Electrostatic Discharge (ESD) Properties of Plastic Packaging: Terminology, Standards, and Measurement

By: Scott Carter
Tek Pak, Inc., www.tekpak.com

Introduction

The topic of electrostatic discharge (ESD) with regard to plastic packaging of electrically sensitive devices is technically complex. A large amount of research has been performed in this area, and experts are still conducting research to further the understanding of the phenomena involved and to develop more reliable and useful testing methods. However, the basic tenets of ESD protection relating to plastic packaging have been well established and are currently being utilized by industry. There are 2 U.S.-based organizations that have published industry standards relating to the ESD requirements for packaging materials of electrically sensitive devices. A large industry has developed worldwide which is dedicated to providing ESD-safe packaging materials. Yet, with the body of scientific knowledge that exists, the availability of industry standards, and the existence of mature industries that produce and use ESD-protective materials, there is still some confusion in industry at large concerning terminology and appropriate test methods for particular applications. The reasons for this are unclear. Perhaps part of the reason is that the topic is technically complex. Another reason is that there are 2 similar, but unaligned, industry standards. And lastly, it is because the ESD-related industry standards do not dictate certain material properties for specific applications. Whatever the reason or reasons may be, there is definitely a need for more education about ESD material properties throughout the industry. The purpose of this document is to point out, and hopefully clarify, some of the more confusing ESD issues and to direct the reader to the ESD resources that are available.

Industry Standards

ANSI/EIA-541-1988

The industry standard that is generally used in the U.S. and worldwide for tape and reel applications is ANSI/EIA-481-C-2003, which is published by the Electronics Industries Alliance (EIA—website is www.eia.org). This standard describes the dimensions and tolerances for tape and reel materials for the automatic handling of surface mount materials. It does not, however, describe the levels or types of ESD properties that the tape and reel materials must have. Instead, it references ANSI/EIA-541-1988 "Packaging Materials Standards for ESD Sensitive Items" as an applicable document. Many other standards published by the EIA relative to handling and shipping electronic components reference ANSI/EIA-541-1988 also. The standard describes 3 ESD material properties as being important for packaging:

1. Prevent triboelectric charging (antistatic)
2. Dissipate a charge by either surface or volume conduction
3. Act as a shield against electrostatic fields

Industry Standards - continued

ANSI/EIA-541-1988 - continued

It is important to understand that ANSI/EIA-541-1988 does not stipulate certain material properties, or levels thereof, for specific applications. The scope of the standard is to define the ESD properties, to describe methods for measuring those properties, and to define categories based on property ranges. To reiterate, the standard does not state that a certain type of packaging must have a particular level of surface resistivity, for example. It does, however, specify categories of surface resistivity, so it is appropriate to say that a particular material is conductive according to ANSI/EIA-541-1988.

As the suffix of the standard number indicates, the standard was last updated in 1988. The standard is distributed by Global Engineering Documents for the EIA. It can be purchased from the Global website (http://global.ihs.com/). Enter "EIA-541" in the document search field to find the document.

ANSI/ESD S541-2003

This standard has been recently published by the ESD Association (www.esda.org). The standard was intended to be an update for the older ANSI/EIA-541-1988 standard. However, there was no collaboration between the EIA and the ESD Association on the new standard. With no official linkage between the two, the industry at large has been left to pick one or the other or both for guidance. The Foreword to the ESD Association standard states the following:

> This document is a substantial refinement of Electronic Industries Association Standard EIA-541-1988. Updates include the adoption of surface resistance (Ohms) in place of surface resistivity (Ohms/square), volume resistance (Ohms) in place of volume resistivity (Ohm-cm), a shielding test that allows penetrating energy (nanoJoules) to be calculated in place of a voltage measurement (volts), and limits the use of static decay testing. While new to 541, these methods have been in use for five years. Resistance is no longer the only property that is used to classify ESD packaging. Low Charging, Electric Field Shielding and Direct Discharge Shielding have been added.

While the terminology in the ESD Association standard is different from the EIA standard and the testing methods are different, the end results are similar or identical in both standards. For example, a static dissipative material in the EIA standard is still classified as static dissipative in the ESDA standard. The ESDA standard describes antistatic (low charging), surface and volume resistivity (resistance), and shielding properties just like the EIA standard. The standard does, however, refer to test methods that the ESD Association considers more appropriate than those described in the EIA standard. The ESDA standard can be obtained from their website at: http://www.esda.org/standards.html#S541

ESD Material Properties

Overview

There are 3 basic ESD properties that are important for packaging. The first is the ability to resist tribocharging. Whenever 2 surfaces are rubbed together, electrons are transferred from one surface to the other creating a charge. When a surface has the ability to resist the generation of charge it is said to be "Antistatic" or "Low Charging". The second ESD property refers to the ability of a material to

Overview - continued

conduct electricity either on the surface or through the volume of the material. If a material is conductive enough, the material takes on the third important ESD property that is electrostatic shielding (this does not necessarily imply EMI/RFI/EMP shielding, however). It is important to remember that these 3 properties are independent. An antistatic material is not necessarily conductive, and, vice versa, a conductive material is not necessarily antistatic. It is also important to stress that the terms "antistatic" and "static dissipative" are not synonymous with each other. These are completely different material properties as will be discussed in the following. Table 1 summarizes the stated limits for ESD properties according to the EIA and ESDA standards.

Table 1.
Comparison of Terminology, Test Methods, and Property Limits Described by ANSI/EIA-541-1988 and ANSI/ESD S541-2003

	EIA-541	ESD S541
1. Resistance to triboelectric charging		
Terminology	Antistatic	Low Charging (Antistatic)
Test Methods	Appendices B-D of EIA-541	ESD AVD11.2-1995
Limits	Depends on method	User Defined
2. Ability to dissipate a charge by surface or volume conduction		
Terminology/Units of Measure	Surface Resistivity in Ohms/square and Volume Resistivity in Ohm-cm	Surface and Volume Resistance in Ohms
Test Methods	ASTM D-257; ASTM D-991	ESD STM11.11; ESD STM11.12; ESD STM11.13; ESD SP11.14
a. Conductive		
i. Surface	$<1.0 \times 10^5$	$<1.0 \times 10^4$
ii. Volume	$<1.0 \times 10^4$	$<1.0 \times 10^4$
b. Dissipative		
i. Surface	$\geq 1.0 \times 10^5$ and $<1.0 \times 10^{12}$	$\geq 1.0 \times 10^4$ and $<1.0 \times 10^{11}$
ii. Volume	$\geq 1.0 \times 10^4$ and $<1.0 \times 10^{11}$	$\geq 1.0 \times 10^4$ and $<1.0 \times 10^{11}$
c. Insulative		
i. Surface	$\geq 1.0 \times 10^{12}$	$\geq 1.0 \times 10^{11}$
ii. Volume	$\geq 1.0 \times 10^{11}$	$\geq 1.0 \times 10^{11}$
3. Shielding against electrostatic fields		
Terminology/Units of Measure	Surface Resistivity in Ohms/square and Volume Resistivity in Ohm-cm	Surface and Volume Resistance in Ohms
Test Methods	ASTM D-257; ASTM D-991	ESD STM11.11; ESD STM11.12
a. Surface	$<1.0 \times 10^4$	$<1.0 \times 10^3$
b. Volume	$<1.0 \times 10^3$	$<1.0 \times 10^3$
Terminology/Units of Measure	NA	ESD Shielding energy in nanoJoules
Test Methods	NA	ESD STM11.31
c. ESD Shielding of Bags	NA	<50

Note: Surface resistivity (Ohms/square) is equivalent to 10 times surface resistance (Ohms) except when materials are laminated with conductive materials. Therefore, both standards categorize the resistance/resistivity of materials equivalently. It is only the test methods and units of measure that are different.

Antistatic

The antistatic or low-charging property is important in applications where surfaces rub against each other and there is potential for tribocharging to occur. The amount of charge generation that occurs between 2 surfaces is dependent on the 2 materials involved, the humidity, the surface area involved, and several other variables. The EIA offers several different methods for measuring charge generation depending on the type of packaging that is involving. The ESDA standard takes a more cautionary stance on quantifying the antistatic (low charging) potential of materials. ANSI/ESD S541-2003 does not establish any sort of property limits for antistatic materials, but it does recommend a test method (ESD-ADV11.2-1995), which cautions on page 8:

> No one test, currently available, can predict general tribocharging properties for a specific material. The amount of charge a material accumulates is dependent upon the second charging material and all of the variables listed below (19 are listed). In many cases, test data does not relate to actual use situations.

Antistatic - continued

When the antistatic properties of a material are to be evaluated, ESD-ADV11.2-1995 recommends that the test method should mirror the application as closely as possible. It also warns that tribocharging testing methods are prone to poor repeatability and large variability. Care must be taken in analyzing the results of such tests.

To summarize, there is no test currently available to unequivocally determine whether a specific material is antistatic or low charging. It is up to the end user to determine the requirements for their particular application and to specify the test that best fits the application.

Charge Dissipation

Charge dissipation by electrical conduction through the volume of the material or on the surface is an important property for packaging because it can allow charge to be drained safely away from a sensitive electronic device. Charge dissipation is a much easier property to measure and characterize compared to the antistatic property. Charge dissipation is basically a measure of electrical resistance. The ANSI/EIA-541-1988 standard specifies charge dissipation as resistivity in the units of Ohms/square, which is taken from the ASTM test D-257. This is not a misprint; the units are supposed to read Ohms/square. The EIA standard also encourages the use of static decay rate measurements according to the Federal Test Method Standard 101, Method 4046 (FTMS 101-4046), but it is not used as a means for categorizing materials as static dissipative.

The ESD Association established their own charge dissipation test, which is described in ESD STM11.11-2001. This test method determines the surface resistance in Ohms. The advantage of the ESDA surface resistance method is that much smaller areas are required for testing. This is important when checking the inside surface of a carrier tape, for example.

At first glance, it may appear that the two organizations are completely unaligned in this regard, but there is a well-accepted relationship between the 2 test methods. Surface resistivity is related to surface resistance by a factor of 10 in most cases. For example, 1×10^5 Ohms/square is equivalent to 1×10^4 Ohms. Volume resistivity in Ohm-cm and volume resistance in Ohms are equivalent numerically. Refer to ESD STM11.11-2001 for questions relating to the applicability of the relationship between resistivity and resistance. For simplicity, the measure of charge dissipation will be referred to as resistance for the rest of this document.

Both the EIA and ESD standards categorize materials into 3 levels of charge dissipation according to the surface and volume resistance. A conductive material has a resistance of less than 1×10^4 Ohms. A static dissipative material has a resistance of 1×10^4 Ohms or greater but less than 1×10^{11} Ohms. An insulative material has a resistance of 1×10^{11} Ohms or greater. These categories and test methods are summarized in Table 1.

The static decay rate according to FTMS 101- 4046 is a popular test used in industry. It has its

ESD Material Properties - continued

Charge Dissipation - continued

limitations as pointed out by ANSI/ESD S541-2003 in that it is only valid for planar, homogeneous, and static dissipative materials. Because thermoforming can sometimes render electrically conductive treatments ineffective, it is often suggested that FTMS 101-4046 be utilized for thermoformed objects, but the results from this test using formed objects must be treated cautiously.

Shielding

Materials are considered to be capable of shielding an electric field if the surface resistance is less than 1×10^3 Ohms. This does not imply RFI/EMI/EMP shielding, however. ANSI/ESD S541-2003 states that a shielding bag may also be considered shielding if less than 50 nanoJoules are detected from the ANSI/ESD STM11.31 test. The EIA standard suggests an additional, but different, shielding test in its standard for finished products (ANSI/EIA-541-1988, Appendix E).

Summary

1. Two industry standards exist relative to ESD and packaging. The 2 standards are not officially linked, so the industry at large must pick between the 2 for guidance. The standards do not dictate material properties, so the end user must specify ESD properties based upon the application.
    a. ANSI/EIA-541-1988
    b. ANSI/ESD S541-2003
2. There are 3 main ESD properties relative to packaging:
    a. Resistance to tribocharging (antistatic or low charging)
    b. Ability to dissipate a charge
    c. Ability to shield an electric field
3. The term 'antistatic' is not synonymous with the term 'static dissipative':
    a. 'Antistatic' refers to the ability of a material to resist the generation of a charge when rubbed against another material.
    b. 'Static dissipative' refers to materials that have a surface or volume resistance of 1×10^4 Ohms or greater but less than 1×10^{11} Ohms.
4. Testing for the antistatic property is subject to a wide array of variables and has poor repeatability. Tests have been developed for specific applications, but there is no single test that can determine whether a material is antistatic or low charging.
5. There are 3 categories of materials relative to their ability to dissipate a charge based on surface and volume resistance:
    a. Conductive—less than 1×10^4 Ohms
    b. Static Dissipative--1×10^4 Ohms or greater but less than 1×10^{11} Ohms
    c. Insulative –greater than or equal to 1×10^{11} Ohms
6. There are 2 test methods for categorizing charge dissipation by surface conductance. For homogeneous materials, the 2 tests are related by a factor of 10. To determine surface resistivity, multiply surface resistance by 10.
    a. ASTM D-257 determines surface resistivity in units of Ohms/square
    b. ESD STM11.11-2001 determines surface resistance in units of Ohms