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Glove Performance Results During Simulated Usage

by Kimberly Mitchell

Cleanroom personnel have long been recognized as a source of contamination, and the cleanroom garment industry has responded through the development of efficient microporous laminates, which effectively encase the wearer in a HEPA grade filter and prevent the emission of particles from the majority of the body's surface area. Powered headgear which draws the breath away from the body and filters it before it is released into the cleanroom removes yet another personnel-related contamination source.

One previously unrecognized source of contamination in the cleanroom is the glove worn by operating and technical personnel. The hand area is particularly critical as a source of particulate, because the hand is frequently close to the sensitive wafers in process. Particles emitted from the hand area may be deposited on wafers being transported manually at any point, including the point subsequent to cleaning.

For cleanroom gloves, the most important evaluation criteria may be particles released in use. Glove performance is critical not only initially, but even more importantly under the constant flexing and rubbing conditions it will endure in use. In this experiment, initial particle release rates are frequently not indicative of the particle release rate after 30 minutes of protocol performance.

This study describes a method to simulate glove usage conditions, to concentrate the particles thus generated, and to detect these particles through the use of an automatic particle counter. Various types of gloves are tested and evaluated. The abraded glove surfaces are then examined by scanning electron microscopy for surface integrity. The procedures described are intended as an aid to microcontamination engineers in their evaluation of gloves for cleanroom use.

It is now reported in the semiconductor industry that fewer than 10 percent of defects to products currently are coming from the operators in the wafer fabs. This improvement (down from 20 to 25 percent a few years ago) is primarily due to advances in cleanroom garment technology, and the willingness of the industry to invest in top quality garments and to ensure discipline in the way garments are worn in the cleanroom.

The cleanroom glove, a key element of good cleanroom protocol, has not seen as significant an improvement. In most cases, the same type of gloves are being worn now as in cleanrooms built 15 years ago.

An operator's hands are often close to sensitive products and equipment; therefore, the contamination control properties of the gloves that they wear on their hands are critical. In many high technology industries, airborne particles are a critical contaminant which must be controlled carefully.

The highly variable nature of airborne particle dispersion makes it difficult to design test methods which detect even substantial real difference in particle control properties. It has become an axiom for testing in the particle control field that "there are many ways to measure no difference." This method has been developed to provide a method to detect real difference in airborne particles between different types or brands of cleanroom gloves.

This method has been developed to measure the contribution of the glove to the aerosol particle load in the immediate vicinity of the hand while the glove is in use.

One of the challenging aspects of measuring aerosol particle counts is their great variability. This variability is increased by the effect of dilution in vertical laminar flow cleanrooms. Although it is critical to test in an area with low background counts for comparative particle testing, the continual flow of clean air may disperse emitted particles, making them extremely difficult to measure.

Several methods of evaluating cleanroom gloves have been outlined in the Institute of Environmental Sciences' IES-RP-CC-005-87T. The wet test of determining glove cleanliness outlined in IES-RP-CC-005-87T measures the number of particles released from the glove surface when immersed in deionized water.[1] The quantity of particles released in DI water may not be well-correlated with the quantity of particles released in abrasive in-use conditions in cleanroom air. In addition, while it may be useful for an initial screening of materials, this method is not useful for examining the glove's performance over time.

The wet method also makes it difficult to distinguish between particles from the outside of the glove and particles from the inside of the glove, which may not be as critical.

On the other hand, a limitation of the proposed method is that the chamber test may not be as effective in detecting larger particles (larger than 5 microns), as they tend to impact on the sides of the sampling tube and never progress to the particle counter to be counted. Observation of particle size distribution in this test indicates that few larger sized particles are indeed counted by the particle counter. Of course, this is a limitation which must be faced whenever airborne particles are being counted by means of an automatic particle counter.

This limitation may not be critical in many industries, as the primary concern is with particles in the 5 micron to submicron size range. In addition, we may be able to make the assumption that the generation of large particles by typical cleanroom activities will be accompanied by a distribution of smaller particles in the size range that is easily measured by the aerosol particle counter.

The evaluation was conducted inside the 125 square foot Class 10 cleanroom laboratory at W.L. Gore & Associates. The room features a fully HEPA filtered ceiling with a nominal 90 foot per minute vertical laminar flow. The floor is raised and perforated so the flow is not disturbed, and there is a small Class 10 change facility. The cleanroom is reserved for particle testing only, so that extraneous sources of particle contamination are eliminated. Background particle counts at the time of the study measured lower than one particle per cubic foot larger than 0.3 micron.

Aerosol particle counts, generated during a standard abrasion protocol, concentrated in a small test chamber, and measured by an aerosol particle counter, were used as the measurement criteria for contamination control performance. High particle counts are assumed to be a realistic representation of a real world problem.

The glove types chosen for this test were selected for their ready availability and for their wide use in the cleanroom industry. All gloves were tested as packaged by the manufacturer for use in the cleanroom and were exposed to only Class 10 air prior to their test.

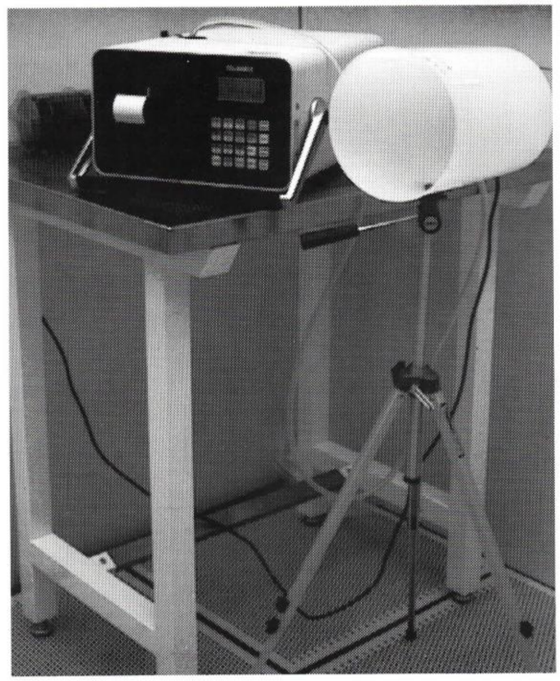
The most popular glove materials in use are vinyl (PVC), represented by two brands (Type A and B) and latex, represented by four brands (Types C, D, E and F). These are compared against bare hands and against gloves manufactured from expanded polytetrafluoroethylene (EPTFE) Teflon.™ The two EPTFE gloves are from the same manufacturer, but are manufactured by two separate methods.

Glove Type G is manufactured from a thin laminate of PTFE membrane and an elastomeric nonwoven material with a fine bonded seam. Glove Type H is a reusable glove manufactured from laminates of a PTFE membrane and a nylon Lycra™ knit. This glove has sewn seams which are protected with seam tape.

A single test subject performed all of the tests outlined in this study to ensure relative consistency in abrasiveness and vigor of the test protocol. Previous testing has shown a significant difference from person to person when performing this test, although the difference observed has been relatively minor compared to the high variability in particle count data.[2]

An 8-quart plastic container was used as the collection chamber. It was mounted on a tripod by means of a small hole cut in its side wall. A length of tubing was fed into a second hole (located at five o'clock) and connected to a one cfm aerosol particle counter (Figure 1).

Figure 1
Chamber Test Apparatus



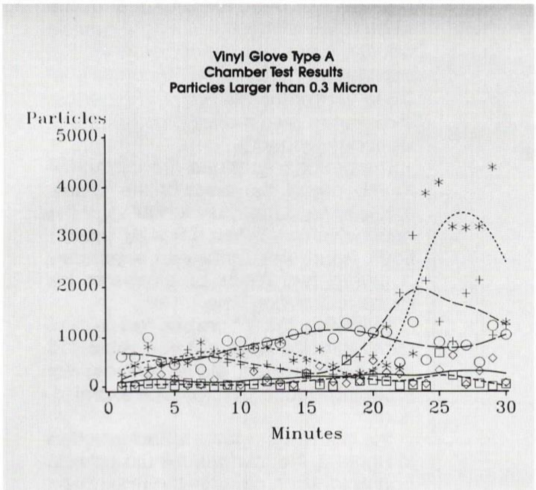
Using a one cfm aerosol particle counter, the 8-quart test chamber will purge in 19.3 seconds, or approximately three times per minute. This chamber is barely large enough to comfortably move one hand, but its small size allows for a continuous sweep of air past the gloved hand into the sampling port.

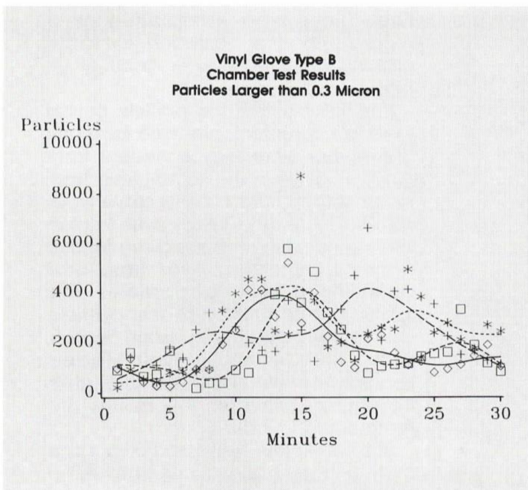
Due to this airflow, particles emitted from the subject's body may also be drawn into the test chamber. For this reason, the test subject should be completely gowned in a high quality cleanroom garment with glove cuffs firmly tucked under stretch garment cuffs made from a particle barrier fabric. Low (close to zero) background counts should be verified with the subject standing in front of the test chamber before the test itself begins. In this test, the subject wore a cleanroom garment system made from expanded PTFE laminate.

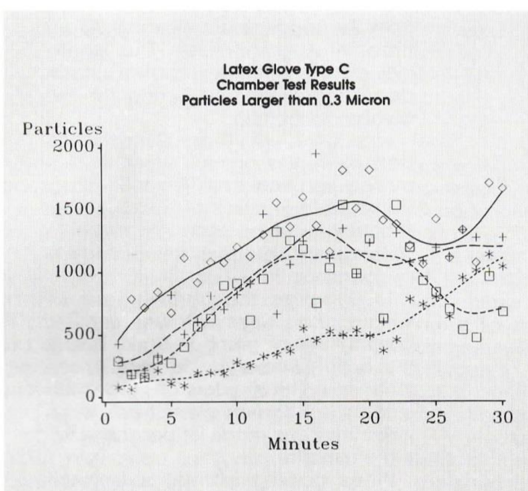
Before testing, the cleanliness of the sampling chamber was verified by several minutes of background counts obtained in the position and setup that was to be used for the test. Any more than one particle larger than 0.3 micron in several minutes of background counts was considered suspicious, and the source was identified and eliminated before progressing with the test.

The gloved hand was introduced into the sampling chamber and an abrasion

Figure 2







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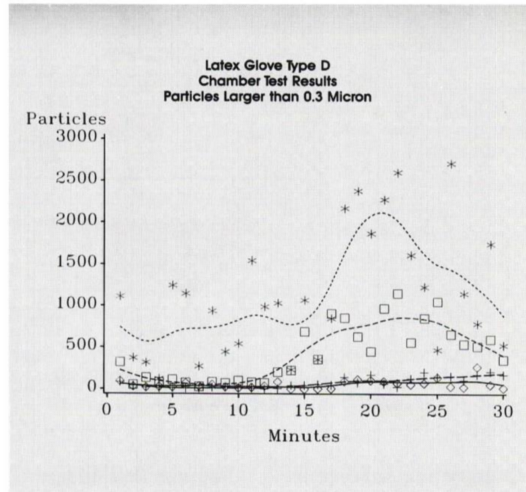

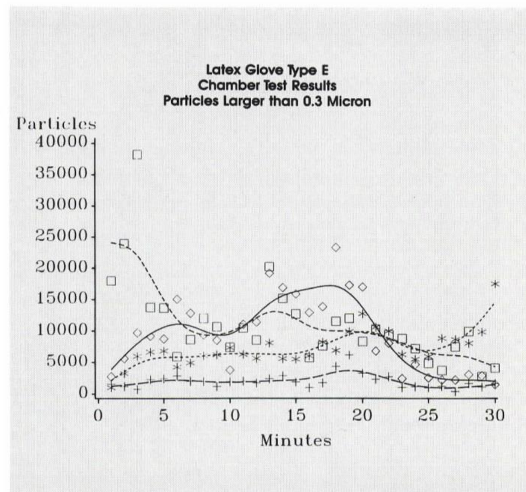

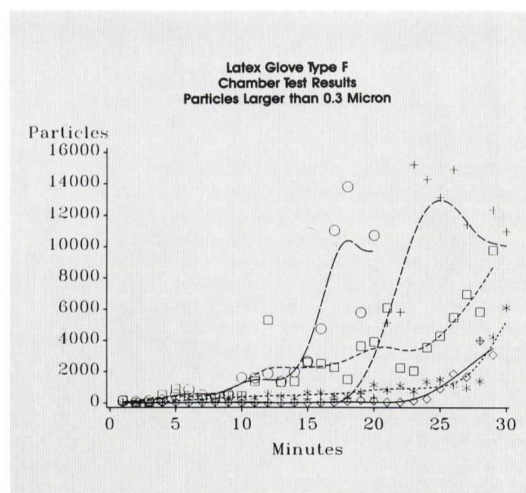

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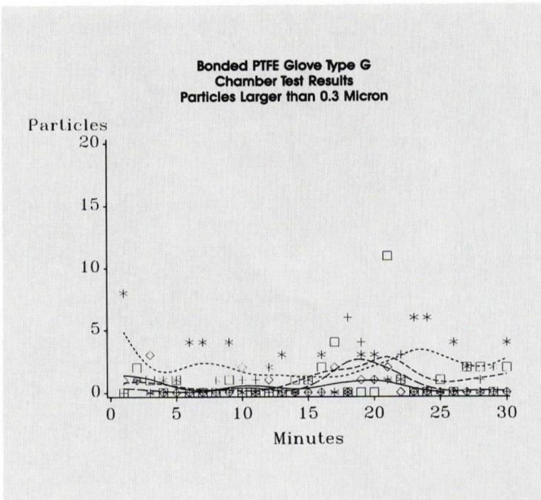
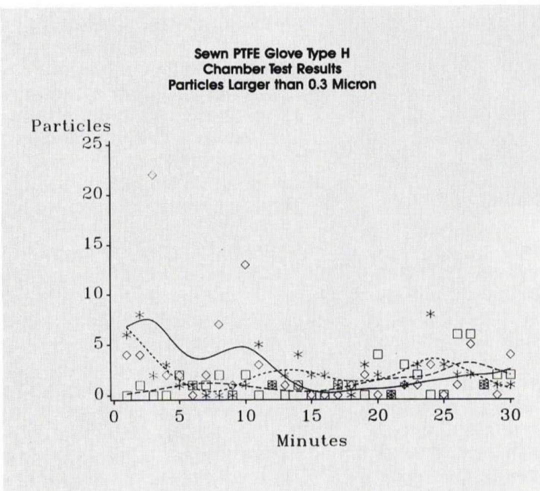
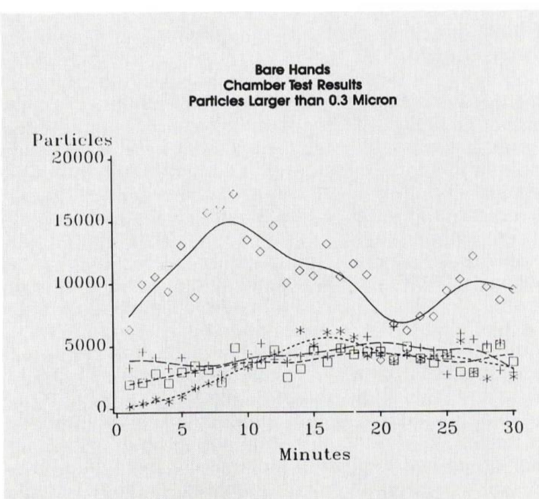






protocol was performed for one minute while a Climet 8060 white light particle counter measured the concentration of released particles in the size range from 0.3 to 10 microns. The protocol cycle was maintained by a metronome set at one beat per second.

The protocol consisted of brushing the thumb across the pads of the fingers, followed by a rapid unclenching of the hand which produced a flick-like motion. Each hand was measured separately, allowing two types of gloves to be measured at one time.

Following the chamber test procedure, samples were cut from abraded and nonabraded glove surfaces for scanning electron microscope examination.

The data for all gloves tested is plotted in Figure 2. The raw one minute particle counts for each glove tested have been plotted over time and a smoothed curve drawn through the data for each glove. Each glove type was plotted on a separate chart for clarity and due to the differing scales required for various glove types.

It is notable that the particle counts were not consistent over time for many gloves, nor were they consistent from glove to glove in the same glove type. Many of the latex and vinyl glove types showed increasing trends over the test period, indicating that the glove surface may be abrading over time and releasing additional particles. The increasing tendency of the particle counts was tested by regression analysis, using the General Linear Models procedure of the SAS statistical analysis computer software. The results are summarized in Table 1.

Both vinyl glove types and all but one of the latex glove types showed a statistically significant increase over time. Neither of the expanded PTFE glove particle counts nor the bare hand particle counts showed a significant time-related increase. This could indicate that no particle related surface degradation was occurring for the duration of the test.

Latex glove Types C and D showed the best examples of how glove performance can vary from glove to glove. This variability implies that multiple gloves should always be tested in order to obtain a representative picture of overall performance.

To compare the performance of various glove types with one another, consult the bar graph in Figure 3 and the data summary in Table 2. These summaries show orders of magnitude difference between glove types, even when they are made of nominally the same material.

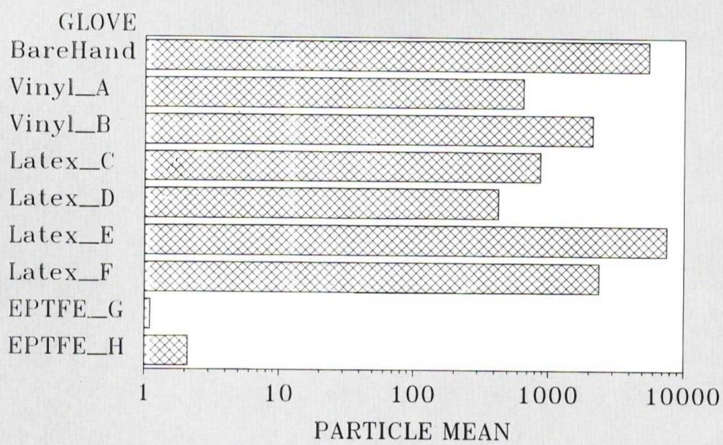
When dealing with particle count data, we frequently see extremely

Table 1
Effect of Time on Particle Counts
Statistical Analysis

Glove Type	Sample Size	Slope Signif.?	P-Value	Model Intercept	Model Slope
Bare Hand	120	No	0.57		
Vinyl A	150	Yes	0.0001	111.5	34.4
Vinyl B	120	Yes	0.0249	1566.9	34.3
Latex C	120	Yes	0.0001	439.6	27.3
Latex D	120	Yes	0.0037	144.6	18.2
Latex E	120	No	0.0579		
Latex F	138	Yes	0.0001	− 1328.0	233.6
EPTFE G	120	No	0.55		
EPTFE H	90	No	0.20		

Figure 3

Summary of Chamber Test Results For Various Glove Types Total Samples Tested



skewed distribution, with variability closely correlated with the means. For a valid statistical analysis, it generally is necessary to transform the data to form a distribution that more closely approximates the normal distribution. To compare the statistical significance of this data, the raw counts were first transformed by taking the base 10 logarithm. Before transformation, a small quantity (0.1 particle) was added to the zero counts to avoid attempting to take the log of zero.

A summary of the significances found by Duncan's Multiple Range Test is presented in Figure 4. The highest particle counts were statistically equivalent to one another, and were found in one of the latex glove types and bare hands.

The lowest particle counts were found for the expanded PTFE bonded and sewn gloves. These low counts were found to be statistically different, although in practical use the difference between 2.1 and 1.1 particle per cubic foot is not likely to have a significant impact on product yields.

Abraded and nonabraded samples of each of the glove types tested were examined by SEM photomicrographs. The abraded surface of the vinyl glove examined (Type A) showed some evidence of material loss and barrier cracking between the PVC granules. This change is observed in Figure 5.

Photomicrographs of the abraded and nonabraded latex glove surfaces (Type D) are shown in Figure 6. The surface of the latex glove appeared to have a good deal of superficial cracking and scoring. After the testing was performed, the loose, scaly surface appeared to have been abraded away.

The test subject noted that the surface of some of the latex gloves became sticky as the test progressed, and that the increase in stickiness was associated

Table 2

Chamber Test Results – 30-Minute Tests
Average Number of Particles Per Minute
(Particles Larger Than 0.3 Micron)

Glove Type	Sample Size (30 Mins./Glove)	Mean Particle Counts per Minute
Bare Hand	120	5444.2
Vinyl A	150	644.7
Vinyl B	120	2098.7
Latex C	120	863.1
Latex D	120	426.3
Latex E	120	7489.0
Latex F	138	2361.2
EPTFE G	120	1.1
EPTFE H	90	2.1

Figure 4

Analysis of effect of glove type on particle count
Log-transformed data

General Linear Models Procedure

Duncan's Multiple Range Test for variable: PARTLOG

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

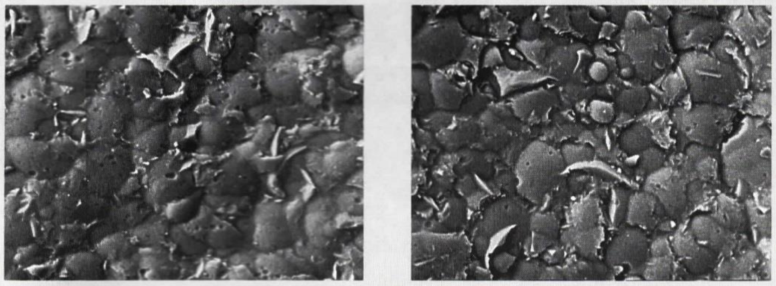
Alpha = 0.05 df = 1089 MSE = 0.383111
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes = 119.9614

Number of Means	2	3	4	5	6	7	8	9
Critical Range	0.159	0.167	0.172	0.176	0.180	0.182	0.184	0.186

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	GLOVETYPE
A	3.7305	120	Latex E
A			
A	3.6463	120	Bare Hand
B	3.2166	120	Vinyl B
C	2.8487	120	Latex C
D	2.5217	138	Latex F
D			
D	2.4868	150	Vinyl A
E	2.1589	120	Latex D
F	−0.0521	90	EPTFE H
G	−0.4278	120	EPTFE G

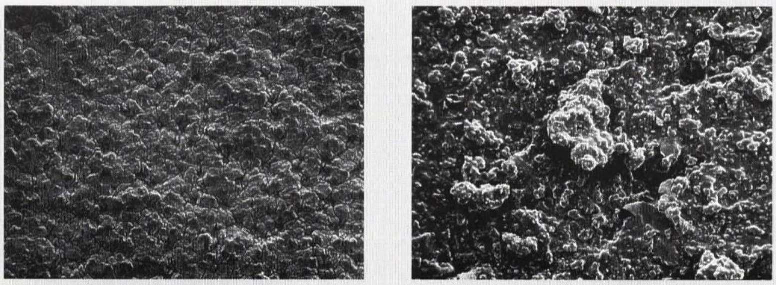
Figure 5



Vinyl Glove Type A – Non-Abraded Surface 250X

Vinyl Glove Type A – Abraded Surface 250X

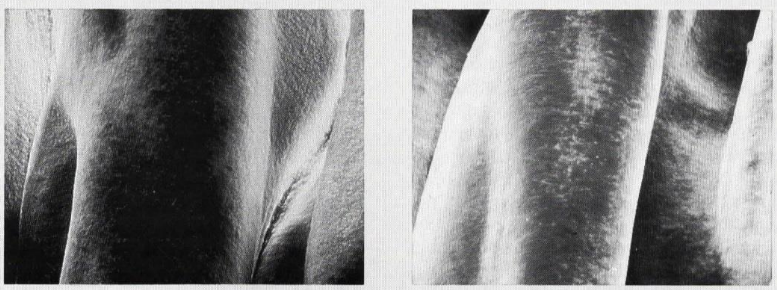
Figure 6



Latex Glove Type D – Non-Abraded Surface 250X

Latex Glove Type D – Abraded Surface 250X

Figure 7



Expanded PTFE Glove Type H – Non-Abraded Surface 250X

Expanded PTFE Glove Type H – Abraded Surface 250X

with an increase in the airborne particle counts. After the testing was concluded for one of the glove types, a visible residue of "dust" was found on the bottom surface of the previously cleaned test chamber. These particles were collected and examined under a light microscope and were visually identified as being latex particles.

Photomicrographs of the expanded PTFE gloves before and after testing (Type H) are shown in Figure 7. The effect of the testing appears to consist of a slight smearing of the porous PTFE surface. The smearing is concentrated in the membrane found on the high points of the knit structure of the laminate. The microporous structure can be seen on surfaces away from these high points where direct contact has been minimal.

The test period described herein has been shown to be an effective method to distinguish between the relative performance of various types and brands of cleanroom gloves as measured by the emission of airborne particles under an abrasion protocol.

The results of this study show that different commercially available cleanroom gloves have significantly different levels of airborne particle counts when subjected to this protocol.

In addition, many gloves tested show increasing airborne particle counts over time, indicating that the surface of the gloves may be degrading. This implies that the test period should be fairly lengthy in order to realistically characterize the glove.

The variability in results from glove to glove in the same type indicates that the results from a single glove may not fairly represent the entire population, and that several samples from each glove under consideration should be tested to make a fair judgement between glove types.

SEM evidence of disruption of the glove surface after the test protocol is consistent with the hypothesis that particles are generated from the gradual breakdown of the glove surface under abrasion. This was particularly true of the latex glove sample, which showed evidence of chunks missing from the surface that were even larger than would be easily detectable by an aerosol particle counter.

The vinyl gloves showed evidence of disturbance of smaller sized particles, and the EPTFE showed almost no disturbance of the glove surface. This corroborates the very low levels of aerosol particles measured for both types of EPTFE gloves. **CR**

About the Author

Kimberley Mitchell is a Research Associate for W.L. Gore & Associates, Elkton, MD. She designs and performs experiments on the contamination control properties of cleanroom garments and accessories. Before joining Gore, she was a statistical quality engineer at an AT&T Microelectronics integrated circuit manufacturing facility.

Mitchell graduated from the Georgia Institute of Technology and has presented papers in the U.S., Canada and Taiwan on the control of contamination from people.

References

1. IES Recommended Practice Tentative, IES-RP-CC-005-87-T "Clean Room Gloves and Finger Cots," 1987.

2. Mitchell, K.M., W.L. Gore & Associates' Internal Memorandum, December 17, 1990.

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