A NEW PUSH-PULL SAMPLE DESIGN FOR MICROSCALE MODE 1 FRACTURE TOUGHNESS MEASUREMENTS UNDER UNIAXIAL TENSION

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The miniaturization of microelectronic devices and the use of thin hard coatings have led to an increased demand for knowledge on the fracture behaviour of microscopic structures. A new geometry called Micro-SENT is proposed in this work that allows performing experiments in uniaxial tension on the microscale using a standard flat punch indenter by making use of a symmetric push-pull sample design. This enables the measurement of mode 1 fracture toughness under uniform tensional far-field loading as opposed to current state of the art approaches based on cantilever bending or micropillar splitting.

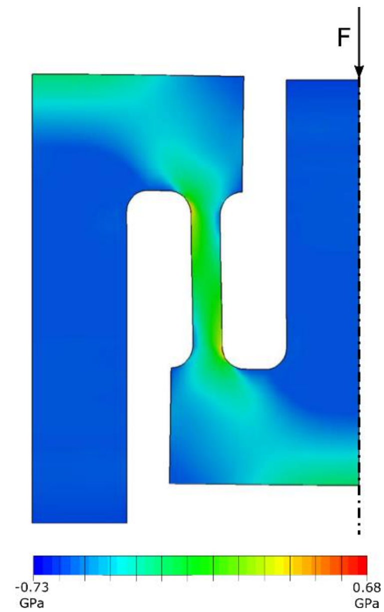

Figure 1 – Maximum principal stress distribution from FEM on the symmetric Micro-SENT sample

Finite element simulations were performed to optimize the sample geometry with respect to homogeneity of the maximum principal stress within the tension rod. The stress state was analyzed and the geometry factor calculated for varying notch depth to rod thickness (a/w) ratios. This was then compared to the standard Single Edge Notched Tension (SENT) geometry, for which an analytical solution for the stress intensity factor exists. A very good correspondence was found for notch depth to rod thickness ratios a/w < 0:3 with differences < 10% compared to the standard SENT sample. Furthermore, it was verified that the mode 1 stress intensity factor KI is nearly constant over the width of the tension rods and that the mode 2 and 3 stress intensity factors are in average one order of magnitude smaller than KI. Therefore, the sample geometry leads to a stress state that may be regarded as pure tensile mode 1 loading. Finally, the influence of the indenter and sample axes was analyzed. It was found that for a misalignment of 0.5° (1°), the geometry factor is changed by a moderate 5% (12%).

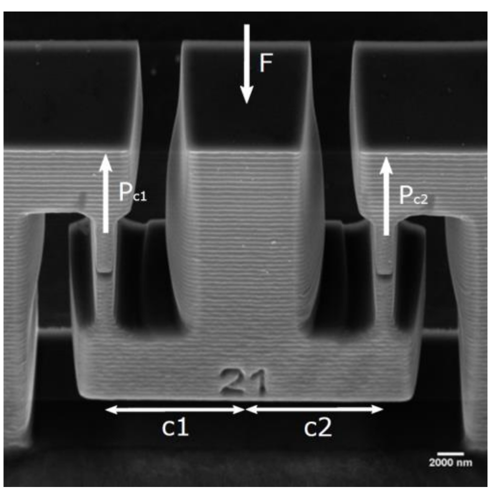

Figure 2 – SEM image of a Micro-SENT sample prepared from a Si single crystal by reactive ion etching and FIB.

A protocol was developed to prepare the new sample geometry using a focused ion beam. Notched samples featuring a/w ratios of 0.3 and 0.4 were prepared from a (100)-oriented Si wafer by a combination of reactive ion etching and focused ion beam milling and tested inside a scanning electron microscope. The measured mode 1 fracture toughness KI;q was found to be constant with a/w and in average 1:05±0:06 MPa√m (n=8), which is in excellent agreement with literature. Error analysis based on Gaussian error progression allowed estimating the experimental uncertainty at around 7%. Post-test high resolution SEM analysis of the fracture surfaces showed very consistent patterns with fracture occurring mostly along (110) cleavage planes.

The proposed geometry was thus fully characterized by finite element simulations and validated experimentally on Si single crystal samples. It may be used for fracture toughness measurements on the microscale in the future. It is especially interesting in cases where a uniaxial and homogeneous stress far-field is desired, if crack tip plasticity plays an important role, or when precise positioning of the indenter on the sample is difficult to achieve