ROLE OF WAFER BOW AND ETCH PATTERNS IN DIRECT WAFER BONDING

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Objective

The use of wafer bonding in the fabrication of microelectromechanical systems (MEMS) often requires the aligned bonding of multiple wafers with etched features on the bonding surfaces. These factors complicate the process and can lead to bonding failure, as is shown in Figure 1. In order to improve the robustness of the process, it is critical to understand how factors such as wafer geometry and etched patterns affect bonding. The current work seeks to develop a general criterion for predicting bonding failure based on the mechanics of the process and to apply the criterion to examine the effect of wafer bow and etch patterns. The validity of the model is examined through experiments and design guidelines based on the model are developed.

Approach

Bonding is typically achieved by initially making contact between two wafers at a point, from which short-range surface forces pull the wafer surfaces into contact. Since wafer surfaces rarely match perfectly, the surface forces must elastically deform the wafers to close any gaps between the bonding surfaces. If the flatness deviations are too large, the surface forces are insufficient to deform the wafers and bonding fails. The bonding criterion that has been developed relies on this fact and compares the strain energy necessary to deform the wafers to the available surface energy. Rather than comparing the total strain energy required to the surface energy available, as has been done in previous work [1,2], the criterion developed here examines the increase in strain energy per unit area of bond front advance. This approach allows the effect of flatness deviations and etch patterns on bonding success to be assessed.

This criterion has been implemented to examine the role of wafer bow and etch patterns in bonding. Using plate mechanics, a closed form solution has been developed to assess the limits of bonding two wafers with initial wafer-scale curvature. The analytical results have been confirmed through finite element analysis. The effect of etch pattern has been examined by accounting for the reduction in bonding area that the features cause.

To validate the model, experiments have been performed in which a residually stressed thin film was deposited on the wafer back surface to induce wafer curvature and test patterns were defined on the bonding surfaces using dry etching. Wafers were bonded at room temperature and the extent of bond front propagation was measured.

Results

The mechanics suggests that the quantity that dictates whether bonding will be successful is dU_E/dA, which is the change in strain energy per unit area of interface advance. If this quantity exceeds the surface energy, the bond front cannot advance. Figure 2 shows how this quantity varies as a function of interface position when bonding two *blank* wafers with initial curvatures. Bonding becomes easier as the bond front advances, thus if the bond front begins to advance, it should propagate to the edge of the wafer. Furthermore, the modeling results show that there is a strong dependence on wafer thickness, *h*. Bonding difficulty also increases with increasing elastic modulus, *E*, and wafer curvature, κ; but is independent of wafer diameter. Modeling has also revealed that etched patterns can make bonding more difficult and may change how dU_E/dA varies with position. Patterns were developed for experimental verification in which the bond front is expected to not propagate to the edge of the wafer. Figure 3 shows an IR image of a wafer pair used in the experimental validation.

Conclusions

A model, based on energy considerations, to predict bonding failure as a result of wafer bow and etch patterns on the bonding surface has been developed. Results indicate that wafer geometry, elastic properties, and etch pattern density and layout are important factors. Experiments demonstrate behavior similar to that predicted by the model. Detailed modeling and experimental results will be presented.

References

[1] Q.-Y. Tong and U. Gosele J. Electrochem. Soc. **142**, 3975 (1995).
[2] H. Yu and Z. Suo, J. Mech. Phys. Solids **46**, 829 (1998)

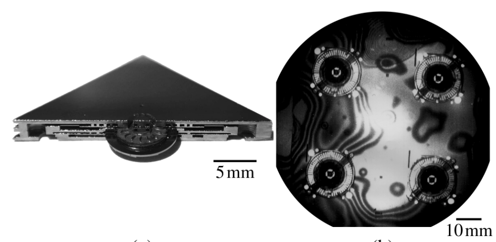

Figure 1 – (a) A six-wafer miniature gas turbine engine fabricated by direct wafer bonding. (b) IR image of a bonded multi-wafer bonded stack showing bonding failure.

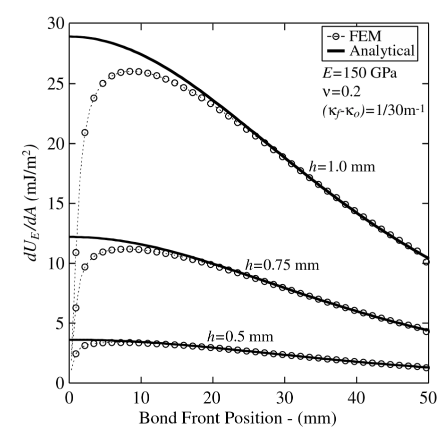

Figure 2 – The bonding criterion as a function of radial position for unpatterned wafers with an initial curvature. Results for 100 mm diameter silicon wafers with a 40 um bow.

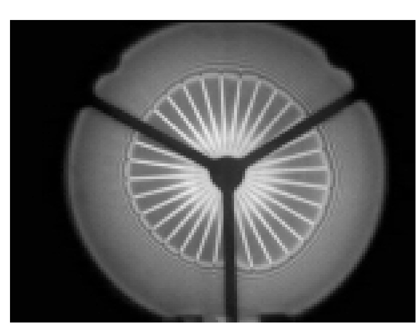

Figure 3 – IR image of a bonded test pair. A residually stressed film was used to induce curvature in one of the wafers and a ‘spoke’ test pattern was defined on the other. As predicted by the model the bond front does not propagate to the wafer edge.