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ESD Flooring : An Engineering Evaluation

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Abstract: An integrated circuit (IC) can suffer catastrophic damage from as little as 50 volts while manufacturing personnel can generate over 10,000 volts by simply walking across a production floor. This paper reports the results of an extensive two year study of over twenty reportedly ESD-safe floors that are used in combating this threat.

INTRODUCTION

A top executive slides her chair across her office to pick up a phone where a key customer is waiting to discuss a possible contractor. Her hand makes contact with the receiver and the line goes dead. Meanwhile, an engineer works on a CAD system, completing an intricate design when suddenly the system goes down. The design is lost. Just an isolated incident? Think again.

A person walking across a standard vinyl tile floor can generate in excess of 10,000 volts. Integrated circuits can suffer catastrophic damage from as little as 50 volts.

To combat this threat, the use of ESD-safe flooring, in conjunction with ESD footwear has become a reality for today's electronics industry. To meet this need, a variety of reportedly ESD-safe flooring materials have become commercially available which are intended to minimize the magnitude of charge generation. As part of this study, various types of ESD flooring materials were installed in an AT&T Allentown manufacturing area and tested over a period of 2 years. The test methodologies and results for each flooring type are reported and compared in this paper.

ESD BASICS

Electrostatic charge is typically generated when two dissimilar materials are brought into contact and then pulled apart, such as rubbing. When separated, one object will exhibit a net positive charge, the other a net negative charge. The exact magnitude of the charge is a function of the materials and of parameters such as surface texture, relative humidity, contact force, etc. The accumulation of charge causes a static potential to develop. A common example of frictional charging is the potential developed on a person walking across vinyl flooring or rolling a char across carpet. The magnitude of the voltage build-up is a function of flooring material, shoe sole material, relative humidity, weight of the person, the capacitance with respect to ground, etc. If the charged person then touches a sensitive electronic part, or if one grounds the part in the presence of a charged source, and Electrostatic Discharge (ESD) transient occurs that may damage or degrade the sensitive part.

EXPERIMENT OVERVIEW

A variety of "ESD-safe" floor materials are now commercially available to minimize the magnitude of the charge generated while walking across flooring. Twenty different types of ESD0-safe flooring materials were included as part of this study.

FLOORING INCLUDED IN STUDY

Floor	Type
A	Cond. Vinyl
B	Diss. Vinyl
C	Diss. Rubber
D	Cond. Epoxy
E	Cond. Vinyl
F	Diss. Epoxy
G	Diss. Vinyl
H	Diss. Quartz
I	Diss. Vinyl
J	Diss. Rubber
K	Diss. Epoxy
L	Diss. Quartz
M	Diss. Urethane
N	Diss. Vinyl
O	Diss. Epoxy
P	Diss. Acrylic
Q	Diss. Epoxy
R	Diss. Vinyl
S	Diss. "Paint"
T	Diss. Epoxy
U	Cond. Epoxy

The flooring test site was located in a production area where integrated circuits (IC's) are routinely handled. Each manufacturer was given 150 square feet of floor space per material type. If the floor was not properly prepared and installed, even the best flooring would have failed to perform as expected. In order to avoid this, each of the floors was installed by the manufacturer or a manufacturer's representative. The study began in January 1993 with it's conclusion in January 1995. During this period, important factors were considered such as the test methodology and it's relevance to real-life applications, traffic patterns, and relative humidity which ranged from 25% during the winter months, to a high of 68% in the summer.

EXPERIMENTAL APPARATUS AND PROCEDURES

Unfortunately, standardized test specifications and procedures available for characterization of ESD flooring materials have not been a topic of concern until recent years. Of those specifications available, many are ill-defined or unrelated to ESD flooring, but adapted by the ESD industry while development of specific ESD flooring procedures are being formulated.

Because of this, prototype test specifications were developed in cases where none currently exist, or modifications to traditionally accepted approaches of testing made when deemed appropriate. The critical aspect of this study was consistency. All floors were tested using identical test methodology, equipment & personnel. Test results should be considered on a comparative basis. The following tests were performed or criteria reviewed during the course of the study:

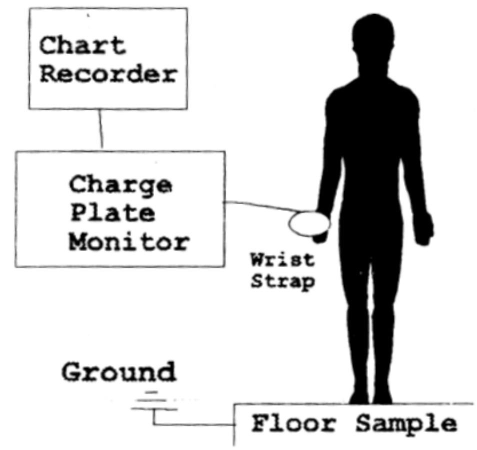
Body Voltage Generation - There is no correlation between surface resistivity of a material and its ability to prevent charge generation.[i] The abilities of a floor to inhibit charge generation and dissipate any accumulated charge are two properties that should always be considered during testing & evaluation. Charge generation caused by rubbing the sole of a shoe on various flooring had to be determined using a variety of shoes and personnel. This was accomplished using a variation of standard AATCC-134 methodology.

Using a charge plate monitor connected to a chart recorder, a designated test operator performed testing on each of the test sites, wearing both ESD footwear and street footwear (Neolite). Measurements were taken with both feet in contact with the flooring and with one foot elevated, a worst case scenario. The difference in resulting voltage levels is due to the direct effect of body capacitance. The formula for parallel plate capacitance is represented by:

$$C = \frac{kA}{d}$$

Where, C = Capacitance
k = Constant
A = Shoe surface area
D = Distance between shoe and floor

Based on this relationship, capacitance (C) is minimized when one foot is raised from the floor surface, resulting in higher voltage levels. As capacitance (C) increases, voltages (V) will decrease[ii]. Another concern is the sole material, frictional force and body capacitance. For these reasons, the same operators performed each of the tests during the length of the study. The ESD footwear were tested for compliance to ANSI Type I specifications prior to starting each test. The footwear were then worn for 10 minutes before beginning each test to insure integrity. Readings were taken every other week for two years.



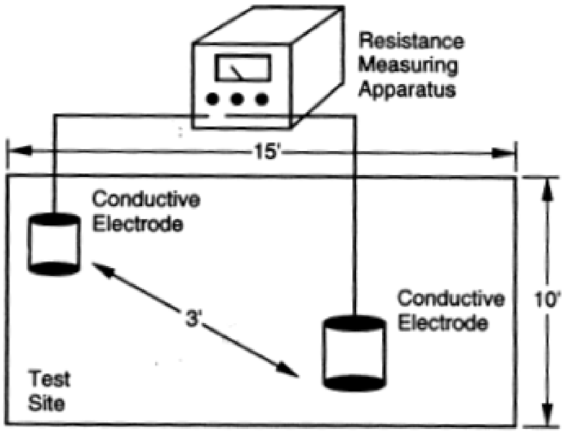
"Body Voltage Test Configuration"
Figure #1

Surface Resistivity – As per ASTM D257, EOS/ESD-DS7.1 and NFPA 99, the point-to-point surface resistivity was checked using (2) 5 pound conductive rubber electrodes connected to a voltmeter, spaced 3 feet apart using a 100 volt source (see **Figure#2**). In addition, readings were taken & noted using a concentric ring apparatus. When using the concentric ring fixturing, resistivity was calculated by using the following expression:

$$SR = \frac{\pi (D_2/D_1)}{(D_2 - D_1)}$$

Where, D2 = inside Ø of outer electrode
D1 = outside Ø of inner electrode
R = measured resistance in Ω

Measurements were taken from various points on the test surface, including the center of the test site and at the edges where there was very little traffic. The electrodes were cleaned, as well as the test patch, using isopropyl alcohol and water between each reading. All equipment used in testing was calibrated and verified according to manufacturer's recommendations. Readings were taken on a biweekly basis for the first two months, and once per month thereafter.



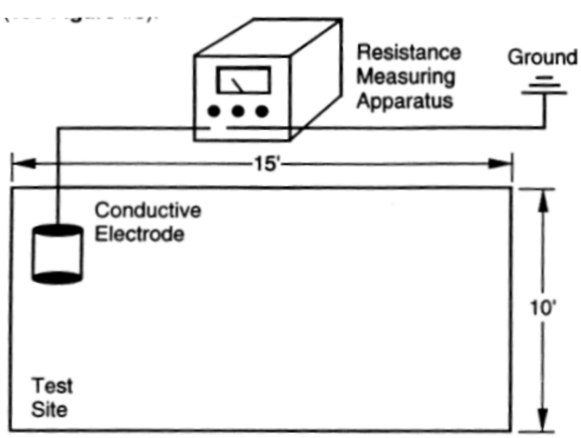
"Surface Resistivity Test Configuration"
Figure #2

Installation Requirements – Each type of flooring had a specific method of installation and floor preparation. Comparisons were made, analyzing length of installation, necessary equipment, chemicals or solvents, fumes, amount of necessary floor preparation, etc. based on the manufacturers' specifications and actual installation.

Appearance – The initial appearance, as well as weekly checks were performed. Color change, loss of finish, lifting, scuffing (see "scuffing") bubbling, and dirt retention was checked and each test site rated on a 1 – 10 scale with 1 being best. During the entire evaluation, there as no major maintenance performed on any of the test sites, other than a once per week buffing at 5000 RPM using a water and ammonia cleaning solution.

Odor – For obvious reasons, the product was expected to have no offensive odor, as per ASTM D4078.

Resistance to Ground – Each of the floors were grounded and verified using a 100 volt source voltmeter and a five pound conductive rubber electrode, per NFPA 99 and EOS/ESD DS7.1 (see **Figure #3**).

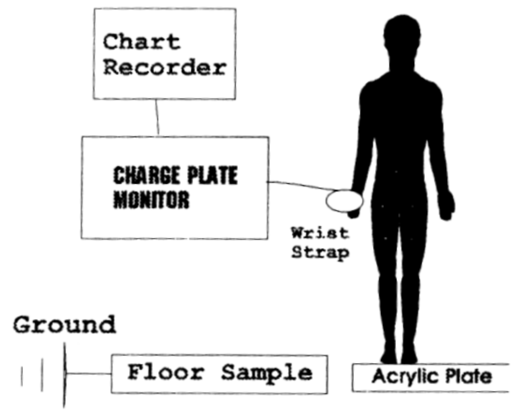


"Resistance-To-Ground Test Configuration"
Figure #3

The necessity of this particular test would depend upon the application. ESD flooring installed in an office area would not typically require grounding. However, in many manufacturing and assembly applications, the use of proper grounding would be essential if the operator were relying on the footwear and flooring as a source to ground.

The test equipment was calibrated and verified every 3 months during the study. Isopropyl alcohol and water was used to clean the test site and test apparatus prior to each reading. Readings were taken once per month over a two year period.

Static Decay – Static Decay tests were performed according to Fed Test Standard 101C, Method 4046, both with and without the addition of the human body. Current Federal test standards do not specify the introduction of a human body during testing. However, in order to properly analyze the floor's ability to dissipate a charge on a human being, the introduction of an operator with and without ESD footwear was included in this study. A 5000 volt charge was generated on each of the test site surfaces, in addition to a separate test using an operator, with the decay time necessary to drain the charge to 0 volts noted.



"Static Decay Test Configuration-w/Human Body"
Figure #4

As **Figure #4** details, a charge plate monitor with 20,000V DC was connected to a chart recorder. The test operator wore verifiable ESD wrist strap with a one meg resistor and chosen footwear. The operator then stood on an acrylic test plate adjacent to the floor sample under test. He was then charged up to +/-5kV and the voltage source turned off. The operator immediately stepped onto the test floor and the decay rates were recorded until the voltage level stabilized or reached zero. This test was performed during the second month of the study.

Scuff Resistance – Black marking resistance, as described in ASTM D 3714, is the ability of a floor to resist black marks usually caused by the impact of heels and soles of footwear, along with various type of wheels rolled across the surface. In addition to using a sheet of 400-A Carborundum, paper and ladder-pendulum test fixtures, real life application testing occurred over the course of the study. The test site was chosen as representative of a typical manufacturing environment with medium traffic, as well as push carts and buggy traffic through the aisles. With this in mind, black marking/scuffing was checked at each of the test sites. Again, as in appearance, they were rated on a 1 – 10 scale, with 1 being best resistance to marking.

Wear - AT&T, like most other companies, strives for flooring that requires very little maintenance or replacement. With the cost of flooring being particularly high, the necessity for replacement or recoating (in the case of "poured" and "rolled-on" flooring) was considered.

Required Maintenance – Most manufacturers of ESD flooring report very little required maintenance, such as an occasional sweeping and wet buffing with a water-and-cleaning mixture to get out ground-in dirt. One goal of this study was to verify what type of maintenance was necessary and the cost of that maintenance over the life of the floor.

Slip-Resistance – For safety reasons, all floors must be UL certifiably slip resistant. This was accomplished using a portable Broom Grapper Machine, in lieu of laboratory testing, which entails the use of a James Machine or equivalent. The portable tester was used was used in order to do on-site evaluations during the first two weeks of the study according to the Underwriter's Laboratory specifications, adopted by the American Society of testing and Materials in ASTM Standard D2047-69. The American Disability Act (ADS), was also considered, verifying that the floor surfaces were "stable, firm & slip resistant."

Cost – Pricing was requested for each of the floor types.

Electrical Safety – In order to insure the safety of operators & maintenance personnel working on electrical while standing on the floor surface, the flooring was checked in accordance with UL Std 779. As standard practice, however, anyone working on electrical should always isolate themselves from the ESD flooring in order to avoid shock or other serious injury.

Sales Support – Sales support is an intricate and important part of any on-going or major purchase arrangement. Each of the companies involved in the study were contacted at various intervals and their response times, as well as levels of satisfaction with their responses noted.

Availability - National and International availability was noted for each of the floor types. Some manufacturers contacted were unable to provide the product to certain areas of the world or perhaps not outside the United States, while others had manufacturing or distribution locations world-wide.

Warranty – Although not a rule, warranties sometimes reflect the quality and level of confidence a manufacturer has with their product. It also serves as an insurance policy for the buyer reducing the risk of loss during the period of coverage.

Most floor "types" had similar warranties on mechanical & electrical properties, while others had superior coverage. Warranty information will be outlined and compared accordingly.

Abrasion – A breakdown of electrical characteristics may occur with a minimal amount of wear on certain types of flooring. Testing that determines the amount of wear a floor will exhibit over a period of time was examined per ASTM D-1044 using a CS-10-F wheel, 500Gm of maximum gauge loss of 0.40% at 2500 cycles and again at 1.6% at 10,000 cycles.

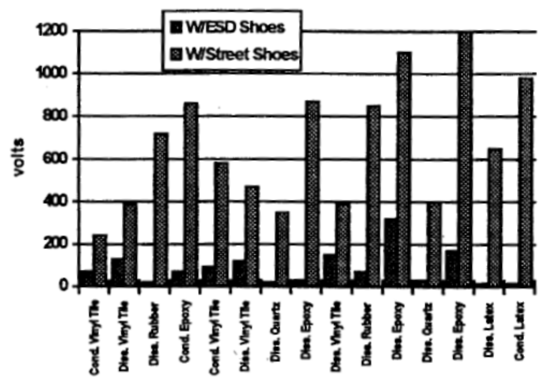
TEST RESULTS

Body Voltage Generation - Charge generation varied between 50 volts and 1,000+ volts. Using the formula for a Gaussian probability distribution:

$$f(N) = \frac{e^{\frac{-N^2}{2\alpha^2}}}{\sqrt{2\alpha}}$$

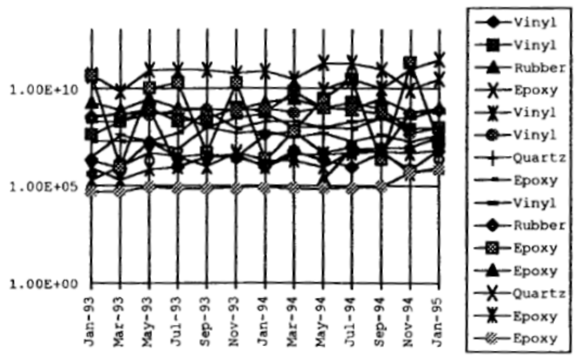
Body voltage generation was calculated within a 0.1% maximum probability range. Tests were conducted using insulative soles and verified ESD footwear, with both feet in contact with the floor and then one foot elevated to create a worst case scenario, representative of a walking motion. Reported data reflects the one foot elevated scenario. The environment in which the floor is to be used would determine what the proper combination of flooring, test criteria and footwear should be.

Figure #5 shows results from Month 31 using approved ESD footwear as well as insulative footwear.

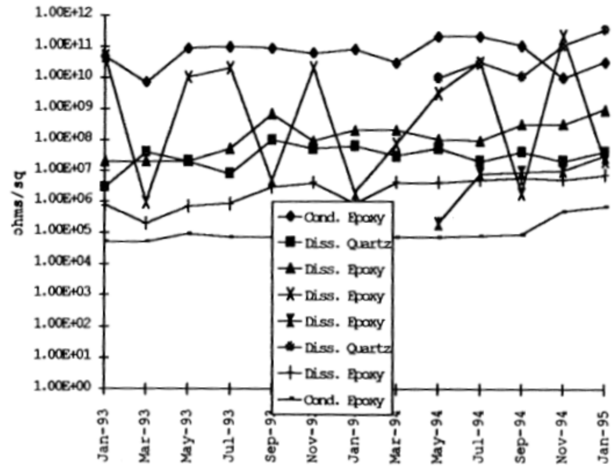


"Body Voltage Generation"
Figure #5
Month #1

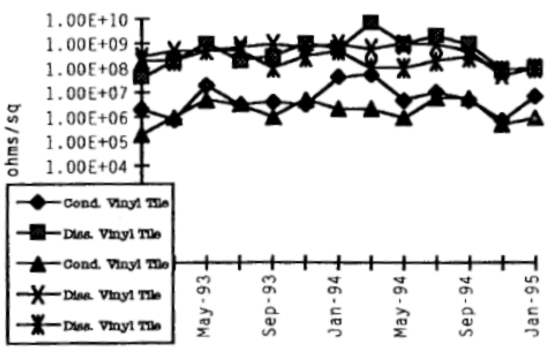
Surface Resistivity – Readings typically fell in the range of **5 x** $10^4\ \Omega/\blacksquare$ **to 20 x** $10^{11}\ \Omega/\blacksquare$ (maximum measureable charge). See **Figure #6** for a view of the overall surface resistivity results. Month #24 results are broken out for comparison by flooring "type" in **Figures #7, #8 and #9.**



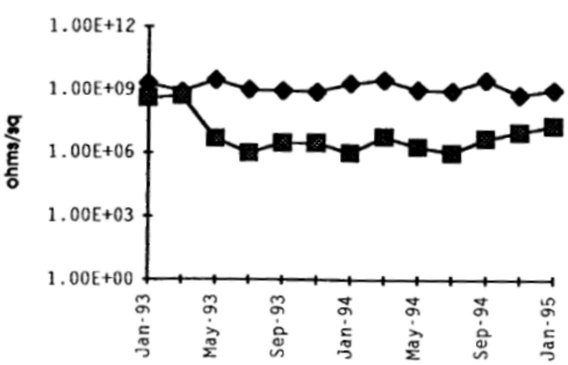
Surface Resistivity
Figure #6
(Range of Results)



Surface Resistivity: "Poured & Rolled"
Figure #9



Surface Resistivity - "Vinyl"
Figure #7



Surface Resistivity - "Rubber"
Figure #8

Based on these results; Floors "C", "A", "B", "E", "G", "N", "H", "J", "O", "F", and "P" were typically less than $10^{9}\,\Omega/\blacksquare$ and more than $10^{4}\,\Omega/\blacksquare$ as of Month #24.

Installation requirements: All of the floors installed were connected to ground (typically using copper foil or wire). In addition, the tile & rubber flooring were installed using conductive adhesive. For purposes of this study, very little prep was necessary. All floors were installed directly over the existing standard vinyl floor tiles. It should be noted that subfloor material may affect test results and the results in this study may not necessarily mimic those performed with a different subfloor, such as concrete or wood.

The epoxies & urethanes required more time & training to install than the tile or rubber floors. In addition, one of the epoxies & urethanes required evacuation of people in the immediate area due to strong odors. MSDS sheets did not reveal any strong health concerns with limited exposure during installation, but personnel in the area have reported throat irritation and other related ailments up to 48 hours after exposure.

From a cost perspective, the conductive adhesive used during tile & rubber installations was considerably more expensive than standard adhesive. It must be applied, in most cases, such that the layer of adhesive is spread evenly & thick enough to allow for even resistance across the surface of the flooring material. Some of the tile manufacturers in stalled their products using too much adhesive, which later bled through the seams. One of the epoxies, Floor "K", dried with extensive bubble formations across its surface.
Floor "L", an epoxy quartz floor appeared to have "Puddles" after final application of the top coat. Floor "F", another type of epoxy floor, was thin enough that the subfloor outlines could be easily seen through it.

Appearance – From a user's perspective, ESD flooring is expected to meet not just electrical criteria, but mechanical as well. The floor should be able to withstand daily usage and maintain a level of appearance acceptable to the user. The floors were rated on a 1 -1 10 scale, with 1 being best cosmetic appearance. Below are the results as of Month 24 for each of the floors:

"Appearance"

Floor	Rating
A (Vinyl)	6
B (Vinyl)	5
C (Rubber)	1
D (Epoxy)	10
E (Vinyl)	5
F (Epoxy)	10
G (Vinyl)	5
H (Quartz)	1
I (Vinyl)	5
J (Rubber)	5
K (Epoxy)	9
L (Quartz)	7
M (Epoxy)	9
N (Vinyl)	5
O (Epoxy)	6
P (Epoxy)	7
Q (Epoxy)	8
R (Vinyl)	5
S ("Paint")	NA
T (Epoxy)	NA
U (Epoxy)	NA

NA = Not available

These ratings were based on the amount of dirt retention, change in appearance over the one year period, scuffing and other measures of general appearance. Floors "C", a rubber floor, and "H", a quartz, were rated best in terms of appearance.

Odor – As discussed earlier, odor was a major consideration. Besides running into odor problems during installation, one of the floors emitted a slight odor for approximately three months after installation. Large fans had to be brought into the area to relieve the area of odors presumably emitted from one of the epoxies. Floor "C", a rubber floor, also emitted a slight odor that dissipated within a few weeks and two cleanings. None of the floors in the study had any long-term problems with odor, although the short-term problems could have been monumental had the area been larger.

Static Decay – During the second week of the study, all of the test sites were tested per Fed Test Standard 101C, method 4046 and a modified version, including the introduction of the human body. All of the floors tested passed the test without the human body. However, some of the floors showed a disconcerting change in decay times when the human body was introduced into testing. This particular test, without the use of the human body, is one of the three traditional approaches to testing & advertising ESD flooring[iii]. Other test methods, including body voltage generation & footwear interactions must also be considered.

Scuff Resistance – Intricately tied to appearance, scuffing was checked per ASTM D 3714 at the beginning of the study. In addition, each floor was then rated on a 1 -1 0 basis (1=best) weekly, based upon the amount of scuffing found within 24 hours after the weekly cleaning. One of the two quartz poured floors, along with the rubber flooring showed remarkable resistance to scuffing. All of the vinyl tiles reflected a higher than expected amount of scuffing & dirt retention. These phenomena can be possibly attributed to the softness of the vinyl and the natural tendency to mark. The majority of urethane, acrylic & epoxy floors had excessive scuffing and marking which became so embedded in the flooring that buffing at 5000 rpm could not remove it. These type of floors experienced a higher rate of scuffing, even more so than the vinyl tiles, especially in areas where chairs were located.

Wear – A combination of both electrical and mechanical properties were looked at to determine the exact rate of wear among various floors. Some of the epoxy, acrylic & urethane based floor systems showed distinct wear problems. The manufacturers recommend a repeat application every 1 – 3 years in most cases. More specifically, the latex epoxy was in need of reapplication after approximately 11 months, while floors "F" and "D", had even earlier signs of wear.

Among the other test sites, wear seemed to improve the appearance of the rubber flooring, presumably removing any residual coating left during the manufacture process (which impeded earlier electrical readings). One of the two quartz floors did not show signs of extreme wear like the other "poured & rolled' types of flooring. However, the other quartz floor (Floor "L") had problems with "puddle formation" a presumed accumulation of "top coat" during the initial application process. This floor also displayed extreme path wear which resulted in statistically significant variation of electrical attributes.

Required Maintenance – In many manufacturing areas, floor maintenance may not be a top priority. Maintenance has traditionally been linked to aesthetics, not ESD prevention. In addition, floor cleanings & waxing may interfere with the manufacturing process and delays are typically costly. A floor which would require as little maintenance as possible was preferable. The cost of maintenance could be extremely high due to the typically large square footage of most IC manufacturing and assembly plants (i.e. 1,000,000+ sq ft).

The vinyl floors included in the study displayed various degrees of necessary maintenance, but all had one common requirement: the need for an ESD wax application to inhibit dirt retention & prevent marking. This was not particularly surprising based on reports detailing performance of standard (non-ESD) vinyl tiles available on the commercial market. Even vinyl's advertised as "NO WAX", typically require a coating of wax at some point in time. ESD vinyl tiles included in this study were no exception.

During the study, all of the floors received once per week cleaning and buffing. For some, such as the rubber and Floor "H", a quartz, this was more than adequate. After the cleaning, the floors' appearance was similar to that of the day of original installation. Others, such as the vinyl tile products appeared to need more than daily sweepings in addition to weekly cleaning and buffing. For the remainder, harsh cleaning agents and extreme buffing would have been necessary for removal of ground in dirt and scuffing.

The ratings on degree of necessary maintenance, with a 1 – 10 scale (1=least amount) follow:

Floor	Rating
A (Vinyl)	8
B (Vinyl)	7
C (Rubber)	1
D (Epoxy)	9
E (Vinyl)	6
F (Epoxy)	9
G (Vinyl)	6
H (Quartz)	1
I (Vinyl)	6
J (Rubber)	2
K (Epoxy)	9
L (Quartz)	2
M (Epoxy)	9
N (Vinyl)	6
O (Epoxy)	6
P (Epoxy)	9
Q (Epoxy)	8
R (Vinyl)	6
S ("Paint")	NA
T (Epoxy)	NA
U (Epoxy)	NA

NA = Not available

Slip Resistance – As per UL specifications, all floors must have a minimal average coefficient of friction of 0.50. All of the floors included in the study met this requirement.

Cost – Pricing was received & analyzed, but is not included in this report for obvious reasons. However, based on an analysis of pricing and test results, it can be concluded that price does not always reflect the quality of the product.

Sales Support – As stated earlier, sales support is particularly important where an on-going purchasing arrangement is being implemented. Like many other products, ESD floors are constantly being reformulated for improvement and the need fore a competent source of information on the product in addition to meeting the needs of a purchasing department is mandatory. Each of the flooring companies were contacted during the study and rated according to"

1. The amount of time it look to return a call
2. The amount of time it took to get an answer/response
3. The amount of available technical support
4. Technical knowledge of product, etc.

Each flooring manufacturer representative was rated accordingly:

1 = very good
2 = good
3 = fair
4 = poor

Availability – Because of many semiconductor companies' manufacturing and assemblies global presence, availability world-wide was considered. Certain manufacturers had distribution and/or manufacturing facilities located outside the United States. Dependent upon the needs of the user, a thorough research of global manufacturing & distribution should be completed prior to any purchase.

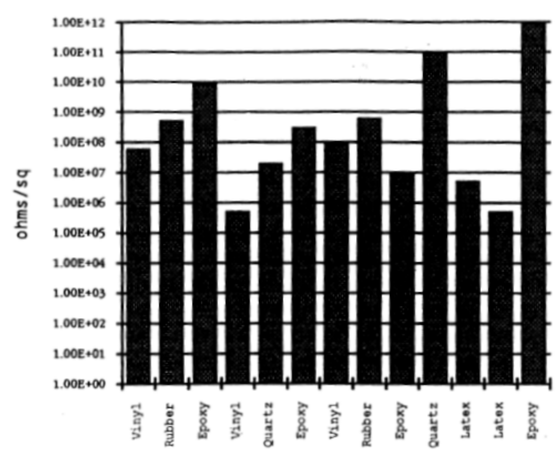
Warranty – The following is a summary of warranties, both mechanical and electrical:

Floor	Warranty
A (Vinyl)	5yr/1yr
B (Vinyl)	NA/5yr
C (Rubber)	5yr/10yr
D (Epoxy)	NA
E (Vinyl)	5yr/1yr
F (Epoxy)	NA
G (Vinyl)	5yr/1yr
H (Quartz)	5yr/1yr
I (Vinyl)	5yr/1yr
J (Rubber)	5yr/5yr
K (Epoxy)	1yr/1yr
L (Quartz)	1yr/1yr
M (Epoxy)	5yr/1yr
N (Vinyl)	5yr/1yr
O (Epoxy)	1yr/1yr
P (Epoxy)	NA
Q (Epoxy)	1yr/1yr
R (Vinyl)	5yr/1yr
S ("Paint")	NA
T (Epoxy)	NA
U (Epoxy)	NA

NA = Not available

Based on information made available by each of the manufacturers, the rubber flooring products had the best warranties. Most manufacturers warranty ESD tile product for 5 years electrical and 1 year mechanical, while epoxies typically cover 1 year electrical and 1 year mechanical. Based on test results, a one year mechanical & electrical warranty may be a very good indication of when the product would need to be reapplied.

Resistance to Ground – Measurements were taken, as described earlier. Results after 24 months were as follows:



Resistance-To-Ground
Figure #10

Abrasion – A breakdown of electrical & mechanical characteristics of a floor may occur with minimal amount of wear for certain types of flooring. Using method ASTM D-1044, testing was conducting during the second week of the study. All of the epoxies exhibited extensive wear, while the rubber floors displayed the least. In particular, Floors "D", "L", "Q", "P" & "F" failed abrasion resistance testing after approx. 2500 cycles. This should not be surprising, considering the thickness of application, which may vary. The vinyl tiles & rubber flooring all met the 1.6% at 10,000 cycle requirement.

SUMMARY

This study was conducted with the intent of providing a thorough characterization of the electrical & mechanical properties of ESD flooring. The three traditional approaches to evaluating floor materials were analyzed and found to be inappropriate methods of characterization for IC handling applications. Many different floor types were included as part of this study. Base don the three traditional test methods, some of the floors appeared to "meet" the requirements. However, when the tests were modified to include various footwear and human body testing, along with mechanical analysis, these same floors failed. Other floors displayed excellent electrical characteristics, but failed mechanical testing, while some failed both electrical & mechanical requirements.

One additional point that needs to be considered is the "TRUE" cost of a floor. The cost of initial installation, along with maintenance and replacement costs needs to be considered before purchasing any type of flooring. All of the vinyl floors displayed varying degrees of marking and dirt retention that could be alleviated by the topical application of an ESD wax on a regular basis. In order to determine the true cost of this type of floor, you may need to factor in the cost of applying an ESD wax over the ESD vinyl tile. Using estimates from a local janitorial service for a 2-coat application of an ESD wax, the following calculations were made.

Based on a room with 2000 square feet of floor space, the average cost of applying an ESD floor finish to a standard vinyl tile over a 10 year span is approximately $2,910 per year. The cost for that same room with a permanent ESD vinyl tile floor without an ESD wax, including the initial cost of installation, over a 10 year span is approximately $1,790 per year. Adjusting these numbers for a room with 10,000 square feet of floor space equates to an annual cost of $8,950 for an ESD floor and $14,500 for the ESD floor finish over standard vinyl tile.

What does this mean? Standard vinyl tiled floors with an ESD wax application may appear to be the least expensive option when choosing an ESD floor. However, when local maintenance costs are factored in, the cost may rise significantly, exceeding the cost of a permanent ESD flooring system. In comparison, the initial cost of the rubber floors may be significantly higher than that of the vinyl floor, but over a ten year period, with no wax applications necessary, the cost may be significantly less than that of the ESD vinyl tiles. The majority of urethanes , epoxies and acrylic floors were quoted at higher than vinyl tile prices, and less than rubber flooring, but may need repeated recoatings. Since the cost of any ESD flooring, ESD wax or labor will vary around the world, a thorough cost analysis, including maintenance, should be calculated prior to making any purchasing decisions.

CONCLUSIONS

The intent of this study was to determine which ESD flooring types and test specifications would be acceptable for us in an IC manufacturing and assembly environment. Seventeen parameters were considered, including cost, maintenance, appearance, mechanical and electrical properties. The task of determining which of the floors to recommend was complex and time consuming.

Many ESD flooring manufacturers were invited to participate. Most accepted while others declined. Reasons for not participating were varied from "we don't give out free samples" to "we're reformulating- call us in 6 months". Sales and technical support was minimal in some cases. Available material pricing varied from approx. $2.00 per square foot up to approx. $9.00 per square foot. Electrical test results ranging from triboelectric propensity to surface resistivity were varied and sometimes surprising. Appearance after 24 months was contradistinctive. Based on the data accumulated, taking into consideration critical vs. non-critical requirements, the following conclusions can be made:

1) In order to properly analyze an ESD product, be it ESD flooring or a static dissipative finger cot, a multitude of tests, including, but not limited to, electrical, mechanical, sales, support, pricing, aesthetics, warranty and ecological evaluations should be considered. All too often, protects are chosen based entirely on electrical data with little or no consideration given to other criteria. This study attempted to take into account all aspects of ESD flooring materials in order to achieve a complete and thorough engineering evaluation.

2) Some "poured" and "rolled-on" type floors displayed a wide variation in electrical readings. In one case, depending upon where the probes are placed on the test site, the floor's electrical resistivity could range from $10^{4}\ \Omega/\blacksquare$ to $10^{11}\ \Omega/\blacksquare$. This type of floor's mechanical and electrical properties appeared to be too dependent upon the method of application. In addition, with only one exception, this type of floor displayed extensive wear after only a few months.

3) Most ESD flooring manufacturers test and advertise their flooring products based on three widely-used electrical tests; the static decay test, body voltage generation & electrical resistance. These approaches are limited and not well defined in many cases. Additional tests must be performed, in conjunction with ESD footwear & "street" footwear in order to determine the floor's true capability of preventing ESD induced damage.

4) Traffic levels need to be considered before purchasing any ESD flooring. In areas with very little traffic, such as an engineering lab, vinyl tile with infrequent ESD wax applications may be appropriate. In heavy traffic areas, with round-the-clock operations, the use of vinyl tile is not recommended if aesthetics are a priority. Rubber floors successfully maintained their original appearance after 24 months with no sign of wear. In fact, one of the two rubber floors, Floor "C", appeared more aesthetically "pleasing" AFTER 24 months than when it was originally installed. Maintenance requirements for most of the

"poured" and "rolled-on" floors were above average. In addition, this type of floor may need reapplication after a one to two year period.

5) When analyzing test data, probability distributions need to be considered. All too often, "average" or "median" readings are reported.

6) The human body needs to be considered during testing. Static decay tests currently specified in ESD floor applications were originally designed for ESD packing material testing & evaluation. In addition, NFPA 99 procedures were intended for medical applications, not the IC industry. Modifications in applied voltages and test gear are appropriate.

7) There was very little statistically significant change in electrical test results among most of the vinyl tile, rubber and one of the "poured" quartz floors after a two year period of time. Variations among some of the "poured" or "rolled-on" floors could be attributed to: 1) wear, 2) dirt build-up and 3) inconsistencies in application during installation.

8) The area and application must be considered. If the floor is intended for office use, in the prevention of ESD-induced failure to electronic office equipment, the requirements may be less stringent than that of an IC manufacturing and assembly area. Cleanroom applications have additional particle count requirements that weren't considered during this study. However, the quartz floors, based on a granular "sand" system, shed noticeably small particles, assumed to be sand, over the course of the study and did not appear to meet strict Class 10 criteria. Additional testing would be necessary on any floor intended for cleanroom applications.

9) ESD flooring advertised as "conductive", defined by Jedec as a material that has a surface resistivity less than 1 x $10^5\ \Omega/\blacksquare$ or a volume resistivity less than 1 x $10^4\ \Omega/\blacksquare$ **-cm**, may in fact be "static-dissipative". A few of the floors included in this study were advertised as "conductive", with resistivity readings as high as 9 x $10^9\ \Omega/\blacksquare$.

10) With few exceptions, almost all of the ESD floors included in this study displayed considerably high body voltage generation when "street" shoes were used during testing. Vinyl tiles used in conjunction with street shoes demonstrated the lowest body voltages. It can be concluded from these results that all ESD flooring systems should be tested for body voltage generation using street shoes (Neolite soles or equivalent) or used only in conjunction with approved ESD footwear in order to keep body voltage generation below 200 volts.

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