Investigation of Au-Si Eutectic Bonding for MEMS Wafer-Level Packaging Application

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Abstract
Eutectic Au–Si bonding enables strong, hermetic, and electrically conductive interfaces for microsystem packaging and heterogeneous integration. It relies on a transient liquid phase above 363 °C, promoting effective wetting and adhesion between gold and silicon. Au–Si bonds combine low process temperature with high electrical and thermal conductivity, chemical stability, and semiconductor compatibility. However, liquid-phase confinement is challenging, risking alloy squeeze-out. We investigate eutectic bonding at 390 °C and solid-state bonding at 350 °C on crystalline (c-Si) and amorphous silicon (a-Si), evaluating bond strength via compression shear testing.

Materials and Methods
This study examines the bond strength of 1000 nm Au bonded to 200 nm amorphous and crystalline silicon (a-Si and c-Si) as a function of pre-bond treatment, bonding pressure, bonding time, and post-bond annealing. Experiments were conducted on 10 x 100 mm coupons using an EVG 540 bonder with a stainless-steel adapter wafer and graphite-film. Post-bond annealing (PBA) at 300 °C for 30 min was evaluated. The bonded coupons were then diced, and the resulting chips were subjected to compression shear testing using a TIRA shear tool to quantify bond strength.

Results and Discussion
Influence of pretreatment on a-Si & c-Si:
For eutectic Au/Si bonds formed at 390 °C (fig. 1), BHF pretreatment leads to similar shear strengths for both a-Si and c-Si with larger spread of the data for Au/c-Si bond. In contrast, without BHF pretreatment, Au/a-Si exhibits significantly higher bond strength than Au/c-Si, indicating that amorphous silicon is less sensitive to native oxide formation and interfacial contamination.

Process optimization for Au/c-Si bonding:
Building on the pretreatment effects, Au/c-Si stack is further evaluated in fig. 2a. An influence on bond strength between solid-state bonding at 350 °C and eutectic bonding at 390 °C using BHF pretreatment, with and without post-bond annealing (PBA) is conducted. Eutectic bonding at 390 °C consistently results in higher shear strength than solid-state bonding at 350 °C. In both cases, PBA at 300 °C for 30 min further increases the bond strength. Fig. 2b illustrates that for eutectic Au/c-Si bonding at 390 °C without pretreatment, the highest bond strength is achieved at a moderate pressure of 10 MPa. The anisotropic reaction of c-Si with Au at 20 MPa is assumed to cause excess squeeze-out that degrade uniformity [2]. Post-bond annealing increases shear strength at both 10 MPa and 20 MPa. Results indicate that moderate pressure combined with PBA is optimal for non-pretreated c-Si.

Influence of bond pressure on Au/a-Si eutectic bonds at 390 °C:
The Au/a-Si eutectic bonds formed at 390 °C with BHF pretreatment show a strong dependence on bond pressure (fig. 3): mean shear strength increases from ~30 MPa at 5–10 MPa to ~73 MPa at 20 MPa, suggesting enhanced Au–Si interdiffusion and improved interfacial cohesion at higher pressures.

Conclusion
Eutectic Au–Si bonding at 390 °C consistently achieves higher shear strength than solid-state bonding at 350 °C, with post-bond annealing further enhancing bond strength. Across the tested conditions, amorphous silicon either matches or surpasses crystalline silicon in shear strength and shows reduced sensitivity to pretreatment, highlighting its superior process tolerance.

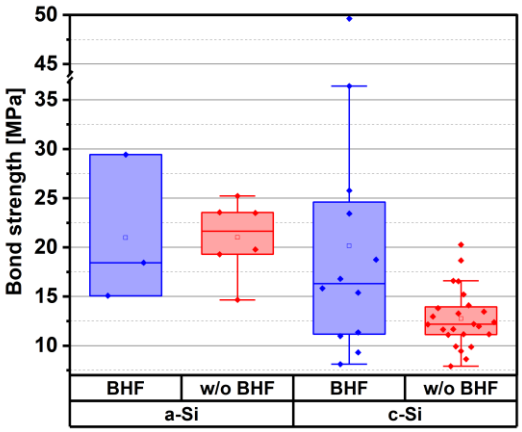

Fig. 1: Influence of BHF pretreatment on the shear strength of Au–Si eutectic bonds on a-Si and c-Si (a-Si: 200 nm; Au: 1000 nm; Bond temperature/ pressure/ time: 390 °C/ 5 MPa/ 15 min)

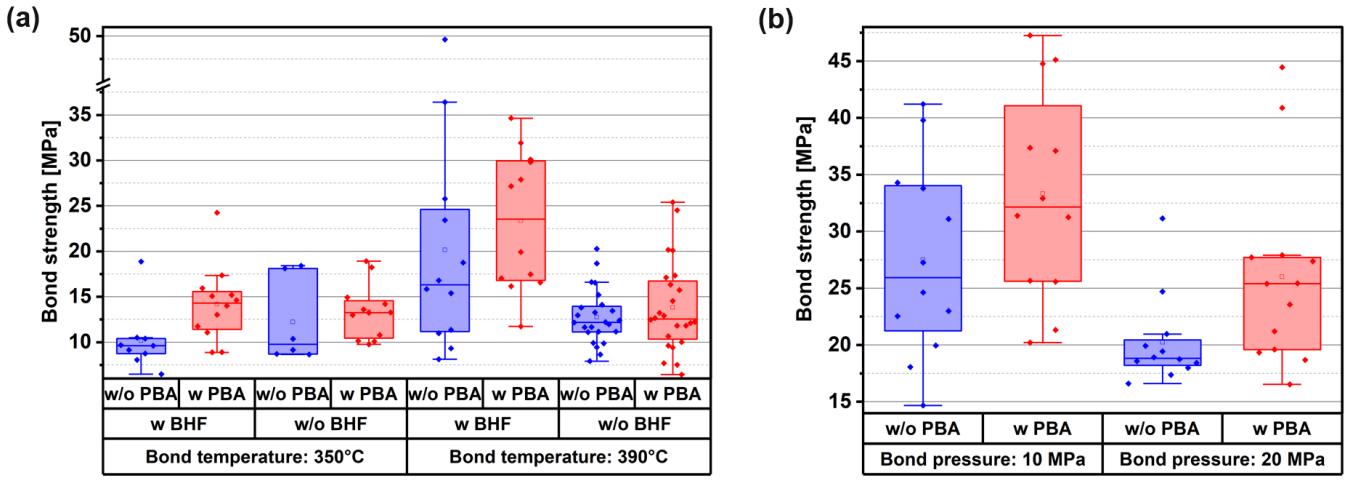

Fig. 2: Process optimization for Au/c-Si bonding: **(a)** Effect of solid-state (350 °C) and eutectic (390 °C) bonding with BHF pretreatment and post-bond anneal (PBA) (Au: 1000 nm; Bond pressure/ time: 5 MPa/ 15 min) and **(b)** Influence of bond pressure and PBA on eutectic bonds at 390 °C without c-Si pretreatment (Au: 500 nm; Bond time: 15 min)

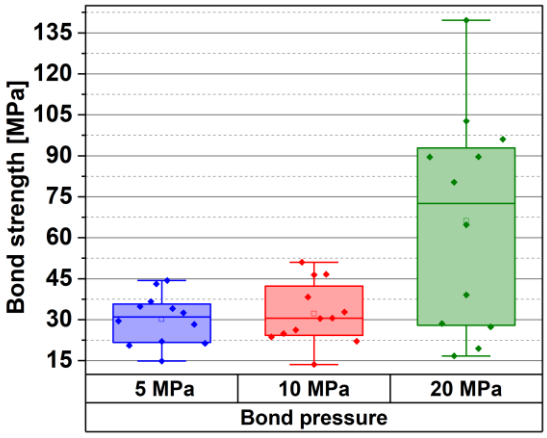

Fig. 3: Influence of bond pressure on Au/a-Si eutectic bonds at 390 °C (Au:a-Si = 500:200 nm; Bond time: 15 min, with a-Si pretreatment), showing a significant increase in shear strength.

References

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2. M. Abouie, Q. Liu, and D. G. Ivey, Mater. Sci. Eng. B 177, 1748 (2012).

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