Discrete Carbon Nanotube Implementation for use in ESD Tooling, Fixtures and Electronics Assemblies

David Torp
Mechnano
AZ, USA
dtorp@mechano.com

ABSTRACT

Discrete carbon nanotubes (CNTs) have shown promise in various applications, including electronics manufacturing operations for Electrostatic Discharge (ESD) tooling fixtures and assemblies. ESD is a critical concern in electronics manufacturing, as it can lead to damage or malfunction of sensitive electronic components. Traditional ESD protection methods involve using materials with high electrical conductivity to dissipate and neutralize static charges.

Carbon nanotubes possess unique electrical, mechanical, and thermal properties that make them suitable for ESD protection. Specifically for protection of highly sensitive electronic devices such as low voltage chiplets, large AI chips as well as system in package (SIP) components. Currently, there is an issue with localized ESD hotspots in ESD component carrier trays and waffle packs. As electronics assemblies become more sensitive, there is a need for better uniformity of ESD trays and carriers.

This research illustrates the improvement in volume and surface resistivity for trays and tooling fixtures that are manufactured incorporating discrete functionalized carbon nanotubes. In addition, the research shows that discrete carbon nanotubes can be used in conjunction with additive manufacturing technologies to make “on-demand” SMT carriers, trays and tooling fixtures for use in electronic manufacturing operations.

Key words: electrostatic discharge, ESD, discrete functionalized carbon nanotubes, CNT, JEDEC trays, SMT carriers, waffle packs, SMT tooling fixtures.

INTRODUCTION

The driving forces within the electronics and microelectronics manufacturing areas are many. There are three primary drivers that keep the electronics industry moving forward at a rapid pace: speed, cost, and performance. Moore’s law is reaching some of its physical limitations in the electronics industry. Miniaturization and speed have pushed the electronics industry beyond some of the materials capabilities. What used to be good enough in the electronics industry is no longer good enough for today's high performance electronic devices.

The hierarchy of electronics manufacturing industry typically originates at the semiconductor fabrication level. Electronic devices are packaged up with much denser configurations and operated at much higher speeds and frequencies than ever before. The sensitivity to electric static discharge in these advanced chips, packages and assemblies is much greater than it has been previously. This creates an opportunity for new methods, equipment, expertise, and materials to be developed.

Electrostatic discharge, ESD, became a problem in the electronics industry in the 1970s. Low threshold level ESD events from people were causing the electronic devices to fail and yields to decrease. The electronics industry has been on a continuous improvement activity ever since. In the 1990s the requirements for increased performance (devices operating at one gigahertz and higher), along with an increase in density of circuits on a device created additional problems to protect the circuits from static events.

Today's semiconductor devices are pushing the limits for high-speed and high-density interconnects at lower voltages. Currently communications systems require very large multi-chip semiconductor packages that need to operate at 10 to 15 gigabytes per second, Gbps. In the future devices will operate at 112-224 GPS at technology nodes of 3 nanometers, nm.

The ESD Association provides electrostatic discharge models for both human body sensitivity limits as well as charge device [1]. Figure 1 illustrates the forecast for the charged device model by package type.

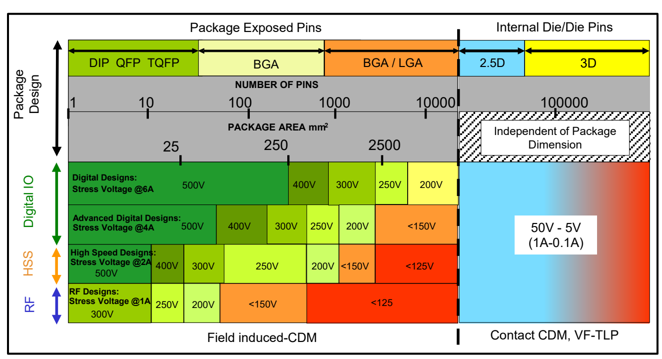

Figure 1: ESDA Projection of Combined Effects of IO Design and IC Package Size on CDM [1]

These new chips, packages, and assemblies will require a greater understanding of ESD events that can occur during transport operations on the manufacturing floor. This challenge has created new opportunities for new materials used to minimize ESD related defects and yield loss. handling and control.

MATERIALS FOR ESD APPLICATIONS

Materials used in electrostatic discharge applications face challenges due to the unique nature of ESD events and requirements for ESD protection. The key challenges for materials in these applications are: conductivity, durability, compatibility, surface resistivity, humidity sensitivity, cleanliness, cost, regulatory compliance, integration, static dissipative time, temperature range, mechanical properties, and consistency of dissipation performance. Meeting these challenges is crucial for ensuring the reliable protection of sensitive electronic components from electrostatic discharge and preventing costly damage. It often requires careful selection and testing of materials for specific ESD applications. These materials are employed in a variety of applications on the factory floors. In semiconductor applications many materials are used in cleanroom environments in electronic packaging applications many materials have to withstand multiple processes including moisture removal oven exposures, soldering operations, coating operations, and a multitude of transport operations.

ANSI/ESD S20.20-2021 Standard provides guidance for control programs used on the manufacturing floor [2]. End users, equipment suppliers, mechanical part suppliers and material supplier all collaborate together to insure that requirements within the Standard are met. The selection of ESD materials depends on the specific requirements of the application. The type of the level of protection needed, the type of electronic components involved in the environmental conditions all have influence over selecting the appropriate materials for a given application.

JEDEC JESD 625B Standard defines the requirements for handling electrostatic discharge sensitive devices [3]. However, this Standard only applies for protection levels down to 100 volts. Below 100 volts is a “custom controls” region which requires special attention.

Traditional materials used in ESD tools, trays, carriers and fixtures have been manufactured with a variety of materials: copper, aluminum, plastics, rubber, foam, metalized films, and a variety of coatings. The ESD materials which move product through the factory are often assumed to be acceptable for use and most have some data to support the use in generally accepted applications. For safe ESD transport through the manufacturing operations using JEDEC trays, waffle packs, SMT carriers, wave soldering pallets, positioning fixtures and a variety of materials that come into contact with state of art ESD sensitive devices there is the issue and concern of are they acceptable.

The standard materials for use in many of these applications are plastics that have been filled with some sort of conductive filler. Popular conductive fillers contain some from of carbon to obtain the conductivity needed for ESD applications. Carbon powder is very fine, light, and does not greatly restrict the flow of the polymer material. Its conductivity range makes it suitable for applications that need higher sensitivity ranges. Carbon powder does not provide any reinforcement to the polymer. The lower the electrical resistivity, the more carbon powder filler is required to achieve target level. The higher the concentration of carbon powder, the greater the reduction in mechanical properties such as tensile strength and impact resistance [4]. Carbon powder is relatively low cost but contamination is often an issue with carbon powder filled polymers. Carbon fibers are composed of thin, long, and highly orientated carbon strands. They are know for their exceptional strength to weight ratio, rigidity, and lubricity. Carbon fibers are chopped into short lengths and blended into base polymer materials for use in ESD applications. Carbon fiber acts a reinforcement within the base polymer as well as a conductor. Carbon fiber is considered to be cleaner than carbon powder and suitable for clean room applications. Carbon fiber offers good mechanical properties and wear resistance. Carbon nanotubes, CNTs, are a relatively new option for ESD plastic materials. Carbon nanotubes are cylindrical structures. CNTs are very small diameter tubes with very high aspect ratios. When used as fillers in polymers for ESD applications, CNTs filled systems provide precise, uniform surface and bulk resistivity which make for improved uniformity. However, since carbon nanotubes are so new to the ESD applications, research is required to verify the application and use of carbon nanotubes as a viable solution for next generation ESD needs.

BACKGROUND CARBON NANOTUBES, CNTS

The concept of carbon nanotubes can be traced back to 1952 when Russian physicist L.V. Radushkevich and his student V.m. Lukanovich published a paper describing the synthesis of “carbon fibers” using arc discharge [5]. In 1993 the discovery and characterization of single walled carbon nanotubes, SWCNTs, opened up new possibilities for research [6]. Early research with CNTs and SWCNTs resulted in limited use and application. One of the primary difficulties in using CNTs in applications is their affinity for each other. CNTs tend to agglomerate into nanotube clusters, balls and bundles which limits their ability to provide uniform material properties within a polymer matrix. In 2015, Clive Bosnyak and Kurt Swogger, were awarded a patent for reliably producing individual carbon nanotubes and functionalizing them for use in polymer materials [7]. This research lead to the product realization of using CNTs within a variety of polymer materials to obtain highly uniform electrical properties such as surface resistivity which is how ESD materials are fundamentally characterized.

EXPERIMENTAL RESULTS: CARBON FIBER VS DESCRETE FUNCTIONALIZED CARBON NANOTUBES IN POLYCARBONATE INJECTION MOLDED MATERIALS FOR USE IN JEDEC TRAYS

EXPERIMENTAL METHOD

The purpose of this experiment was to compare the key performance properties for polymeric materials used in the fabrication of JEDEC trays for electronics assembly operations. Figure 2 illustrates the type of JEDEC tray that is currently being used for high performance chips used in high speed data applications.

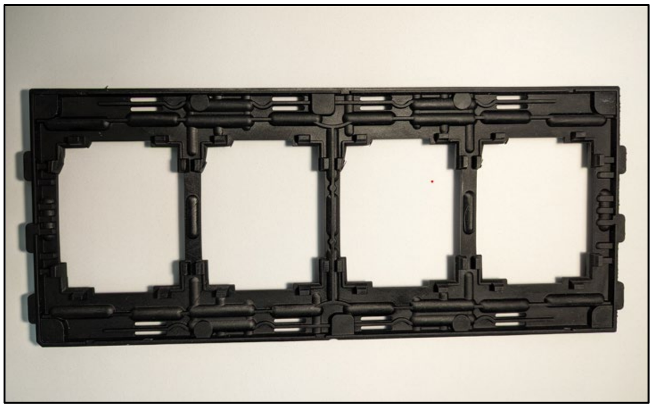

Figure 2: Example JEDEC Tray Commonly Used in Electronics Manufacturing Operations

The material selected as base polymer was a standard polycarbonate material used in injection molding applications. Two sets of polycarbonate base polymers were filled with different fillers: One set of polycarbonate materials was compounded using 30% by weight carbon fiber filler. The second set of test specimens was compounded using discrete functionalized carbon nanotubes with 30% glass flake filler. Test specimens consisted of injection molded dog bones per ASTM D638 [8] for tensile strength and elongation and ASTM D790 [9] molded for flexural strength and modulus. Electrical and mechanical properties were measured for each set of specimens including: tensile strength, elongation, flexural strength, surface resistance. The Injection molded dog bone specimens were used to analyze surface resistance using a standard 2-point probe ohm meter for ESD applications. Multiple locations within the dog bone specimens were measured to understand the variation that occurs within injection molded materials. Measurements at the top, middle and bottom positions within the dog bone specimens were measured. These locations correspond to the distance away from the injection mold gate location.

EXPERIMENTAL RESULTS

Visual exam results are given in Figure 3 which shows the differences in surface finish between specimens molded with carbon fiber versus specimens molded with discrete carbon nanotubes and glass flake filler. Results indicate that more variation in color is noticeable in carbon flake molded specimens. Table 1 shows a comparison of mechanical properties between the two specimen sets. Results indicate that the carbon fiber filled material has greater tensile strength and slightly better elongation. The flexural modulus information is similar between the two materials tested.

Figure 3: Top test specimen molded with polycarbonate filled with discrete carbon nanotubes and glass flake. Lower test specimen molded with carbon fiber.

Table 1: Mechanical property comparison in polycarbonate polymer with carbon fiber and carbon nanotube fillers

Property	**Carbon Fiber Filled Polycarbonate**	**Carbon Nanotube Glass Flake Filled Polycarbonate**
Tensile Strength, Mpa	118	84
Elongation, Percent	4.0	3.2
Flexural Stength, Gpa	137	126
Flexural Modulus, Gpa	7.36	6.77

Average surface resistance measurements are reported in Table 2 for each set of specimens with respect to location from injection mold gate. Figure 4 illustrates the locations of Top, Middle and Bottom as measured with the 2-point probe meter for each set of specimens. Results indicate that carbon fiber filled polycarbonate material has a large range of resistance measurements over the surface of the dog bone specimens. The top location, near the injection gate, exhibits low resistance values. The bottom location, furthest away from the injection gate, has very high resistance values. The middle location has surface resistance that is considered to be normal for ESD materials. The polycarbonate material filled with discrete carbon nanotubes and glass flake filler shows much more consistent surfaces resistance measurements all falling within the accepted tolerance limits for ESD materials.

Figure 5 illustrates the overall comparison in variation of the surface resistance between carbon fiber filled polycarbonate and carbon nanotube glass flake filled polycarbonate. This indicates that less variation occurs with the carbon nanotube polymer system than the carbon fiber filled system.

Figure 4: Locations of top, middle, bottom for 2-point surface resistance measurements

Table 2: Surface resistance for carbon fiber filled polycarbonate versus carbon nanotube glass flake filled polycarbonate as a function of measurement location

	Carbon Fiber Filled Polycarbonate	**Carbon Nanotube Glass Flake Filled Polycarbonate**
Measurement Location	**Surface Resistance, Ohms**	**Surface Resistance, Ohms**
Top	**<1.00E+03**	**9.73E+08**
Middle	**5.49E+09**	**1.12E+08**
Bottom	**>1.00E+12**	**2.20E+08**
Average	**1.76E+08**	**2.88E+08**
Range	**>1.00E+09**	**8.69E+00**

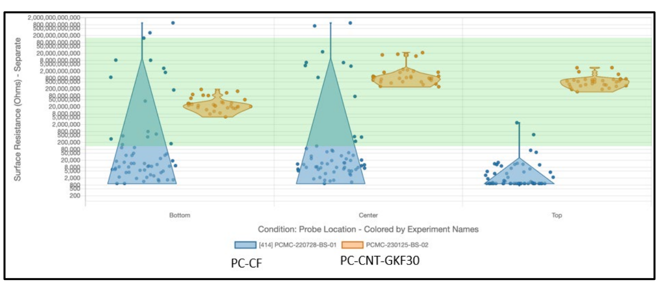

Figure 5: Violin plot of surface resistance by measurement location

CONCLUSIONS

This study indicates that current materials being used for ESD applications may have too much variation to protect high performance electronic devices from electrostatic discharge events. Advanced technology devices may require a new materials set for minimizing ESD related defects within the manufacturing operations. The large variation found with carbon fiber filled plastics may no longer be acceptable. This study indicates that advanced materials such as carbon nanotubes may play a role in solving some of the upcoming needs for more consistent electrostatic performance in surface resistance.

FUTURE WORK

Incorporating carbon nanotubes into additional materials including materials used in 3D applications will provide the electronic industry with the ability to print ESD fixtures, JEDEC trays, waffle packs, SMT carriers in an on-demand basis at point of use. Combining advanced materials with advanced additive manufacturing technologies can create an agile way to keep up with the rapid rate of change that is a hallmark of the electronics industry. Ensuring the industry is ready to safely handle the next generation of electronic devices.

REFERENCES

[1] Industry Council on ESD Targets, White Paper 2: “A Case for Lowering Component Level CDM ESD Specifications and Requirements,” April 2010 Revision 2.0, esda.org

[2] ANSI/ESD S20.20-2021, “Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment”, January 2021, esda.org

[3] JEDEC JESD 625B “Requirements for Handling Electrostatic-Discharge-Sensitive (ESDS) Devices”, January 2012, jedec.org

[4] Schwartz, Seymour “Plastics Materials & Processes”, Van Nostrand Reinhold Company, 1982, 467-505

[5] L.V. Radushkevich, V.M. Lukyanovich, On the structure of carbon produced at thermal decomposition of carbon monoxide on an iron contact, Journal of Physical Chemistry 26(1) (1952) 88-95

[6] Iijima, Sumio, “Single-shell carbon nanotubes of 1-nm diameter”, Nature 363, 1993 603-605

[7] Bosnyak, Clive, “Dispersions comprising discrete carbon nanotubes”, US9636649B2, USPTO, 2016

[8] ASTM D638-22, “Standard Test Method for Tensile Properties of Plastics”, Book of Standards Volume 08.01, 2022, astm.org

[9]ASTM D790-17 “Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials”, Book of Standards Volume 08.01, 2017 astm.org