The Effect of Intermetallic Compound Evolution on the Fracture Behavior of 
Au Stud Bumps Joined with Sn-3.5Ag Solder

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The microstructure and joint properties of Au stud bumps joined with Sn-3.5Ag solder were investigated as functions of flip chip bonding temperature and aging time. Au stud bumps were bonded on solder-on-pad (SOP) at bonding temperature of 260°C and 300°C for 10 s, respectively. Aging treatment was carried out at 150°C for 100 h, 300 h, and 500 h, respectively. After flip chip bonding, intermetallic compounds (IMCs) of AuSn, AuSn₂, and AuSn₄ were formed at the interface between the Au stud bump and Sn-3.5Ag solder. At a bonding temperature of 300°C, AuSn₂ IMC clusters, which were surrounded by AuSn₄ IMCs, were observed in the Sn-3.5Ag solder bump. After flip chip bonding, bonding strength was approximately 220.5mN/bump. As aging time increased, the bonding strength decreased. After 100 h of aging treatment, the bonding strength of the joint bonded at 300°C was lower than that bonded at 260°C due to the fast growth rate of the AuSn₂ IMCs. The main failure modes were interface fractures between the AuSn₂ IMCs and AuSn₄ IMCs, fractures through the AuSn₂ IMCs and pad lift. Initial joint microstructures after flip chip bonding strongly affected the bonding strengths of aged samples.

Keywords: Au stud bump, flip chip bonding, shear strength, failure mode

1. INTRODUCTION

The Au stud bump process has been regarded as an uncomplicated bonding process for several packaging components such as the high frequency modulus,[1] the flip-chip-packed LED chip,[2] and the high-speed DRAM.[3] In particular, flip chip LED packaging has employed Au stud bumps with solder to enhance thermal conductivity with high light extraction efficiency.[5,6] Compared with the wire bonded LED package, the flip chip-bonded LED package has the good advantage of heat dissipation. For LED flip chip bonding, Au-20Sn (in wt. %) eutectic bonding is preferred in order to get good properties.

An Au stud bump joint with Sn-based solder possesses complicated Au-Sn intermetallic compound (IMC) layers at the joint interface. The phase and structure of the Au-Sn IMC layers depend on the reaction temperature, time and volume ratio of Au/Sn.[7-14] Previous researches revealed that the joint strength of an Au stud bump bonded with Sn-based solder was very low because of the brittleness of the Au-Sn intermetallic compounds.[15,16] In addition, the Au-Sn IMCs tend to grow extensively during flip chip bonding due to the high dissolution rate and the diffusivity of Au in molten solder. Such rapid IMC growth in the Au-solder joints deteriorates the mechanical strength of the solder joint severely. Until now, many researches have focused on the Au-Sn IMC evolution with respect to varying conditions of the flip chip bonding or thermal aging. However, research regarding the relationship between the IMC structure and fracture behavior of Au stud bumps with Sn-based solder is insufficient. The objective of the present paper is to evaluate the relationship between the IMC evolution and fracture behavior of Au stud bump joined with Sn-3.5Ag solder.

2. EXPERIMENTAL PROCEDURE

The sizes of the test chip and the substrate in this study were 1.95 mm × 1.95 mm and 2.64 mm × 2.64 mm, respectively. On the test chip, peripheral pads of Ti (50 nm)/Au (300 nm) were formed with a lift-off technique. Au stud bumps were formed on the Ti/Au pads using a conventional wire-bonding machine and leveled to make the bump height uniform. The Au stud bumps formed on the test chip are shown in Fig. 1(a). The diameter and height of the Au stud bumps were approximately 75 µm and 54 µm, respectively. On the substrate, Sn-3.5Ag solder-on-pad (SOP) was electroplated on Ti (50 nm)/Cu (500 nm) pads. The Sn-Ag
The plating solution was obtained from Ishihara Chemical Co. The SOP-formed substrate is shown in Fig. 1(b). The current density of the Sn-Ag plating was 400 A/m². The plating temperature and time were 25°C and 30 min, respectively. The size and the height of the Sn-3.5Ag SOP were 155 µm and 35 µm, respectively.

For the flip chip bonding, the Au stud bump on the test chip was optically aligned with the substrate whereupon the test chip was thermo-compressed with a flip chip bonder (FCB3, Panasonic Co.). The schematic diagram of the flip chip bonding is shown in Fig. 1(c). For the flip chip bonding, two conditions of peak temperatures were used: 260°C and 300°C. The holding time and bonding pressure at the peak temperatures were 10 s and 2 N, respectively. To investigate the IMC evolution, the bonded samples were thermally aged at 150°C for up to 500 h.

The IMC formation and the microstructure change of the solder joints between the Au stud bump and Sn-3.5Ag solder bump were observed with field emission scanning electron microscopy (FESEM, FEI Inspect F) in a back-scattered electron (BSE) mode. Energy-dispersive x-ray spectroscopy (EDS) was also employed to detect the phase of IMCs at the joints. The mechanical strength of the joint was measured by a shear tester (Dage 4000) at a constant shear speed of 200 µm/s and at a fixed shear tip height of 12.5 µm above the substrate surface. After the shear tests, fracture surfaces were also investigated to understand the fracture modes of the solder joints.

### 3. RESULTS AND DISCUSSION

#### 3.1 Microstructure Evolution with Flip Chip Bonding

Figure 2 shows the cross-sectional BSE images of Au stud bump-Sn3.5Ag SOP joint after the thermo-compression flip chip bonding. Figure 3 shows a schematic illustration of the IMC structure of Fig. 2. In the case of the 260°C flip chip bonding, large chunks of AuSn₄ IMC formed in the SOP region. Such large AuSn₄ IMC clusters in the SOP region precipitated from the Au-saturated Sn-3.5Ag solution during the flip chip bonding. Previous researches of an invariant reaction in Au-Sn system also reported of AuSn₂ clusters were surrounded by AuSn₄. Lee et al. reported the AuSn₄-covered AuSn₂ chunks in the solder region from their bonding study of Au and SnAgCu solder at 290°C. They observed that the AuSn₄-covered AuSn₂ chunks resulted from a spalling of an interface AuSn₂ chunk. In our case, the formation of the AuSn₄-covered AuSn₂ chunks can also be explained with the spalling mechanism. In this mechanism, the AuSn₄ layer was formed first on the Au stud during the initial stage of the bonding process.