The Use of COMSOL Multiphysics® for Studying the Fracture Pressure of Rectangular Micro-Channels Embedded in Thin Silicon Substrates

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Introduction: Micro-channel silicon cooling plates for silicon detectors are currently used at CERN. For evaluating cooling plate reliability when internally pressurized, an investigation has been launched for understanding the mechanical performances of rectangular micro-channels embedded in mono-crystalline silicon subject to internal hydraulic pressure.

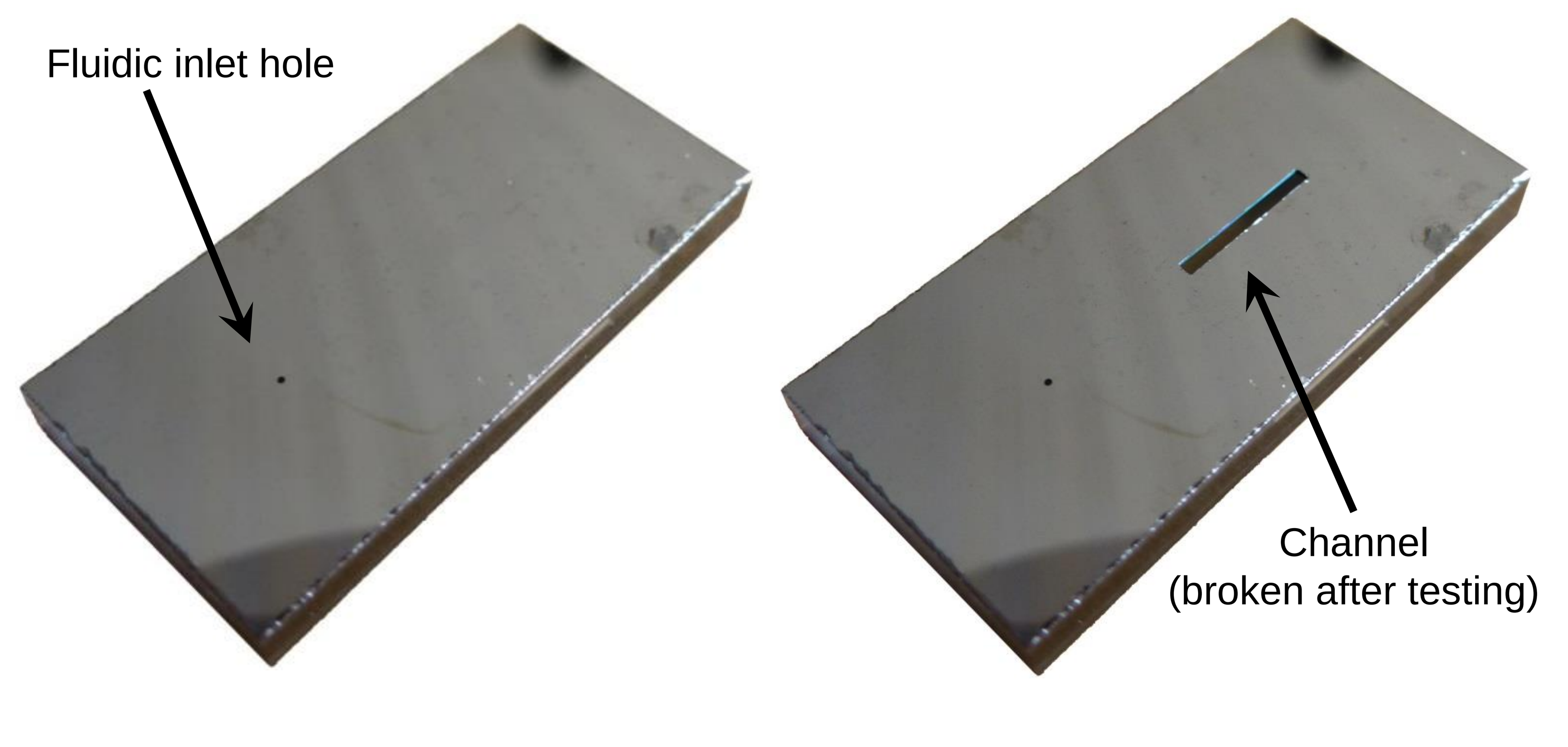

Figure 1. Silicon Microchannel Samples before and after testing.

Computational Methods: Both a 3D and two 2D models of silicon micro-channels samples were created in the Structural Mechanics Module of COMSOL. Fracture, calculated by the J-integral, is considered to have occurred when the strain energy release rate is greater than the critical elastic energy release rate for that geometry and materials.

$$J = \int_{\Gamma} W dy - T_i \frac{\partial u_i}{\partial x} ds = \int_{\Gamma} \left(W n_x - T_i \frac{\partial u_i}{\partial x} \right) ds$$

The micro-channels are etched in a silicon wafer and then closed by anodic bonding with a 2 mm Pyrex wafer. The silicon "cover" height, the channel width and the internal pressure are changed parametrically. The internal pressure is introduced as a boundary load equally on all sides of the channel. The samples are experimentally tested by injecting water into the channel and increasing the pressure till the rupture of the "cover".

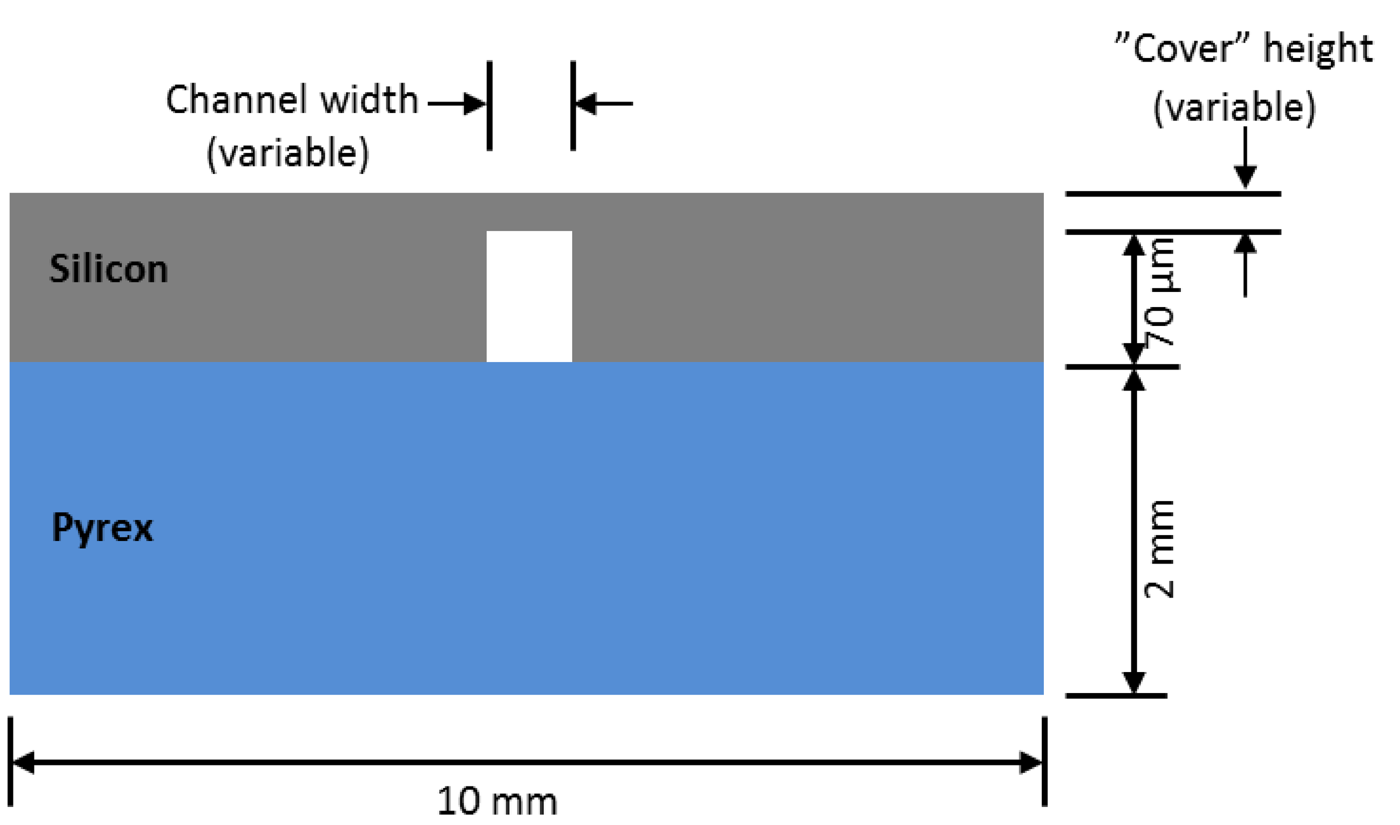

Figure 2. 2D Geometry of Microchannels in COMSOL

Results: The fracture pressure for each geometry is determined when the maximum stress measured within the channel or the J-integral calculations exceeds the analytically calculated critical stress. All three models are compared to experimental results.

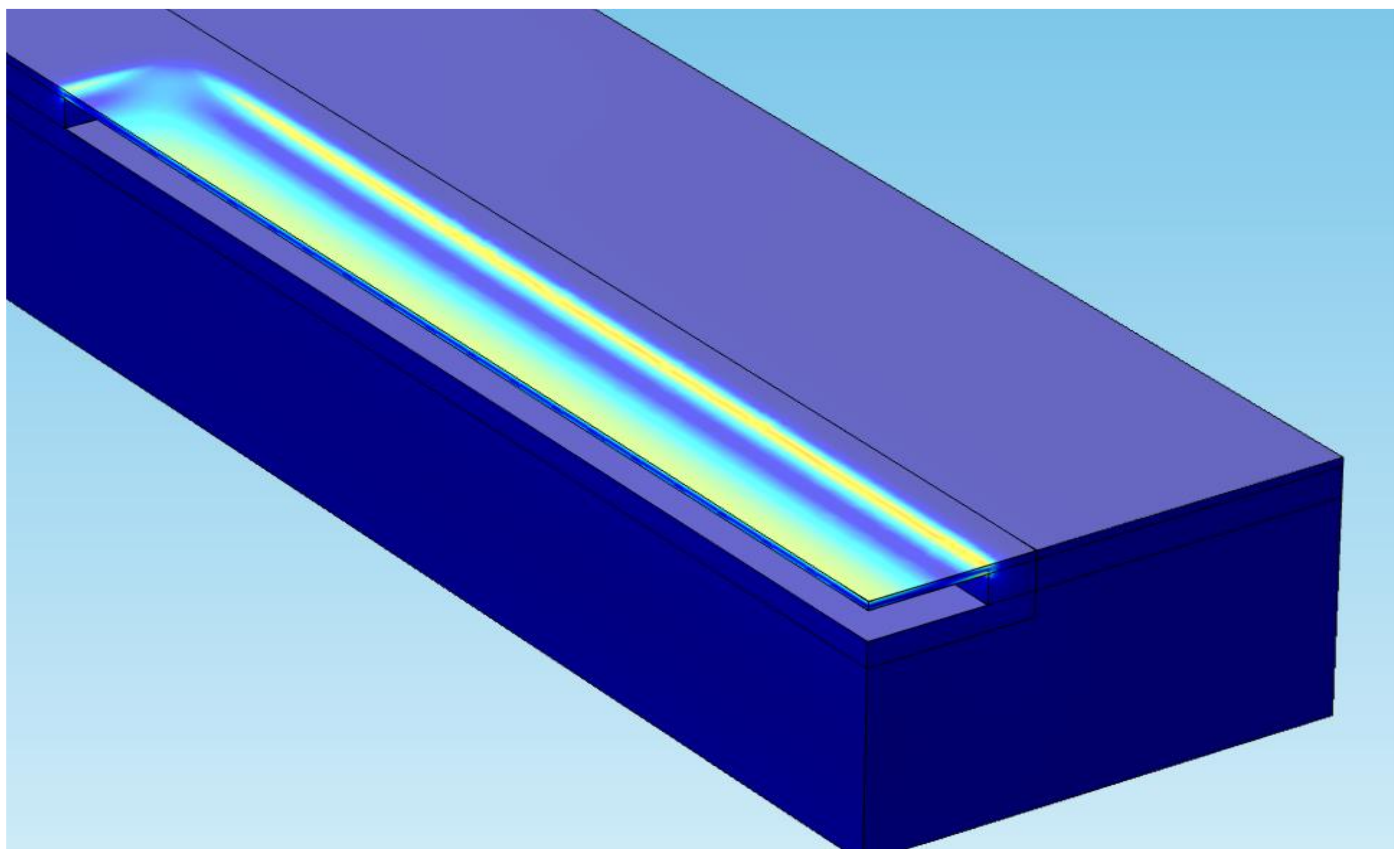

Figure 3. 3D Model with Stress Analysis

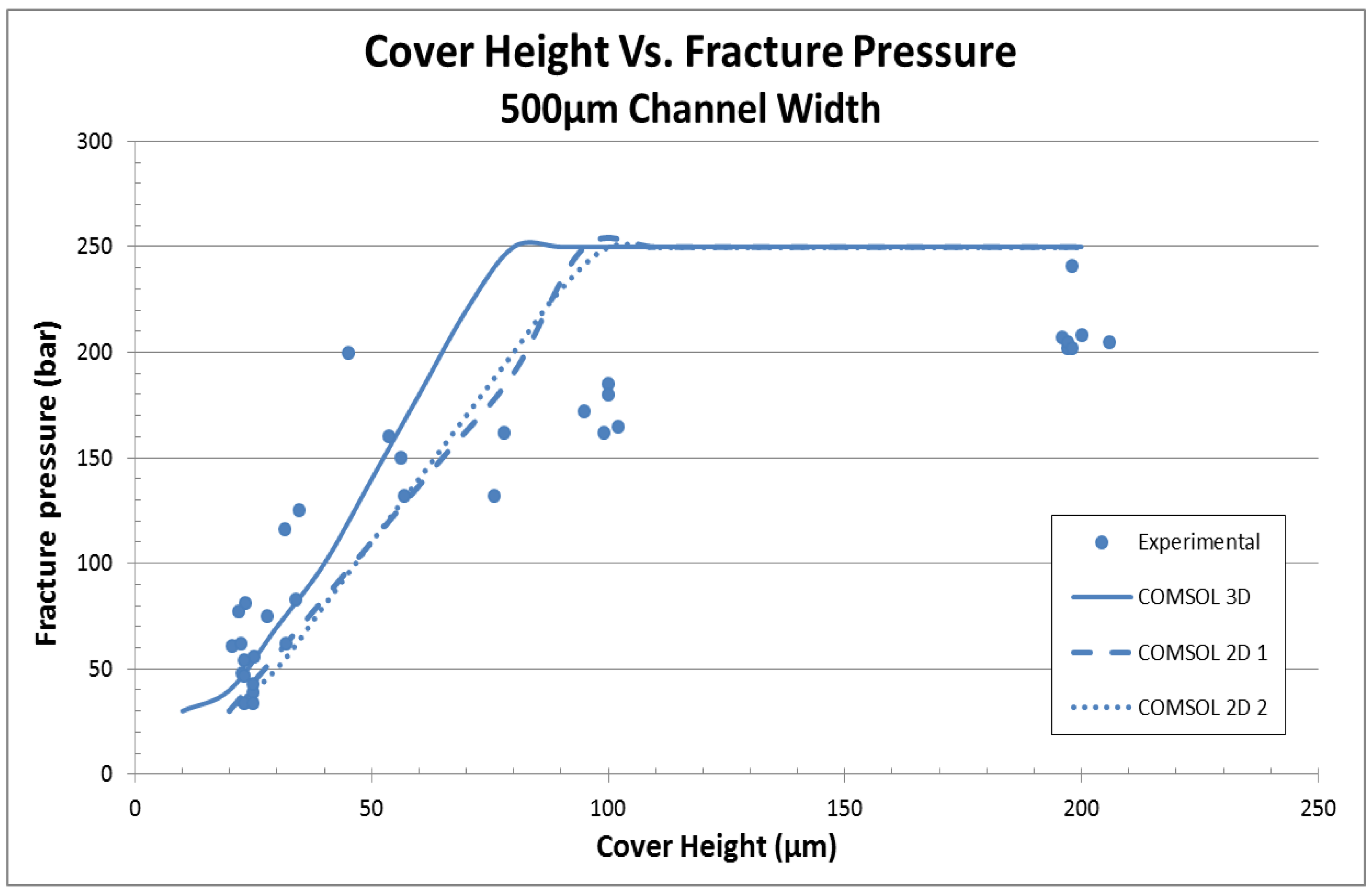

Figure 4. Comparison of Experimental Results to COMSOL Models.

Conclusions: Preliminary results of 3D and 2D COMSOL models compare well to experimental testing of fracture pressure. Understanding the reliability of these devices is paramount to develop them as extremely efficient thermal solutions.

References:

1. COMSOL; Single Edge Crack, Model Documentation
2. Lawn, Brian; Fracture of Brittle Solids, Cambridge University Press, Ch.9.1 (1993)
3. A.Francescon, A.Mapelli, G.Nuessle, P.Petagna, A.Pezous, P.Renaud, G.Romagnoli "Application of Micro-channel Cooling to the Local Thermal Management of Detectors Electronics for Particle Physics" Microelectronics Journal 44 (2013), pp. 612-618 DOI information: 10.1016/j.mejo.2013.03.012

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