Measurement of the Local Strength Distribution of Directly Bonded Silicon Wafers Using the Micro-Chevron-Test (MC-Test)

contact: pe@iwmh.fhg.de

J. Bagdahn[1], A. Plößl[2], M. Wiemer[3] and M. Petzold[1]

[1] Fraunhofer Institute for Mechanics of Materials, Heideallee 19, 06120 Halle, Germany

[2] Max Planck Institute of Microstructure Physics, Weinberg 2, D-06120 Halle, Germany

[3] Fraunhofer Institute of Reliability and Microintegration, Reichenhainer Str. 80, D-09126 Chemnitz, Germany

1 Introduction

- For the development, quality control and failure analysis of wafer-bonded micromechanical devices an exact knowledge of the bonding strength as a function of the bonding parameters is required.
- In addition, it is frequently observed that wafer-bonded devices with a "poor" bond strength stem from adjacent regions of the wafers. Therefore, also the local distribution of the bonding strength as a function of wafer position is of considerable interest.
- Most strength tests, e.g. the crack propagation method (DCB-Test) as well as tensile or bending tests cannot be applied to study the local strength distribution due to the excessive specimen size or because of inherent measurement uncertainty.
- To overcome these shortcomings, a new and more reliable strength testing method termed the Micro-Chevron-Test (MC-Test) was developed. The bond strength is characterized by the fracture toughness, K_{IC}, as is common in fracture mechanics.

2 The Micro-Chevron-Test

- (100) Si wafers were wet anisotropically etched to form 52 single MCT specimens on a 4'' wafer with a chevron pattern (see Fig. 1 and 2).
- After pre-treatment (RCA- or plasma cleaning), the patterned wafer was directly bonded to a flat wafer. Due to the specimen geometry, bonding is limited to the chevron region (right orange part in Fig. 2). Subsequently, the bonded wafer pairs were annealed at different temperatures (range: 200°C to 1100°C) and diced.
- Studs were glued onto the specimens at the non-bonded edge of the samples. Using a tensile testing machine, the samples were loaded (Figure 2) until fracture occurred.

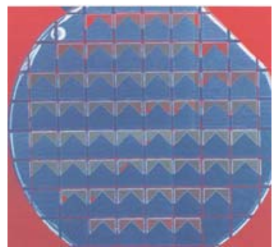


Figure 1: Scanning acoustic micrograph of a bonded wafer pair containing 52 single MC samples

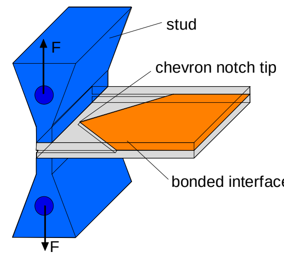


Figure 2: Schematic drawing of the MC-Test arrangement

- During loading, a crack initiates in the wafer-bonded interface at the chevron notch tip (see image included in figure 3). The crack grows continuously as a function of the testing load until it reaches a critical length. At this point, the crack accelerates causing the fracture of the sample. The load decreases thus defining a load maximum F_{max} (Fig. 3).
- Using 3D FEM calculations, a relationship between the measured load maximum F_{max} and the fracture toughness K_{IC} was derived

$$K_{IC} = \frac{F_{max}}{B\sqrt{w}} \cdot Y(\alpha)_{min} \qquad Y(\alpha)_{min} = \frac{5.805 * \alpha_o + 0.725}{H^{3/2}}$$

(α: ratio of crack length and sample length, α_o: ratio of the chevron tip distance and sample length, H: wafer thickness, B: sample width and w: sample length)

Figure 3:

Force-displacement plot of a typical MC test. An in situ IR transmission image of a crack in the bonded interface is included.

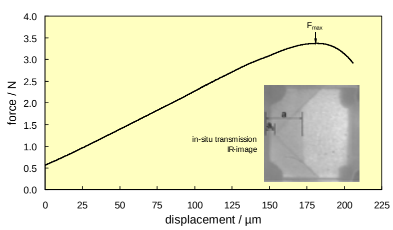
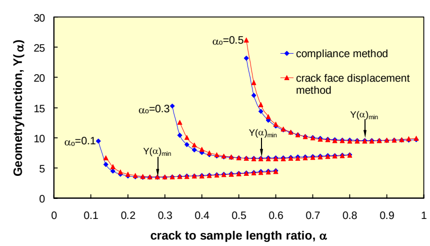


Figure 4:

Results of FEM calculations of the geometry function $Y(\alpha)$ for different values of α_o.



3 Application of the MC-Test and conclusions

Figure 5:

Fracture toughness, K_{IC}, versus annealing temperature as function of the pre-treatment for samples with native-thermal interfacial oxide

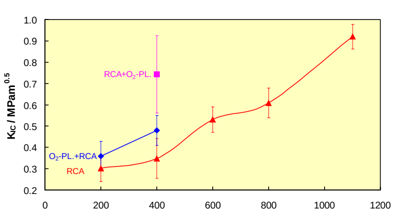
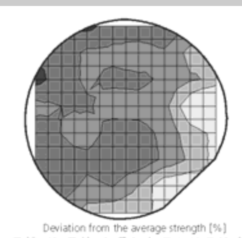


Figure 6:

Plot of strength distribution across a bonded wafer pair (RCA, annealing temperature 400°C) derived by MC-Test.



- It could be shown that the MC-Test allows to measure the adhesive bond strength with an accuracy of $\pm$ 3% on the chip size level. Therefore, the test can advantageously be applied to study the atomic bond strength as a function of bonding technology (Fig. 5).
- Furthermore, the small sample size and high accuracy allows the determination of the local strength distribution if the strength results are plotted as a function of the sample position at the wafer (Fig. 6)
- Compared to alternative methods, the advantages of the MC test are its superior accuracy and its potential to study local strength distributions.
- Thus, the test can be applied as a versatile tool to measure the strength as a function of bonding parameters as well as to follow up sources of yield problems during the fabrication of micromechanical components.

Max-Planck-Institut für Mikrostrukturphysik

Fraunhofer Institut Werkstoffmechanik

Fraunhofer Institut Zuverlässigkeit und Mikrointegration