Debonding of directly wafer-bonded silicon after high temperature process steps

J. Bagdahn[1)], H. Knoll[1)], M. Wiemer[2)] and, M. Petzold[1)]
[1)] Fraunhofer Institute for Mechanics of Materials, Heideallee 19, 06120 Halle (Saale), Germany
[2)] Fraunhofer Institute for Microintegration and Reliability, Reichenhainer Strasse 88, 09126 Chemnitz Germany

The debonding of directly bonded wafers, sometimes called reversible waferbonding, has different promising applications for fabrication of microelectronic devices based on thin, flexible and brittle wafers, for optoelectronic devices like LED's, solid state lasers or solar cells, as well as for MEMS (Microelectromechanical Systems).

Reversible wafer bonding can be used, in general, for four different applications (i) mechanical stiffening of brittle thin wafers by a "thick" handling wafer in order to avoid bending and fracture during fabrication (Figure 1), (ii), debonding of not well bonded wafers and re-bonding after a new cleaning process in order to increase yield, (iii) protection of semiconductor surfaces during transportation and storage, and (iv) transferring of expensive layers to a low-cost substrate.

Different approaches can be found in literature, based on the splitting of a wafer-bonded interface by applying an external mechanical force. It was shown that a wedge inserted at the rim of the bonded wafers can be applied to cleave the bonded wafers. This idea is similar to the well-known crack propagation test that is used to measure the interfacial fracture surface energy. Later on different techniques addressing the problem of the mechanical damage of the wafer surfaces during mechanical cleaving have been proposed. In these approaches, the required cleaving force is provided by either the vaporization of a water drop enclosed in the bonded interface or by applying a high-pressure gas (e.g. air or N_2) or liquid jet at the wafer edge or the mechanical cleaving is enhanced by debonding in water.

However, all these approaches are restricted to the case of directly bonded interfaces with low strength, thus limiting the bond annealing temperatures to the range from room temperature to about 110°C. They can not be applied for debonding of wafers after typical higher annealing temperature (400 °C up to 1100 °C), where stable covalent bonds have been formed.

In order to split directly bonded wafers even after a high annealing step a new patented debonding approach was developed. The technique is based on a controlled slow crack propagation due to the stress corrosion of siloxane bonds in the bonded interface. To achieve a reliable control of the crack growth without kinking into the wafer requires the knowledge of several fracture mechanics parameters, which have to be determined by preceding experimental measurements.

In case of cleaving bonded wafer pairs by subcritical crack growth, the process speed becomes a critical issue. It was shown that splitting velocities up to several millimeters per second can be reached in general by the technique.

However, further investigations demonstrated that the possible maximum splitting rate depends on the wafer material (Si/Si, Si/GaAs), the wafer thickness ratio, the bonding process parameters, and the environmental conditions during cleaving. In addition, also details of the cleaving process, in particular the precision in loading conditions, and the wedge geometry are of considerable influence on the results. These requirements could be addressed by using a special cleaving setup which was accordingly adapted to the required high precision in the loading conditions [Figure 2].

The technique allows to debond directly bonded silicon wafers after hydrophilic pre-treatment even after an annealing temperature treatment at 1100°C. In combination with wafer bonding, the method can be used for a temporary stiffening and handling of thin and brittle wafers during fabrication, even if the wafers are exposed to high process temperatures. The approach may also be applied to fabricate MEMS by transferring a thin wafer which was temporally bonded to a handle wafer to the sensor substrate.

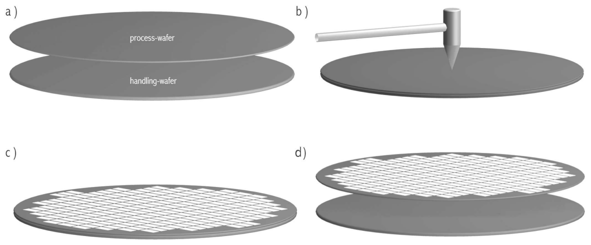

Figure 1: Schematic representation of wafer bonding and debonding a) Alignment of the carrier and the process wafer, b) waferbonding, c) Fabrication of electronical and mechanical structures on the surface of the process wafer, d) separation of the process wafer from the handling wafer

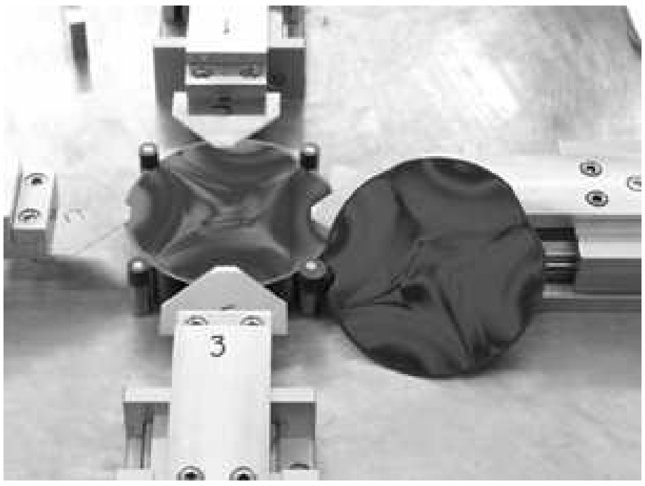

Figure 2: Cleaving device with completely debonded wafer pair. The wafers bonded under hydrophilic condition and annealed at 1100° C for 5 h.