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Contaminants on Electrical Contacts Used in Semiconductor Device Testing

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Abstract: Electrical contacts used in semiconductor device testing are often deposited with a small pip of dark colour contaminants after being subjected to repeating cycles of impact loading. Samples of used electrical contacts are checked under SEM and EDX. It is discovered that the contaminants contain high percentage of tin elements. The reason as to why the contamination formed is investigated and it is found to be the result of material transfer from device lead. It is caused by the molten metal bridge formed when the contact begins to move apart.

Key words: Contaminants · Electrical contacts · Semiconductor

INTRODUCTION

In the industry of semiconductor device testing, the quality and lifespan of electrical contacts used is of paramount importance because of high manufacturing cost of electrical contacts used due to the demand of small size and high precision. However, engineers are troubled with the fact that electrical contacts are always deposited with a pip of contaminant after a cycle of make and break operation. Contaminants formed will affect the accuracy of testing due to increasing contact resistance. The conventional practice in the industry is to remove the contamination by either physical or chemical means. However, this could not be an ultimate solution because same accumulation of contaminants would occur again after cycles of impact loading. The removal of contaminants would also damage the surface of the electrical contacts. To solve this problem, samples of used electrical contacts and semiconductor devices are investigated under scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX) to determine the material composition of the contaminants and compared it with uncontaminated surface.

Contact Resistance: The contact resistance is the most important and universal characteristic of electrical contacts [1]. Contact resistance (R_c) is the sum of constriction resistance (R_s) and the resistance of film (R_f) [2].

$$R_c = R_s + R_f \tag{1}$$

Constriction resistance itself is caused by the fact that real surfaces are not flat but comprise of small asperities [2]. Hence, the conducting path of current is constricted to only a small fraction of the apparent contact area as illustrated in the following Figure 1.

Metal surface of electrical contacts are not clean since oxides, sulfides, inorganic and organic compounds are present. These combine effect results in film resistance [1].

Hence, it is obvious that contact resistance would rise when the contaminants accumalated on the electrical contacts increases.

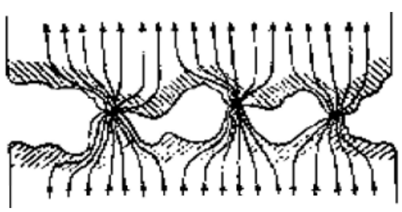

Fig. 1: Constricted current flow causing constriction resistance (photo reprinted from [1])

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Contact resistance is found to be a function of load applied to the electrical interface, hardness of the softer material and resistivity of the contact materials. Assume that the surface is clean of contaminants, contact resistance can be approximated as [3].

$$R_c = \sqrt{\frac{\rho^2 \pi H}{4F}} \tag{2}$$

If the upper and lower half of consist of different contact materials, contact resistance is derived as:

$$R_c = \sqrt{\frac{(\rho_1 + \rho_2)^2 \pi H}{16F}} \tag{3}$$

where R_c is the contact resistance, ρ_1 and ρ_2 are resistivity of contact materials, H is the hardness of the softer material and F is the load applied to the electrical interface.

Investigation on Contaminant Using SEM/EDX: In order to identify the material composition of the contaminants and the nature of its formation, samples of used electrical contacts were taken from the industry and put under scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX). The samples used in this investigated are electrical contacts made of copper berrylium coated with gold. These contacts were previously subjected to impact loading by semiconductor leads made of copper coated with tin under the following conditions:

Contact load: 0.625N
Contact time: 20ms
Voltage: 5V
Number of cycles: 3.3 million

The following Figure 2 shows the SEM image of the contamination.

The dark grey part is the contaminants and the light grey part is the uncontaminated surface.

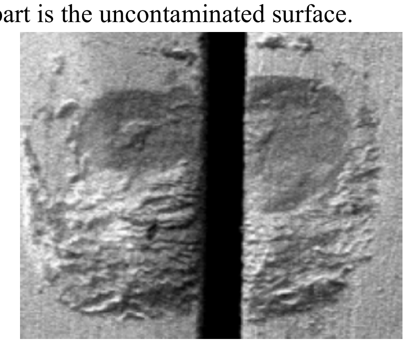

Fig. 2: SEM image of contaminant under 50X magnification

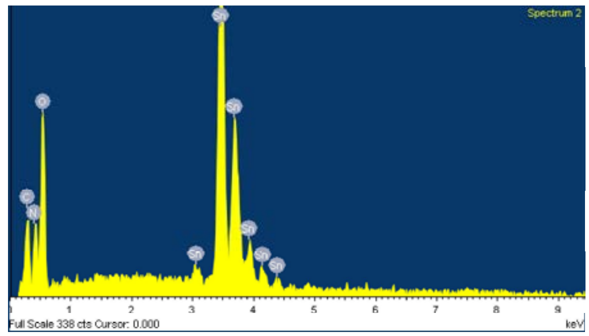

Fig. 3: EDX results of the contaminated surface

Table 1: Material composition of contaminated surface

Element	Weight%	Atomic%
C	5.19	13.71
N	0.65	1.48
O	34.79	68.95
Sn	59.36	15.86
Totals	100.00	

Table 2: Material composition of uncontaminated surface

Element	Weight%	Atomic%
C	6.98	55.18
Au	93.02	44.82
Totals	100.00	

As shown in Table 1, the contaminant comprise of high percentage of tin and oxygen. For comparison sake, the following Table 2 shows the material composition of uncontaminated surface.

The uncontaminated surface only contains the gold plating and some carbon.

DISCUSSION

Results reveal that the contaminant is of high tin content, oxygen elements represents the oxides, indicating that the contaminants contains metal oxides. Carbon elements exist on the surface may originated from the ambient air as studies by Rieder [4] did point out that ambient air is often contaminated with organic vapors. Organic vapors are obviously high carbon content. More than 300 organic vapors were identified in Skylab 4 [5].

The high tin content is obviously originated from the semiconductor device leads which are coated with tin. There are two possible theoretical explanations for the tin transfer from device leads to the electrical contact, namely adhesive wear and metal molten bridge.

Adhesive wear results from friction. Transfer of material of material from one surface to another occurs due to localized bonding between the contacting surfaces. When both bodies are pulled apart, material transfer take place from the cohesively weaker material (softer) to the stronger material (harder) [1]. However, sliding motion are minimum in impact motion and the only apparent cause of friction is from the bouncing motion of electrical contacts. Aside from that, tin (51MPa) is harder than gold (25MPa) in Brinell scale. Also, from the SEM image, there is very little sign of scratching, which indicates that there is not much friction comes into play. Hence, it is highly unlikely that the high percentage of tin element found in the contaminant pip results from adhesive wear.

Tin transfer from one surface to another can also occur as a result of molten metal bridge. The physical explanation is given by Slade [6] which state that as the contact begins to move apart, contact resitance increases as the load on contact decreases as shown in Eq. 3. Voltage drop across the contact is given by:

$$V = IR_c \qquad (4)$$

where V is the voltage drop, I is the current. Kohlrausch [3] derived a relationship between the voltage drop and temperature as:

$$V = \left[2\int_{T_1}^{T_m} \lambda_1 \rho_1 dT\right]^{1/2} + \left[2\int_{T_2}^{T_m} \lambda_2 \rho_2 dT\right]^{1/2} \qquad (5)$$

where T_m is the maximum temperature, T_1 and T_2 is the bulk temperature, ρ_1 and ρ_2 are the electrical resistivity of contact materials and λ_1 and λ_2 are the thermal conductivities of contact materials.

As the contact force slowly decreases when the contact parts, temperature of the contact spot will reach the melting point of the metal. Once the contact spot has metled and the contacts continue to part, a molten bridge is drawn between them [6]. Holm [2] confirmed that molten metal bridge always form between the contacts even at low currents [2]. Studies by Utsumi [7], Slade [8] and Koren [9] also prove that molten bridge can form when contact open with high acceleration. As the bridge is drawn further, it will rupture. The rupture of the bridge will followed by arc formation and eventually results in accumulation of material on the cathode.

CONCLUSION

From the SEM images and EDX results, it can be concluded that the contamination is primarily caused by net material transfer as a result of molten metal bridge and electric arc. Further research needs to be carried out to identify the physical factors that directly affect the net mass or volume gain on the electrical contacts. Once the factors are determined, metallurgical solution can be formulated.

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