Studying Package Delamination by TOF-SIMS and XPS

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Keywords: Delamination, Solder Paste, Solder Wire, TOF-SIMS, XPS

Abstract

Delamination is the most common reliability issue of IC and will cause severe damage to function/life. In this paper, TOF-SIMS and XPS were taken to analyze the chemical status of leadframe surfaces with different die bonding processes. From the analysis, the root cause of delamination at the interface between molding compound and leadframe was due to additional tin and lead on the leadframe surface.

INTRODUCTION

In semiconductor packaging, solder can be used for die attachment of power devices to provide high heat transfer capability. A solder wire process, which is flux free was used for a power package to improve the wire bonding reliability. Tin contamination will deteriorate the Al-Au intermetallic when using the current solder paste process[1][2][3]. However, serious delamination occurred with the solder wire process. Since the leadframe design was unchanged, the mechanical stress should be the same. So the chemical status is likely changed due to the fact that the solder wire process is completely different than the solder paste process, which requires flux, reflow and cleaning steps. TOF-SIMS and XPS were taken of the leadframe surface to determine whether there were in fact any differences.

TOF-SIMS STUDY

Fig.1 is the TOF-SIMS positive ion spectrum. The upper scan is the SIMS spectrum of the sample built with solder wire and the lower scan is the SIMS spectrum of the sample built with solder paste. More gold (mass:197) appeared on the leadframe surface when using solder wire than when using solder paste. Tin (mass:120) and lead (mass:206,208) were found on the leadframe surface with the solder paste process, but didn't appear with the solder wire process. Fig.2 is the TOF-SIMS negative ion spectrum. Again more gold was observed on the leadframe surface with the solder wire process than with the solder paste process: this is consistent with the results of the former positive spectrum. Phosphate and iodine in the solder paste process may come from the flux clean solvent.

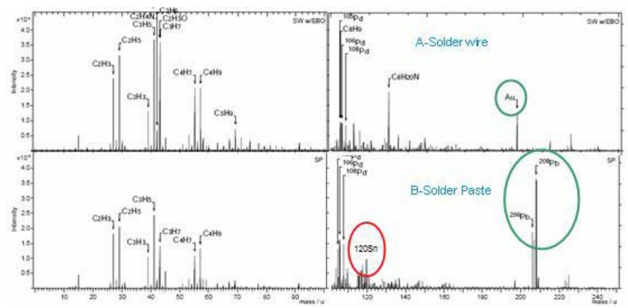


Fig.1 TOF-SIMS positive ion spectrum (mass: 1~250amu)

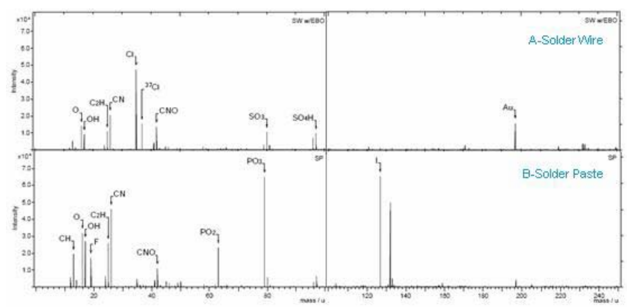


Fig.2 TOF-SIMS negative ion spectrum (mass: 1~250amu)

XPS STUDY

Fig.3 is the XPS spectrum of the die flag of the fresh leadframe. Gold and small amounts of copper, carbon and oxygen were found. Fig.3.1 shows the peak of copper and Fig.3.2 shows the peak of gold both after analysis by XPSPEAK. The binding energy of $Au4f^7$ is same as that of the atom state. The binding energy of Cu2p is 952.5eV which indicates that it is part of Cu_2O.

Fig.4 is the XPS spectrum of the die flag with SW and WB. Gold, oxygen, carbon, palladium and small amounts of sulfur and silicon were apparent. From analysis with XPSPEAK, gold(Fig.4.1) and palladium(Fig.4.2) exist in the atomic state.

Fig.5 is the XPS spectrum of the die flag with SP and WB. Oxygen, carbon, tin, lead, palladium, gold and small amounts of sulfur and silicon were apparent. From analysis with XPSPEAK, tin (Fig.5.1) and lead (Fig.5.2) exist as ions. The binding energies of the $Sn3d^5$ and $Pb4f^7$ are higher than those of the atomic states. Tin and lead lost electrons to form the compounds $Pb_{98}Sn_2$ and $AuSn_4$.

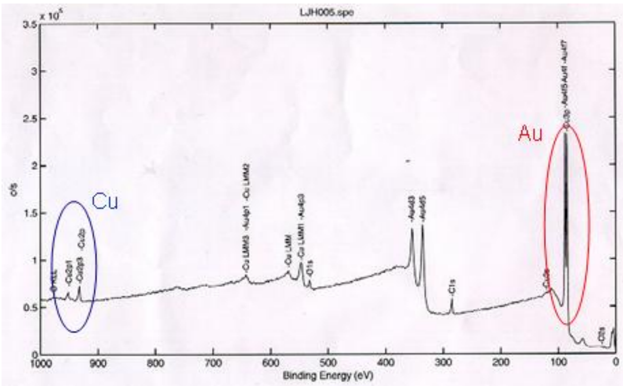


Fig.3 XPS spectrum collected on die flag of fresh LF

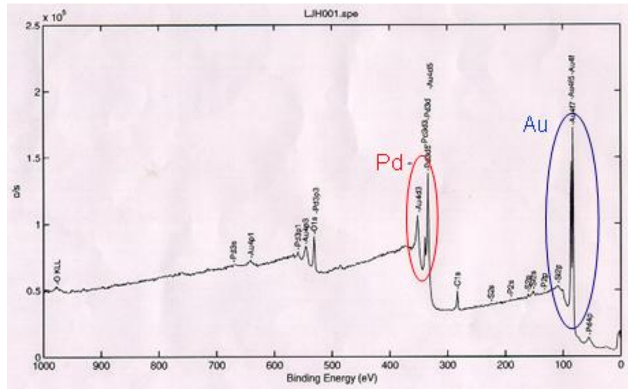


Fig.4 XPS spectrum collected on die flag with SW+WB

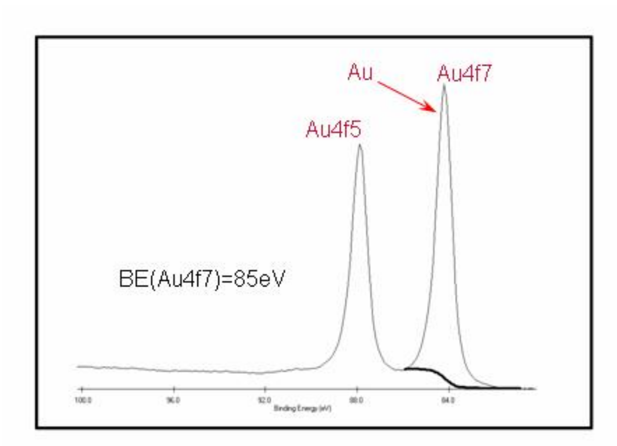


Fig.3.1 XPS peak of Gold

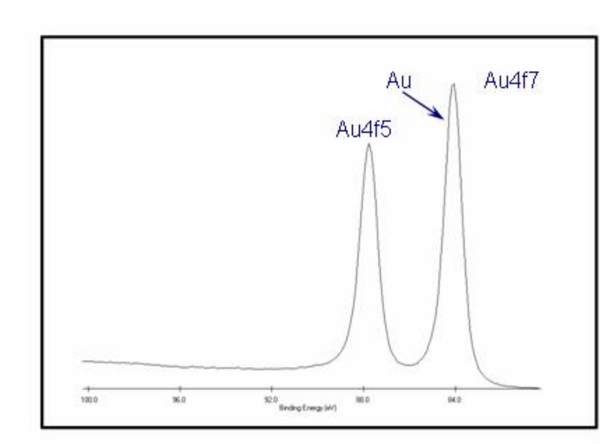


Fig.4.1 XPS peak of Gold

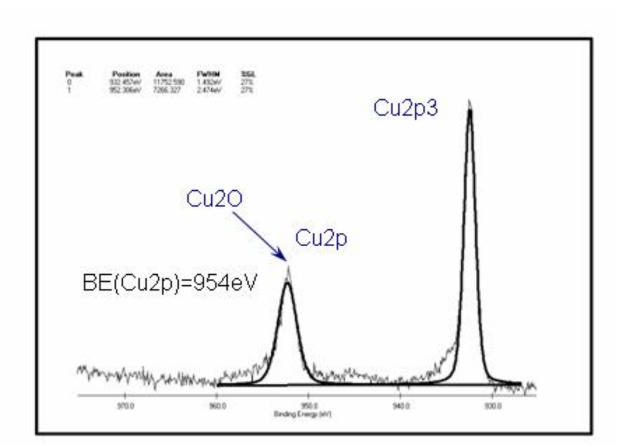


Fig.3.2 XPS peak of Copper

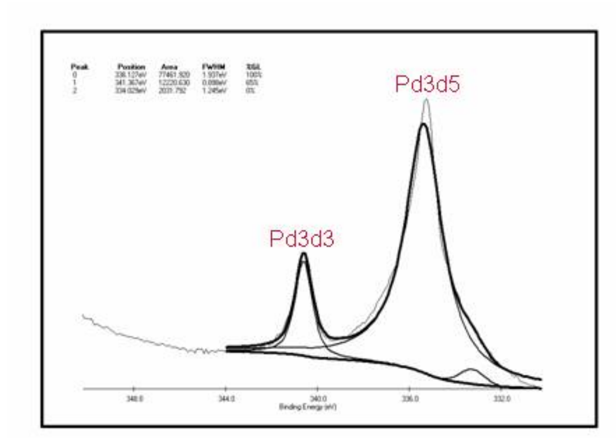


Fig.4.2 XPS peak of Palladium

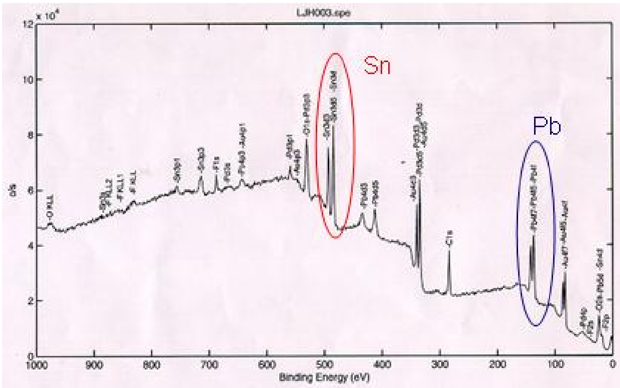


Fig.5 XPS spectrum collected on die flag with SP+WB

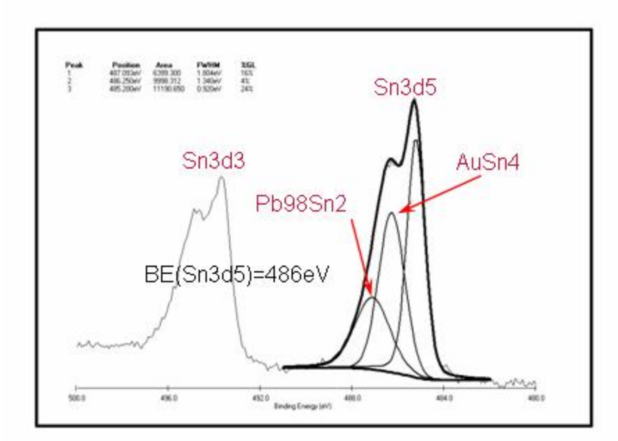


Fig.5.1 XPS peak of Tin

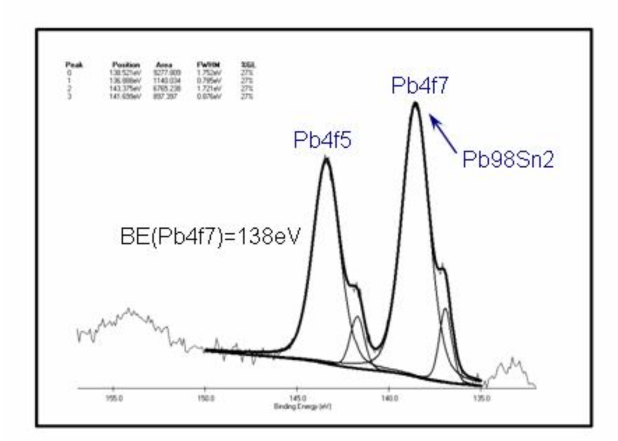
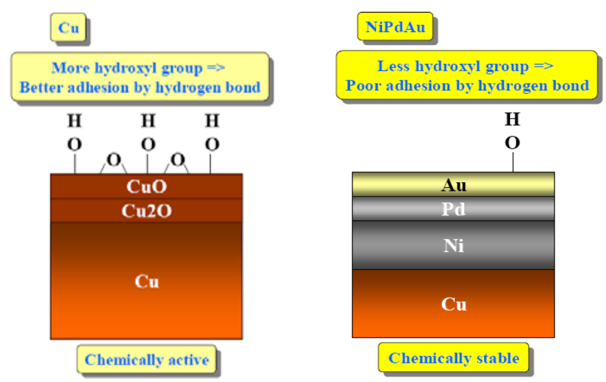


Fig.5.2 XPS peak of Lead

As we know, there are three theories for adhesion between the molding compound and metal leadframe[4]:

1) Physical adhesion theory. A rougher surface should have stronger anchor effect and bigger contact interface between molding compound and leadframe surface;
2) Chemical adhesion theory. O-H and O were absorbed on the metal surface. H of the hydroxyl group and O can produce a strong polar bond by hydrogen bonding, so the metal absorption capability with O or O-H is a very important factor in the adhesion strength. If the molding compound has more O and O-H, the hydrogen bond is stronger;
3) Chemical bond force. When the distance between the epoxy molecules and metal molecules is about 1~3 angstrom, a chemical reaction will occur and will form a chemical bond between the epoxy and metal. Certainly, other factors like shrinkage, CTE, Tg will affect the integrity of the interface between molding compound and leadframe surface.

The roughness of the PPF leadframe surface is not much different whether using solder paste or solder wire, but the chemical status of leadframe surface is totally different as was seen from the TOF-SIMS analysis results. The solder paste process has solder paste reflow and additional flux cleaning compared with the solder wire process. Tin and lead will be vaporized with the flux volatile and deposited on the leadframe surface during reflow. At the same time, many organic macromolecules will be absorbed on leadframe surface after the flux cleaning process. These organic molecules maybe have more O-H or O to provide better adhesion at the interface.



(a) Copper adhesion theory (b) NiPdAu adhesion theory

Fig.6 The adhesion comparison between Copper/NiPdAu and molding compound

In the previous research, copper has stronger adhesion with the molding compound than PPF. When copper is oxidized to cupric oxide[5][6][7], the cupric ion has a low energy empty outer orbit which can accept the electron of a ligand and form a complex compound. At the same time, the organic should have plenty of coordination groups. So copper has the better adhesion with O and O-H. But NiPdAu is more stable than copper and the adhesion capability with the organic molecular is weaker. Fig.6 is the comparison between Copper and NiPdAu.

Copper's empty outer orbit:
Cu: $[Ar]4s^2 3d^8 \rightarrow [Ar]4s^1 3d^{10}$ -2e $\rightarrow Cu^{2+}$: $[Ar]\ 4s^1 3d^8$

From the chemical activation sequence shown below, tin and lead are more activated than copper, so may have a similar effect as copper. From the analysis of chemical valence, tin and lead don't exist on the surface as simple substances. They lose an electron and have an empty orbital to accept the electron from an organic ligand to form a strong bond. That's to say there is stronger adhesion with the molding compound when using the solder paste process, though tin and lead will weaken the reliability of wire bonding.

Chemical activation sequence:
Kalium (K) > Calcium (Ca) > Sodium (Na) > Magnesium (Mg) > Aluminum (Al) > Zinc (Zn) > Iron (Fe) > Tin (Sn) > Lead (Pb) > Hydrogen (H) > Copper (Cu) > Mercury (Hg) > Sliver (Ag) > Platinum (Pt) > Gold (Au)

Tin's empty outer orbit:
Sn:$[Kr]5s^2 4d^{10} 5p^2 \rightarrow [Kr]5s^1 4d^{10} 5p^3$
-2e$\rightarrow Sn^{2+}$: $[Kr]5s^1 4d^{10} 5p^1$
-4e$\rightarrow Sn^{4+}$: $[Kr]4d^{10}$

Lead's empty outer orbit:
Pb:$[Xe]6s^2 4f^{14} 5d^{10} 6p^2 \rightarrow [Xe]6s^1 4f^{14} 5d^{10} 6p^3$
-2e$\rightarrow Pb^{2+}$:$[Xe]6s^1 4f^{14} 5d^{10} 6p^1$
-4e$\rightarrow Pb^{4+}$:$[Xe]4f^{14} 5d^{10}$

CONCLUSIONS

Leadframe surface elements should have good affinity with organic moleculares (O-H, O) to get better adhesion with the molding compound and should have better chemical activation, but can't worsen the wire bonding capability.

ACKNOWLEDGEMENTS

The authors would like to thank the Physical Analysis Lab in Tempe, Arizona for their help and all team members' support of Tianjin WPSL-TSO.

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ACRONYMS

SW: Solder wire
SP: Solder paste
WB: Wire bonding
XPS: X-ray Photoelectron Spectroscopy
TOF-SIMS: Time of Flight - Secondary Ion Mass Spectroscopy
PPF: Pre-plating Leadframe