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-fluidic silicon devices are being developed and studied for high energy physics applications at CERN since 2009.

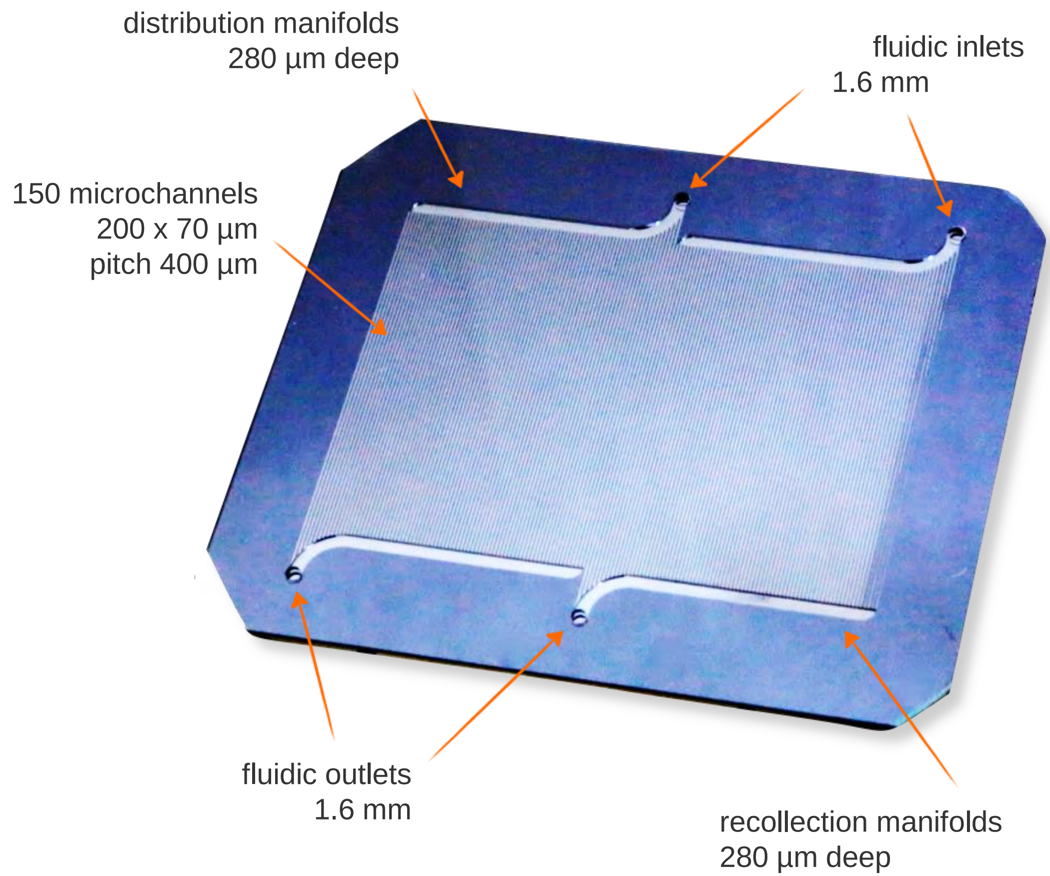

Figure 1: Microchannel Cooling Plate

Introduction

The amount of material in the sensing area must be minimized.

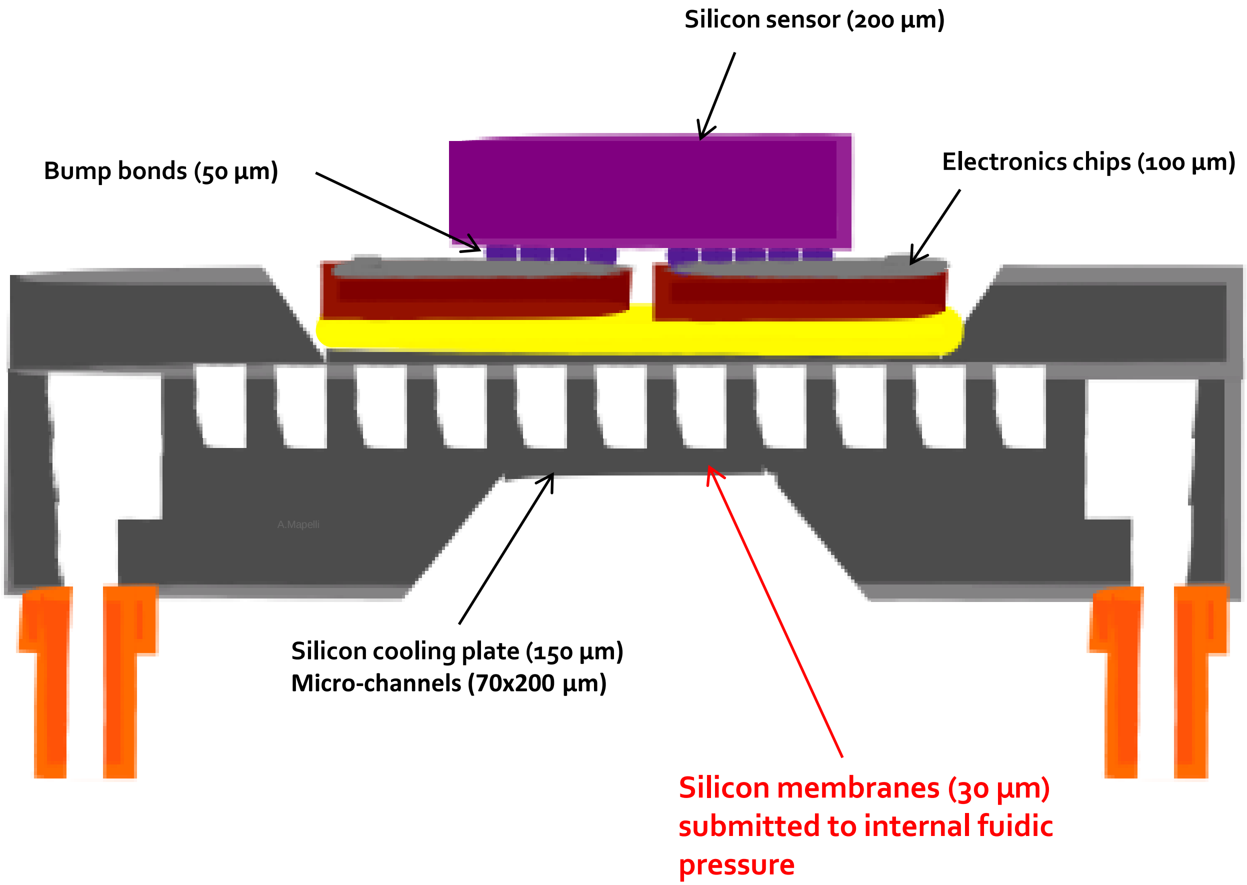

Figure 2: Microcooling Device Thermally Connected to a Detector

Geometry of Pressure Test Samples and Comsol Models

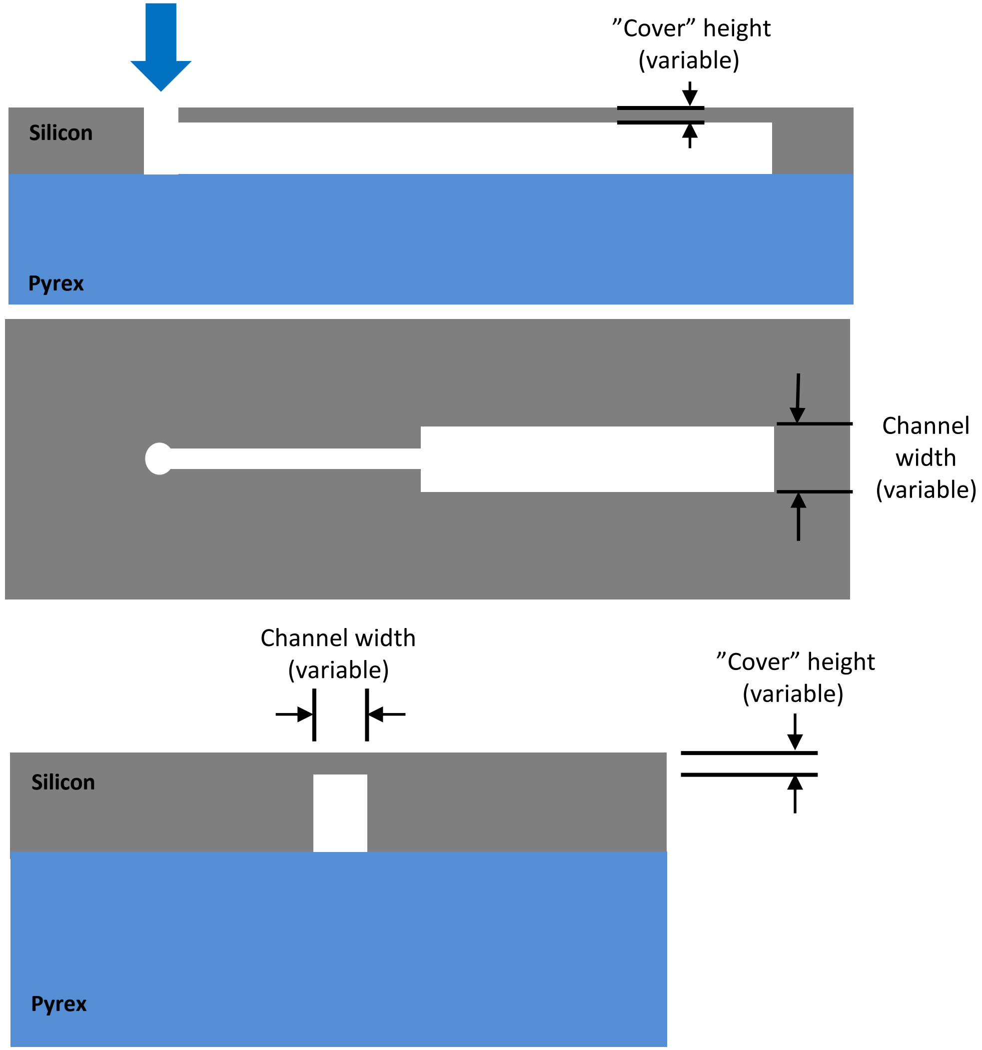

Figure 3: Schematic of Geometries for Pressure Test Samples and Comsol Models

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Experimental Testing for Fracture Pressure

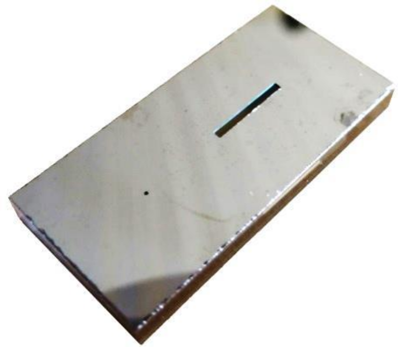

Figure 4: Sample after Silicon Fracture

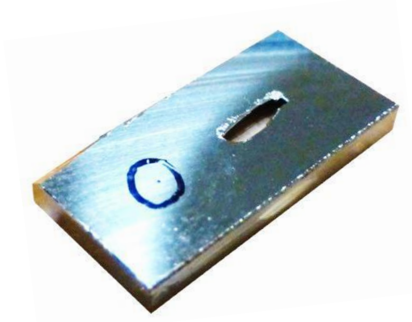

Figure 6: Sample after Pyrex-silicon Delamination Fracture

Figure 5: Qualitative View of Silicon Fracture

Figure 7: Qualitative View of Pyrex-silicon Bonding Fracture

- Fabricated pressure test samples with simple microchannel geometry.
- Introduced internal hydraulic pressures until fracture of silicon or Pyrex-silicon bonding interface.

Comsol Models

- Structural Mechanics Module
- One 3D, two 2D models
- Parameters:
  - Cover height of silicon
  - Channel width
  - Pressure
- Materials: Pyrex, silicon
- Conditions:
  - Union between Pyrex and silicon
  - Fillet at bottom of channel
  - Physics generated mesh - Finer
  - Pressure load on all sides of channel
  - Symmetry to create half device
  - Fixed contact on ends of device, top/bottom free
- Results: J-integral calculations at corners of channel, von Mises stress

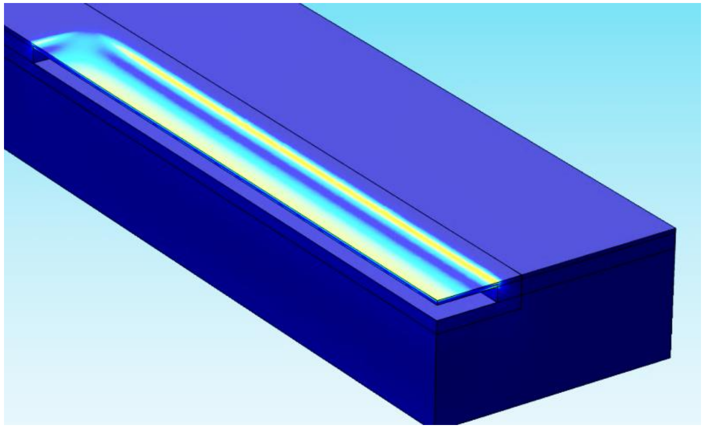

Figure 8: 3D Model with von Mises Stress

Figure 9: 2D Model with J-Integral Contours

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Analytical Formula and J-Integral

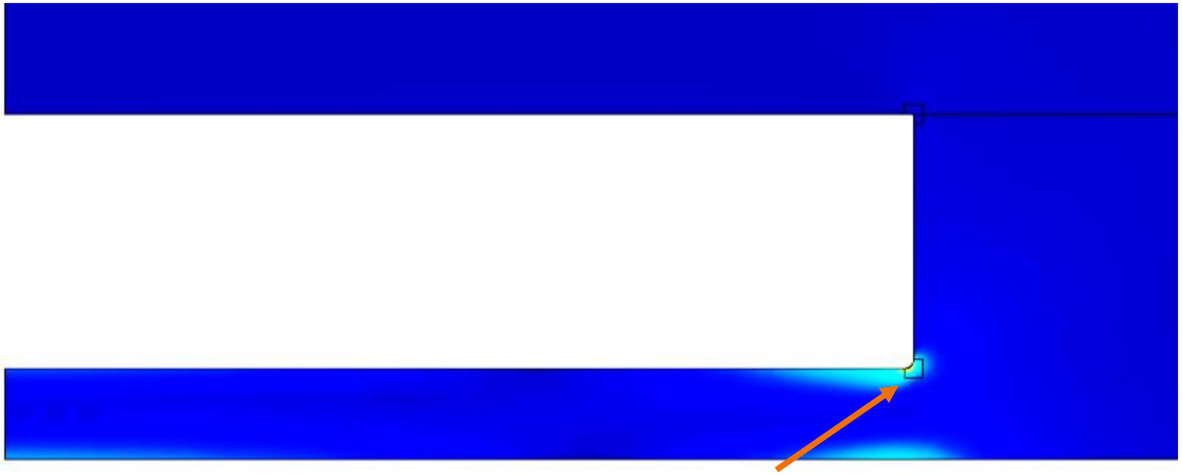

Figure 10: 2D Model with J-Integral Contour

- Analytical model is based off a clamped plate model for channel-like cavities.
- If J-integral values were greater than analytically calculated critical strain energy release rate, fracture.
- Integration contour is square with 5μm.

$$G_{\mathrm{Ic}} = \frac{p^2 a^4 (1-\nu^2)}{24Et^3}\left(1 + \frac{6\alpha_s t^2}{a^2(1-\nu)}\right).$$

Equation 1: Analytical Formula for Critical Strain Energy Release Rate [2]

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

Equation 2: J-Integral for Comsol Model [3]

Initial Results

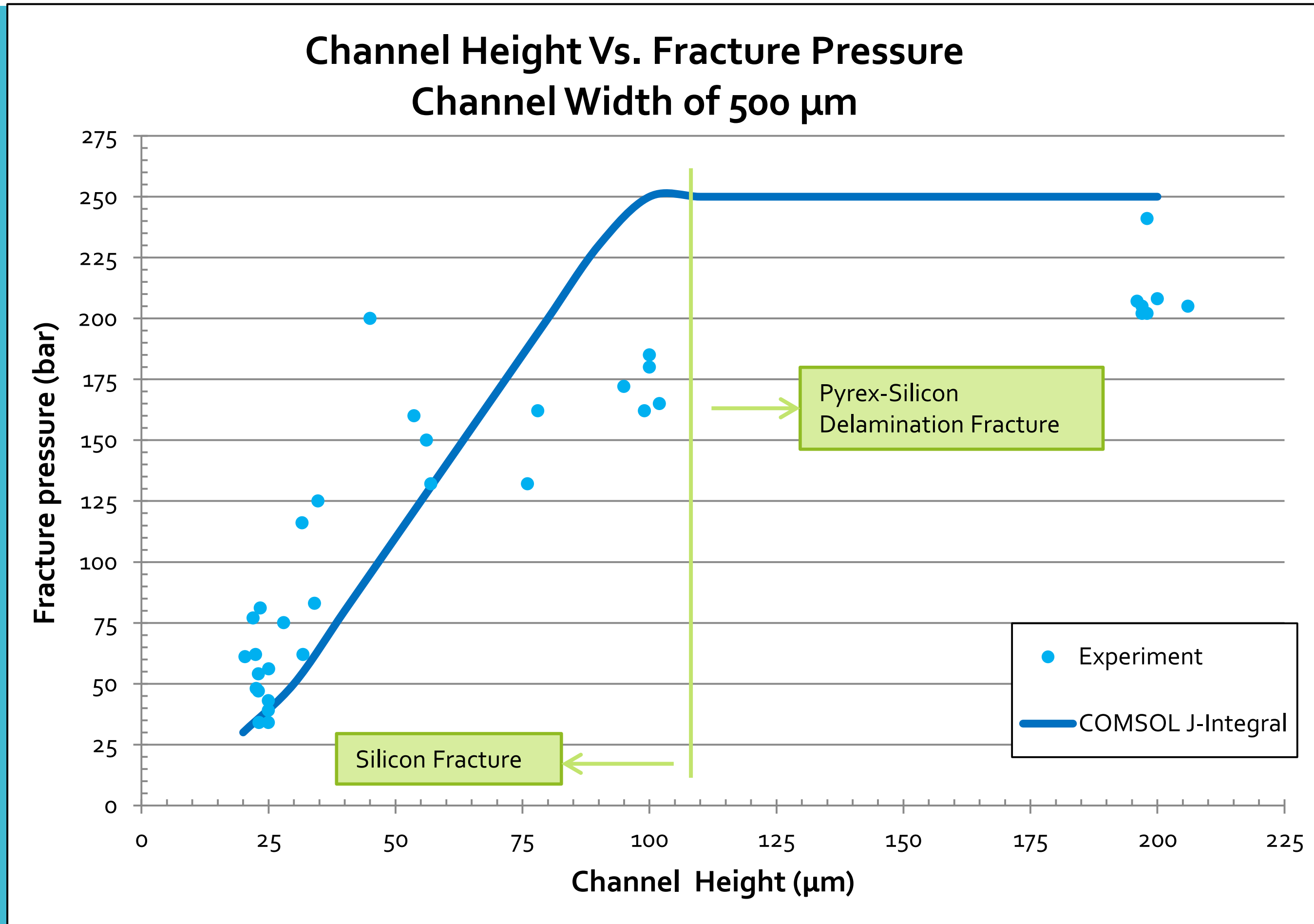

Figure 11: Results of Comsol Models versus Experimental Testing with a Channel Width of 500µm

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Conclusions and Future Goals

- Initial Comsol results correlate well to experimental results.
- Will conduct full parametric analysis of cover height versus channel width versus pressure with Comsol models.
- Fine tune J-integral 2D model for better accuracy and precision.
- Create a technique to predict fracture conditions and behavior of future micro-channel devices.

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References

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- [2] Örjan Vallin, Kerstin Jonsson, Ulf Lindberg, Adhesion quantification methods for wafer bonding, Materials Science and Engineering: R: Reports, Volume 50, Issues 4–5, 30 December 2005, Pages 109-165, ISSN 0927-796X, 10.1016/j.mser.2005.07.002.
- [3] COMSOL; Single Edge Crack, Model Documentation