in situ Monitoring of Microstructure and Phase Changes of AuSn Solders for Hermetic Wafer-Level Packaging

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***Abstract* — Wafer bonding to achieve hermetic wafer-level packaging is highly dependent on the state of the bonding surface and the microstructure of the layers involved. Herein, we identify the changes occurring in the AuSn layer during the annealing prior to TLP (transient liquid phase) bonding through *in situ* PEEM (photoemission electron microscopy), AES (Auger electron spectroscopy) and XPS (X-ray photoelectron spectroscopy). We identify a major structural transition occurring around 190°C coinciding with a chemical modification of the surface. AES and XPS showed that the Ti used as an adhesion layer diffused through AuSn to reduce the SnO_2 surface oxide and form a TiO_2 layer, along with Sn metallic clusters.**

Keywords—Wafer bonding; Wafer-level packaging; Alloy stability; AuSn solder

Wafer-level packaging (WLP) is an important technology allowing the fabrication of multiple chips on a single wafer thus reducing greatly the fabrication cost. Devices fabricated through WLP, such as MEMS, can be formed of mobile parts needing protection from physical contacts or require a specific environment. Microbolometers are an example of the later, requiring high level of vacuum to minimize heat losses through convection. Hermetic wafer bonding allows the fabrication of those devices under vacuum at low cost. AuSn eutectic and TLP bonding are promising techniques because AuSn is considered a fluxless solder and its eutectic point of 278°C is sufficiently low to be compatible with most materials involved in MEMS fabrication. A good understanding of the thermal behavior of AuSn layer is imperative to optimize these bonding processes.

The fabrication of the samples starts with an Ar+ etch of a Si 8-inch wafer, followed by *in situ* sputtering of Ti(10 nm)/TiN(100 nm)/Ti(10 nm)/Au(50 nm). Ti is used as adhesion layers, TiN as a diffusion barrier and Au is an electric contact for the electroplated AuSn (2 µm, 78 weight % of Au). The AuSn layer can be patterned either in the form of 50 µm seal rings or into 7x7 mm patches. Those samples are characterized using three method: PEEM, XPS and AES. *in situ* annealing is achieved individually in each of these setups.

Figure 1 presents PEEM snapshots of a AuSn seal ring annealed from 100 to 200°C. Around 180°C the AuSn surface becomes much brighter and elongated grains of more than 10 µm form. PEEM contrast depends on the work function of the surface compared with the emission threshold of the UV lamp (4.9 eV). Initially, AuSn is covered with a SnO_2 layer with a work function of 5.7 eV[1] thus explaining the dark contrast of the seal ring. The evolution of the chemical state of the AuSn surface is presented in Figure 2. Around 200°C, the Sn3d peaks shift from an oxidized state to a metallic state, which coincides with the apparition of Ti2p peaks. AES coupled with SEM imaging have confirmed that, after annealing, Ti oxide has replaced Sn oxide and Sn is now present in the form of 10 nm size metallic clusters, as shown in Figure 3. Given that TiO_2 and Sn have work functions around 4.2[2] and 4.4[3] eV respectively, this behavior is consistent with the sudden increase in PEEM signal of the seal ring. Figure 3 also shows that the dark patches remaining after annealing are parts of the initial SnO_2 layer that didn't react with the Ti.

We have shown that the 190°C AuSn phase transition triggers a Ti reduction of the SnO_2 to form a TiO_2 layer and Sn clusters, which can be detrimental to eutectic or TLP bonding process.

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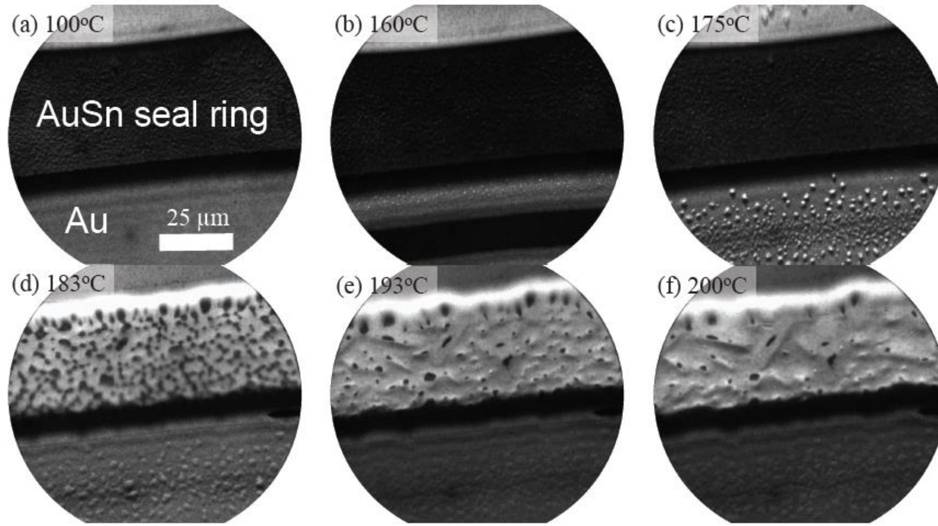

Figure 1 PEEM snapshots of a AuSn seal ring under *in situ* UHV annealing.

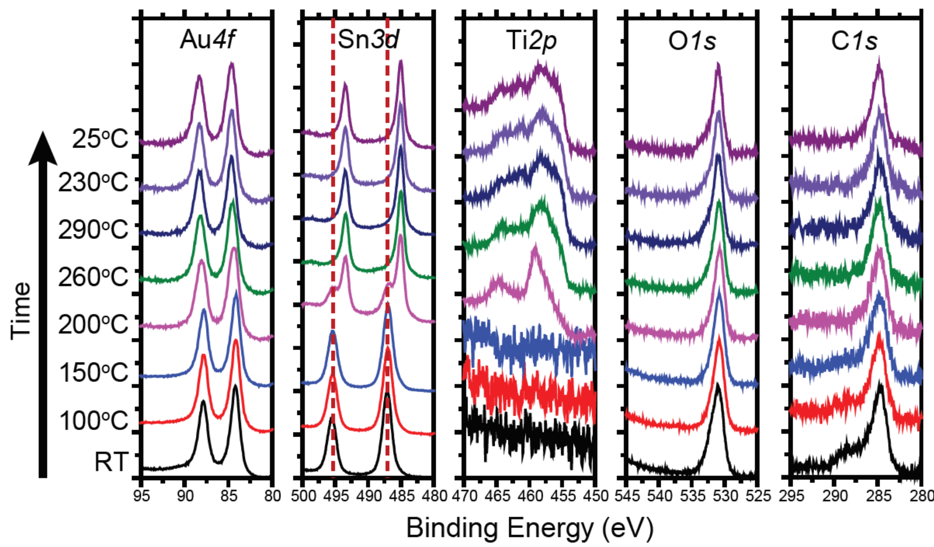

Figure 2 XPS spectra of AuSn solder after different anneals under UHV.

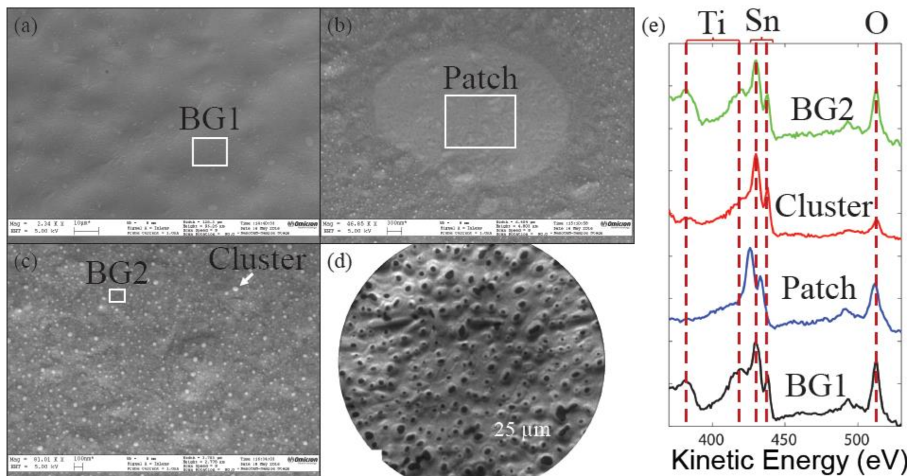

Figure 3 (a)-(c) SEM images and (d) PEEM snapshot of AuSn after annealing at 200ºC. (e) AES spectra of different areas.