Ag wire and Ag alloy wire reliability and molding compounds

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Abstract

Ag wire and Ag alloy wire reliability experiments were conducted on both 28-lead SOP and 96-pin PBGA packages. Biased HAST (b-HAST) of Ag-wired packages with higher ion content molding compouds generated obvious defects promoted by ion accumulation mechanism. Intermetallic compounds (IMCs) at the corroded interface are identified using cross-sectional TEM/EDX. Ion selective affinity of intermetallic compound is rationalized using *ab initio* molecular dynamics simulation.

Keywords

molding compound, corrosion, Ag wire, ion impurity, ion mobility, simulation

Introduction

Metal wirings other than Au in semiconductor packages have been extensively studied for several years, mainly driven by their cost advantage. Copper-based wiring is accepted for some applications in place of Au because of its inherently excellent electric properties and lower cost. Meanwhile, silver-based wiring has emerged more recently to contact some mechanically sensitive dies or stacked dies, which Cu wire may not be fully applicable. Bare Ag wire can cause corrosion under humidity reliability conditions [1]. For these observations, interest has shifted to Ag-alloy wire materials that are more resistant to corrosion [1-3].

Previously we reported on reliability of Cu wire in molded packages [4]. It was shown that one of these intermetallic compounds is selectively corroded by ionic promotion. Affinity of the selected ionic species to possible intermetallic compounds are calculated by computer program and correlated with the experimental observations.

Here we describe on humidity reliability tests of Ag and Ag-alloy wire with higher ion content molding compounds. Mechanistic insight was obtained by ion mobility control and computer simulations on ion-IMCs interaction as our previous report on Cu wire.

Experimental

As presumed packages of Ag wire application, 28-lead SOP and 96pin-PBGA platform are employed for b-HAST experiments. TEG chips are bonded by Ag paste on lead frame/substrate. Pure Ag wire and Ag alloy (96.5% Ag) wire are supplied by Tanaka Denshi Kogyo K.K. Pd-coated Cu wire was used for reference. All these wires are 20μm (0.8mil) in diameters. Thermosonic bonding with the optimized parameters are conducted using Shinkawa UTC-3000.

Experimental molding compounds with higher amount of ionic impurities were prepared by adding corresponding additives to our standard formulation. Resin molding is done at 175degC x 2min with additional curing at 175degC x6h.

Ionic content of each experimental molding compound are quantified by using the standard test method.

Biased HAST parameters was fixed at 130degC/85RH% for all samples. Applied voltage was 5V for SOP and 5V for PBGA.

Cross-sectional image with elemental quantification were made using JEOL JEM-2100F TEM/EDX systems.

Desorption energies of selected ions from each intermetallic compounds were simulated by Hitachi Research Laboratory using the in-house software package based on *ab initio* molecular dynamics calculation. Atomistic models of Ag_xAl

intermetallic alloys are generated for x = 2, 3, 4. Single ion is placed on the alloy surface is submitted to a molecular dynamics simulation to achieve the equilibrium. Desorption energy is calculated from this atomistic model.

Results and Discussion

Ionic impurity plays a major role in promoting metal corrosion of microelectronic packages under humidity reliability conditions. Electric field impressed through encapsulation resin attracts ionic species to each electrode, causing accumulation of ions on electrodes and corrosion. To elucidate the effect of ionic impurities on promoting corrosion, experimental resins with more ionic impurities are shown in Table 1. In addition, formulations with intended retardation of moving ion by (a) addition of ion-trapping material, or (b) control of molecular network structure, are prepared.

Computer simulations of intermetallic compounds at bonding interface

Formation of intermetallic compounds at the bonding interface is simulated by computer programs. Through the mutual diffusion reproduced in the computer resulted in (Fig.1) the formation of Ag-rich μ-phase (Ag_4Al, Ag_3Al) and relatively Ag-poor δ-phase (Ag_2Al), consistent with the literature [5].

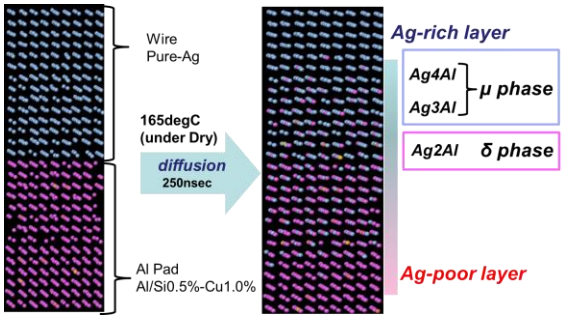


Fig. 1 Atomistic simulation result of IMC formation

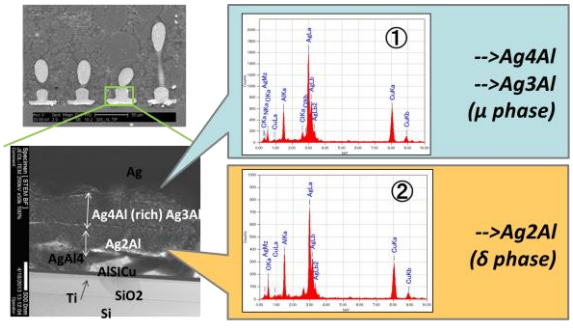


Fig. 2 Cross-sectional TEM-EDX before b-HAST

Cross-sectional TEM/EDX view of package for HAST is presented in Fig. 2, to show that intermetallic compounds with these compositions are actually observed.

To estimate the affinity of common ionic species to these intermetallic compounds, desorption energies of ions from intermetallic alloys were calculated. Both chloride ion (Cl^-) and sulfate ion (SO_4^{2-}) showed a similar picture given in Fig. 3. Thus, desorption energy is relatively higher on pure silver than the silver alloy. Higher desorption energy (i.e. higher affinity) is given at x = 3, both for Cl^- and SO_4^{2-}. In case of pure Ag wire, Cl^- seems to fit into alloys with smaller x (x=3, 2) whereas SO_4^{2-} more likely attach to larger x (x=3, 4).

(a) Pure Ag (b) Ag Alloy

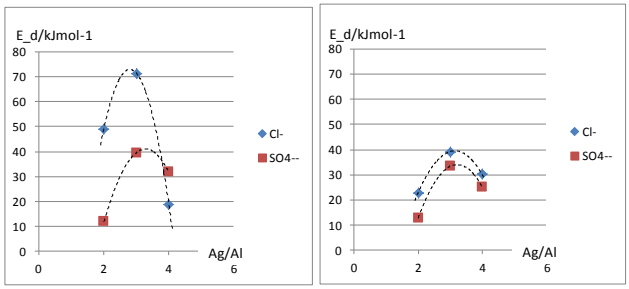
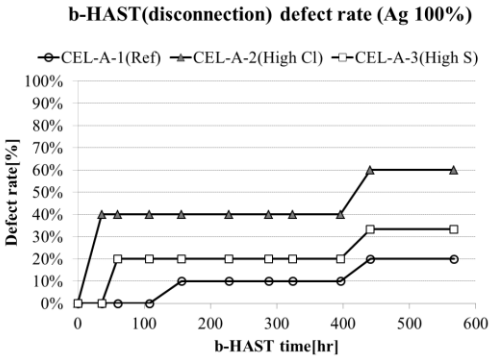


Fig. 3 Calculated desorption energy of ions from IMCs.

(a) Pure Ag



(b) Ag alloy

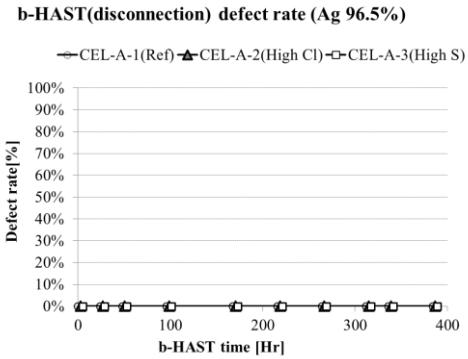


Fig. 4 Biased HAST results on 28-lead SOP

b-HAST evaluation on 28-lead SOP

Biased HAST experiments on 28-lead SOP with ion-skewed molding compounds (Table 1) were carried out. Results are shown in Figure 4. For pure silver wire, all legs including the standard molding compound failed with a high-resistance mode (Fig. 4a). Compared with chloride ion (Cl^-), Sulfate ion (SO_4^{2-}) caused defects in delayed period. For Ag alloy, no defect was observed up to 400h.

Table 1. Ion-stained molding compounds

	pH	Cl^-/ppm	SO_4^{2-}/ppm	
CEL-A-1	6.7	15	2	Standard
CEL-A-2	6.5	35	2	High Cl
CEL-A-3	6.4	15	30	High S

Destructive inspection of the defected bonding interface revealed that corrosion was promoted by ionic impurities. Thus, cross-sectional TEM/EDX view of the interface region indicated selective corrosion of particular intermetallic layer. As seen in Fig. 5a, chloride ion (Cl^-) corroded Ag_2Al layer. On the other hand, sulfate ion ($SO4^{2-}$) corroded Ag_4Al layer (Fig 5b). This observation is consistent with the prediction of ion selection in alloys made by computer simulation.

(a) Pure Ag / CEL-A-2 (b) Pure Ag / CEL-A-3

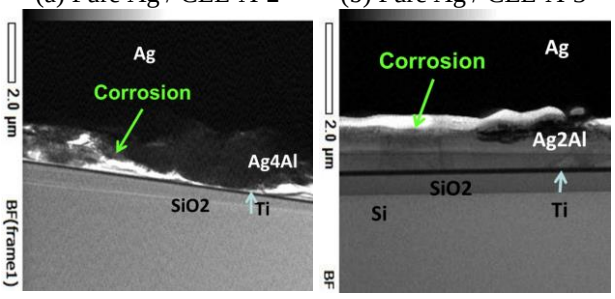
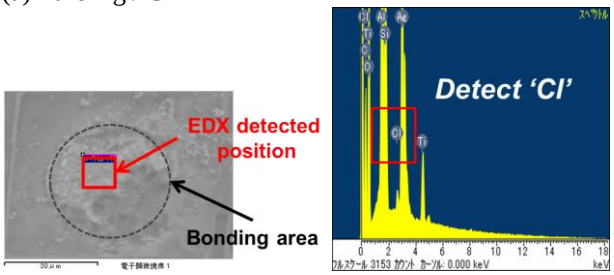


Fig. 5 Cross-sectional TEM images of bonding interfaces.

In addition, exposed intermetallic surfaces were examined using SEM/EDX. It was proved that ionic species are accumulated at corroded intermetallics, confirming presumed ionic mechanism (Fig. 6).

(a) Pure Ag / CEL-A-2



(b) Pure Ag / CEL-A-3

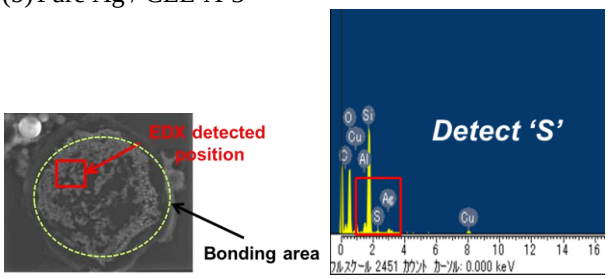
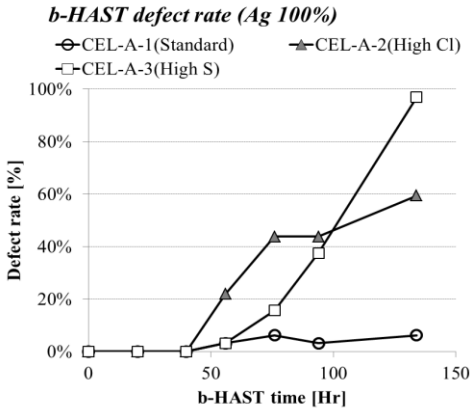


Fig. 6 SEM/EDX analysis of exposed surfaces

b-HAST evaluation on 96-pin PBGA

Similarly, biased HAST experiments on 96-pin PBGA package with ion-skewed molding compounds (Table 1) were also carried out. This package is more susceptible to the electrochemical migration because of its finner inner lead geometry i.e. narrower pad distance of 70um. Results are shown in Figure 7. For pure silver wire, both higher Cl and higher S showed failures with high-resistance mode while the standard molding compound failure rate was low (Fig. 7a). Ag alloy wire caused no defect during the experiment (250h) (Fig. 7b). Electrochemical migration was not observed at all legs.

(a) Pure Ag



(b) Ag alloy

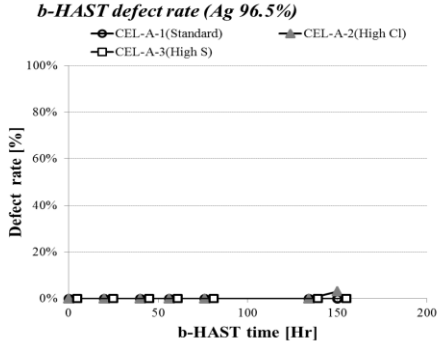


Fig.7 b-HAST results on 96-pin PBGA package

Overview of Ag-wire corrosion mechanism is shown in Fig. 8. Ionic species are attracted to electrodes and accumulated on a specific intermetallic layer, depending on their inherent affinity. This picture is principally a same as that of Cu wire's we reported previously.

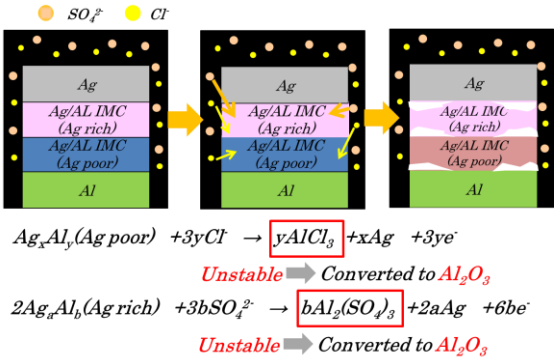


Fig.8 Overview of Ag wire corrosion mechanism

According to the ion-promoting mechanism described above, ion mobility must be the critical factor of corrosion rate at a given ion concentration. Lowering ion mobility can be achieved by tightening resin's molecular network. CEL-D-1 molding compound, which is a "tightened" version of CEL-A-1, was prepared. Ion mobility change of these molding compounds was confirmed by a separate evaluation (non disclosed data). b-HAST experiment of CEL-D-1 and CEL-A-1 on 28-lead SOP are shown in Fig. 9. As expected, CEL-D-1 generated delayed defect even with the high chloride ion content.

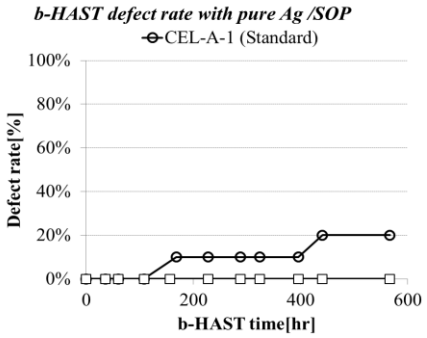


Fig.9 b-HAST evaluation at ion mobility study with pure Ag / 28-lead SOP

In place of direct measurement of ion mobility, volume resistivity after moisture absorption (absorbed volume resistivity, AVR) is indicator of the ion-mobility for this phenomena. AVR is measured at 500V after moisture absorption at 130degC/85%/72h.

Apparent relationship between the absorbed volume resistivity and b-HAST defect rate was observed (Fig. 10). Higher AVR than 10^{13} Ω cm did not cause the corrosion.

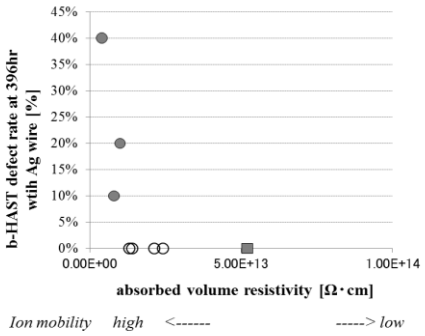


Fig.10 Relationship between AVR and b-HAST

Another way to reduce ion mobility is to apply better ion trapper. CEL-E, with newly developed ion trapper, gave no failure up to 600h under b-HAST evaluation. As shown at Fig. 11, AVR of CEL-E is higher than its corresponding counterpart, CEL-A-1, which is consistent with above observation at Fig 10.

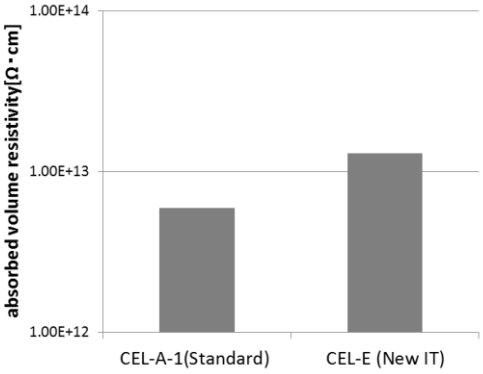


Fig.11 AVR with new ion trapper

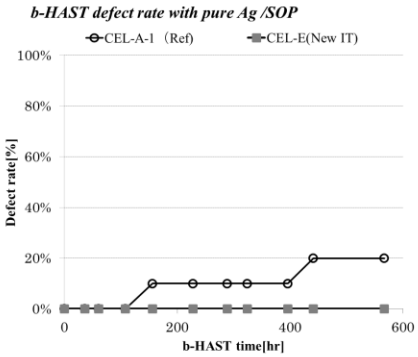


Fig.12 b-HAST results with new ion trapper

Conclusion

Ag-wire packages with ion-skewed molding compouds were evaluated under the biased HAST condition. Ag alloy wire

gave no failure so far in this study. Ion-promoting mechanism of the corrosion is rationalized by destructive inspection of corroded intermetallic compounds and also atomistic computer simulation. Both chloride ion and sulfate ion promote corrosion but attack different intermetallic compounds. Ion mobility control in molding compound was effective to improve reliability of pure-Ag wired packages.

References

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