# Crack propagation in micro-chevron-test samples of direct bonded wafers

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## Introduction

Micro Electro Mechanical Systems (MEMS) are applied in a wide industrial range. Their structures become more complex by using different materials in one sample. MEMS have at least one typical component size in sub-millimetre range (smaller than 100 µm) which determines its function [1]. They often consist of two or more components and have to be joined by wafer bonding. To ensure the quality during the manufacturing process as well as to provide data for further FE-simulations, significant material parameters are required to characterise new structures.
The behaviour of the structure depends on the bonded interface and the bonding process itself. Wafer bonding describes all technologies for joining two or more substrates directly or using certain intermediate layers. Current investigations are focused on the so-called low temperature bonding without intermediate layers and temperatures below 400 °C [2]. Low temperature bonding requires a pre-treatment of the wafer surfaces in a plasma, pre-bonding at room temperature and heating to temperatures between 200 °C and 400 °C [3]. Additional to the bonded materials, the toughness of the bonded interface is also directly related to the bonding process. An increased temperature leads to a higher toughness of the bonded interface.
The fracture toughness is a suitable value to describe the damage behaviour of the bonded interface. Based on a micro-chevron-specimen, the fracture toughness of this specimen can be determined numerically and experimentally. The experimental determination can be executed by combining experiment with numerical analysis.

## Theory

The analyzed samples consist of two single chips bonded together. Because they have a quadratic footprint, their width $w$ and thickness $t$ are equal [4]. The analysis is focused on specimens with both a width and a thickness of 10 mm, Fig. 1.
The height of the specimen depends on the height of the unstructured wafer hw1 and the height of the structured wafer $h_{w2}$ as well as the structure height, Fig. 2. While the height of the structured chip is kept constant, the height of the unstructured chip varies for different material combinations.
The bonded chip is loaded perpendicular to the x-y-plane in front of the sharp notch. The lifting of the crack fronts leads approximately to a Mode I crack opening. So the fracture toughness $K_{IC}$ can be calculated against the geometrical parameters width and thickness by

$$K_{IC} = \frac{F_{MAX}}{t \cdot \sqrt{w}} \cdot Y_{MIN} \qquad (1)$$

While the maximum force $F_{MAX}$ can be measured during a tensile test, the minimum of the stress intensity coefficient $Y_{MIN}$ is determined by FE-simulation.

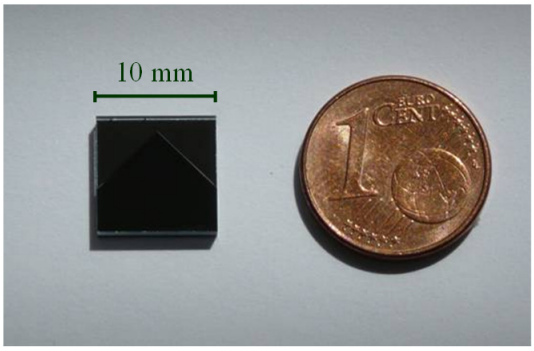


Figure 1: Geometry of a micro-chevron-specimen compared to an one cent coin.

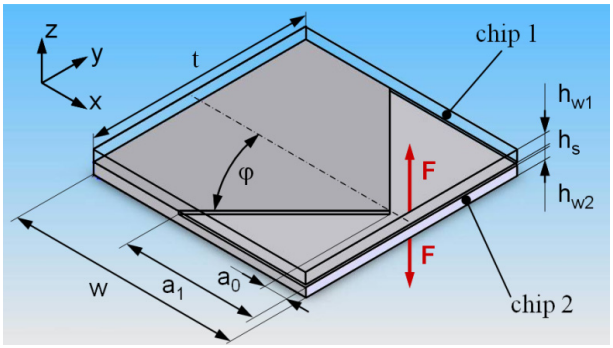


Figure 2: Micro-chevron-specimen prepared from a processed wafer.

One possibility to estimate the stress intensity coefficient is the compliance method. It combines experiment with numeric analysis. With an extension of the crack length, the compliance of the specimen increases too. By keeping the displacement $u_z$ constant, the reaction forces $F$ are simulated subjected to a well defined crack propagation. For different relative crack lengths

$$\alpha = \frac{a}{w} \tag{2}$$

the compliance $C(\alpha)$ can be interpolated, using the equation

$$C(\alpha) = \frac{u_z}{F(\alpha)} \tag{3}$$

After scaling the compliance with the thickness $b$ and the weaker materials YOUNG's modulus for plane strain [5]

$$C'(\alpha) = \frac{E \cdot b}{1-\nu^2} \cdot C(\alpha) \tag{4}$$

the function of the stress intensity coefficient can be determined

$$Y(\alpha) = \sqrt{\frac{1}{2} \cdot \frac{d}{d\alpha} \cdot C'(\alpha) \cdot \frac{\alpha_1 - \alpha_0}{\alpha - \alpha_0}} \tag{5}$$

Its minimum, the stress intensity coefficient $Y_{MIN}$ can be calculated. Inserting $Y_{MIN}$ in equation (1) leads to the fracture toughness.

## EXPERIMENT

In addition to the numerical determination of the stress intensity coefficient the maximum force is measured during a tensile test. To initiate the force, two studs are glued on the top and the bottom of the specimen, Fig. 3.

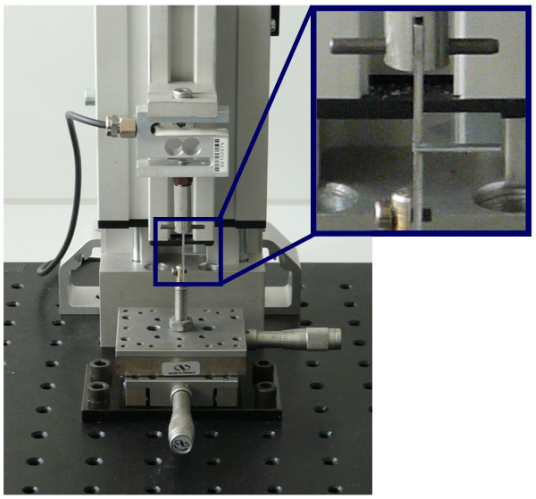

Figure 3: Experimental setup for the determination of the maximum force

The experiment is carried out displacement controlled. When the crack length $\alpha$ reaches its critical value, the measured force converges toward the maximum force $F_{MAX}$ before decreasing again. When the crack length exceeds the value $\alpha_1$ the stable crack propagation becomes instable and the specimens fails.

## RESULTS

The variation of geometries and wafer materials leads to different functions for the stress intensity coefficient and therefore to different fracture toughness.

By keeping the structure height $h_S$ constant, using the same material combination (silicon-silicon-samples) and changing the position of the structure by using two structured wafers (Si-Si geometry 2) instead of a sample consisting of an unstructured and a structured chip (Si-Si geometry 1), only a negligible variation of $Y(\alpha)$ can be observed, Fig. 4.

The variation of the wafer height leads to a significant deviation between the functions and minima of the stress intensity coefficients. So the values of $Y(\alpha)$ decrease with increasing wafer height.

With the substitution of the unstructured silicon by a borosilicate glass chip (while keeping the structured chip) the height of the unstructured chip changes too. In addition to the variation of the sample geometry the scaling of the compliance is carried out using the material properties of the weaker glass instead the once of silicon, because the compliance of the samples is mainly affected by the borosilicate glass. This leads to smaller values of the stress intensity coefficient for silicon-glass-samples compared to silicon-silicon-specimens, Fig. 4 (Si-Si geometry 1 and Si-glass).

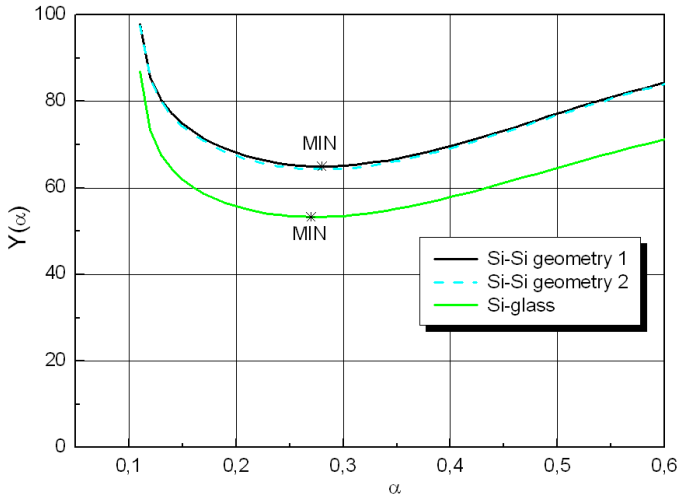


Figure 4: Estimation of dimensionless stress intensity coefficient as a function of geometry and wafer materials.

Based on the geometry, the minima of the stress intensity coefficients and the maximum force measured during experiment the highest fracture toughness is presently observed for direct bonded silicon-silicon-wafers.

## CONCLUSION

The compliance method is a suitable approach to estimate the fracture toughness of direct bonded wafers. While the influence of the specimen geometry is considered during the calculation of stress intensity coefficient, the pre-treatment and the bonding temperature itself directly affect the measured maximum force.
Currently, the stress intensity coefficient is calculated using another numeric approach, the energy release rate, to verify the results of the compliance method. In addition to the numeric calculations the measurement of the crack length depending on the applied load will be carried out.

## REFERENCES

[1] G. Gerlach, W. Dötzel, Introduction to microsystem technology, John Wiley & Sons, Ltd., (2008).
[2] M. Wiemer, J. Froemel, T. Gessner, T. Otto, Wafer bonding in micro mechanics and microelectronics – an overview. in Ed. B. Michel, R. Aschenbrenner: The world of Electronic Packaging and System Integration. ddp goldenbogen Dresden, (2004) 307.
[3] M. Wiemer, J. Froemel, M. Haubold, C. Jia, D. Wuensch, T. Gessner, ECS Transactions, 16 (8) (2008) 81.
[4] J. Bagdahn, A. Plößl, M. Wiemer, M. Petzold, Electrochemical Society, (2001) 218.
[5] D. Munz, R.T. Bubsey, J.E. Srawley, International Journal of Fracture. 16 (4) (1980) 359.