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

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

Figure 1: Microchannel Cooling Plate
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
Experimental Testing for Fracture Pressure

- 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
Analytical Formula and J-Integral

- 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.

![Figure 10: 2D Model with J-Integral Contour](image)

\[
G_{lc} = \frac{p^2 a^4 (1 - v^2)}{24 E t^3} \left( 1 + \frac{6 \alpha_s t^2}{a^2 (1 - v)} \right)
\]

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

\[
J = \int Wdy - T_{i \frac{\partial u_i}{\partial x}} ds = \int (Wn_x - T_{i \frac{\partial u_i}{\partial x}}) ds
\]

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

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


• [3] COMSOL; Single Edge Crack, Model Documentation