Surface Analysis of SiO_2 for Die-to-Wafer Hybrid Bonding

Yuki Yoshihara, Junya Fuse, Daiki Kobayashi, Marie Sano and Fumihiro Inoue*.

YOKOHAMA National University
79-5 Tokiwadai, Hodogaya, Yokohama, Kanagawa, 240-8501, Japan

Advanced packaging and chiplet integration are being explored as an alternative integration scheme for achieving higher yield, density and energy efficiency[1]. A key technology required for advanced node chiplet is die-to-wafer (D2W) hybrid bonding. The bonding quality, i.e. bond strength, is a critical factor in ensuring the robustness of subsequent processes. In wafer level hybrid bonding, the bonding dynamics and bonding surface are well-controlled since the cluster system of wafer bonding equipments are available in mass-production[2,3]. However, the understanding of “D2W” bonding dynamics and the surface state after plasma activation is insufficient since the die bonder for D2W hybrid bonding is still not fully commercialized. Furthermore, the lack of the quantitative and robust bond strength measurement method for D2W bonding makes characterization of surface more challenging. In this study, the investigation of bonding surface is executed for die level hybrid bonding. In particular, the surface state before and after plasma activation was deeply analyzed. In addition, the bond strength measurements by nanoindentation (NI) were used to measure bonding energy[4].

A 300 mm silicon wafer is used for the origin of the substrates. A Si dioxide (SiO_2) layer with 100 nm thickness was used as the bonding interface. Fig. 1 provides an image of the sample structure used in this study. The D2W bonding process was executed using an optimized top bonding head and non-contact die transfer system. NI test, typically used for measuring Young’s modulus and hardness of the materials, was employed to measure bonding energy. As shown in Fig. 2(a), a sample was prepared by completely removing the upper silicon substrate to expose the bonding film. Indentation was then performed vertically on this exposed bonding layer, introducing delamination around the indentation (Fig. 2(b)). The size of the delaminated region was used to calculate the bonding energy.

Fig. 3 shows the relationship between bonding energy and PBA temperature. The measured bonding energy on D2W samples showed equivalent value range for the W2W samples. Therefore, the NI method is applicable for D2W bonding interface. It is observed that as the PBA temperature increases, the bonding energy also increases linearly. The amount of water desorbed from surface of SiO_2 with increasing temperature was evaluated by TDS (see Fig.4). The results revealed that higher temperatures led to greater surface water release. These results suggest that higher PBA temperatures increase water supply to the bonding interface. Furthermore, we propose a model shown in Fig. 5 by integrating the results from Fig. 3 and Fig. 4. This model indicates the state of the bonding interface at various PBA temperatures and suggests that higher annealing temperatures result in more water release from the film, leading to an increased supply of water to the bonding interface. The water fills the minute gaps at the bonding interface, thereby increasing the contact area between the upper and lower films. As a result, this process enhances the bond strength[5]. This suggests that the amount of water present at the bonding interface plays a critical role in the bond strength of hybrid bonding. it will be necessary to develop D2W bonding processes that take this factor into account.

From these results, the relationship between PBA, water content at the bonding interface, and bond strength in hybrid bonding has been clarified. These findings are expected to accelerate the research and development of hybrid bonding for future chiplet integration.

References

1. Debendra Das Sharma “Universal Chiplet Express (UCle)® : Building an open chiplet ecosystem” 2022.
2. J. H. Lau, “Recent Advances and Trends in Advanced Packaging,” in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 12, no. 2, pp. 228–252, 2022.
3. Fumihiro Inoue et al., “Area-Selective Electroless Deposition of Cu for Hybrid Bonding”, IEEE Electron Device Letters, Volume 42, Isuue 12, P1826-1829, 2021.
4. Y. Yoshihara et al., "In-Depth Analysis of Bonding Interface at Die Level Hybrid Bonding," 2024 International Conference on Electronics Packaging (ICEP), Toyama, Japan, pp. 3-4, 2024.
5. F. Fournel et al., “Water Stress Corrosion in Bonded Structures,” 2015 ECS J. Solid State Sci. Technol. 4 P124, 2015.

* *corresponding author e-mail: inoue-fumihiro-ty@ynu.ac.com*

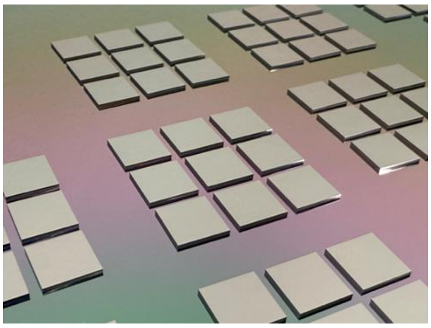

Fig. 1. Image of D2W sample.

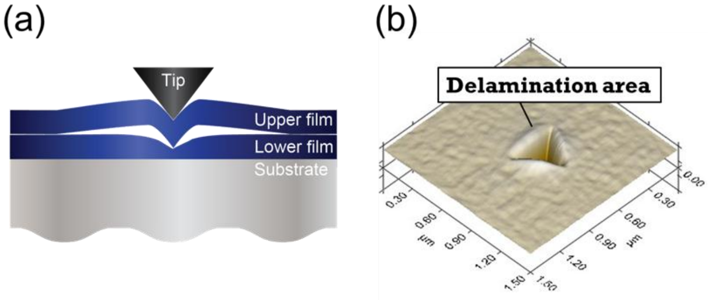

Fig. 2. Delamination behavior with Nanoindentation test (a) schematic illustration, and (b) 3D image.

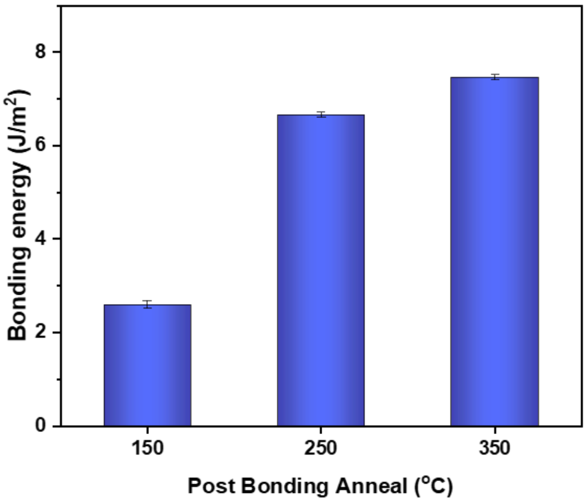

Fig. 3. Transition of bonding energy with post bonding anneal temperature.

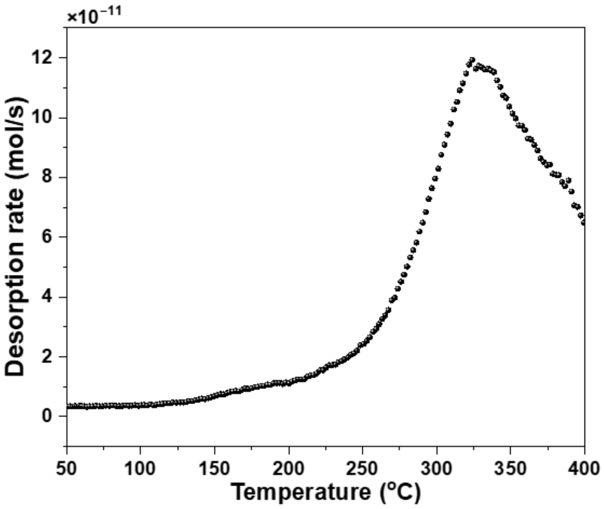

Fig. 4. TDS spectra of mass number of 18 M/e (water) for SiO_2.

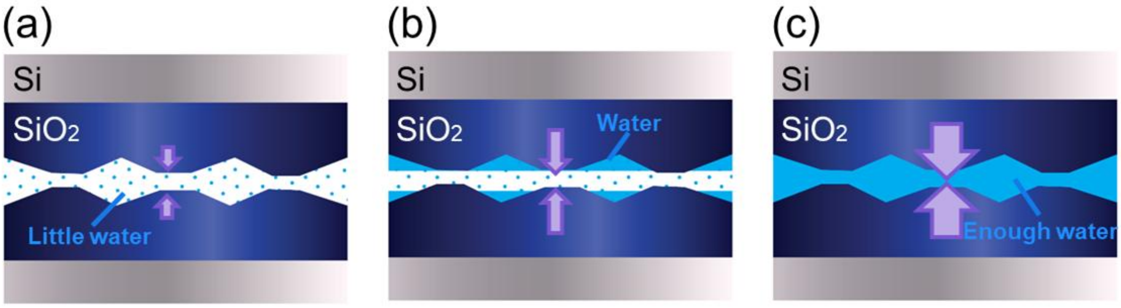

Fig. 5. Water content at the bonding interface during annealing at (a) 150 degrees, (b) 250 degrees, and (c) 350 degrees.