

## **In-situ Real-time Observations of Reactions between Different Lead-free Solder Pastes and Surface Finish Substrates**

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Real time solidification observation of Sn-0.7wt%Cu, Sn-0.7wt%Cu-0.05wt%Ni, Sn-3.5wt%Ag and Sn-3wt%Ag-0.5wt%Cu solder pastes on different FR4 substrates with Cu organic soldering preservative (Cu-OSP) and electroless nickel immersion gold (ENIG) surface finish were achieved using a synchrotron X-ray imaging technique. It was found that, upon wetting, the rapid dissolution of Cu adjacent to the solid-liquid interface was followed by near-instantaneous interfacial intermetallic compound (IMC) formation and later by the independent nucleation and growth of primary intermetallics in the solder alloys. The presence of independent primary intermetallics is dependent on the dissolution of Cu from the substrate. The results provide direct experimental evidence of the effect of different substrate metallization on the formation and growth behaviour of primary intermetallics in solder alloys during soldering.

**Keywords:** In-situ X-ray imaging, soldering, solidification

### **Background and aim:**

Recently electric and electronic devices have rapidly become more advance with denser assemblies requiring stronger and higher reliability interconnects. The advances of electric and electronic devices have stimulated research to achieve higher quality solder alloys with good reliability. A major consideration related to the properties of solder alloys is how the solder reacts with the substrate. Recently, several industrial common Cu substrates with varying surface finish such as organic soldering preservative (OSP) and electroless nickel immersion gold (ENIG) have been widely adopted [1][2]. Solder joint reliability is known to be dependent on the formation of an intermetallic compound (IMC) layer which itself is dependent on factors such as surface finish and substrate and solder composition [1]. Although many researchers have studied the metallurgical reactions of the solder material itself, there is a need to understand the reactions with different substrates and surface finishes.

### **Experimental:**

Four solder pastes, Sn-0.7wt%Cu, Sn-0.7wt%Cu-0.05wt%Ni (SN100C solder), Sn-3.5wt%Ag, Sn-3.0wt%Ag-0.5wt%Cu (SAC305 solder) paste and a fire retardant 4 (FR4) substrate with Cu organic soldering preservative (Cu-OSP) and electroless nickel immersion gold (ENIG) surface finishes were used for this experiment.

The experiments were performed at BL20XU beamline in the SPring-8 synchrotron using an in situ X-ray real-time solidification observation setup developed from previous research [3][4]. Figure 1 shows (a) The synchrotron real-time in-situ observation heating furnace setup, (b) the soldering sample cell setup, and (c) the FR4 substrate with 0.5 mm ball grid array (BGA) pitch. FR4 substrates were grounded horizontally until 100  $\mu\text{m}$  thickness. With a high degree of coherence, absorption contrast and phase contrast are observed on transmitted images with enhanced boundaries. The collected signals are then converted into a digital format of 2000 x 2000 pixels. This area represents a 1 mm x 1 mm area on the BL20XU experiments (giving a resolution of 0.5  $\mu\text{m}$  per pixel). A planar undulator was used as a light source and the radiation was monochromatized with Si double-crystal monochromators. An exposure time of 1 s per frame was used to capture the images. To mimic the process of reflow soldering, a furnace with graphite heating elements where heat is transferred through radiation in an enclosed sample chamber was used. The solder paste and substrate were used at 100  $\mu\text{m}$  thickness. The sample was then placed in a sample cell with an observation window

area of 10 x 10 mm<sup>2</sup> with a vent for flux outgassing created using a 100 μm thickness polytetrafluoroethylene sheet placed between two SiO<sub>2</sub> plates. Samples were set to be heated from room temperature to approximately 250°C at 0.17 °C/s and cooled down at 0.33 °C/s.

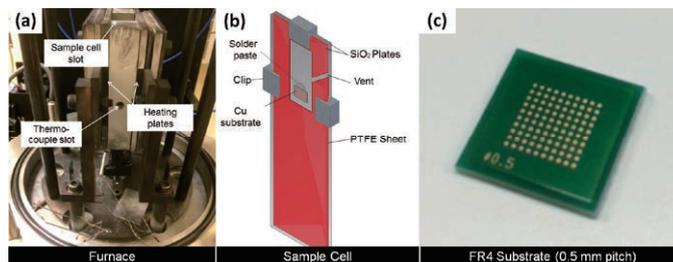


Figure.1. (a) Synchrotron real-time in-situ observation heating furnace setup, (b) soldering sample cell setup, and (c) FR4 substrate with 0.5 mm ball grid array (BGA) pitch.

### Results and discussion:

Reactions of the full soldering process were observed for each sample focusing on the nucleation and growth of the interfacial and primary intermetallic compounds.

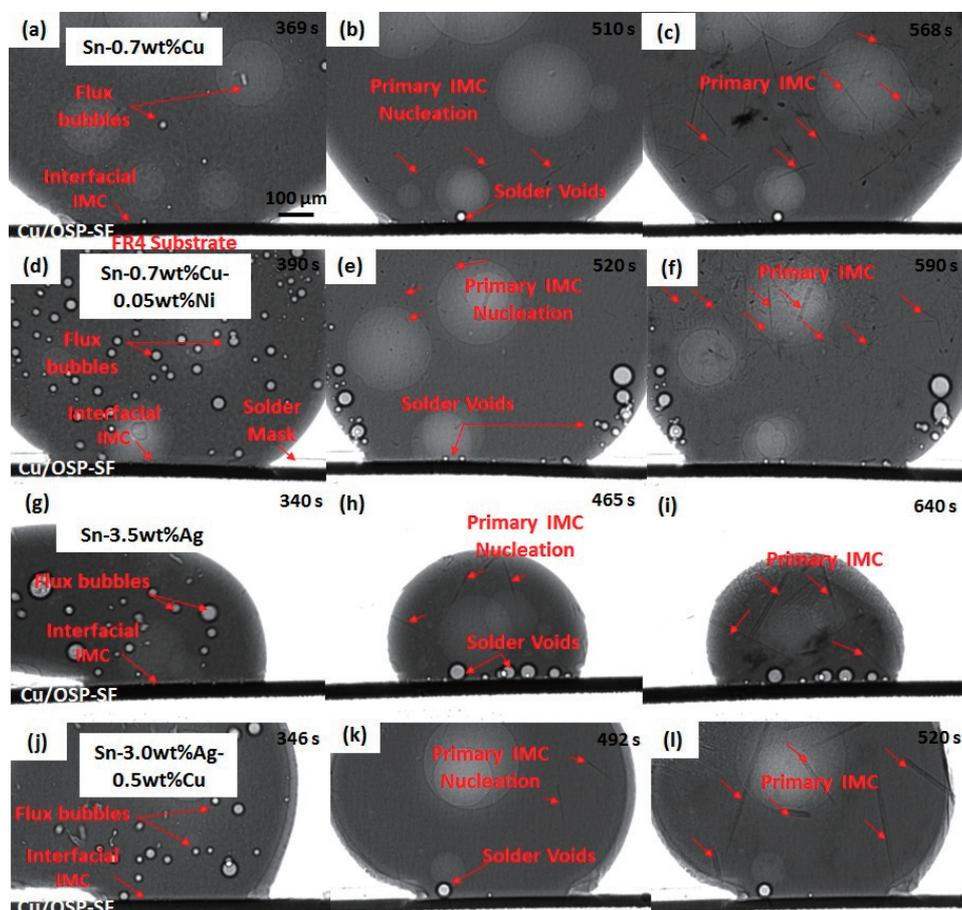


Figure.2. In-situ real-time observations of reactions between different solder paste and the Cu organic soldering preservative (Cu-OSP) surface finish substrate. Sn-0.7wt%Cu solder paste at experimental time of (a) 369 s, (b) 510 s, (c) 568 s; Sn-0.7wt%Cu-0.05wt%Ni solder paste at experimental time of (d) 390 s, (e) 520 s, (f) 590 s; Sn-3.5wt%Ag solder paste at experimental time of (g) 340 s, (h) 465 s, (i) 640 s; Sn-3.0wt%Ag-0.5wt%Cu solder paste at experimental time of (j) 346 s, (k) 492 s, (l) 520 s.

Figure 2 shows the reactions between different solder pastes and the Cu/organic soldering preservative (OSP) surface finish substrate. Sn-0.7wt%Cu solder paste at experimental time of (a) 369 s, (b) 510 s, (c) 568

s; Sn-0.7wt%Cu-0.05wt%Ni solder paste at experimental time of (d) 390 s, (e) 520 s, (f) 590 s; Sn-3.5wt%Ag solder paste at experimental time of (g) 340 s, (h) 465 s, (i) 640 s; Sn-3.0wt%Ag-0.5wt%Cu solder paste at experimental time of (j) 346 s, (k) 492 s, (l) 520 s.

It was observed that upon wetting, the rapid dissolution of Cu adjacent to the solid–liquid interface was followed by the near-instantaneous precipitation/growth of an interfacial intermetallic compound (IMC) and later by the independent nucleation and growth of primary intermetallics in the solder alloys away from the substrate. From figure 2, the primary intermetallics formed on a Cu-OSP surface finish are finer on Sn-0.7wt%Cu-0.05wt%Ni solder paste. On the other hand, Figure 3 shows the reactions between different solder pastes and the electroless nickel immersion gold (ENIG) surface finish substrate. Sn-0.7wt%Cu solder paste at experimental time of (a) 363 s, (b) 510 s, (c) 640 s; Sn-0.7wt%Cu-0.05wt%Ni solder paste at experimental time of (d) 185 s, (e) 319 s, (f) 350 s; Sn-3.5wt%Ag solder paste at experimental time of (g) 363 s, (h) 455 s, (i) 534 s; Sn-3.0wt%Ag-0.5wt%Cu solder paste at experimental time of (j) 205 s, (k) 340 s, (l) 364 s. It is clearly observed that with ENIG surface finish, primary intermetallic formation in the bulk solder of Sn-3.5wt%Ag and Sn-3.0wt%Ag-0.5wt%Cu could be eliminated.

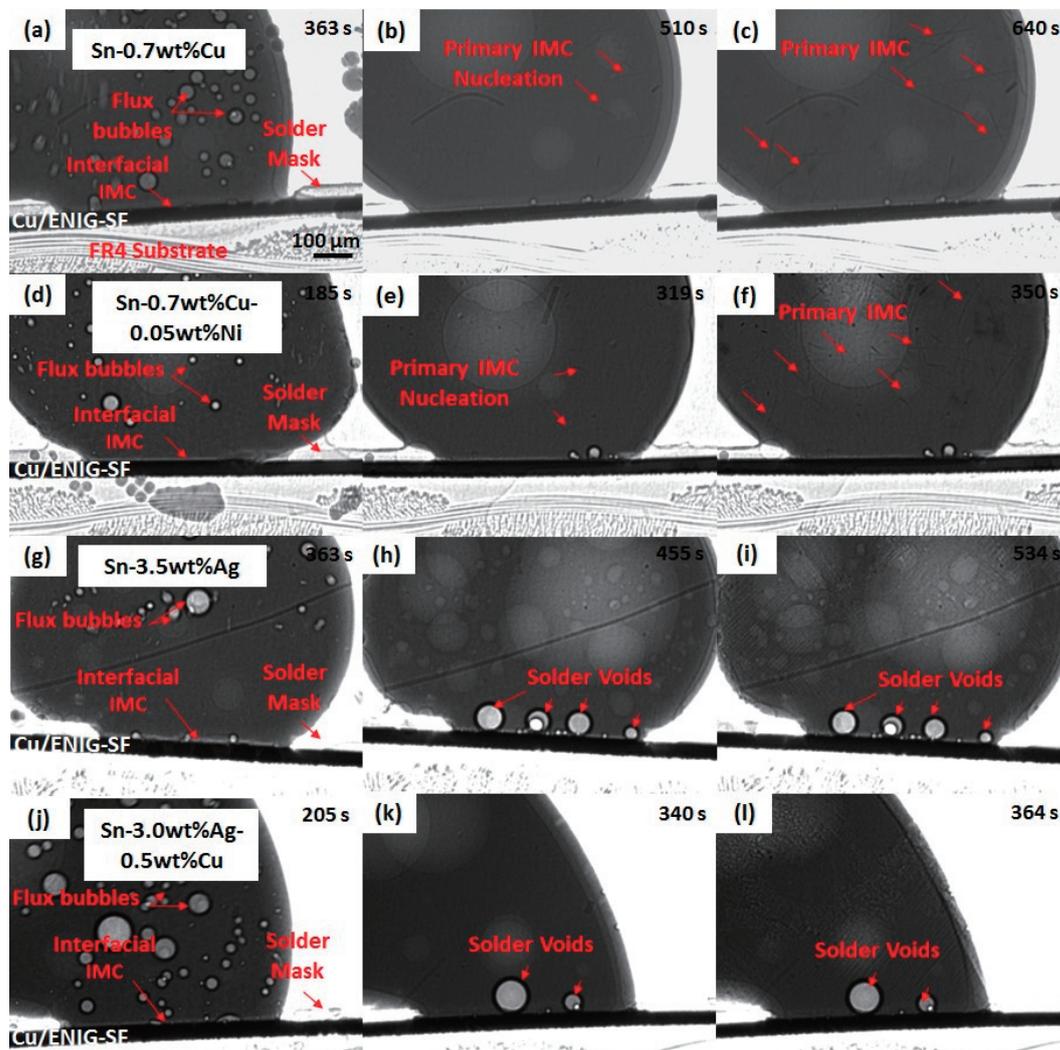


Figure.3. In-situ real-time observations of reactions between different solder paste and the electroless nickel immersion gold (ENIG) surface finish substrate. Sn-0.7wt%Cu solder paste at experimental time of (a) 363 s, (b) 510 s, (c) 640 s; Sn-0.7wt%Cu-0.05wt%Ni solder paste at experimental time of (d) 185 s, (e) 319 s, (f) 350 s; Sn-3.5wt%Ag solder paste at experimental time of (g) 363 s, (h) 455 s, (i) 534 s; Sn-3.0wt%Ag-0.5wt%Cu solder paste at experimental time of (j) 205 s, (k) 340 s, (l) 364 s.

**Conclusions and future works:**

From real-time soldering observations using a synchrotron radiation facility it is clear that substrate plays a significant role in the formation of primary intermetallics in the bulk solder. In addition to that, certain element addition such as with Ni can suppress the growth of the primary intermetallic as obtained in the experiment results. This observation gives a useful insight into the metallurgical reactions during soldering on various solder materials and substrates. Based on these results, investigation of the most dominant contributing factor relating to intermetallic formation will be investigated further.

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