# A STUDY ON THE DEPOSITION OF TIN ON THE CONTACTS SUBJECTED TO HIGH FREQUENCY IMPACT LOADING IN SEMICONDUCTOR DEVICE TESTING

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*ABSTRACT*

*Semiconductor device leads were previously plated with Lead (Pb). Due to environmental concern, the plating material has been switched to Tin (Sn). However, due to the softness of Tin element plating, it often wears off and its residues deposited to the surface of the contacts used in semiconductor device testing. As a result, significant drop of contact performance has been observed. This study intends to find out a theoretical explanation to the problem of tin deposition. As soon as the root cause is identified, studies go into the details of how to solve this problem. One of the economical suggestions is to apply lubricants on the contact. A theoretical calculation is derived to verify if the lubricant would significantly altered the overall resistance.*

*KEYWORDS: Contact, tin, adhesive wear, semiconductor device testing.*

## 1.0    INTRODUCTION

To date, the phenomenon of tin deposition on the electric contacts used in semiconductor device testing is still not very well understood in the industry. Prior to going into the phenomenon itself, it is convenient to first understand the problem from the basics.

We know that semiconductor devices are used in every electronic device around us. Some of the notable semiconductor devices are diode, transistor, integrated circuits (IC), microprocessor etc. However, in reality, there are always mixtures of good and bad semiconductor devices in mass production. A "good" semiconductor device is one that is having product specifications within the tolerance limit and vice versa for a "bad" one. To verify if a particular semiconductor device is good or bad, it needs to be tested.

There are many testing methods available in the market. Some uses electro-pneumatic machine to pick semiconductor devices up and place them on electric contacts (or contactors) connected to a tester machine, the tester machine will read the semiconductor device and determine whether it is "good" or "bad", this type of testing is often called the pick and place method in the industry. Another popular type of testing is using gravitational force to draw the semiconductor devices downwards, as they passes through the electric contacts at the bottom which are also connected to the tester machine; they will be verified and sorted out. This type of testing method is industrially known as gravity fed method.

Common to all testing methods, the semiconductor device' leads or pads must touches with the electric contacts (which can be either contacting blades or pogo pins depends on application) so that the current could flow through the device. The technology today has enable the process of picking, placing semiconductor devices on electric contacts for testing and picking it up from electric contacts to be done in merely 0.09 seconds. In this particular case, an electric contact is subjected to approximately 11 impact loadings from the leads of the semiconductor device in just one second.

Although achieving very high unit per hour (UPH) performance, there is still one serious issue bothering the engineers. It is found that there are always some tin residues deposited on the electric contacts after several cycles of testing. The tin residues come from the plating material of the semiconductor device leads or pads. The increase of tin deposition on the contacts brings about an increase of electrical contact resistance as the contacting cycles increases. The usual practice has been to clean the contacts by grinding off the tin residues. However, this measure causes considerable damage to the contacts itself.

Thus, this paper studies about the possible root cause of the deposition or adhesion of tin on contacts used in semiconductor testing.

## 2.0    LITERATURE REVIEW

Before venturing further, it is important to first knowing what materials these contacting surfaces are made of. The lead of semiconductor device is often made of Alloy 42 plated with pure Tin (Epistola, 2009). Alloy 42 is an Iron alloy consists of 41% of Nickel, 0.8% of Manganese, 0.5% of Cobalt. As for the electric contacts used in semiconductor device testing as shown in Figure 1, there are a huge variety of alloys used

for different applications, such as Copper Beryllium, Nickel Beryllium, Tungsten, and some with Gold or Rhodium plating.
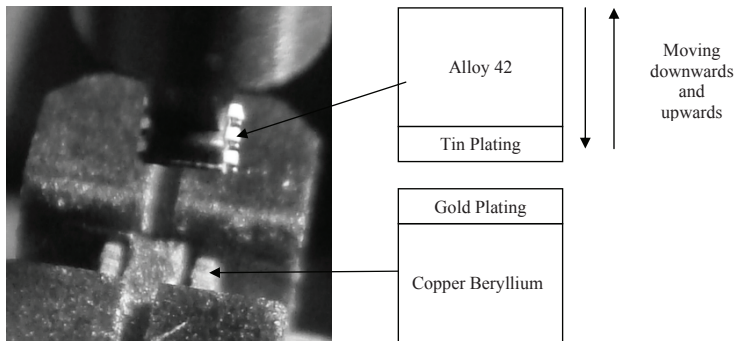


FIGURE 1: Contact materials

There are various perspectives are being looked upon to identify why tin deposited on the contacts. It bears resemblance to solid-state welding, it can be seen as an adhesive wear, and the volume of wear can be calculated.

The first concept to be taken serious attention is the concept of asperity. It has to be accepted that no surface are perfect. In practice, there are no ideal surfaces which are completely flat. So, it should be accepted that in certain level of magnification, the truth that surfaces are all rough and uneven. Such uneven surfaces are called asperity.

Beginning with the problem of Tin deposition, the direct contact of the electric contacts with the semiconductor device leads can be understood in three levels of complexity, namely:

- simple lead-to- contact contacting
- lead-to- contact impact contacting
- lead-to- contact impact contacting with current

Also, there is a high possibility of sliding contact between the lead to electric contact contacting, which will also be taken into consideration.

For the first type of contact which neither involve repeating cycles of impact loading nor the interference of current flow, bares resemblance to solid-state welding. The principle of solid-state welding is demonstrated best with two clean surfaces being brought into atomic contact with each other under sufficient pressure, they form bonds and produce a joint.

According to Kalpakjian (2006), it is essential that the interface be free of oxide films, residues, metalworking fluids, other contaminants to form a strong bond. Based on the criteria mentioned, it is easy to imagine that heat generated through friction improves the transfer of atoms across an interface. Relative interfacial movements of the contacting surfaces occur, even at very small amplitudes will disturb the mating surfaces which will break up any oxide films, and generate new clean surfaces which improve the strength of the bond. If the pressure is high enough, plastic deformation will occur at the interface also promote stronger bonding. Experiments also reveal that when adhesion measurements are performed in vacuum, where the degree of surface contamination is reduced and adhesion between metals become very large (Bowden., and Rowe, 1956). Hence, summarizing from the experience gained from solid-state welding, the following criteria influences the bond strength of solid-state welding:

- Pressure applied to the interface of contacting surfaces
- Cleanliness of the contacting surfaces
- Heat generated from internal friction between contacting surface
- Relative interfacial movements that breaks up the contaminants
- Air density (strongest adhesion occurs in vacuum)

The deposition of tin on the electric contacts could also be a result of adhesion or adhesive wear which is already being studied extensively in the field of tribology. Adhesive wear occurs as a result of the transfer of softer metal (weak material) to the harder metal (stronger material) by means of friction. (Stachowiak and Batchelor, 2005).

The question of practical interest is what properties of metal that favour such adhesive wear?

Buckley (1981) discovered that greatest adhesion occur between like materials. Iron to iron adhesion for example exhibits the ratio of adhesion force to contact force which can be as high as 20.

Jellium model (Ziman, 1963) explains the metal to metal adhesion as a result of electron transfer between contacting surfaces. When the distance between two surfaces become sufficiently close, i.e. <1nm, electrons which are not bound by the rigid structure can move from one body to another. This theorem relates the strength of adhesion to the electron density of metal.

Crystal structure also influences the adhesive strength. Metals with hexagonal close packed structure show much less adhesion than other crystal structures (Sikorski, 1963). This is because hexagonal closed pack metals have far fewer slip systems and are therefore less ductile than face-centered and body centered metals.

High hardness, large elastic moduli and surface energy of metals also suppress adhesion too (Sikorski, 1963). Apart from that, adhesive strength is also a function of the chemical reactivity of metals. Chemical reactivity is often defined as values in electropositivity. Chemically active metals such as aluminium bond more readily and there show stronger adhesion than noble metals.

Summarizing from the study conducted the material properties of practical importance in contributing to the effect of adhesive wear are divided into mechanical properties and chemical properties. The mechanical properties are

- Crystal structure
- Hardness
- Elastic Modulus
- Surface Energy

Meanwhile, the chemical properties are:

- Electron density
- Chemical Reactivity

The severity of wear can be determined by how much volume of material is rubbed off or carried off from the origin material. There is a mathematical relationship described by Archard equation as a means to determine wear volume as shown in Equation 1. (Harris, 2002)

$$Q = \frac{KWL}{H} \tag{1}$$

## 3.0   DISCUSSION

Using the technical computing software, Wolfram Mathematica Documentation 7, the following table of material properties is constructed. The properties of the material are arranged in the order of from the lowest electrical resistivity.

TABLE 1: Material Properties

| Element | Group | $\rho$ (m$\Omega$) | E (GPa) | G (Gpa) | HB (Mpa) | $T_m$ (K) | X | Crystal Structure |
|---------|-------|--------------------|---------|---------|----------|-----------|------|-------------------|
| Ag | 11 | $1.60\times10^{-8}$ | 83 | 30 | 24.5 | 1234.93 | 1.93 | FCC |
| Cu | 11 | $1.70\times10^{-8}$ | 130 | 48 | 874 | 1357.77 | 1.9 | FCC |
| Au | 11 | $2.20\times10^{-8}$ | 78 | 27 | 2450 | 1337.33 | 2.54 | FCC |
| Al | 13 | $2.60\times10^{-8}$ | 70 | 26 | 245 | 933.47 | 1.61 | FCC |
| Ca | 2 | $3.40\times10^{-8}$ | 20 | 7.4 | 167 | 1115.00 | 1 | FCC |
| Be | 2 | $4.00\times10^{-8}$ | 287 | 132 | 600 | 1560.00 | 1.57 | Hexagonal |
| Rh | 9 | $4.30\times10^{-8}$ | 275 | 150 | 1100 | 2237.00 | 2.28 | FCC |
| Mg | 2 | $4.40\times10^{-8}$ | 45 | 17 | 260 | 923.00 | 1.31 | Hexagonal |
| Ir | 9 | $4.70\times10^{-8}$ | 528 | 210 | 1670 | 2739.00 | 2.2 | FCC |
| Na | 1 | $4.70\times10^{-8}$ | 10 | 3.3 | 0.69 | 370.87 | 0.93 | BCC |
| Mo | 6 | $5.00\times10^{-8}$ | 329 | 20 | 1500 | 2896.00 | 2.16 | BCC |
| W | 6 | $5.00\times10^{-8}$ | 411 | 161 | 2570 | 3695.00 | 2.36 | BCC |

Since, the hardness is of central importance of a contact, Gold, Iridium and Mobylenum may well be the alternative substitutes for Copper.

As seen from the study above, the principal reason for wear is a result of the softness of tin plating itself. However, the tin plating is already a standard plating material for semiconductor device lead. Hence, the only thing can be altered is the contact itself, be it by changing the material, changing the surface treatment or using lubricants.

Instead of changing the building material or surface treatment of the material, it is easier if not better to try lubrication. Lubrication can be a good solution as it is known that lubricants reduce wear rate. However, it is of engineering interest that whether lubrication would reduce the overall electrical conductivity of the contact. Since lubricant constitute a thin layer of electric contact itself, one important aspect to consider is whether such thin layer of lubricant affect the overall electrical resistance of the contact as the electrical resistance is of primary importance for the system itself.

Since resistance elements are in series of each other, the total resistance of the system before lubricant is added would be

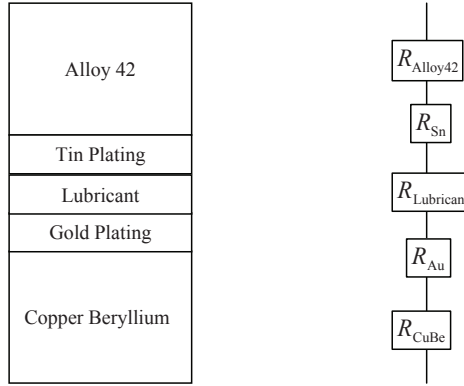$$R_T = R_{Alloy42} + R_{Sn} + R_{Au} + R_{CuBe} \tag{2}$$

FIGURE 2: Resistance model of contact materials with an addition of lubricant

When a layer of lubricant is added as shown in Figure 2, the total resistance would change to

$$R_T{}' = R_{\text{Alloy42}} + R_{\text{Sn}} + R_{\text{Lubricant}} + R_{\text{Au}} + R_{\text{CuBe}} \qquad (3)$$

According to Bueche (1995), resistance is mathematically defined as

$$R = \rho \frac{L}{A} \qquad (4)$$

Since the thickness of the lubricant, L in common sense would be very much smaller compared to the thicknesses of contact and lead, it is assumed that L is close to zero, i.e.

$$L_{\text{Lubricant}} \cong 0\,\text{mm} \qquad (5)$$

When L is of negligible length, the resistance of the lubricant would be

$$R_{\text{Lubricant}} = \rho \frac{\left(L_{\text{Lubricant}} \cong 0\,\text{mm}\right)}{A} \cong 0 \qquad (6)$$

Hence

$$R_T{}' = R_{\text{Alloy42}} + R_{\text{Sn}} + \left(R_{\text{Lubricant}} \cong 0\right) + R_{\text{Au}} + R_{\text{CuBe}} \cong R_{\text{Alloy42}} + R_{\text{Sn}} + R_{\text{Au}} + R_{\text{CuBe}} \cong R_T \qquad (7)$$

$$\therefore R_{T}{}' \cong R_{T} \tag{8}$$

The overall resistance of the system is not significantly altered.

## 4.0   CONCLUSION

As seen from the study above, the principal reason for wear is hypnotized as a result of the softness of tin plating itself. However, the tin plating is already a standard plating material for semiconductor device lead. Hence, the only thing can be altered is the contact itself, be it by changing the material, changing the surface treatment or using lubricants. Since changing the surface treatment and material takes a very long time and not necessarily an economical way, lubricant may be recommended. Testing will be conducted in the future to verify the proposed hypothesis.

## 5.0   SYMBOLS

Q       total volume of wear debris produced
W       total normal load
H       hardness of the softest contacting surfaces
K       dimensionless constant
L       sliding length
        electrical resistance before lubrication
        electrical resistance after lubrication
        electrical resistance of Alloy 42
        electrical resistance of tin
        electrical resistance of lubricant
        electrical resistance of gold
        electrical resistance of copper beryllium
        electrical resistance
        resistivity
        length/thickness
        ross-sectional area
        lubricant thickness

## 6.0   ACKNOWLEDGEMENT

## 7.0    REFERENCES

Buckley, D. H. 1981. Surface effects in adhesion, friction, wear and lubrication. Elsevier.

Epistola, E. 2006. What is a semiconductor. Silicon Far East. Retrieved from April 9, 2010 from http://www.siliconfareast.com/whatissemicon.htm.

Harris, C. K., Broussard, J. P. and Whitcomb, P. J 2002. Determination of wear in a tribo-system. Proceedings of the 2002 ASEE Gulf-Southwestern Annual Conference.

Kalpakjian, S. 2006. Manufacturing engineering and technology (5th edition). Singapore: Prentice Hall.

Sikorski,M.E. 1963. Correlation of the coefficient of adhesion with various physical and mechanical properties of metals, Transactions ASME, Series D - Journal of Basic Engineering, Vol. 85, pp. 279-285.

Stachowiak, G. W. and Batchelor, A. W. 2005. Engineering tribology (3rd edition). Burlington:Elsevier Butterworth-Heinemann.

Ziman, J. M. 1963 Electrons in metals - a short guide to the Fermi Surface. London: Taylor and Francis.