TECHNICAL PAPER

"Electrostatic Discharge in Semiconductor "

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Technological progress within the semiconductor industry brings with it greater yield sensitivity with the desire to reduce costs a constant driver. How well defects are controlled throughout an increasingly automated manufacturing process plays a critical role.

K. Beekmann, Marketing Manager Semiconductor, Precision Polymer Engineering looks at the management of electrostatic charging.

In a world where most things tend to get more expensive with time, the electronics industry strives to give us more for less. A perfect illustration of this trend can be seen from a simple comparison of the cost and speed of early computers and their modern counterparts. Moore's law combines the principles of achieving ever increasing transistor densities at reduced cost.

Anyone close to this subject will no doubt be familiar with the prediction of the end of Moore's law, either due to the physics or the economics (1). Whether such predictions are right or wrong, one thing is for sure, the electronics industry will not just pack up and go away anytime soon. New technologies and designs are developed and the industry still requires the supply chain to provide new materials, improve wafer throughputs and lower defects in order to reduce costs, regardless of whether this is for existing or, new technology.

Electrostatic discharge (ESD) is one of the key areas of focus for device manufacturers, affecting yield, quality and reliability of the final product. Estimates for cost of damage due to ESD vary widely and have been reported at an average of between 16-22% for component manufacturers (2), although these numbers are based on devices going back several technology nodes. Given that the global semiconductor industry today is > $300B, it's clear that the cost of ESD damage to manufacturers still runs into many $billions.

Background to ESD and how things charge

Electrostatic charges occur when there is an imbalance of electrons on or within a material creating a resultant electric field. Electrostatic discharge occurs when objects are at different electrostatic potentials and are brought together resulting in a rapid flow or transfer of charge between the objects, often as a spark.

This occurs when the potential difference is sufficiently strong to break down the ambient or material that separates the objects. The initial creation of electrostatic charge requires some form of energy to be transferred to a material.

This is often the case when materials simply contact one another and are subsequently separated again and is known as triboelectric charging. During the contacting and separation process, electrons are transferred from one material to another, creating a charge imbalance in each material, one becoming positively charged and the other negatively charged.

The level of charging and sign of charge will depend on the types of materials in question and other factors, such as the relative humidity of the environment. Materials can be characterised by their position in the triboelectric series (3), where those materials contacting and separating that are furthest apart in the series, create higher charges (See Table 1). Insulators are very easily charged and the main sources of static electricity include materials such as glass or silica, plastics and elastomers. The use of such materials is a fundamental requirement of semiconductor device manufacturing either as a handling material, or as an integral part of the device. Furthermore, once a material has become charged, the electrostatic field generated can induce a charge distribution in ungrounded conducting materials in close proximity to the statically charged object or material.

+ Positive	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminium
	Paper
	Cotton
	Steel
	Wood
	Amber
	Sealing Wax
	Nickel, Copper
	Brass, Silver
	Gold, Platinum
	Sulfur
	Acetate rayon
	Polyester
	Celluloid
-	Silicon
Negative	Teflon

Table1. Example materials in the triboelectric series

Consequences of electrostatic charging for semiconductor production

The effect of ESD or electrostatic charging on semiconductor devices can have various consequences. Damage can be immediate and catastrophic rendering the device inoperative. Electrostatically induced charge flowing through an integrated circuit can lead to high currents which, in view of the short duration of the event, can also generate high levels of heat sufficient to breakdown the gate structure, burn the interconnects, cause spiking in contacts and junction breakdown. This kind of failure would be measurable before the part has been shipped. Alternatively, the ESD event can simply create a weakness in the device that is not immediately measurable, however this can lead to reliability issues, or premature failure within the warranty period after the part has been incorporated into an electronic system(4).

In addition to creating the potential for device damage through ESD events, electrostatic charging of materials or surfaces can also lead to attraction and subsequent adhesion of particles either from the ambient, or from within the process tools. Electrostatic attraction will not distinguish between material types as both insulating and ungrounded conducting matter can be attracted and hence create potential yield reducing damage.

There is one further consequence of electrostatic charging. ESD events have the potential to interfere with process tools or, specifically the control electronics of the process tool. ESD creates electromagnetic energy transmitted in the form of waves in the radio frequency range leading to electromagnetic interference EMI (5).

As device technology has progressed through shrinking dimensions and new 3D gate architecture, this in turn has led to increased emphasis on minimizing electrostatic charging and ESD due to reduced voltage tolerances and lower capacity for heat dissipation. Susceptibility to electrostatic charging is not limited to mainstream silicon processing and is also very relevant to other technologies including but, not limited to, high brightness LED (6), disk drive and display manufacturing (5).

Device manufacturing

The semiconductor manufacturing environment provides many opportunities for static charges to accumulate and discharge. This is inherent from the materials and processes that are required to make many modern devices. To a large extent, static build up is inevitable and needs to be carefully managed through control of the environment and use of appropriate materials and equipment. The level of fab automation has dramatically increased in modern production plants. Depending on the complexity of the device being made, wafers can undergo >1000 process steps and multiple robotic wafer handling cycles per process step. System manufacturers now carry a far greater proportion of responsibility for controlling ESD and ensuring adequate grounding of the equipment and providing controlled leakage paths through use of appropriate materials.

“Elastomeric materials such as ethylene-propylene polymers (EPD/EPDM) can be readily obtained in dissipative variants; however these invariably contain metallic elements. Dissipative elastomer materials for semiconductor processing or handling should have very controlled constituents and avoid commonly used metallic fillers such as silver, nickel or copper”

Common materials used to contact or support substrates as they are handled through production lines include plastics and elastomers. They serve their main purpose very well in several ways. Substrates should not slide as they are accelerated or decelerated by the movement of the handler and they should potentially be able to withstand raised temperatures as wafers come out of high temperature process environments without creating adhesion issues.

These contact materials however, are primarily insulators. Whenever a substrate is in contact with a handling device where such insulating plastics and elastomers are used and subsequently separated; triboelectric charging will take place. This leads to an increased likelihood of a subsequent ESD event or, induced charging of materials present on the substrate. Rather than using insulators to contact the substrates, these materials would ideally be electrostatically dissipative and have a low resistance path to ground. Electrostatically dissipative materials need to have a defined volume or surface resistance between that of insulating and conducting materials at between 1x104 and 1x1011 ohms (3).

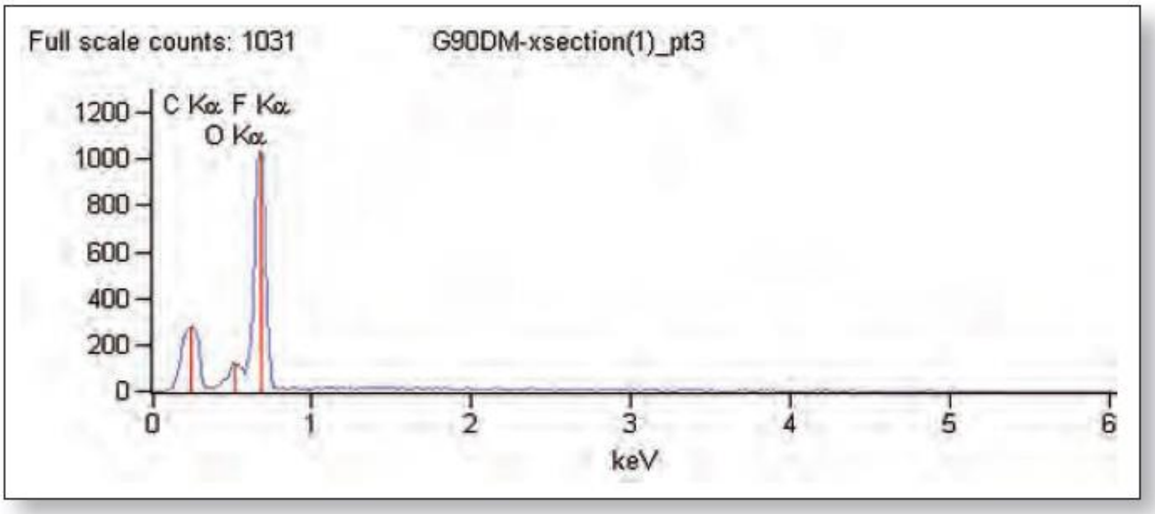

*Figure 1. EDX spectra of electrostatically dissipative perfluoroelastomer**

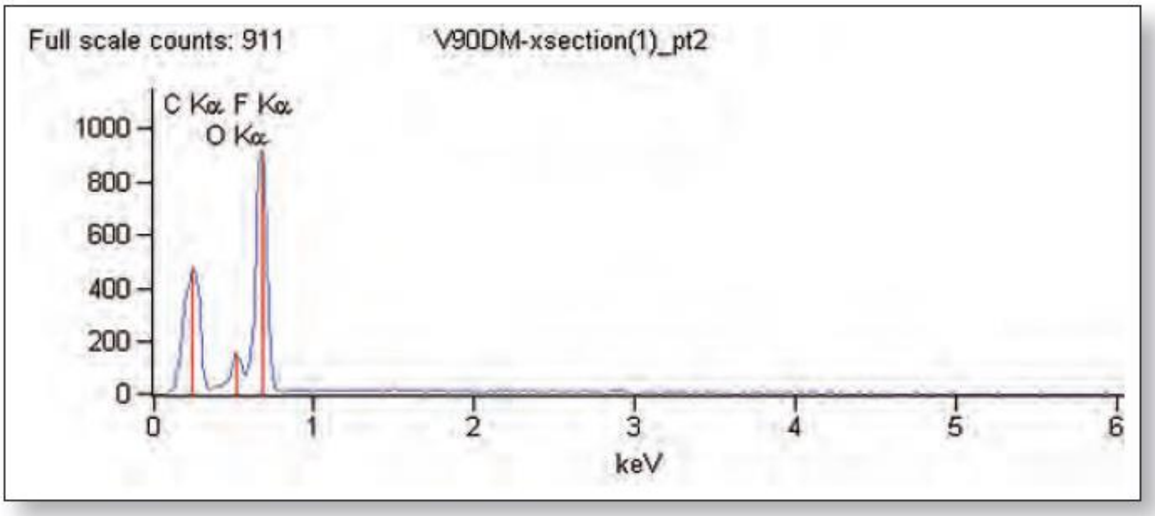

*Figure 2. EDX spectra of electrostatically dissipative fluoroelastomer**

Material	C-K	O-K	F-K
Perfluoroelastomer	15.21	7.89	76.90
Fluoroelastomer	22.71	8.06	69.22

Table 2. EDX compositional analysis in weight%#
#EDX analysis carried out by TNO

Dissipative elastomers

Fluoroelastomers and perfluoroelastomers are commonly used in critical sealing applications in semiconductor process tools. Their properties include chemical resistance, higher temperature compatibility and in particular, low levels of contaminants. These features make them particularly suitable for semiconductor applications. It is however, extremely rare to find such materials available with electrostatic dissipative properties.

A new range of dissipative materials based on fluoroelastomer and perfluoroelastomer polymers has been developed and specifically designed to meet the needs of wafer processing and in particular, wafer handling applications; the perfluoroelestomer having a slightly higher temperature capability. Energy dispersive X-ray spectroscopy (EDX) analysis has been carried out on both polymer types and shows a complete absence of metallic based filler and an entirely organic composition as shown in Figure 1 and Figure 2 and summarised in Table 2. Despite avoiding the use of metallic based additives, volume resistance values can be obtained that are well within the dissipative range as shown in Figure 3 and Figure 4.

This would create a slow leakage path to ground and avoid charge build up on the material itself. It's easy to see why the current crop of materials has been chosen. In addition to providing the properties previously mentioned, they need to be generically compatible with semiconductor devices and not contribute to contamination from mobile metallic ions that can alter device characteristics. Elastomeric materials such as ethylene-propylene polymers (EPD/EPDM) can be readily obtained in dissipative variants; however these invariably contain metallic elements.

Dissipative elastomer materials for semiconductor processing or handling should have very controlled constituents and avoid commonly used metallic fillers such as silver, nickel or copper.

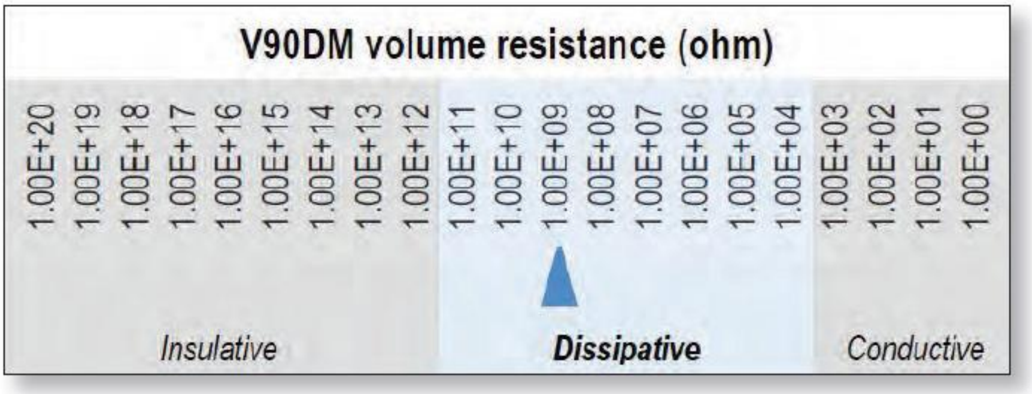

Figure 3. Perfluoroelestomer volume resistance#
#Volume resistance measurements according to ASTM D-257

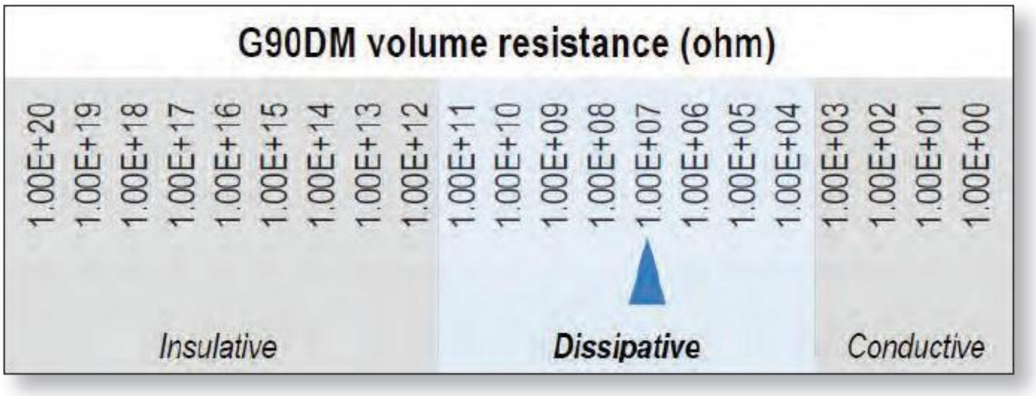

Figure 4. Fluoroelastomer volume resistance#
#Volume resistance measurements according to ASTM D-257

Summary

Technological progress within the semiconductor industry brings with it greater yield sensitivity. The desire to save cost is a constant. Cost is related to yield which is also related to defects and hence, how well those defects are controlled throughout an increasingly automated manufacturing process. An important part of this includes management of electrostatic charging in order to avoid damage from ESD events, particle contamination through electrostatic attraction and process tool interference through EMI. Greater use of dissipative materials is an obvious way of minimising charge build up and reducing ESD events however, these materials must also be compatible with the process environment and the devices themselves.

References

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