Sub-Micron Aligned Wafer Bonding via Capillary Forces

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Aligned wafer bonding is an important process for the fabrication of high-density vertically integrated microelectronics, optoelectronics, and micro- and nano-electromechanical systems. In all of these applications, the achievable alignment in the bonding process directly impacts the design and performance of the devices. For example, in the fabrication of 3-D integrated circuits, the wafer-to-wafer alignment accuracy determines the size, pitch, and number of interconnects at the interface, and as the critical dimensions of these devices shrink there is a dramatic need for processes with nanoscale alignment capability. Traditional alignment schemes, which rely on precisely positioning substrates relative to one another prior to bonding, cannot easily achieve sub-μm alignment and thus new strategies are essential. A key contribution to the alignment error in the traditional approach is elastic deformation that occurs during bonding and distorts the patterned surface (Fig. 1). The current work examines a new capillary force-based alignment approach and is focused on assessing the capability of the process to enable nanoscale alignment through management of the elastic deformations.

The concept of wafer-scale capillary assisted alignment, which has been previously demonstrated experimentally[1], is shown in Fig. 2. The process uses complementary hydrophilic and hydrophobic regions patterned on the two wafers in conjunction with confined water droplets placed on the hydrophilic pads. A key advantage of this approach is that the confined water droplets apply forces tangential to the surface of the wafer and thus can pull the substrates into alignment during bonding and mitigate the effects of elastic distortion.

Numerical simulations and experiments have been performed to examine the ability of the capillary assisted approach to minimize misalignment during bonding. For the simulations a local model that describes the normal and tangential stiffness of the confined droplet and a global model that predicts the deformations of the wafers during bonding were developed. The results of the simulations (Fig. 3) show that the capillary assisted scheme results in less misalignment than the traditional approach. Parametric studies using the models as well experiments on 100 mm diameter glass wafers have been completed and the results allow the capabilities and limitations of the process to be identified. The model and results from this study enable quantitative design of the process.

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[1] B. R. Martin, D. C. Furnange, T. N. Jackson, T. E. Mallouk, and T. S. Mayer, Advanced Functional Materials **11**, 381 (2001).

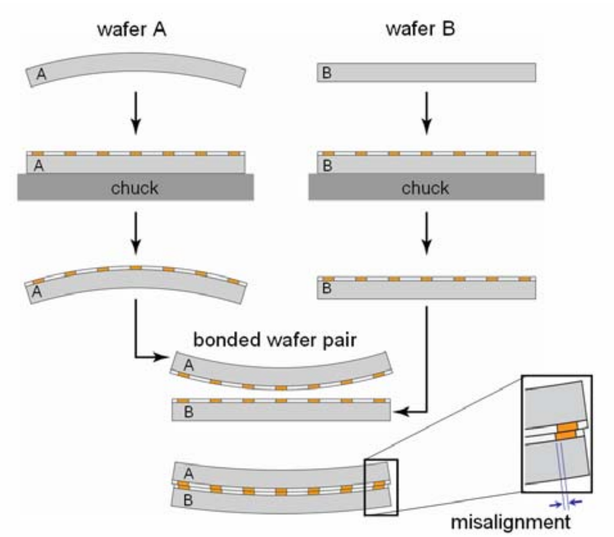

Figure 1 – Schematic of the contribution of elastic deformation to misalignment.

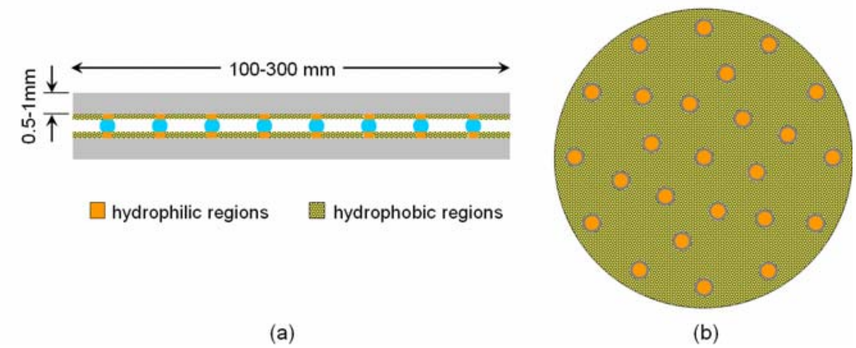

Figure 2 – (a) Illustration of capillary assisted wafer alignment scheme.
(b) Alignment pattern on a 100 mm wafer used in the model and experiments.

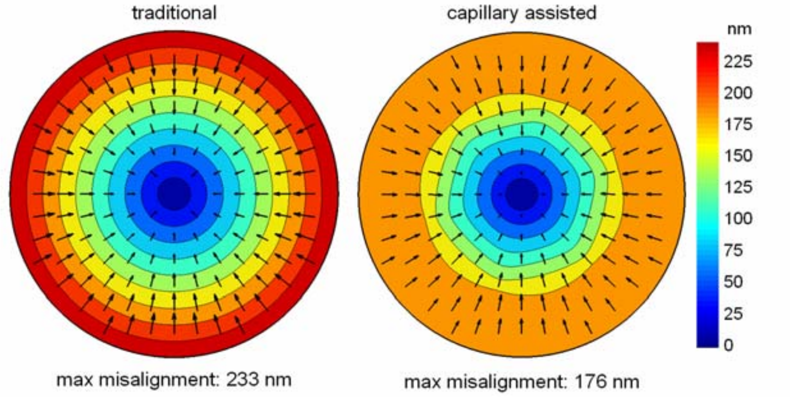

Figure 3 – Predicted misalignment after bonding in traditional and capillary assisted alignment schemes for a 100 mm wafer with a bow of 25 μm.