Effects of Triboelectrostatic Charging Between Polymer Surfaces in Manufacturing and Test of Integrated Circuit Packages

Rahul Panat, Jinlin Wang, and Edward Parks

***Abstract*—Integrated circuit (IC) package assembly and test processes include several industrial steps involving physical contact and/or friction between polymer surfaces of handlers and packages. The trend toward smaller and sleeker gadgets has resulted in a dramatic reduction in the package weight due to thickness and size miniaturization. In this paper, we show that the forces created through triboelectrostatic charging between surfaces of handlers and packages are comparable with the weight of thin and small IC packages. Furthermore, the voltages generated in such triboelectric interactions are rather small—typically below the concern levels set in the IC industry. The results show that for IC packages with a subgram weight, the impact of the triboelectrostatic force on the assembly processes is significant and occurs at low static voltages (<200 V). The data presented in this paper provides valuable insights into the selection of materials for handler designs in contact with IC packages during assembly and test processes.**

***Index Terms*—Assembly, electrostatic charging, friction, integrated circuit, triboelectricity,**

I. INTRODUCTION

TRIBOELECTRIC/TRIBOELCTROSTATIC charging[1] involves a transfer of electrons or ions between two physically contacting surfaces. This phenomenon has found uses in many applications including waste management [1], polymer separation [2], and coal separation [3]. Although useful in some industries, the static electricity (caused by friction, i.e., tribological reasons, or by other means) can cause problems in industries where contacting moving parts are commonly found; for example, semiconductor industry, piping industry [4], and so on. It is well known that a static charge developed in equipment close to a chip can cause electrostatic discharge (ESD) that can destroy the silicon circuitry [5]–[7].

TABLE I

TRIBOELECTRIC SERIES [8], [9]

Tend to lose electrons	Positively charged
↑	Asbestos
	Glass
	Nylon
	Wool
	Lead
	Silk
	Aluminum
	Paper
	Cotton
	Steel
	hard rubber
	brass & silver
	synthetic rubber
	Orlon
	Saran
↓	polyethylene
Tend to gain electrons	Teflon
	silicone rubber
	Negatively charged

The triboelectric charging involves one contacting material losing electrons and the other contacted material gaining them. The ability of materials to realize the triboelectric charging depends upon the relative tendencies of the materials to have electron transfer, which can be graded in a triboelectric series shown in Table I [8], [9]. The materials on the top of the Table I have a stronger tendency to lose electrons compared with those at the bottom. The triboelectric series are qualitative since the material rank also depends upon the test conditions, such as shearing speed, rubbing pressure, contact time, and humidity. Furthermore, the charge on the conductor surface is uniform while it varies by location in the case of an insulator [8]. Polymeric materials used in handlers in integrated circuit (IC) assembly and test are typically negatively charged upon friction. The interaction of functional groups in the polymers with their triboelectrical properties was examined in [10]. They constructed a tribocharging series that includes a wide range of synthetic and natural polymers. Their results revealed that the charging develops from the transfer of protons between the contacting surfaces. Soh *et al.* [11] and Cademartiri *et al.* [12] concluded that the charge transfer can occur via ions rather than by electrons in some cases. In addition to physical contact, charges can build up when a high electrostatic field develops between two closely located objects [5]–[7], [13].

Although efforts have been made to resolve the ESD issue for handling of silicon [13], limited published information exists for the triboelectrostatic charging forces created in

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[1] The two terms are synonymous in the literature and we have used them interchangeably in this paper.

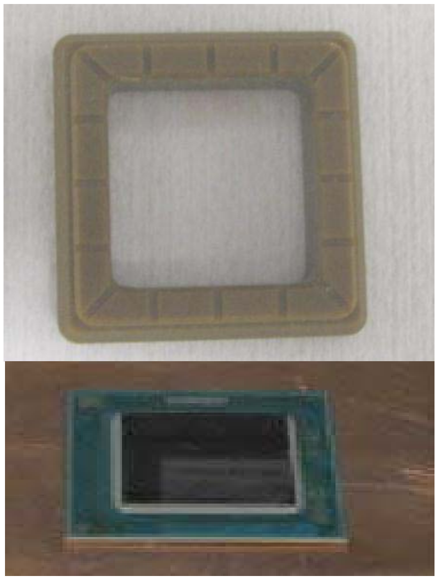


Fig. 1. Image of the handler (top) and an integrated circuit package (bottom) used in the experiments.

the handlers used in the IC assembly and test processes. These forces are expected to be encountered in the pick-and-place processes, where the die or package is usually picked up (by a vacuum or otherwise) and then placed (for example, by turning off the vacuum). In the past, these Coulomb forces resulting from triboelectrostatic charges were countered by the weight of the IC packages preventing any sticking of the surfaces.

In this paper, we investigate the issue of sticking of polymer surfaces in IC assembly and test due to forces generated by triboelectrocharging. The surfaces chosen are handler and IC package (polymer–polymer) and Si and handler (ceramic–polymer), as observed typically in industry. The triboelectrostatic forces between these surfaces are shown to be comparable with the weight of the packages indicating their increasing importance in the handling of thinner, smaller, and lighter ICs. Furthermore, the voltage measured across these surfaces is shown to be low (less than 200 V), typically below the alarm levels set in the semiconductor industry for ESD. These finding are highly useful to industry in providing guidelines to prevent process malfunction and/or package surface property modifications under high-volume manufacturing environment.

II. Experimental Setup

The experimental setup was designed to mimic the industrial processes and materials. The polymer surface to mimic handlers in industry was chosen to be polyamide-imide, industrially known as torlon [14]. Torlon is a high-strength and high wear-resistant thermoplastic with a rank in the triboelectric table close to that of teflon [8], [9], indicating its tendency to easily gain electrons with friction. A typical IC package surface (package in high-volume manufacturing) with photo-definable thermoset polymer from the acrylate family was chosen to represent the polymer contacting the handler. Pieces of silicon wafer, Cu, and Al were also used as other contacting surfaces to further gain an insight into this problem. The voltages and forces between the torlon handler and the package were measured by a commercially available voltmeter [15]. The humidity and temperature near the experimental setup were carefully recorded. A torlon pusher along with the Intel package is shown in Fig. 1.

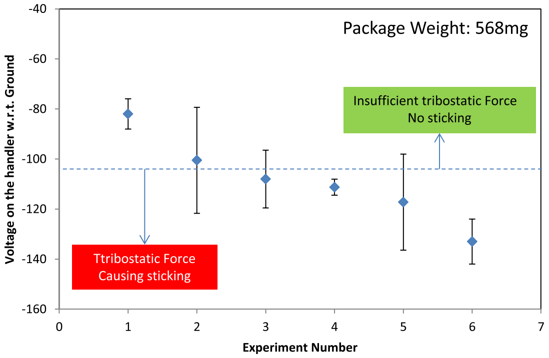


Fig. 2. Voltage versus sticking of the handler with an integrated circuit package.

To measure the electrostatic forces between the pusher and the package, a piece of silk cloth was rubbed against the pusher to generate a static charge. The pusher was then taken in contact with the package as well as the pieces of silicon, aluminum, and copper of known weight on an insulating table. As expected from the triboelectric series, the voltmeter showed the cloth positively charged and the pusher negatively charged after rubbing. The distance between the voltmeter (i.e., field meter) and the pusher was kept at 25 mm. This distance was specified by the manufacturer of the field meter to get accurately calibrated results. Note that the pusher voltage (upon rubbing against the piece of cloth) was observed to vary from location to location. Accordingly, the voltage was measured on four sides of the pusher for each of the tests. To rule out the possibility of contaminant-based sticking between the surfaces, a detailed surface chemical analysis (not discussed in this paper) of the handler and the integrated circuit packages was performed to confirm that there were no organic contaminants.

III. Results and Discussion

The torlon voltage after grounding was measured (consistently ~ 25 V) and subtracted from the torlon voltages reported post rubbing of the silk cloth. Fig. 2 shows the voltage of the handler as a function of the sticking phenomenon. It was observed that the sticking occurred above a voltage of about 110 V. Each data point of Fig. 2 shows the average of the voltage of the four corners of the pusher shown in Fig. 1. The error bar is equal to the standard deviation of the four data points per unit.

Considering that the handler area was about 125 mm^2, we conclude that at 110 V, the force per unit area between the handler and the package is about 4.56 Pa (0.57 g/125 mm^2). Thus, the force per unit area per unit charge is 0.0415 Pa/V. Once the sticking occurred, we observed that the IC package could easily be moved around the pusher as long as no

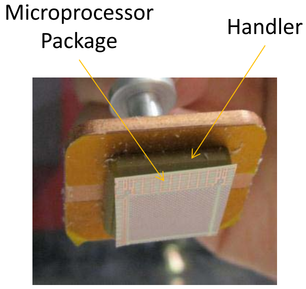
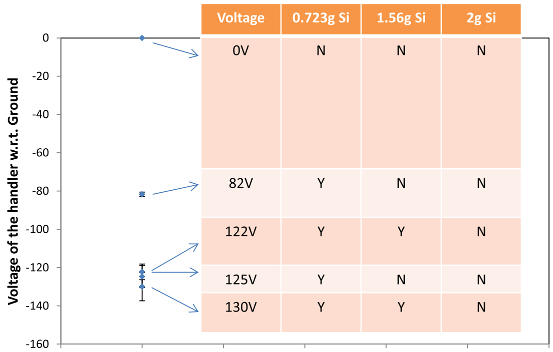


Fig. 3. Integrated circuit package sticking with the handler due to trioelectrostatic forces.



Voltage	0.723g Si	1.56g Si	2g Si
0V	N	N	N
82V	Y	N	N
122V	Y	Y	N
125V	Y	N	N
130V	Y	Y	N

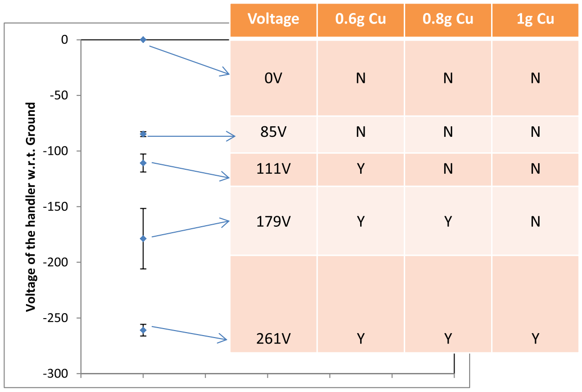
Fig. 4. Map showing sticking of flat Si pieces with the handler for different weights of Si. Y indicates that the triboelectrostatic force is sufficiently high for Si to stick with the handler and N indicates otherwise.

conductor touched the contact area of the handler with the IC package. Fig. 3 shows the phenomenon of package sticking with the handler due to the triboelectrostatic forces.

Similar to the IC package, Si and aluminum (flat) pieces also showed thresholds below 200 V for submilligram weight. Fig. 4 shows the map of sticking of Si pieces to the handler as a function of the static voltage.

It is clear that in case of Si, the sub-1-g piece is the most vulnerable for triboelectric charging with the vulnerability reducing as the weight increases. The small discrepancy we observed at 122 V (force appears to be higher for 122 versus the 125 V) is attributed to the variability in measurement observed in an experimental environment. Note that we repeated above experiment with a rough and polished Si wafer and found no difference in the results. We thus discount the possibility of sticking of the Si to handler due to the effect of smooth contact causing a suction effect. In case of Si, the force at ∼82 V is >723 mg, while that for a IC package at 110 V is ∼570 mg under identical moisture and temperature conditions. This indicates that Si is more vulnerable to the triboelectrostatic forces as compared with integrated circuit packages for the handler material selected for this paper. Obviously, a systematic study of all the materials used in semiconductor packages can map the relative risks and vulnerabilities of the triboelectrostatic forces in IC assembly and test.

A similar plot for flat Cu pieces is shown in Fig. 5. Clearly, the 600-mg Cu can be picked up somewhere between 85 and 110 V indicating a similar behavior as that for the packages.



Voltage	0.6g Cu	0.8g Cu	1g Cu
0V	N	N	N
85V	N	N	N
111V	Y	N	N
179V	Y	Y	N
261V	Y	Y	Y

Fig. 5. Map showing sticking of flat Cu pieces with the handler for different weights of Cu. Y indicates that the triboelectrostatic force is sufficiently high for Cu to stick to the handler and N indicates otherwise.

In case of the metal sheets, a small touch from a conductor to the sheet resulted in the separation of the sheet confirming the role of static electricity in the sticking process. Note that although we had to use an external means of creating static electricity in the handler, the actual industrial processes do involve a localized relative motion between the processor and handlers.

We note that our voltage measurement has a precision of ±1 V. The RH and temperature during these experiments were 40% and 25 °C, respectively. The actual conditions in the clean rooms used in industry may be slightly different depending upon the class of the clean room. Furthermore, although we discuss this phenomenon for packages, we also show similar triboelectrostatic behavior for Si. This indicates that this phenomenon may be relevant to Si fabs, but the weight of the wafers is expected to easily counter the triboelectrostatic forces. Finally, the charge density varies on the surface of the polymers and the distance to the contacting surface is not a constant from point to point. The data presented in this paper, however, clearly show that for thin and small packages (typically with a sub-gram weight), the impact of the triboelectrostatic force on the assembly process can be significant even if the voltages are rather low. Several solution paths need to be engineered to solve these issues. A systematic study characterizing the triboelectrostatic behavior of different contacting materials in semiconductor packaging industry is needed to develop materials and design guidelines for handlers and other contacting equipment parts.

IV. CONCLUSION

The attraction forces caused by static electricity due to frictional contact between polymer–polymer interfaces in ICs can impact the assembly and test processes. This effect is increasingly important as the processors become lightweight in response to the industry wide miniaturization of electronic devices and systems. In this paper, we demonstrate that the triboelectrostatic forces in assembly and test are comparable with the weight of thin and light ICs at voltages lower than those for which alarms are set in the semiconductor industry. Similar behavior is demonstrated in the case of contacting polymer–Si and polymer–metal surfaces. These results provide useful guidelines to industry in designing the handlers and other process equipment in semiconductor assembly and test.

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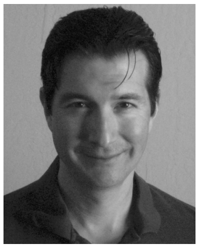

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