Bond Front Kinetics and Adherence of Direct Wafer Bonding in Dielectric-Dielectric Interfaces

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Direct wafer bonding of dielectric materials is a cornerstone of 3D integration and a precursor to fine-pitch hybrid bonding [1]. While dielectric-to-dielectric fusion provides the necessary mechanical stability and hermetic sealing for heterogeneous integration, the underlying physical and chemical mechanisms governing bond front propagation and post-bond adherence energy remain insufficiently understood. This study systematically investigates these dynamics across various PECVD films, including SiO_2, SiON, and TEOS SiO_2, to establish a predictive framework for optimizing surface kinetics and bond strength in next-generation interconnect architectures.

All dielectric layers were deposited via PECVD on 150 mm Si wafers with a nominal thickness of 500-570 nm. Following Chemical Mechanical Polishing (CMP), all surfaces achieved a root-mean-square (RMS) roughness below 0.25 nm to ensure spontaneous bonding [2]. The room-temperature bonding process was captured via infrared (IR) camera under monitored ambient conditions. The impact of surface pre-treatments, such as DIW rinse, a standard RCA cleaning, and plasma activations, such as N_2 + DIW rinse, O_2 + DIW rinse and Ar + DIW rinse was also studied. An AI-based algorithm was employed to extract the bonding speed from the IR footage. Finally, the resulting adherence energy was quantified through Maszara's blade insertion method [3] [4].

These findings provide a high-resolution benchmark for selecting dielectric-activation pairings tailored to specific integration requirements. Ongoing work focuses on the development of multi-physics models to correlate these experimental kinetic data with simulated surface energy and stress distributions. These modeling efforts aim to provide a predictive tool for optimizing bond uniformity and interface integrity in next-generation high-density 3D integration technologies.

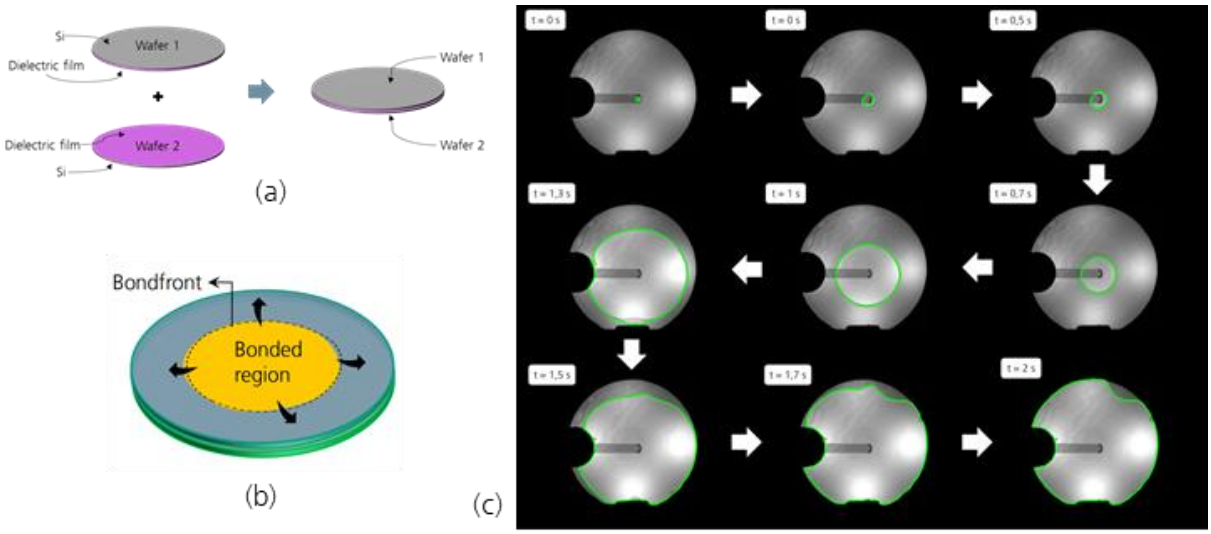

Figure: (a) A schematic showing dielectric to dielectric direct wafer bonding; (b) A schematic showing bond front during bond front propagation; (c) A sequence of images showing bond front propagation (green annotation for bond front) with time stamps

References

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