TRIBOELECTRIC CHARGE: ITS ESD ABILITY AND A MEASUREMENT METHOD FOR ITS PROPENSITY ON PACKAGING MATERIALS

In principle, triboelectrically generated charge can cause device damage by induction via dielectric breakdown or charging-discharging currents. Existing methods and a new method for evaluating the antistaticity of materials will be reviewed. A study of the damaging ability of triboelectric charge on several common devices in practical circumstances is presented.

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INTRODUCTION

The antistatic behavior of materials has been and continues to be a concern in many industries. In the textile and plastics industries, concern has been over how much charge the material itself accumulates and retains. Thus, reasonably conductive grounded materials have been considered antistatic. However, for containers used to transport static sensitive electronic components, concern must be directed to whether the packaged component, not just the packaging material, accumulates charge. Since most components, whether PC boards or discrete devices, have large nonconductive areas, they can be charged in shipment and handling by rubbing against even a grounded, highly conductive packaging material. Thus, to ensure protection against damage from such charge, a method for evaluating the triboelectric propensity of container materials as well as knowing what charge levels are hazardous to devices is necessary. At this time, the Electronic Industries Association (EIA), military/government, and the EOS/ESD Association are developing standards for evaluating static control products, which will include testing for their triboelectric propensity. This article will discuss several aspects of the measurement of triboelectric properties and will investigate the actual hazard to devices having triboelectric charge.

ANTISTATICITY OF FILMS AND BAGS

Existing Test Methods

For "antistatic" materials having hygroscopic additives, decay time for surface resistivity tests, which are relatively convenient, can be used, provided that a correlation between these tests and a triboelectric generation test has already been established. A resistivity method is simpler, less expensive, and less susceptible to misleading results than a decay time method. The decay time method is suitable for homogeneous materials, but it is virtually useless for indicating the surface resistivity of laminate materials having one highly conductive layer. The effect of an exterior conductive layer has already been reported.[1] Although in such a case the outer layer of the material charges and discharges directly, the equivalent effect occurs even if the conductive layer is an intermediate layer which does not electrically contact the sample holder's electrodes.

To show that this phenomenon holds true and why, several materials having different surface resistivity were tested individually in a decay time apparatus and then in a three-layer laminate as the middle layer between layers of 1 mil polyester terephthalate (PET). To avoid electrical contact between the middle layer and the electrodes, the PET layers were about 1/4 inch longer at each edge than the middle conductive layer. The results are given in Table 1.

The laminate samples have a decay time essentially the same as if there were no PET outer layers. The reason is not that the conductive layer is directly charged but rather that it is charged by induction as illustrated in Figure 1.

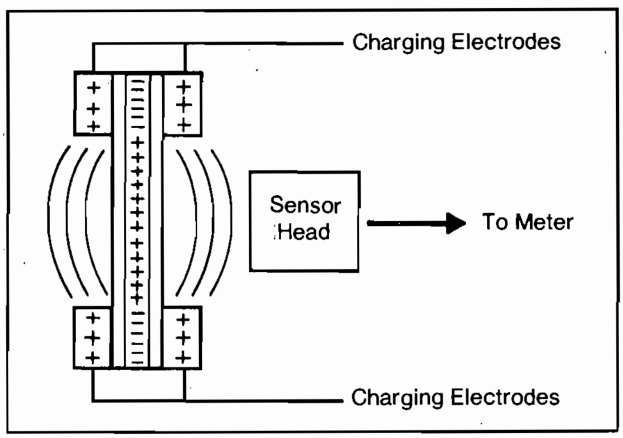

Figure 1. Decay Time Mechanism of Laminate Material Having a Conductive Middle Layer and Nonconductive Outer Layers.

Material	Decay Time[1] (seconds)	Resistance[2] (ohms)
1. Aluminum foil	0.02	<1
2. Carbon loaded plastic	0.03	80 K
3. Antistatic plastic	2.30	>100 M
4. Conductive coated PET	0.03	35 K
5. PET	(Didn't charge.)	$>10^{14}$
Laminate[3]		
5/1/5	0.03	$>10^{14}$
5/2/5	0.03	$>10^{14}$
5/3/5	2.10	$>10^{14}$
5/4/5	0.03	$>10^{14}$

[1]Average of five readings; background decay time was 0.02 to 0.03 seconds; [2]Resistance of film between clamping electrodes; [3]Numbers correspond to those materials above. For example, 5/2/5 means a 3 layer laminate with carbon loaded plastic on the interior and PET as both exterior layers. RH was about 40%.

Table 1. Decay Time and Resistance of Some Materials.

Material	Decay Time (seconds)	Resistivity[1] (ohms/sq.)
1. Antistatic plastic #1	2.10	2.7×10^{12}
2. Antistatic plastic #2	0.21	1.8×10^{11}
3. Conductive coated PET	0.08	1.8×10^{10}
Laminate[2]		
1/3/2	0.08	—
1/2	0.22	—

[1]The method of ASTM D-257 was used; RH was 40%.
[2]Numbers correspond only to those materials above in this table.

Table 2. Decay Time and Surface Resistivity of Some Materials.

The field from the charging electrodes inductively charges that portion of the conductive layer of the laminate between the electrodes. Since this induced charge is opposite in polarity of the electrodes and is drawn from the center of the conductive layer, the center portion of the conductive layer becomes charged to the same polarity as the electrodes (i.e., the conductive layer is polarized). This center portion emanates a field which is detected by the sensor. When the electrodes are grounded, the inductivity polarized charge in the conductive layer redistributes itself at a rate determined by that layers's resistivity, causing the field to diminish as if the conductive layer alone were being tested.

Although this represents a case where only one layer is conductive, a similar phenomenon happens when all layers are conductive. To illustrate this situation, samples of two antistatic plastics and a conductive coated PET were tested as before. The results are given in Table 2.

Although the outer PET layers in Table 1 do not charge, the outer layers in Table 2 samples do charge. In the latter case, when the electrodes are grounded, the charge of the most conductive layer can "follow" by induction the charge of the slower layers, creating charge dipoles near the laminate interfaces and thereby causing, in effect, no field at the sensor. Thus, the "decay time" of any laminate is determined by its most conductive layer, wherever it is, not by the conductive outer layer.

To observe the nature of the time decay, the output of the decay time meter was interfaced to a storage oscilloscope. The decay process for the conductive coated PET of Table 2 from 5,000 volts is shown in Figure 2.

There is an initial drop in voltage probably caused by capacitive suppression effects upon grounding the electrodes, while the ensuing decrease is essentially exponential and indicative of the conductive material itself. A trace of the 1/3/2 laminate of Table 2 was virtually identical to Figure 2, supporting the contention of decay process dominance by the most conductive layer.

Several commercially available transparent bags having an intermediate metallized conductive layer were then measured for their apparent decay time and for inside surface resistivity. Insulative tape was placed over all edges to prevent contact between the conductive layer and the electrodes. The results are given in Table 3. Although the surface resistivities vary considerably, the decay times are constant.

Therefore, a decay time measurement cannot be used as a measure of either inner or outer layer surface resistivity for laminates having a more conductive layer. Figures 1 and 2 do suggest that a decay time apparatus interfaced with an oscilloscope could possibly be used to indicate the resistivity and, therefore, the shielding ability of a highly conductive, intermediate layer in such laminates. In order to do so, however, switching, triggering, bandwidth, and slew rate of the decay meter's sensor and amplifier would have to be significantly improved.

Materials with a highly conductive surface or volume can also be evaluated with a decay time apparatus and an oscilloscope, but without the field sensor, by placing a current probe on the sample's discharge wire to ground. For a carbon loaded plastic, the decay time from 5,000 volts is shown in Figure 3.

Only one electrode clamp was connected to ground, and the resistance to ground via the sample from the other electrode clamp was about 62 k-ohms. The current probe was such that 1 ma = 1mV, and therefore the initial peak current observed (ca. 80 ma) agrees with the theoretical value (81 ma). Use of the sample's discharge current with either a current probe or an inserted, precision, low-ohm resistor requires careful attention to triggering because of the initial capacitive discharge of the ground-connected electrode clamp. Theoretical treatments of decay time versus material resistivity can also be utilized.[2,3,4,5] To simplify the analysis and perhaps even the capacitive effects of the electrode clamps, two circular clamps (with only one metallic clamp) could be used.

New Test Method

In general, a meaningful test for antistaticity requires that the components to be packaged be rubbed against the packaging material and that any accumulated charge be measured by a Faraday Cup method. A specially-built, reciprocating apparatus which can rub DIP style devices against the film material has been described.[6] Although effective, such a method is somewhat cumbersome for routine evaluation of materials; and its apparatus is not available commercially. But since a method for evaluating the antistaticity of DIP tubes has been described,[7,8] it would be desirable to have a similar test for film material utilizing much of the same apparatus. The following method was, therefore, investigated for its suitability for evaluating film materials.

Sample	Decay Time (seconds)	Inside Surface Resistivity (ohms/sq.)[1]
Al foil	0.03	—
A	0.03	1×10^{14}
B	0.03	2×10^{14}
C	0.03	5×10^{12}
D	0.03	3×10^{13}
E	0.03	1×10^{13}
F	0.03	1×10^{14}
G	0.03	3×10^{13}

[1]The method of ASTM D-257 was used; RH was 40%.

Table 3. Decay Time and Surface Resistivity of Commercial Bag Materials with an Intermediate Conductive Layer.

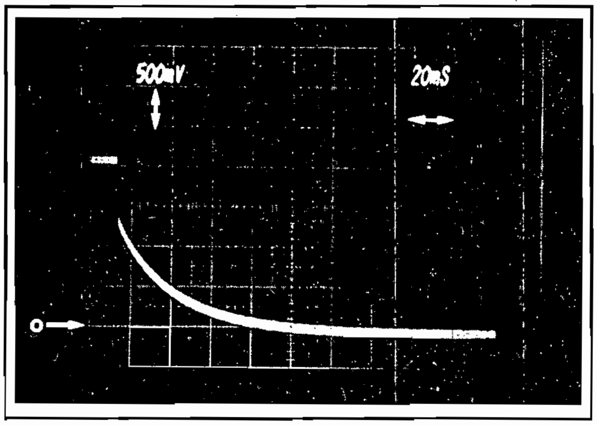

Figure 2. Decay Process of the Conductive Coated PET of Table 2 from 5,000 Volts in a Decay Time Apparatus Interface with a Storage Oscilloscope.

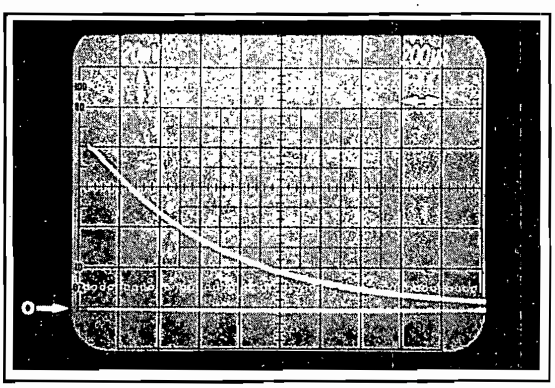

Figure 3. Decay Process From 5,000 Volts for Carbon Loaded Plastic Using a Current Probe Such that 1 ma = 1mV.

The method involves an inclined roll, where a cylinder of a specified material is allowed to roll across the supported surface of a film material and then allowed to drop into a Faraday Cup so that the charge developed on the cylinder is measured. A rolling cylinder is used because flat objects are difficult to slide down a film material, especially consistently. A simplified diagram of the method is illustrated in Figure 4.

The film sample (ca. 8 x 10 inches) is adhered to a smooth support board (ca. 12 x 18 inches) so that the film wraps around the bottom edge of the board. Tape at the four corners of the film usually suffices to hold the film sample. The board is inclined at the desired angle from the horizontal, which in this investigation was 45°; and its bottom edge is above a large Faraday Cup. To accomodate large cylinders as well as to allow for their variability in exit distance, the Faraday Cup comprises a one-gallon metal container, electrically isolated within a grounded, five-gallon metal container. The inner container is connected through the wall of the outer container to an electrometer having a coulometer mode.

Factors associated with the cylinder which will affect the amount of charge produced on it include its material, weight, area, surface roughness, surface cleanliness, and rolling speed. The most difficult variable to define is the material of the cylinder. Ideally, it should acquire very little charge from highly antistatic films and a lot of charge from static prone films. To determine cylinder material suitability, cylinders were machined from brass, stainless steel, Teflon, acrylic, polycarbonate, and polypropylene. The cylinders were 0.50 inch in diameter by 2.00 inches in length. In the test, each cylinder was positioned manually above a line drawn on the board nine inches from the bottom edge. The cylinder was released and allowed to roll down the film sample and into the Faraday Cup ten times. Before each roll, the film sample and cylinder were blown with ionized air for about five seconds. Before rolling across each film sample, each cylinder was cleaned with isopropanol and allowed to stand for at least one hour before use. Although the cylinder might likely acquire some antistatic agent from some films, the cylinder was not cleaned for each roll because transfer of some of the film's antistatic lubricious layer is probably a relevant occurrence to achieve antistaticity. The film samples tested included plain polyethylene and PET as static prone materials; two very lubricious, commercial antistatic films; five films cut from transparent, metallized bags; and one film from a carbon loaded bag. The film samples were conditioned at 72°F and 15 percent RF for at least 48 hours before testing, and all tests were conducted at 72°F and 15 percent RH. To account for any systematic charge due to the manual release of the cylinder or its falling into the Faraday Cup, an average "background" charge for each cylinder was determined from dropping the cylinder by hand into the Faraday Cup ten times. This background charge was algebraically subtracted from the average charge from rolling to give an adjusted average charge. The adjusted average charge in nanocoulombs on each cylinder for ten rolls across each materials is given in Table 4.

Of the cylinder materials tested, brass would be recommended for use since it significantly distinguished between the static prone materials and the antistatic ones. All the other cylinder materials acquired charge from one of the antistatic materials similar (in magnitude) to that for PET. (In view of the lack of sufficient statistics, a charge magnitude less than 0.05 nC should not be considered significantly different from zero.) Use of the materials other than brass could falsely indicate that PET was generally as antistatic as the hygroscopic antistatic films. It is interesting how little charge the polypropylene and PET cylinder acquired, suggesting that polypropylene might be somewhat intrinsically antistatic or that it would be antistatic with an appropriate additive or treatment.

This investigation was not intended to define a method but rather to evaluate the feasibility of this approach. Its principal advantages are its low cost, especially for those already having a Faraday Cup and coulometer, and the absence of human interaction and mechanical movement. Also, it can be used to evaluate rigid materials. To evaluate the triboelectric interaction of rigid materials (e.g., PC board) with a bag, the cylinder can be coated with an adhesive, and the bag's film material can be wrapped around the cylinder. The wrapped cylinder could then be rolled down the PC board material. Before use as general test, however,

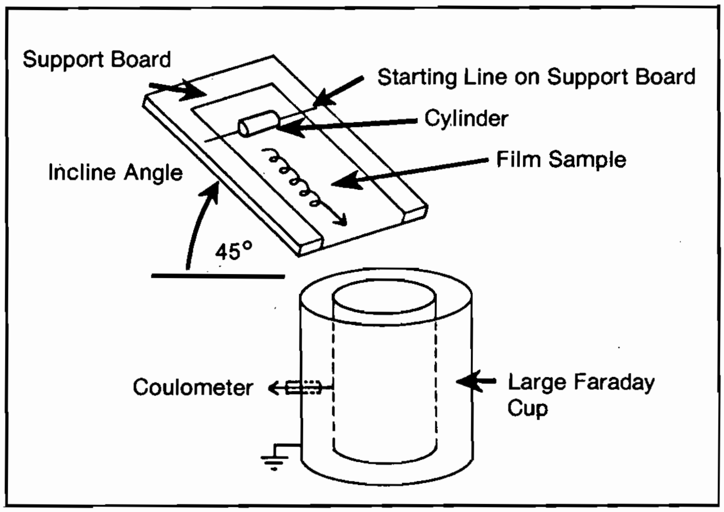

Figure 4. Apparatus arrangement for the inclined roll method of evaluating the antistaticity of film material.

	Cylinder Material					
Film Sample	Brass	S. Steel	Teflon™	Acrylic	P-carbonate	P-propylene
Plain Poly	2.54 (.12)	2.43 (.18)	-1.76 (.39)	0.26 (.04)	0.33 (.02)	0.09 (.04)
PET	2.38 (.21)	0.68 (.08)	-0.40 (.11)	0.47 (.07)	0.63 (.09)	0.06 (.01)
Carbon Loaded	0.10 (.03)	0.11 (.02)	-2.71 (.46)	0.68 (.08)	0.41 (.09)	-0.14 (.04)
Metal Lam. 1	0.09 (.06)	-0.10 (.05)	-1.46 (.29)	0.29 (.06)	0.27 (.05)	-0.39 (.12)
Metal Lam. 2	-0.22 (.06)	-0.28 (.05)	-1.10 (.23)	0.44 (.07)	0.16 (.06)	-0.40 (.09)
Metal Lam. 3	-0.86 (.08)	-0.87 (.08)	-0.91 (.11)	0.25 (.04)	0.20 (.06)	-0.49 (.11)
Metal Lam. 4	-0.76 (.07)	-0.76 (.05)	-1.97 (.11)	0.70 (.08)	0.42 (.08)	-0.74 (.09)
Metal Lam. 5	-0.35 (.07)	-0.24 (.06)	-0.78 (.17)	0.37 (.08)	0.35 (.05)	-0.24 (.05)
Antistatic 1	-0.43 (.04)	-0.53 (.05)	-0.44 (.14)	-0.09 (.03)	0.02 (.02)	-0.07 (.03)
Antistatic 2	-0.08 (.01)	-0.10 (.02)	-0.84 (.15)	0.77 (.10)	0.22 (.04)	-0.78 (.21)

*The number in parentheses is the standard deviation around the average.

Table 4. Average Charge* (nC) on Each Cylinder after Ten Inclined Rolls.

several parameters need definition:

Cylinder material, dimensions, and weight. Other materials relevant to devices but not able to be included here are Kovar, ceramic and plastic DIP body material, and fiberglass. Metal cylinders are heavy, causing more pressure and rolling speed than do the polymeric materials. Increased pressure and speed usually enhance triboelectric generation so that a heavy cylinder might be desirable. Polymeric materials could be bored out and a metal cylinder placed inside in order to add weight without changing the surface characteristics. Also, the test should, perhaps, include more than one cylinder material. Similarly, known static prone and antistatic films should be used in each test as controls and for comparison to the film samples tested.

Incline angle and film sample length. The incline angle will affect rolling speed, and the film sample length determines the amount of area undergoing contact and separation. The angle of 45 inches used here seemed somewhat steep. At a too steep angle, the cylinder can slide or skid rather than roll. This occurred sometimes with the metal cylinders on the smooth surface PET. An angle of 20° to 30° and a film sample length of 12 to 15 inches may be a better combination. Also, a mechanical rather than manual release of the cylinder could improve consistency.

Charge level criteria. Unless damaging charge levels on devices can be quantitatively correlated to the charge produced in any test method, packaging materials can only be ranked and not qualified. Such a correlation should be done with actual devices and could be done with the apparatus described elsewhere.[1,6] It is hoped that others will investigate this method in order to define the suitable parameters to make it a simple yet meaningful test method.

Work Function Approach to Antistaticity

The principal phenomenon of the efficacy of lubricious antistatic materials is that interfacial separation is within the lubricious layer rather than strictly at the surface boundary of the material or packaged component. Although some charge might transfer at the material-lubricious layer interface, unless the lubricious layer is highly conductive, it is difficult for charge transfer to occur between the packaging material and the packaged item. Thus, there is little net charging upon separation. There are, however, some applications where surface contamination by the lubricious layer is undesirable. In such cases, it is necessary to have clean, dry, antistatic surfaces. Where clean, dry surfaces separate without excessive friction, the work function of the materials involved can sometimes be utilized to describe the charge transfer.[9,10,11] Where the work function of two materials is identical, electron transfer should not occur. It is, therefore, possible that some materials could be selected for antistatic purposes based on their work function. In this approach, it is necessary that the work function of both the packaging material and the item to be packaged be known.

Test methods for determining the work function and its effect on charge transfer have been described.[12,13,14] In essence, one uses materials with a known work function which causes the material to be tested to acquire positive and negative triboelectric charge. Charge density is plotted against work function, and the work function of the tested material is interpolated from where the charge density would be zero. It's best to have at least four materials of known work function, two of which produce one charge polarity on the test material, while the other two produce the opposite polarity.

Commercial utility of this approach would require establishment of standard test methods and specification by vendors of their materials' work function. Similarly, users would have to determine the work function of their products. Although requiring some development effort, it seems an effective and practical alternative to the lubricity approach for specialized antistatic packaging.

DAMAGING ABILITY OF TRIBOELECTRIC CHARGE ON DEVICES

Another commonly used static protective container is a DIP tube. As in the case of bags, DIP tubes must protect against static discharges, electric fields, and triboelectrically generated charge. The ability to damage ICs in nonshielding DIP tubes by an external static field has been shown using an electric field sensitive device.[15] The importance of antistaticity in DIP tubes arises from the fact that charge produced on the device by sliding in the tube might cause damage when the device exits and contacts a conductive surface. This phenomenon is known as the charged device model (CDM) of static damage.

Although a tube's rigid geometry makes instrumental evaluation of shielding difficult, its structure does make antistatic evaluation easier than it would be for a bag. One method is to allow a test object such as a DIP device to slide through the tube and into a Faraday Cup where the net charge produced on the device is measured.[7] This method has been used to evaluate the antistatic property of various DIP tubes.[8] The method presently considered in the EIA standard uses a manual rotation, six times, with a single device. Manual rotation, unless very carefully and reproducibly done, will likely produce more variable results than a single slide with the tube held firmly at a fixed angle. A single slide usually produces less charge than a six-time rotation so that data showing normally occurring levels of charge on DIPs is still needed in order to determine the appropriate number of slides.

Like shielding effectiveness, criteria for acceptable antistatic performance are more difficult to establish than the measurement methods. Establishing a single charge level as "safe" for all devices can either not cover the most sensitive devices if set too high or can unduly limit a user's choice of packaging products if set too low. An acceptable charge level must be based on individual device sensitivity. However, an accurate method for determining device sensitivity to self-discharge has yet to be firmly established. The only method reported so far[7,16,17,18] uses a power supply to charge the lead frame of the device via one pin through 100 megohms resistance and then discharges the device from that pin directly or through a relay to ground. However, this method has some shortcomings which must be resolved before it can be used as a valid procedure. First, although device damage was reported, no control sample was reported to ensure that the charging procedure itself was not the cause of the damage. Secondly, there are no data which correlate a *damaging* level of charge on a *lead frame* to a corresponding *damaging* level of *triboelectrically* generated charge on the DIP body. Thirdly, the time of charging a pin is not defined. Lastly, and most importantly, there are no published experimental data where devices actually charged by sliding down a DIP tube have been damaged upon contacting a grounded, highly conductive surface. Though theoretically possible, such a damage model lacks statisti-

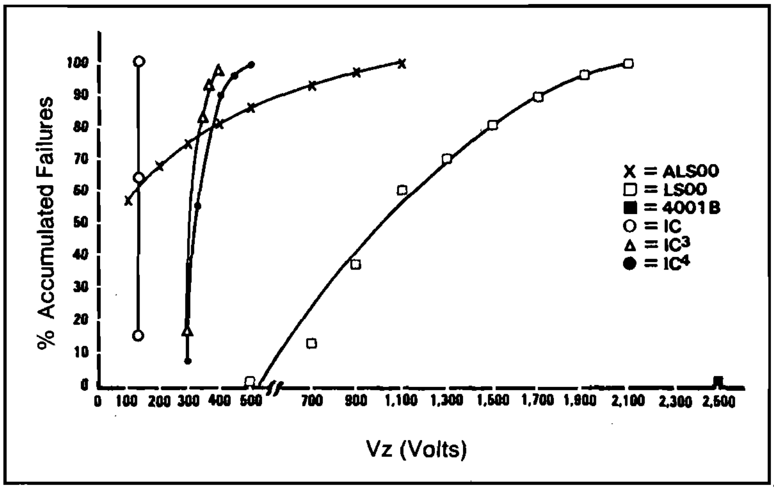

Figure 5. Percent Accumulated Failures versus Voltage which Causes Damage (Vz) from Data Comprising Results in Table 5.

Device	N	$\overline{Vz}$	σ	Voi	Δ Vo
ALS00	25	229[1]	219	100	50
LS00	15	1,197[1]	385	200	100
4001B	15	>2,500[1,2]	—	2,500	—
IC	25	152	7	130	10
IC[3]	25	333	30	300	10
IC[4]	25	355	42	300	10

N = number of devices; $\overline{Vz}$ = average voltage of charged capacitor which causes damage; σ = standard deviation around $\overline{Vz}$; Voi = initial voltage of capacitor; Δ Vo = incremental step in voltage of capacitor.

[1] The average is for all 8 input pins per device, 200 pins total.
[2] Only 4 of 120 pins suffered damage at 2,500 volts.
[3] All pins except input pin tied together but ungrounded.
[4] All pins except input pin ungrounded and not tied together.

Table 5. V-zap Characteristics for Four Devices.

cally sound, experimental verification and quantitative definition.

To define and to quantify these unresolved questions, several experiments were performed on four devices: A low power Schottky and an "advanced" low power Schottky quad, 2-input NAND gate (LSOO and ALSOO, respectively); a quad, 2-input CMOS NOR gate (4001B); and an IC with a p-MOS input and bipolar output (IC). All were 14-pin, plastic DIPs. First, the V-zap level of each device was determined using the apparatus of Test Method 3015, MIL-STD-883 (100 pF and 1,500 ohms). Five discharges were made at each voltage only on the device's input pin(s); all pins other than the discharge input pin were grounded except as noted. The data are given in Table 5 and as a Weibull-type plot in Figure 5.

The data indicate that the ALSOO device is much more sensitive to discharge than the corresponding LSOO version but is about as sensitive as an ALS hex inverter as reported previously.[19] The IC is also very sensitive, and it is about twice as sensitive when all other pins are grounded vs. ungrounded. The 4001B device showed little sensitivity up to the test limit of 2,500 volts in previous tests so a voltage of 2,500 volts was used for the entire sample lot.

The next step was to determine the sensitivity of each device to self-discharge. However, other factors which needed to be investigated first were the time to charge a pin and maximum accumulatable charge. Pin 1 (a gate input pin) of 15 ALSOO devices with pins up on a ground plane was charged at 1,000 volts for several different time intervals, and the total charge on each device measured in a Faraday Cup. In a second test, all pins were touched for one second, and the device's charge measured. The averaged results for 15 devices are plotted in Figure 6.

The data indicate a definite time dependence for accumulated charge. The accumulated charge after 15 seconds (1.46 nC) was about 50 percent more than the charge after 1 or 2 seconds. This is most likely due to charge accumulation on other pins via the chip's internal impedance because the long-time (15 to 20 seconds) accumulated charge is essentially the same as touching all pins for only one second (1.44 nC). This time dependence is reasonably consistent for internal impedance of 10^{12} ohms. In further testing, a 15 second charging time was used to allow essentially complete charging of the device.

To determine whether there is a maximum voltage that can be placed on a lead frame of these devices, a charge measurement was done as before at 500 and 2,000 volts. If "saturation" does not occur, then Q(nV) = nQ(V). The results were an average charge of 0.66 nC and 1.75 nC at 500 and 2,000 volts, respectively. These data in conjunction with that from Figure 6 (Q=1.46 nC at 1,000 volts) indicate that some saturation does occur, possibly at about 1,500 volts. This voltage limit could be caused by corona at the pin ends which are sharp edged. Thus, charging a lead frame to much higher than 2,000 volts might not result in a proportionately larger charge. This limit will likely be different for other IC package designs and should be determined in any CDM testing.

Because of its low V-zap level and current sensitive bipolar technology, the ALSOO device was chosen initially for charged device model testing. Each device in a sample of ALSOO devices was placed, pins up, on a grounded metal plane; and each gate's input pin was charged through 100 megohms and discharged via a wire to ground. As a control, some devices were discharged through 1,000 megohms. The premise here is that if the device is not damaged by charging through 100 megohms, then it should not be damaged by discharging through ten times larger resistance if discharge currents are the cause of damage. There was no signficant difference between the control and test samples in the voltage level which caused damage, the average being about 1,500 volts with about 20 percent undamaged at 2,500 volts. To determine whether even 1,000 megohms provided a too rapid discharge, a third test was done where charging was the same but discharge was by bathing the device in ionized air for 5 to 7 seconds. This procedure should provide as slow a discharge rate as is practical. Only about 40 percent of the pins went undamaged at up to 2,500 volts. These data are plotted in Figure 7 and indicate it is likely that the charging process, not the discharging process, was responsible for the observed damage.

About one inch of lead wire had been left on the 100 megohm resistor to facilitate touching the device's input pins in the previous tests. Since it is possible the capacitance of thie wire might store enough charge to damage a device upon contact, the wire was cut back, leaving only 1/4 inch of wire. A test was done by contacting each input pin of an ALSOO device in a sample lot with this

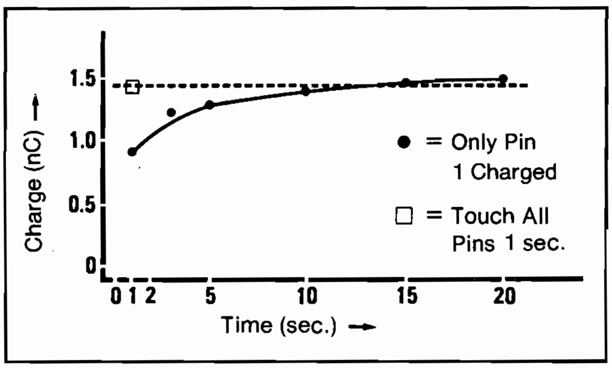

Figure 6. Average Charge on ALSOO Device vs. Time of Charging on Pin 1 at 1,000 Volts.

short resistor wire, while this wire was also in contact with the author's finger tip, and by then removing the finger tip. Since the author was grounded with a wrist strap through 1 megohm, any charge which might otherwise accumulate on the resistor tip would be shunted to ground. This procedure, in effect, made the contact behave as a make-before-break relay and also provided voltage division of the source voltage. Discharge of this sample lot was via ionized air. Sixty-four percent of the pins were undamaged at 2,500 volts, with the remaining 36 percent damaged between 1,500 and 2,500 volts. Ideally, if the charging process caused no damage, 100 percent of the pins would have been undamaged at the test limit (2,500 volts). ALSOO devices in another sample lot were "shunt charged" at each input pin as before but were discharged directly to ground. These data are also plotted in Figure 7, along with the previous data. That the failure level for shunt charging, ionized air discharging (Δ) is somewhat higher than for shunt charging, direct grounding (X) is due likely to the high variability in the method (and perhaps in the devices) and the smaller sample size (i.e., 10) for the former data. However, the data from the last two tests are statistically different from the previous data. Although this procedure of shunting the contact lead with a finger was not 100 percent effective in forestalling damage, it was the best approach and was used through the remaining self-discharge tests. The control sample data for these four devices are given in Table 6. Because damage levels were within the test limit of 2,500 volts for only the IC, its damage level is given as an average. For the other three devices, damage is given in terms of percentage of the sample lot damaged at a specific voltage.

The procedure was repeated, but this time the charging pin was discharged directly to ground. The results are given in Table 7.

Except for the IC, the data in Table 7 indicate no statistically significant basis for concluding that direct grounding caused more damage than occurred in the control sample. The large standard deviation for the control IC (Table 6) casts doubt on how much the smaller average voltage for damage in Table 7 is statistically significant. Comparing Tables 5 and 7, the damaging level of voltage for self discharge is 3 and at least 10 times larger for the IC and ASLOO devices, respectively, than for the V-zap test.

These data strongly suggest two conclusions. First, the charging process in such a method is a likely cause of damage that would be attributed to the discharging process if proper control sample data were not taken. Second, direct grounding might not pose as serious a problem

Device	N	$\bar{V}_D$	σ	% damaged at 1,500 V & 2,000 V	% damaged at 2,500 V	% damaged at > 2,500 V
ALSOO	15	—	—	19	17	64
LSOO	10	—	—	—	—	100
4001B	15	—	—	—	—	100
IC	25	764	302	—	—	—

$\bar{V}_D$ = average voltage on device which caused damage upon device discharge; to be distinguished from $\bar{V}_Z$.

Table 6. Control Sample Data for 100 Megohm Shunt Charging and Ionized Air Discharging.

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as presently thought, at least for these commonly used devices. This does not imply, however, that tribo-electric charge is not a concern at all. It should be, but only if properly quantified.

The method of charging-discharging is to estimate the likelihood of damage to devices which slide out of a tube and contact a ground plane. To obtain an indication of the correlation between this method and the likelihood of damage from self-discharge upon exiting a DIP tube, two tests were done. First, each of twenty-five ALSOO devices was slid back and forth at 45°, six times in a plain PVC DIP tube held in a mechanical rotator; and the charge developed was measured in a Faraday Cup. The average charge was 2.28 nC with a standard deviation of 0.63 nC and a range of 1.43 nC to 4.05 nC. The average charge per pin was, therefore, 0.16 nC. Second, the procedure was repeated; but instead of falling into a Faraday Cup, the tube was positioned so that upon exiting the tube, pin 1 of the device contacted a grounded copper plate. The input leakage of pin 1 was measured before each test and did not exceed 0.1 na. It was measured again after each of the Faraday Cup and grounding tests, and it did not exceed 0.1 na for any device. Even though this charge level was higher than that for direct lead frame charging at 2,000 volts (1.75 nC), it was not sufficient to cause damage, which is consistent with the previous charging-discharging data and also with data for thin film components.[1,7] In a similar slide test, the LSOO and 4001B devices were not damaged. Another device type was then tested. It was a CMOS, quad, analog switch whose four input pins are at four corners in a ceramic DIP; it is reported to be very static sensitive. The six rotation test in a plain PVC tube produced an average charge of 1.2 nC. Since this device had sensitive input pins at both ends, each device was tested twice by sliding (six rotations) and exiting by each end. As for the other devices, no damage was detected on any input pin of 15 devices tested. Because none of these devices could be damaged sliding out of a static prone DIP tube, no further testing on them was done. (When slide testing is done on tubes, especially static prone ones, e.g., plain PVC, the tube must be thoroughly neutralized with ionized air before each slide. The placing of a device while held by a grounded person into a charged DIP tube can cause inductive damage which would otherwise be attributed to the sliding. Also, the DIP tube should not be close to an open Faraday Cup since charge at the tube's tip will reduce it's oppositely charged the device's charge reading.)

Because the IC was variably affected by the charging-discharging tests and is electric field sensitive, it was used for further investigation of the correlation between damage from direct pin charging-discharging and damage from charge on the IC's body. To simulate the effect of charge on the device's body, a strip of adhesive-backed copper foil was placed on the IC's underside, covering virtually its entire area but without being close to the pins. A controls sample of 25 devices was tested by charging the foil while the IC was pins-up on a grounded metal plane to a known voltage and then by discharging with ionized air as before. In this orientation most of the field from the foil should pass through the device body and chip in order to couple to the ground plane. The voltages used were 500, 1,000, and 1,500 volts. The device was checked for damage for each voltage. No damage occurred to any device, and this result further supports the charging process as a likely cause of the damage in Tables 6 and 7. The charge on the foil was measured at 500 and 1,000 volts and found to be 0.63 nC and 1.27 nC average, respectively.

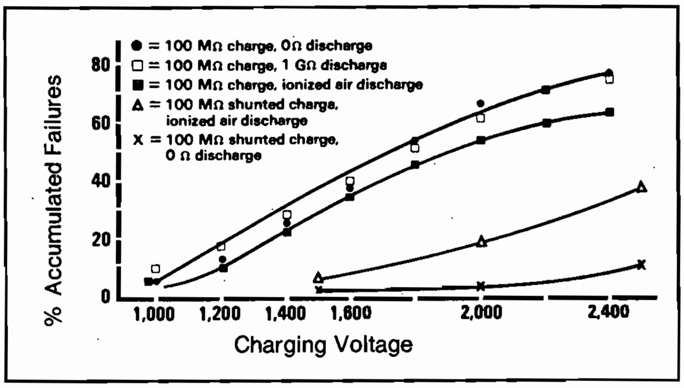

Figure 7. Charged device model testing of ALSOO devices, showing accumulated failure vs. charging voltage for various modes of charging and discharging. A single line is drawn through the • and ■ data points because lines through them individually would overlap.

Device	N	$\overline{V}_D$	σ	% damaged at 1,500 V & 2,000 V	% damaged at 2,500 V	% damaged at > 2,500 V
ALSOO	15	—	—	3	6	91
LSOO	15	—	—	6	3	91
4001B	15	—	—	—	—	100
IC	25	464	89	—	—	—

Table 7. Charged Device Model Data for 100 Megohm Shunt Charging and Direct Ground Discharging.

There was, therefore, no saturation at 1,000 volts, and the calculated Q/V ratio of the foil (lead frame ungrounded) was 1.3 pF. For comparison, from Figure 6, the charge on the ALSOO device from direct pin charging was about 1.4 nC at 1,000 volts (Q/V = 1.4 pF). Although the chip in the IC is different from the ALSOO chip used for Figure 6, it is unlikely there would be any significant difference in capacitance because the device capacitance is likely dominated by the lead frame capacitance rather than by the chip's capacitance.

This foil charging procedure was repeated for another sample of 25 ICs, but discharge was by connecting pin 4 (the input pin) directly to ground. The average voltage for damage was 713 volts with a standard deviation of 142 volts. This voltage corresponds to 0.92 nC on the foil (Q/V = 1.3 pF). In this instance, it can be inferred that the damage was due to the direct grounding of the sensitive input pin and that the cause of the damage is attributable to the inductive effects of the charge on the device body (foil). However, the average voltage for damage here is much higher than that for direct pin charging and grounding (464 volts, Table 7), and the ratio of the damaging voltages for direct pin charging to foil charging is 0.65, indicating possibly that as much as 35 percent of the foil's charge did not contribute by induction to the damage (assuming equal capacitances).

To compare this charged foil data with actual triboelectrically generated charge, each IC in a sample lot of fifty was rotated six times in a plain PVC tube and at the end of the sixth slide allowed to fall into a Faraday Cup where its charge was measured. The average charge was 2.35 nC with a standard deviation of 0.33 nC and a range of 1.73 nC to 3.33 nC. The average charge per pin was, therefore, 0.17 nC. Each device was also checked for damage which might have occurred upon "grounding" by contacting the Faraday Cup. No device was damaged, even though this charge level is nearly three times larger than the charge on the foil which caused damage upon direct grounding. This data does not imply that triboelectric charge could not cause damage, but rather that on average, probably more than 2.35 nC would be necessary, or also, that a specific distribution of the charge on the DIP body might be necessary for induction into the most sensitive part of the chip.

The foil charging method used here is a useful technique because it allows controlled investigation into the nature of inductive effects between the DIP body, lead frame, and chip. The use of a piece of foil much smaller than the DIP's bottom surface can even allow the placement of charge on only certain areas of the DIP body. However, the procedures and analysis of the data are not obvious and should be conducted after consideration of theoretical principles. It also must be emphasized that this data is for only this IC and that the results could be different for other devices. All these data, however, quantitatively support the inaccuracy of using the present direct pin charging method to determine maximum triboelectric charge levels.

An important consideration is whether the device charging-discharging method correlates with in-use conditions. It is likely more a matter of degree than of fact. Since the cause for such damage requires the dissipation of stored energy through a sensitive pin, the nature of the stored energy at *pin contact* must be considered. From the definition of potential, it can be seen that as the pins of a lead frame, whether charged directly or by induction from charge on the DIP body, approach a ground plane, the lead frame potential to ground will decrease greatly within the last fraction of a millimeter distance before contact; and therefore the energy (QV/2) will also decrease correspondingly. Unless the voltage at discharge is known, an accurate level of acceptable charge will be difficult to determine. Another view of this concept has been discussed by Chubb and Butterworth.[20] They show that only the charge on a body not coupled to the approaching ground plane will contribute to a current at contact. The coupled charged is neutralized at contact without causing a current flow through the charged body. Thus, not all the triboelectrically generated charge on a DIP will become a current through the chip at contact with a ground plane.

In the method of direct charging-discharging, the total device charge cannot constitute the initial transient current through one pin at grounding. Charge throughout the lead frame will have to pass through various, large internal impedances to reach the grounded pin, a process which can take a time much longer than the time for the grounded pin to discharge only itself initially. This time difference can lead to internal potential differences which could cause dielectric breakdown between regions separating the residual transient charge and the already discharged charge. Devices which are highly sensitive to electric fields will likely experience this mode of failure. Also, field sensitive devices could be damaged at the contact of the charging probe before charge flows into the lead frame. The probe tip is at a high potential, and its contacting a pin can cause immediate potential differences by induction via the contacted pin. Any large internal impedance will also retard reaching equipotential equilibrium during induction. It, therefore, might be better to increase the potential of the probe tip very slowly, perhaps by connecting it to a capacitor in an RC circuit with a time constant similar to or longer than the chip's. The capacitor (e.g., 1 nF) could be charged by switching it to a voltage supply via the resistor (e.g., 1 gigohm). However, the capacitor must be grounded each time before contacting a pin with the probe. In this way, both transient currents and transient potential differences within the chip should be minimized; and the method would be far less likely to cause damage during charging.

SUMMARY

A test method for the antistaticity of packaging materials should meet several criteria:

1. It must have contact and separation between the material and a test item.

2. It must correlate quantitatively with intended use.

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3. It must measure charge produced, not electrical resistivity or decay time.

4. It should employ controllable variables and should avoid human interaction.

5. It must be used in conjunction with a quantitatively defined damage mechanism for the component to be packaged, including specific charge and voltage levels.

6. It should employ known control samples to ensure reproducibility and accuracy.

The experimental determination of damaging levels of charge when induction occurs requires careful attention to conditions and calculations consistent with theory. The present method of charging-discharging devices for determining CDM sensitivity is insufficiently defined at this time to allow easy and meaningful use of it as a general method. A charging method must be determined which does not cause damage. Unless a correlation between triboelectrically generated charge which causes damage on a device and the charge from a charging-discharging method can be established, data from the latter will have limited practical value. ■

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