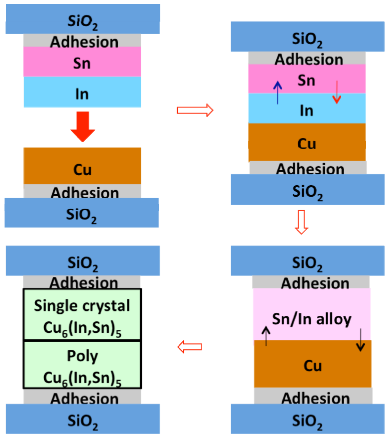

Fig. 1. Schematic diagram of Sn/In-Cu low temperature bonding procedure.

RESULTS AND DISCUSSION

A. Evaluation of Sn/In-Cu Bonded Interconnects

The quality of wafer level bonded sample at 180°C was evaluated by scanning acoustic tomography (SAT), as shown in Fig. 2. The SAT image shows a well-bonded result across the wafer. The XRD analysis on bonded interconnects shows that η-Cu_6Sn_5 was found in the sample bonded at 180 °C without Sn or In peaks, as shown in Fig. 3. The XRD results suggest that In and Sn atoms were completely consumed and reacted with Cu after bonding.

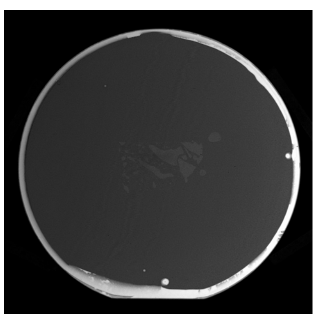

Fig. 2. SAT analysis of the 6-inch blanket wafer bonding result.

TEM analysis of the bonded sample in Fig. 4(a) shows a uniform bonding interface without voids. In Fig. 4(b), EDX line scan analysis in the bonded structure shows of the composition profile of approximately 60 % Cu, 20 % Sn, and 20 % In. According to the Cu-In-Sn system interface reaction research reported by Sommadossi *et al*. [4], the IMC formed in the bonding reaction zone should be η-$Cu_6(Sn,In)_5$. Electron diffraction analyses were performed to identify the crystal structure of $Cu_6(Sn,In)_5$. The cross-section of Sn/In-Cu bonded interface from 180 °C bonding is presented in Fig. 5(a), where the diffraction patterns are indicated in Fig. 5(b) and (c). The results show that during bonding In and Sn atoms diffused into Cu layer of another wafer to form poly-$Cu_6(Sn,In)_5$, while the Cu atoms diffused into Sn/In alloy layer to form single crystal $Cu_6(Sn,In)_5$.

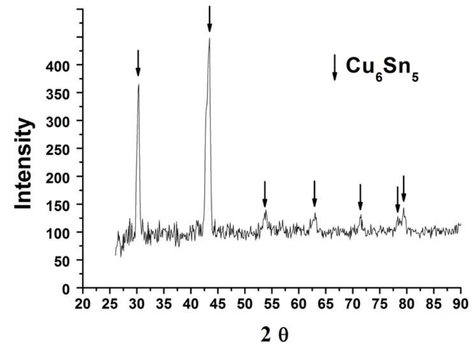

Fig. 3. XRD result of interface at the bonding interface

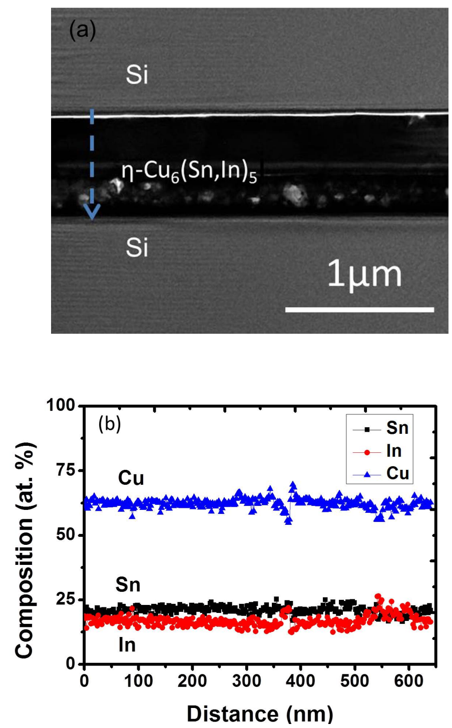

Fig. 4. TEM image of a Sn/In-Cu sample boned at 180℃ for 50 min (a) and the composition versus distance relation along the dashed line determined by EDX on a cross-section of a Sn/In-Cu interaction zone (b).

Due to the Sn-In binary system with an eutectic temperature of 118 °C, In atoms would interdiffuse with Sn atoms to form a thin liquid solution at the interface between In layer and Sn layer at 118 °C [6]. As the bonding temperature reached 180 ℃, the liquid phase dissolved the adjacent In and Sn atoms and the molten solder layer eventually diffused into Cu pad to form poly crystal $Cu_6(Sn,In)_5$ phase. However, the Cu atoms also diffused into molten solder to form single crystal $Cu_6(Sn,In)_5$. Due to the melting point of $Cu_6(Sn,In)_5$ is about 500 °C, the Sn/In-Cu interconnects bonded at low temperature allowed application at high service temperatures in a low thermal budget procedure. This result agreed with the phase identification suggested by the EDX line scan and XRD analysis.

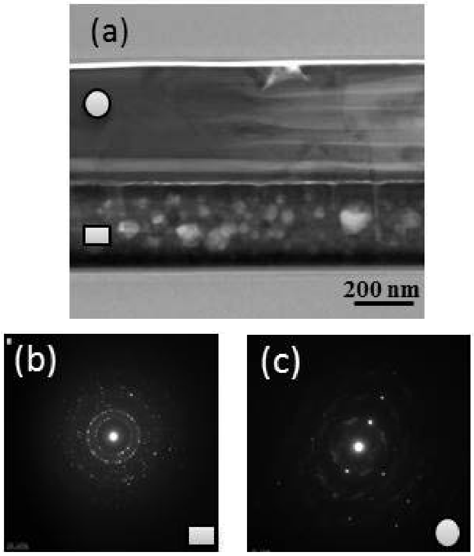

Fig. 5. TEM image of a Sn/In-Cu sample boned at 180℃ for 50 min (a), where the diffraction patterns of (b) poly η-$Cu_6(Sn,In)_5$ and (c) single η-$Cu_6(Sn,In)_5$ are presented.

B. Contact Resistance Measurement

The contact resistances of Sn/In-Cu interconnects bonded at 180 °C, 160 °C, and 140 °C, respectively, are shown in Fig. 6. The specific contact resistance ρ_c was approximately 1.25×10^{-5} Ω-cm^2 both at 180 °C and 160 °C, while approximately 5×10^{-5} Ω-cm^2 at 140 °C. There was no deviation of resistance during measurement, indicating a reliable bonded structure with a stable electrical performance was formed during the low temperature bonding procedure.

C. Multiple Current Stressing

To evaluate the stability of Sn/In-Cu bonded interconnects, the contact resistances of interconnects bonded at 180 °C, 160 °C, and 140 °C were investigated after 1000 current stressing loops, as shown in Fig. 7. Both the contact resistances bonded at 180 °C and 160 °C are approximately 0.02 Ω, while that bonded 140 °C is approximately 0.08 Ω. This result suggests that the Sn/In-Cu bonded interconnect was reliable and could withstand a long term electrical current.

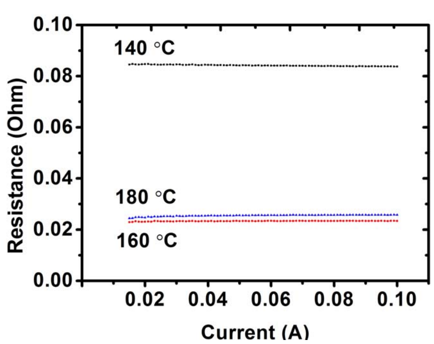

Fig. 6. Contact resistance measurement of Sn/In-Cu bonded structure.

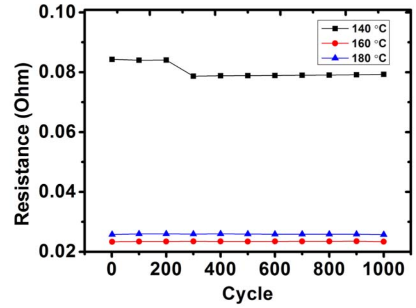

Fig. 7. Contact resistance measurement of Sn/In-Cu bonded structure under multiple current stressing cycles.

CONCLUSION

Sn/In-Cu interconnects boned at low temperature have been developed and evaluated for 3-D integration. The full presence of $Cu_6(Sn,In)_5$ with a melting point of 500 °C formed in this interconnect meets the requirement of following high processing temperature. The bonding performed at 140 °C, below the melting points of Sn and In, exhibits similar great electrical properties and reliability against current stressing to the interconnects bonded at 160 °C and 180 °C. The Sn/In-Cu bonding technology has the great potential in low thermal budget 3-D integration applications.

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