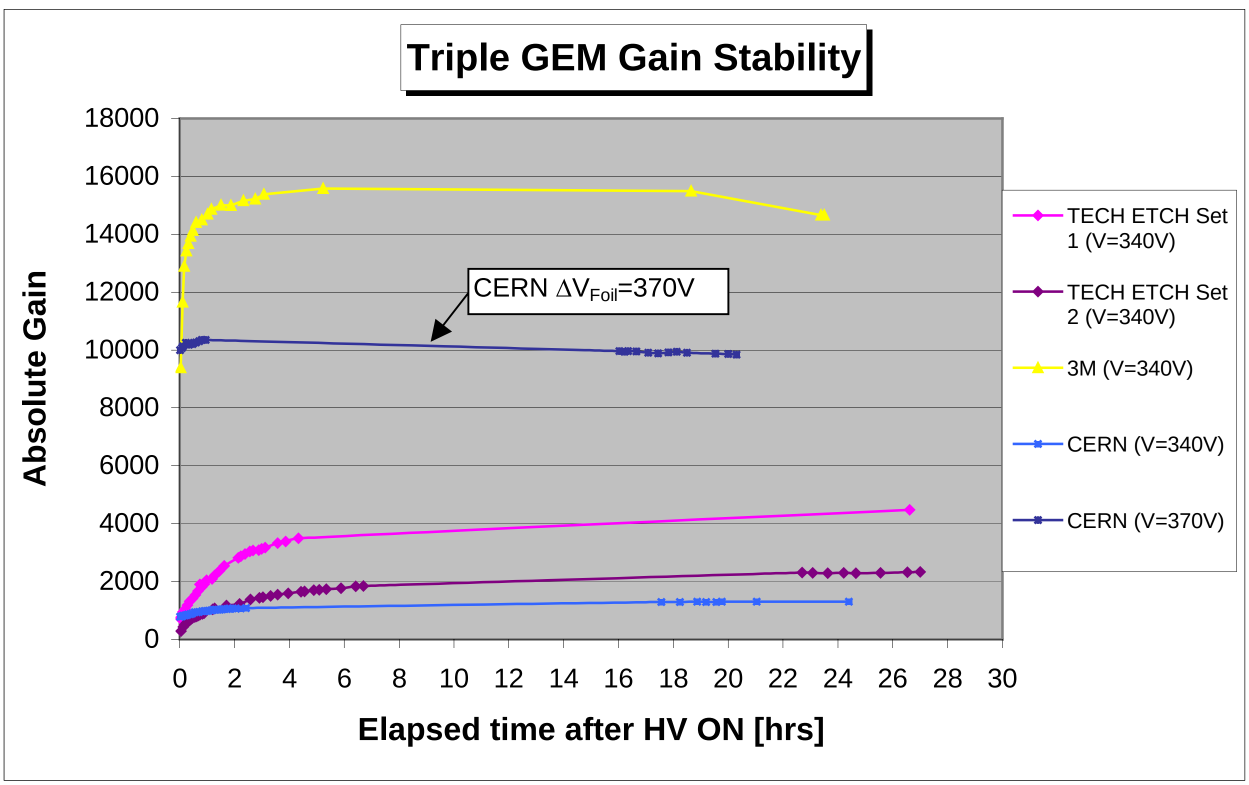

Figure 3: Absolute Gain Vs. Elapsed Time after HV ON.
(First gain measurement was performed 2-4 minutes after HV ON)

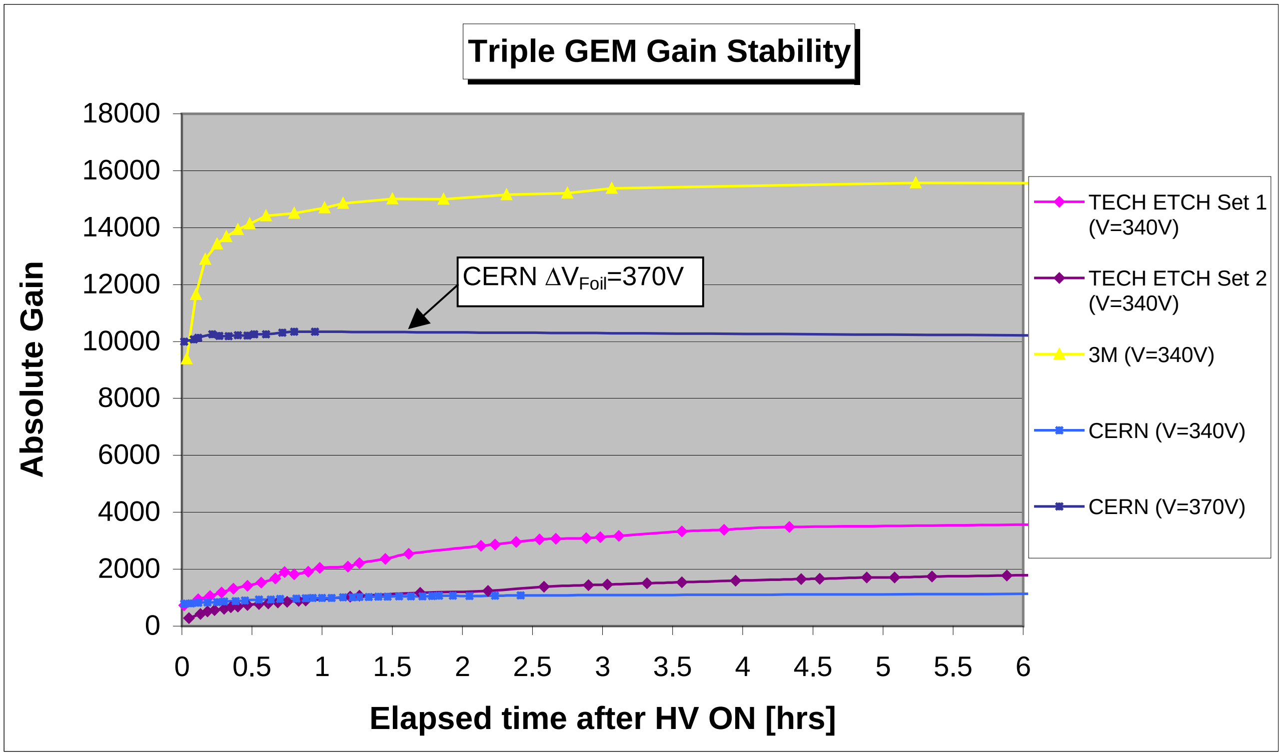

Figure 4: Detail of the first 6 hours of the plot in Fig. 3.

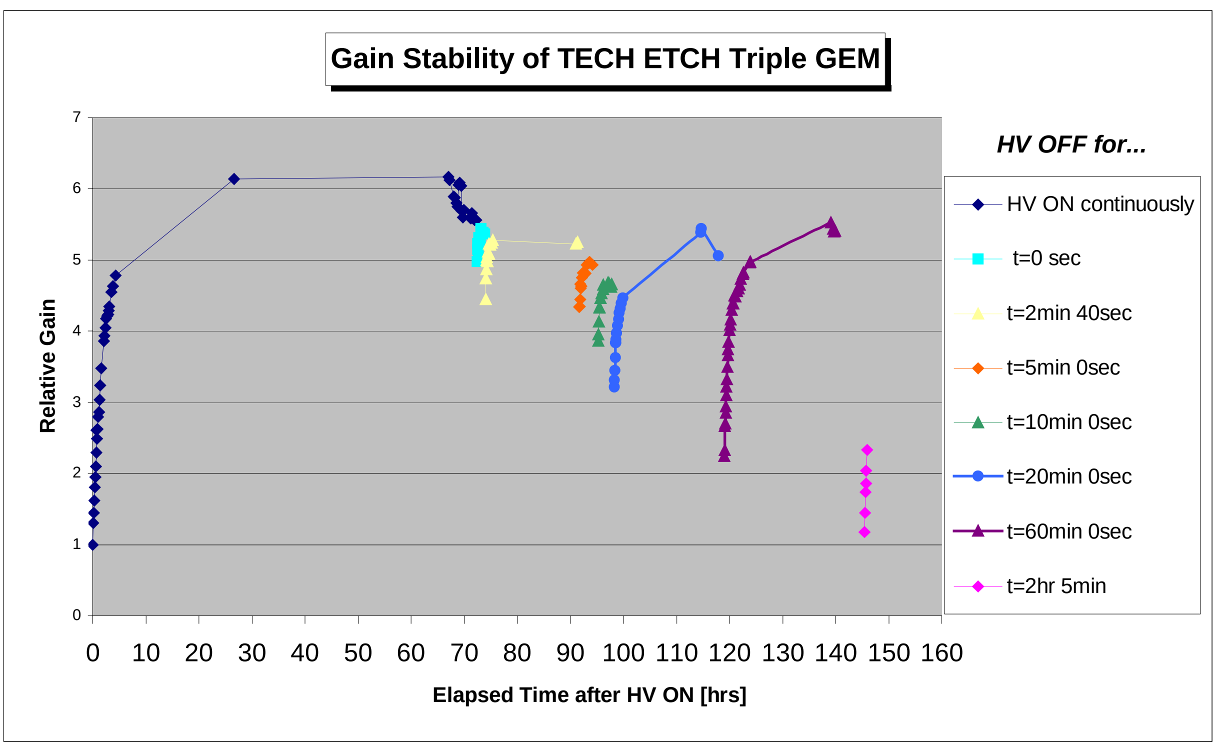

Figure 5: Relative Gain Vs. Elapsed Time after HV ON, with power intentionally interrupted for various periods of time to observe the affects of discharging. The 3M foils exhibit similar behavior.

Figure 5 shows a series of tests performed with the Tech Etch foils where the high voltage was intentionally switched off at certain times after the detector reached its gain plateau value. This was done in order to observe the effect of discharging and recharging the foils. After switching off the high voltage, the gain dropped to several times below its plateau value, and then started to increase along more or less the same rising curve as it did initially. However, it appears that the time required with the high voltage off for the gain to drop back its initial value is on the order of several hours.

Table I gives the energy resolution for the CERN, 3M and Tech Etch foils obtained using an ^{55}Fe source. The CERN foils gave the best energy resolution, with the Tech Etch showing somewhat better resolution than the 3M foils.

Manufacturer	**CERN**	**3M**	**Tech Etch**
FWHM % Resolution	*18 - 21%*	*28 - 32%*	*24- 26%*

Table I: Energy resolution for ^{55}Fe for the CERN, 3M and Tech Etch foils

Discussion

The CERN foils, which served as a reference, performed as expected under the standard operating conditions. The higher gain observed with the 3M and Tech Etch foils can be at least partly attributed to the different size and shape of the holes. Both of these foils have a smaller hole size than the CERN foils, which produces a higher electric field inside the hole, and therefore higher gain. However, it is unclear at this point why the 3M foils exhibit significantly larger gain than theTech Etch foils.

The large initial increase in gain observed during the first several hours after applying high voltage to the 3M and Tech Etch foils appears to be due to a charging up effect in the foils. This effect is also observed, although to a much lesser degree, in the CERN foils, and over a much short time (< 30 minutes). This could also be due to differences in the hole pattern between the three types of foils, or also due to differences in the type of material or process used to produce the foils. The CERN foils are produced using Apical[4] as the polyimide material, whereas 3M and Tech Etch use Type E Kapton[5]. These materials have different dielectric properties, as well as a different propensity to absorb and retain moisture. This could affect the rate at which charge can collect or leak off the foils. The different hole patterns also affect the ratio of the exposed polyimide area to the hole area, which can also affect the amount of charge collected and retained inside the hole. One can also speculate on other differences between the foils due to the manufacturing process, such as etching, pre or post treatment, cleaning, etc. However, in order to understand these differences, one must have a detailed knowledge of the each step in the various processes that are used by each manufacturer to produce the foils, and this information is not readily available.

Conclusions

We have tested GEM foils produced by three different suppliers (CERN, 3M and Tech Etch) and found them to have distinctively different properties. All foils were tested in a standard triple GEM detector under identical conditions. For the same set of operating voltages, the CERN foils produced the lowest gain, but exhibited the best gain stability over time. The 3M foils produced the highest gain (approximately an order of magnitude higher than the CERN foils with the same set of voltages), but showed a large increase in gain over the first several hours after the voltage was first applied. The Tech Etch foils produced a gain in between the CERN and 3M foils, but also showed a large increase in gain over the first several hours after initially applying the high voltage. Due to the time constants involved, it appears that this initial gain variation is due to a charging up effect in the foils, which may be due to differences in the materials or process used to produce the foils. A systematic series of tests involving a direct comparison of the materials and processes used by the three different manufacturers would be required to determine the underlying cause of these effects. However, if this type of study could be carried out, it should provide a much better understanding of the basic properties of GEM foils, and lead to overall improvements in their performance.

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[3] Tech Etch, Inc, Plymouth, MA, Kerry Kearney, 508-747-0300 x3018
[4] Apical is produced by Kaneka High Tech Materials, Inc., Pasadena, TX
[5] Kapton is a registered trademark of E.I. Du Pont, Inc.