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ESD Safety in Cleanrooms: Natural vs. Man-made Materials

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Electrostatic charge build-up in cleanrooms can produce higher levels of surface contamination, electrostatic discharges that damage integrated circuits, MR and GMR heads, and electromagnetic pulses that can disrupt robotics. [The July/August 1998 issue of INSIGHT was largely devoted to electrostatic discharge and its effects.] Cleanroom fabrics and document materials ("papers") made of natural fibers are somewhat hygroscopic and are often assumed to be static dissipative, in contrast to materials made from artificial fibers (e.g., polyester and nylon). To handle special situations that involve low humidities, the ESD Association test for surface resistivity (S11.11, ESD Association, 1993) is run at 12 ± 3 percent relative humidity (RH).

"Humidity and Temperature Effects on Surface Resistivities" was reported by Kolyer and Rushworth. (Kolyer and Watson, 1996). They studied antistatic polyethylene, antistatic nylon, polyethylene with radiation cured coating, cellophane (bare, plasticized, coated and plasticized), filter paper, paper, static limiting floor finish, detergent, and leather. They noted that surface resistivity has been assumed to follow relative humidity (H) exponentially, with R(H) proportional to exp($_{-b}$H), but that this behavior was seen only for paper, cellophane and leather in their study. On their graphs of log(R) vs. H graphs, a straight line would correspond to:

$$R(H) / R(0) = \exp\,(_{-b}H).$$

In most of their cases, R(1)/R(0) = 1/(1 million) to 1/(10 million), which would be a value of about b = 14 to 16. This corresponds to halving the resistivity for every +5 percent RH increment.

The graphs of Kolyer and Watson (1996) show surface resistivities at 100 percent RH that were between 0.1Mohm/square and 100Mohm/square, with 1Mohm/square being typical. At 100 percent RH, one would expect a monolayer of water to exist, having almost the resistivity characteristic of pure water, or more due to the very shallow depth. At zero percent RH, one would expect a surface resistivity wholly characteristic of the solid material, independent of water, so this could have any value, though the materials of interest were primarily insulators, having resistivities on the order of Tohm/square or even more. ASTM (1993) noted a somewhat similar effect, "A change from 25 to 90 percent relative humidity may change insulation resistance or conductance by as much as a factor of 1,000,000 or more." This corresponds to halving the resistivity every +3 percent RH increment.

A simple, heuristic model to explain the exponential dependence of surface resistivity on relative humidity would be that high resistance is associated with the probability of finding zero water molecules per unit (small) area. This probability is approximately P(0) = exp (-m), where m is the mean number per unit area. An uncomplicated isotherm, relating number of molecules per area to humidity at a particular temperature, would be m = $_b$H, the surface concentration being proportional to the relative humidity. Combined, these relationships would give an exp($_{-b}$H dependence on relative humidity, which is a straight line with a negative slope on a graph of log(R) vs. H. Depending on the surface, however, there are various isotherms that are appropriate. Another common isotherm is Langmuir, with the surface molecular coverage fraction being given by k H / (1 + k H). This isotherm rises linearly with H at H < < 1, approaching one (1) asymptotically, implying the slope of resistance change would become less negative as H approached H = 1 = 100 percent RH, behavior found for a detergent—coated plastic and for material coated with “static-limiting floor finish”.

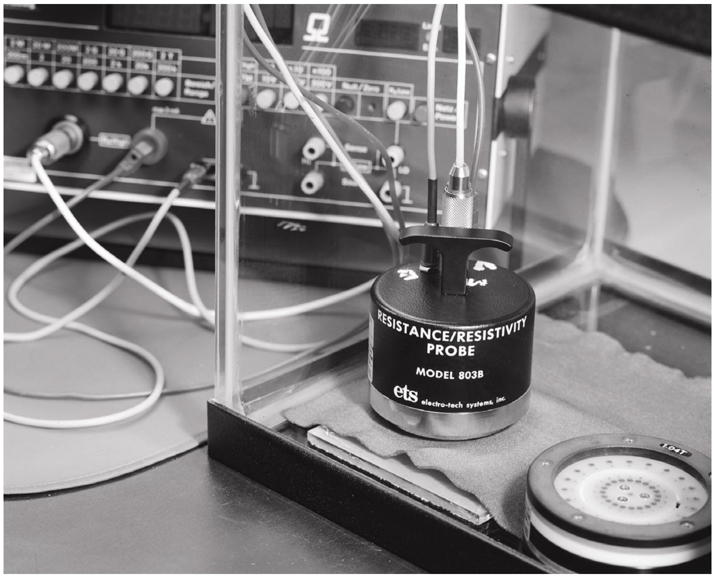

Figure 1. *Surface resistivity of a fabric being measured in a controlled humidity chamber*.

The solid surface and the water “film” can be viewed as two resistances in parallel, Rs and Rw. The combined resistance becomes 1/(1/Rs + 1/Rw). The lower resistance dominates. Thus, we expect the water film to have a more pronounced effect when the solid surface resistivity is relatively high. “Halving every +5 percent RH” cannot be universally true, becoming less accurate the lower the solid surface’s resistance is. This idea of parallel resistances also illuminates the measurement of thin films. At low relative humidity (c. 12 percent RH), we found that thicknesses of 0.6, 1, 2, 4 and 125 mil static dissipative polymer alloy had surface resistivities that decreased as the thickness increased, consistent with a dependence of apparent surface resistivity on depth of penetration of the current. Subsequently, both sides of the same polymer films were exposed to 48 percent RH for 66 hours, then the resistivity was measured. Much the same trend with thickness was found at this moderate humidity (c. 50 percent RH), except that the thinnest film was intermediate in resistivity and all were less resistive than at the low humidity. It seemed probable that the current penetrated the thinnest film and used the water on the bottom surface as another current path.

Triboelectrification represents charge generation by contact, offset by charge loss (due to conduction, air ionization, etc.). Some measured values (by McFarland) of electrostatic voltage in practical situations at various relative humidities were cited by McAteer (1990). Halving every five percent RH would have produced smaller ratios. As McAteer noted, the decreased accumulated charge was probably due both to some decrease in resistivity (thus more rapid dissipation) and to some increase in lubricity (thus lessening of the charge generation). Similar information (from Moss) presented in the book by Amerasekera and Duvvury (1995) for 20 percent RH and 80 percent RH indicated the voltages were typically an order of magnitude different, less than 2x change per five percent RH. There are other paths for charge dissipation besides that of surface conduction.

Test Methods and Results

We tested a variety of materials, at various humidities, near the ESD S11.11 relative humidity condition of 12 ±3 percent RH or the "typical" value of 50 percent RH. The S11.11 test involves placing onto a flat sample (on an insulating base) a probe made with an annular electrode that surrounds a disk electrode (See Figure 1). The resistance is obtained from R=V/I, voltage / current. Resistivity (in ohms for this standard geometry or in ohm/square) is determined by the material's resistance and geometry. A criterion for being static dissipative is having surface resistivity <1000Gohm/square, <1 Tohm/square (ESD Association, 1994).

At 12 percent RH, a special cleanroom paper fabricated from natural and man-made material was found to have a resistivity of 3.2Gohm/square, with a standard deviation of 0.1Gohm/square. [1 Gohm = 10^9 ohm.] Under the same conditions, common cellulosic notebook paper had a resistivity hundreds of times higher, 9300Gohm/square, with a standard deviation of 290Gohm/square. Standard cleanroom document material was tested after c. 30 minutes of exposure to air at 52 percent RH and was found to be static dissipative (near 0.04Tohm/square). At 12 percent RH, the same materials had been insulative (>1 Tohm/square), about 1000 times as resistive as they were at 52 percent RH. Humidity had rapidly made a big difference in surface resistivity, roughly consistent with halving the resistivity for every five percent RH increase. In a similar series of tests, five types of cleanroom document materials were tested at both 12 percent RH and 50 percent RH, and the surface resistivities were found to be between 100x and 1000x as high at 12 percent RH than at 50 percent RH. At 12 percent RH, they were insulative; at 50 percent RH, they were static dissipative. Halving every five percent RH predicts a 128x to 256x change for a +35 percent RH to +40 percent RH change, in rough agreement with these measurements.

Wipers are another important cleanroom consumable. At 13–17 percent relative humidity (not wholly within ESD S11.11 specification of 12±3 percent RH), after conditioning for 48–72 hours, a set of textile wipers showed these results (Table 1).

The natural cotton was about as resistive as the least resistive artificial polyesters, and none of these qualified as static dissipative.

WIPER	MATERIAL	MEAN (Tohm/sq)	STD.DEV. (Tohm/sq)
A	polyester	13.2	3.5
M	polyester	12.0	2.5
T	cotton	5.3	1.3
S	polyester	4.0	0.6
AS	polyester	3.9	0.4
Q	polyester	11.6	1.5
M	nylon	16.9	4.8
P	polyester	11.5	3.3

Table 1

Silk, being a natural material, seemed likely to be sensitive to RH. We tested seven different types of silk fabrics that were allowed to equilibrate in the lab room at 40–50 percent RH for three days before testing. They all tested in the 10 to 100 Tohm/square range, clearly not static dissipative, despite the moderate humidity.

Tests for resistivity were done on some other wipers after 68–72 hours of exposure to intermediate-humidity conditions (42–48 percent RH, 24–25°C).

Designed not to rely on humidity for static dissipation, ESD Wipes gave 0.019Tohm/square at 43 percent RH, 0.007Tohm/square at 41 percent RH, 0.016Tohm/square at 13 percent RH and 0.013 Tohm/square at 17 percent RH. All were clearly static dissipative. There was little change with RH.

Cotton wipes (TexWipes) gave 0.71Tohm/square [barely dissipative] at 46 percent and 0.24Tohm/square at 41 percentRH, but 5.3Tohm/square [insulative] at 13 percent RH and 29Tohm/square at 17 percent RH, resistivities 7.5x to 100x higher, depending on which values are compared. [Doubling every -5 percent RH would have given a reading approximately 128x higher.]. Whether or not they were static dissipative depended on the humidity.

Polyester knit wipes (Alpha 10) at 47 percent RH gave 17Tohm/square [insulative] and at 12 percent RH gave 7.3Tohm/square. This is only a 2x ratio, for about -35 percent RH change, much less difference in resistivities than the cotton wipes showed, but they were not static dissipative at either humidity.

Although relative humidity was important in influencing the surface resistivity of the natural materials we tested (roughly halving the resistivity for every five percent RH increment), silk did not become static dissipative even at 40–50 percent RH and cotton did not become static dissipative at 17 percent RH. Paper was not static dissipative at 12 percent RH, though it was static dissipative at 52 percent RH. The widely held view that natural materials are static dissipative was not supported by our results. Whether they are static dissipative or not depends on the relative humidity. The artificial materials tested showed less sensitivity to humidity.

References

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