Design of a Compact Pressure Sensor for Multi-Layer Insulation in a Vacuum

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Presentation Overview

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Presenter: Michael Kiefer

Project Scope

- The goal of this project is to design and implement a compact pressure sensor that is easily embedded between layers of Multi-Layer Insulation (MLI).
  - Rapid Response Time
  - The ability to measure a low pressure range
  - Noninvasive to the MLI
- This interstitial pressure is measured to quantify the heat transfer through the system
- Heat transfer is critical to cryogenic storage and applications in space

Project Objectives

- Develop a pressure sensor with minimal parts
- Minimize the wiring and power consumption of the device
- Minimize the heat produced by the sensor

Project Constraints

- Pressure Sensor
  - Be able to measure a pressure as low as 10^{-2} Pa
  - Have a minimum response rate of 1 sample per second
- Multi-Layer Insulation
  - Sensor dimensions shouldn’t exceed interlayer spacing
    - 12 layers is roughly 5 mm
- Working environment
  - Temperature conditions range from 293 K to 77 K
  - Outgassing
  - Vacuum
  - Cold Welding

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House of Quality

Table 1 - House of Quality for Pressure Sensor Design

Engineering Characteristics / Customer Requirements	Customer Importance	Materials	Power Consumption	Geometry	Cost
Minimal Invasiveness	5	3	6	9	
Accuracy	5		6		6
Minimal Heat Produced	4	3	6		
Reading Range	4				6
Reading Speed	3		6		6
Total Weight		27	102	45	72

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Fiber Optics

- Observes change in phase, polarization, transmit time, or wavelength to measure pressure
- Pros
  - Good in high vibrational, wet, noisy, corrosive, and extreme heat environments
  - Immune to electromagnetic interference
  - Ability to measure a large range of pressures
  - High Sensitivity and Bandwidth
  - Size (125 micrometers)
- Cons
  - Relatively difficult design
  - Cost
  - Assembly requires special equipment

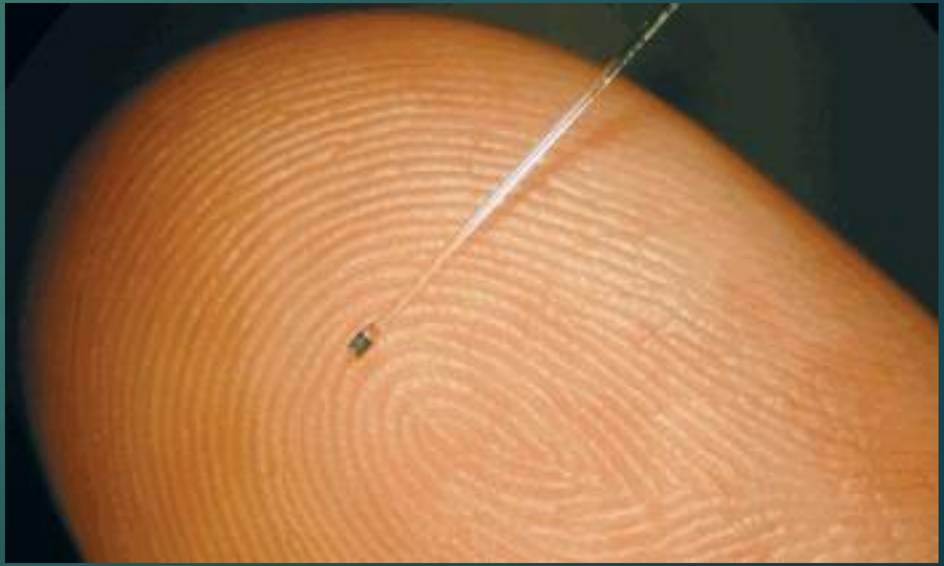

Figure 1 Displays the size of a fiber optics pressure sensor

Fiber Optic Design

- 1: Silica diaphragm
  - 125 µm OD
  - 85 µm ID diaphragm
- 2: Silica core
- 3: Lead-in optical fiber
  - Multimodal or single modal

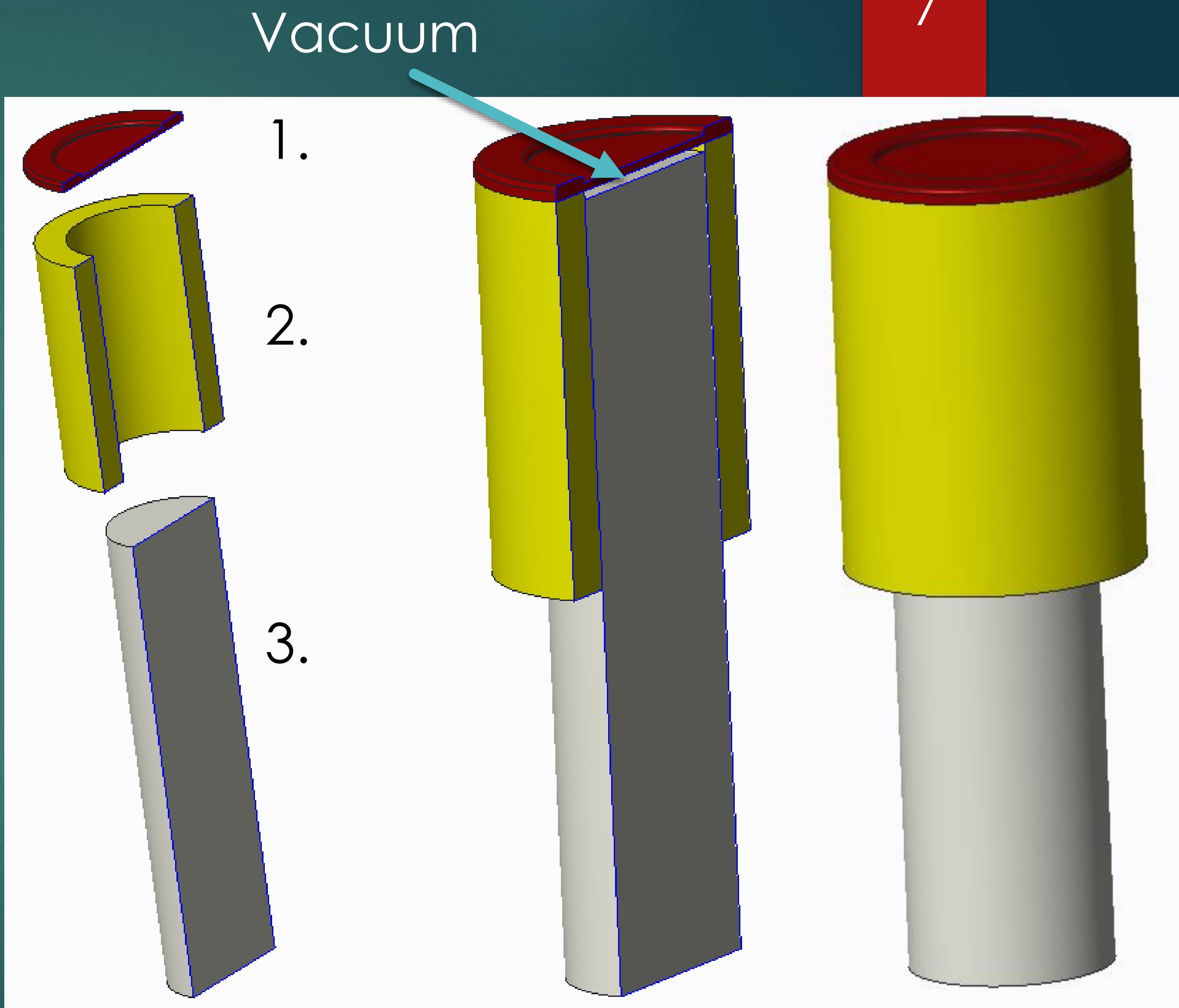

Figure 2 Cross section view and fully assembled view of Fiber optics sensor

Research on Efficient Production

- UV polymer cavitation creation technique used to increase sensor batch success rates
  - Technique could be implemented in nano-capacitor design to decrease cost
- “The sensor fabrication follows simple, repeatable processes and safe procedures, and uses less expensive materials and equipment. ”

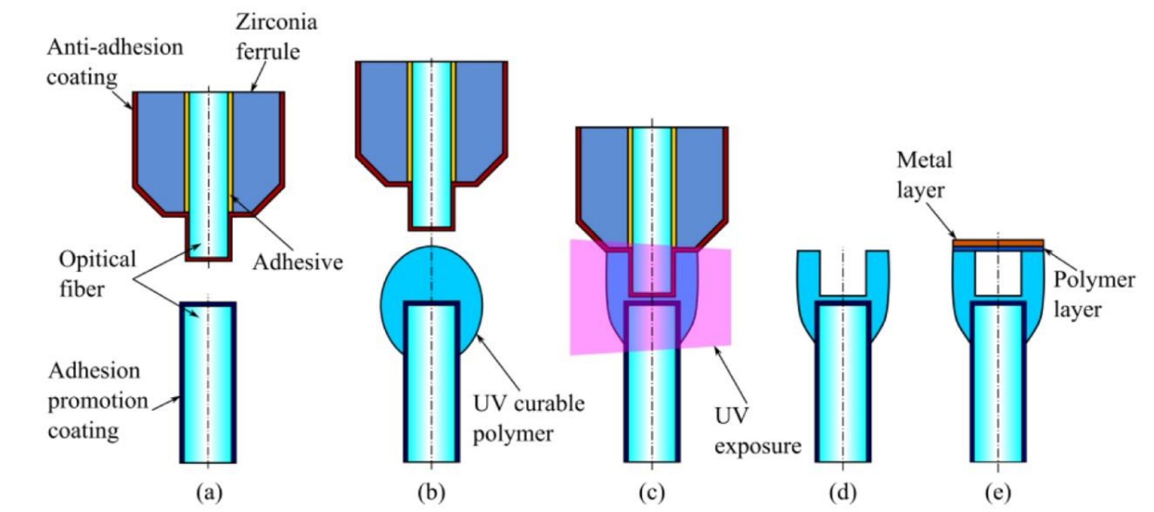

Figure 3 Shows UV polymer adhesion of a miniature Fabry-Perot fiber optic pressure sensor

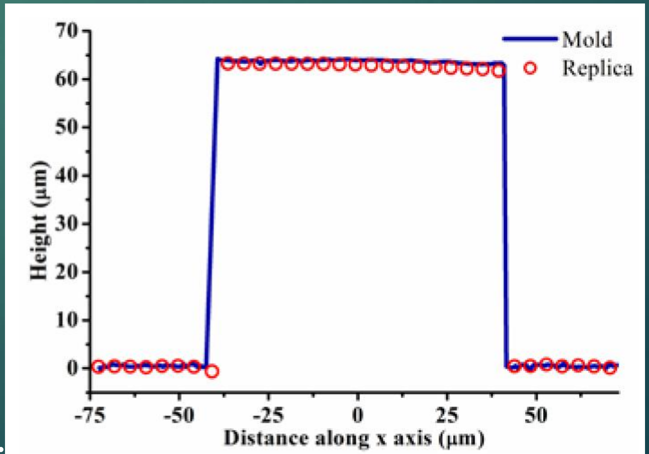

Figure 4 Shows cavity creation accuracy (RED) against the starting mold shape (BLUE).

H. Bae and M. Yu, "Miniature Fabry-Perot pressure sensor created by using UV-molding process with an optical fiber based mold," Opt. Express 20, 14573-14583 (2012)

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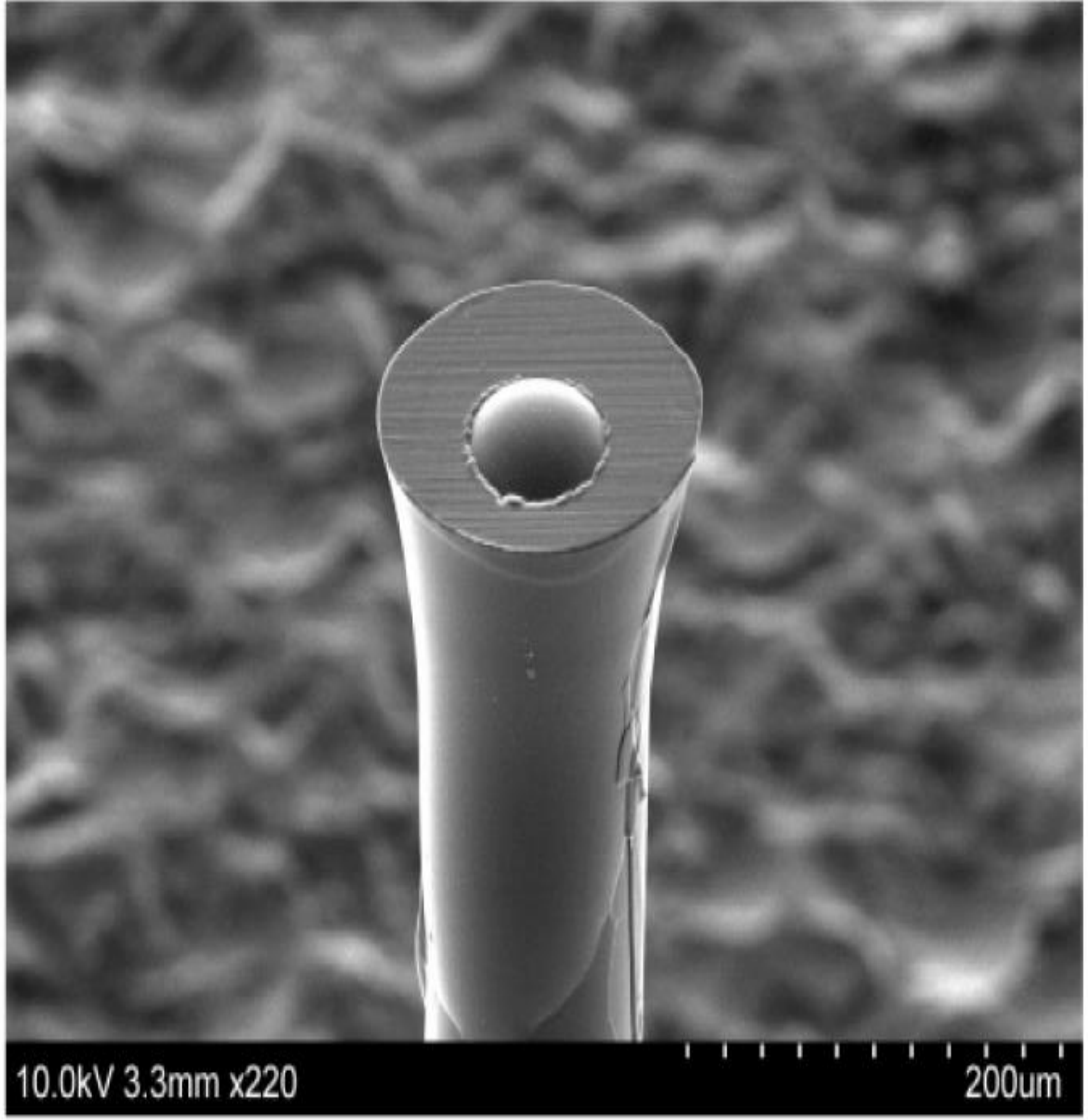

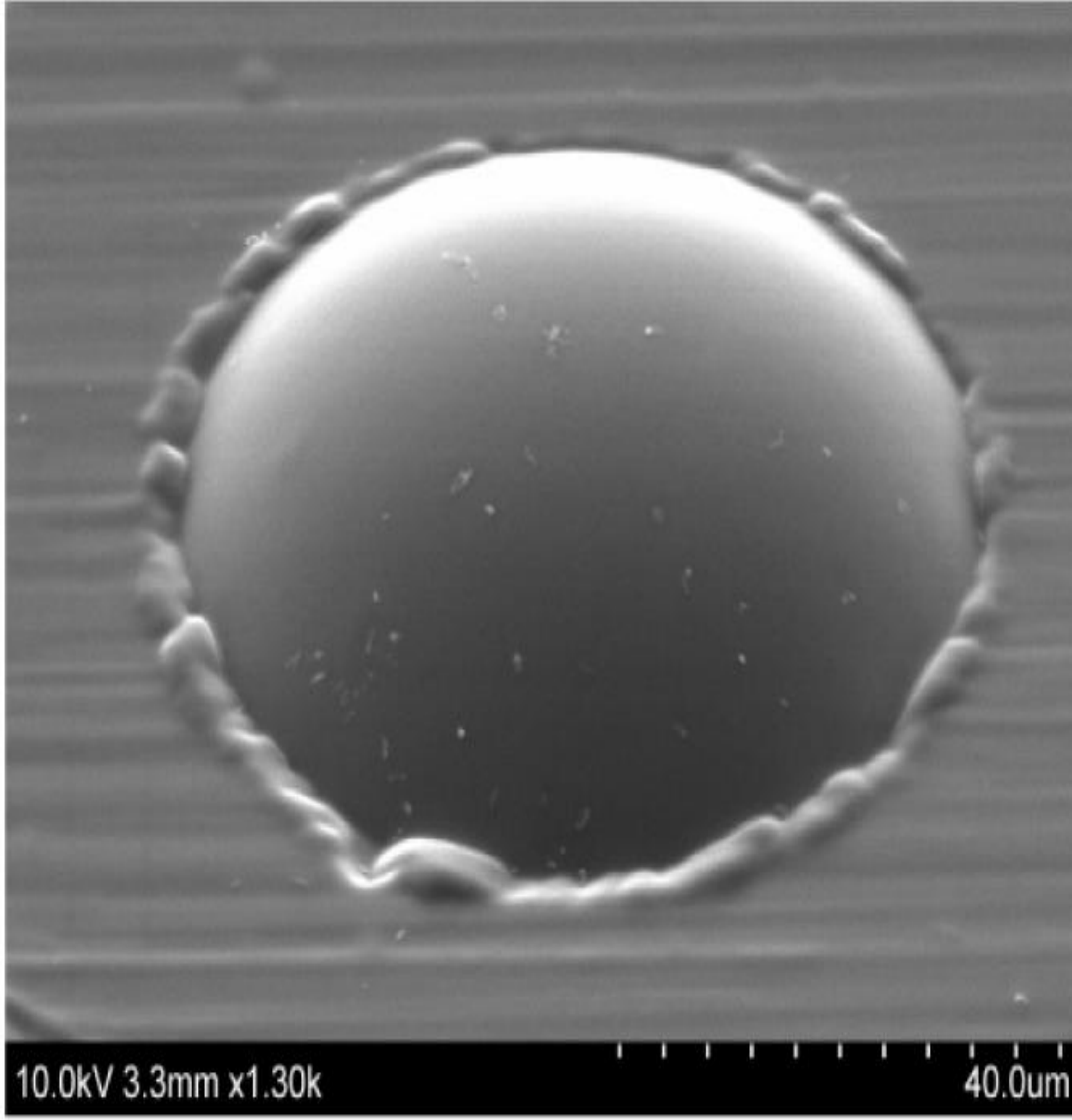

Figure 5 (left) Sensor base manufactured, (right) sensor diaphragm manufactured

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Capacitor Design

1. Capacitor top diaphragm:
   - High sensitivity – reads low pressures
   - 125 µm OD, 85 µm ID diaphragm
   - Nano-metallic coating to create capacitor plate

2. Silica Base plate

3. Capacitor bottom plate:
   - Rigid metallic plate

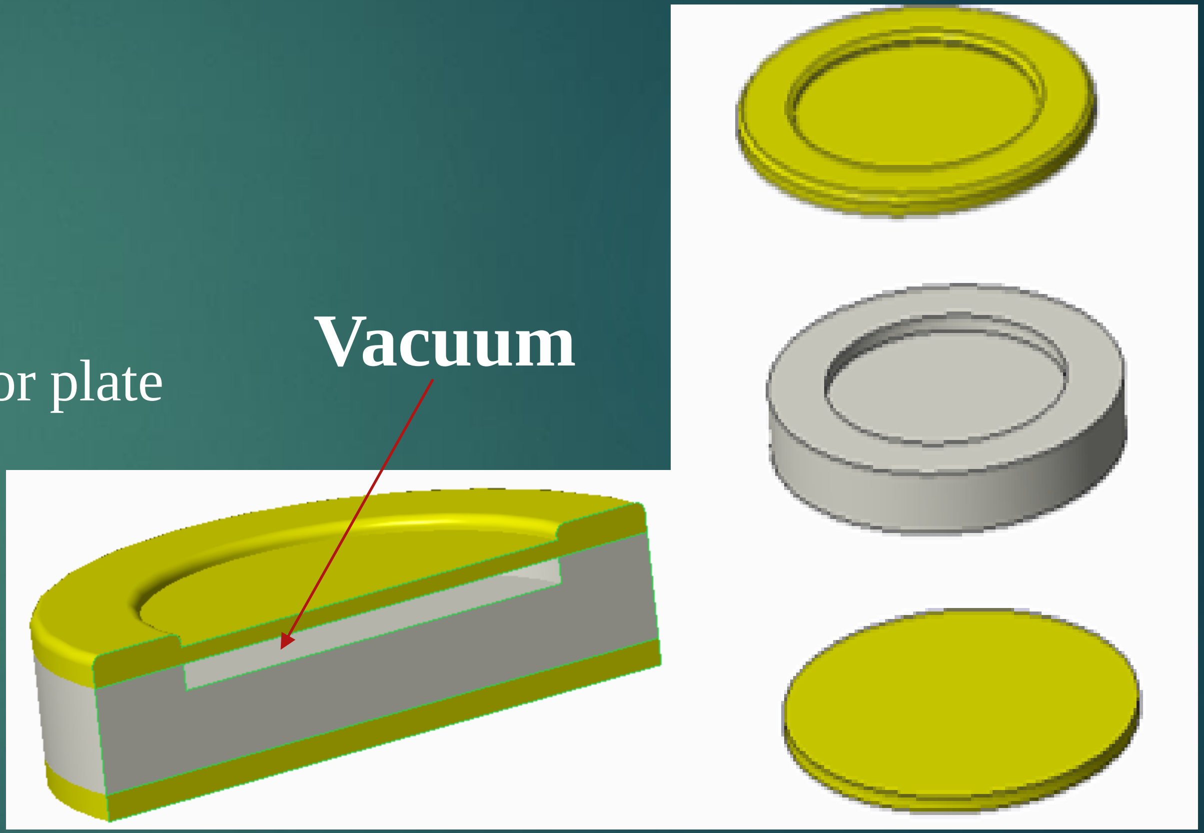

Figure 6 Cross section view of capacitor (left), and exploded view (right)

Multi-Stage Capacitor Design

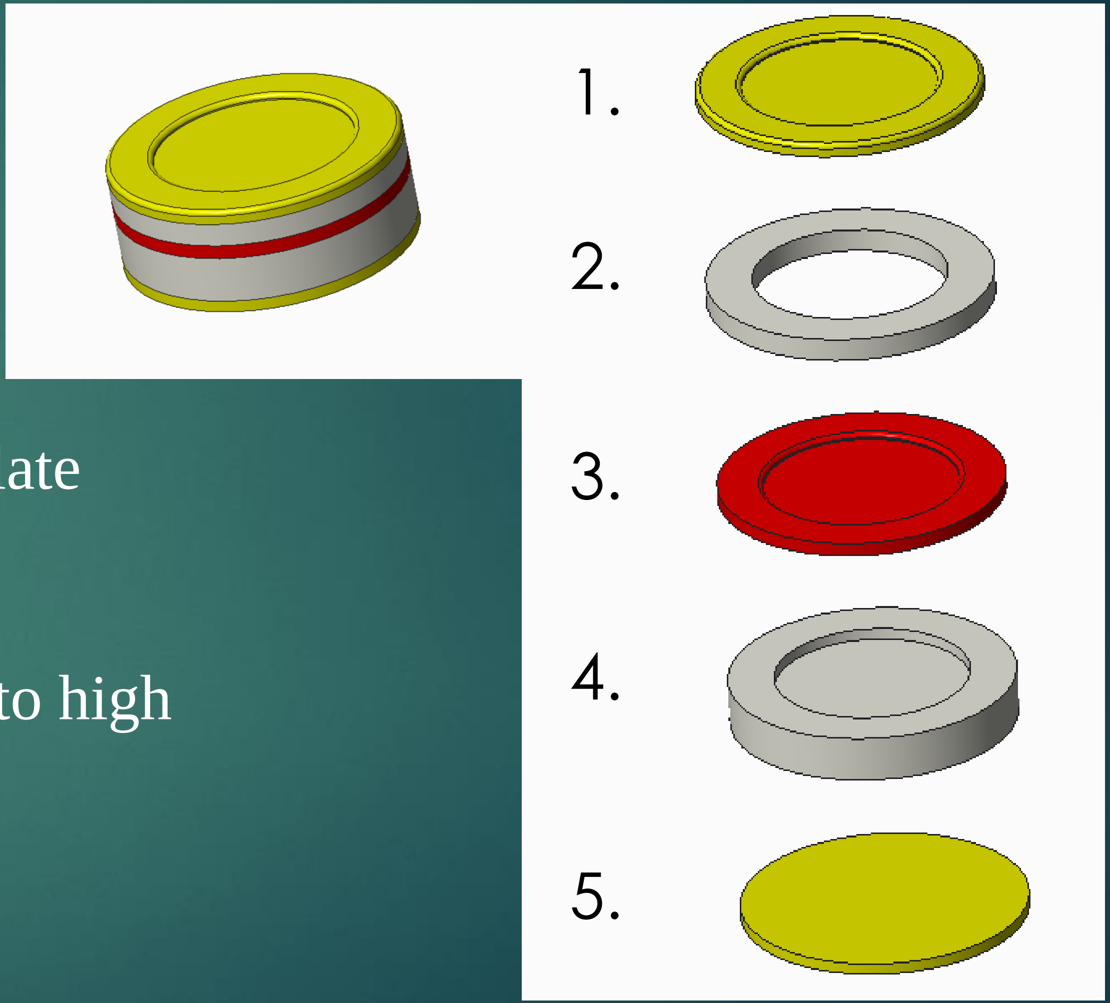

Figure 7 Displays the exploded view of the multi stage capacitor

1: Capacitor top diaphragm:
- -High sensitivity – reads low pressures
- -125 μm OD, 85 μm ID diaphragm
- -Nano-metallic coating to create capacitor plate

2: Silica spacer

3: Intermediate diaphragm:
- -Medium to low sensitivity – reads medium to high pressure ranges.

4: Silica Base plate

5: Capacitor bottom plate:
- -Rigid metallic plate

Multi-Stage Capacitor Design

- Cavities formed in the silica base by germanium doped etching
- Capacitor assembled in a vacuum
- Parts either fused together, or set with a UV-reactive polymer

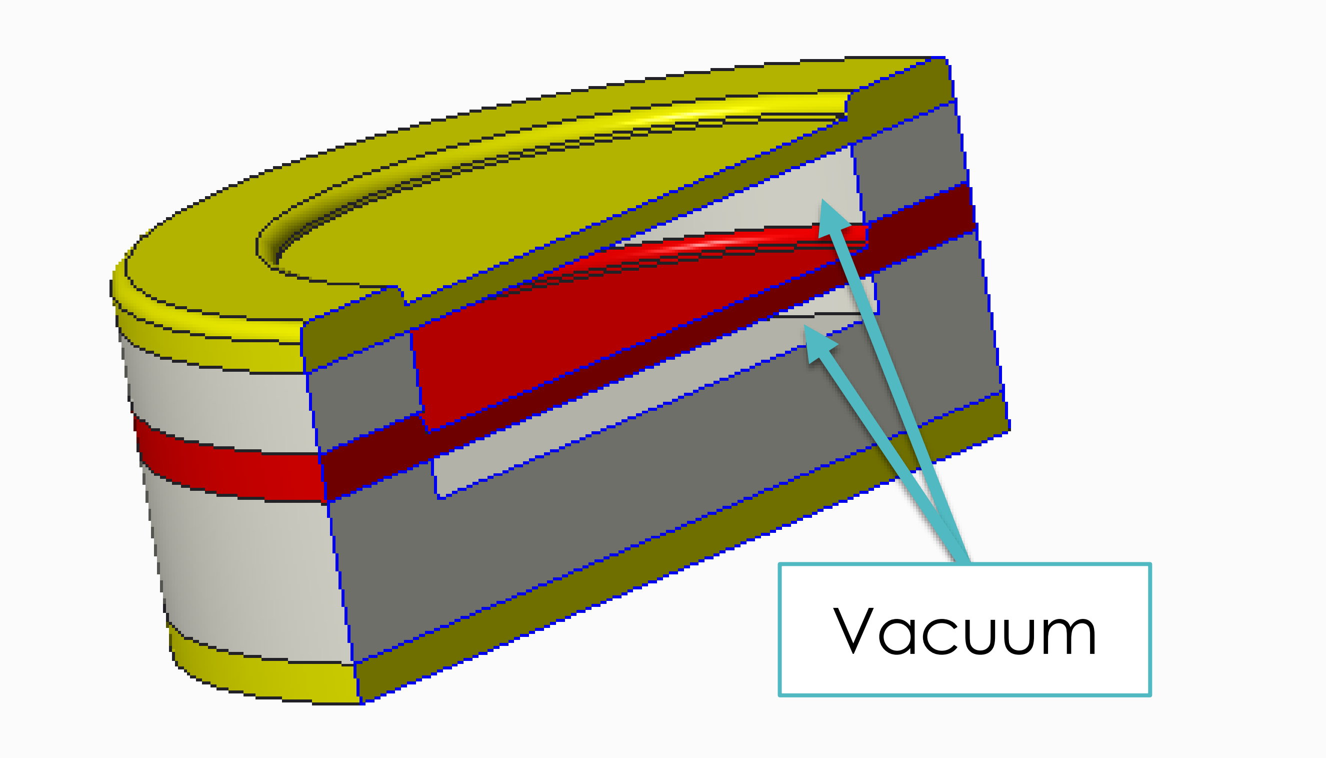

Figure 8 Multi stage capacitor cross sectional view

Decision Matrix

Table 2 - Pugh Decision Matrix for pressure sensor concepts

	Capacitor	Fiber Optics	Multi-Stage Capacitor
Accuracy	0	1	0
Minimal Invasiveness	0	0	0
Heat Production	0	-1	0
Reading Range	0	2	1
Reading Speed	0	0	0
Total	0	2	1

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naNO

- Creating the nano capacitance prototype falls outside of the time restraint and budget
- To progress with a prototype and testing, scaling must occur
- Wish to scale from 125 μm OD to a more pragmatic 12.5 – 25 mm (100 – 200x)
  - Enables the experimentation of capacitance pressure sensors in the previously shown design
  - Easier implementation with ongoing sensor research directed at temperature detection

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Prototype Production

- Create a 3D printed mold
  - High Impact Polystyrene (HIPS)
  - Dissolvable in D-Limonene
- Epoxy will be used as a substitute to create silicone base
- Silicone diaphragm
  - Palladium-Gold sputtering

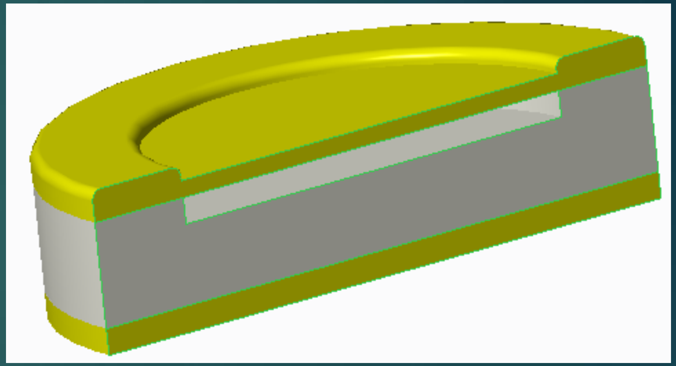
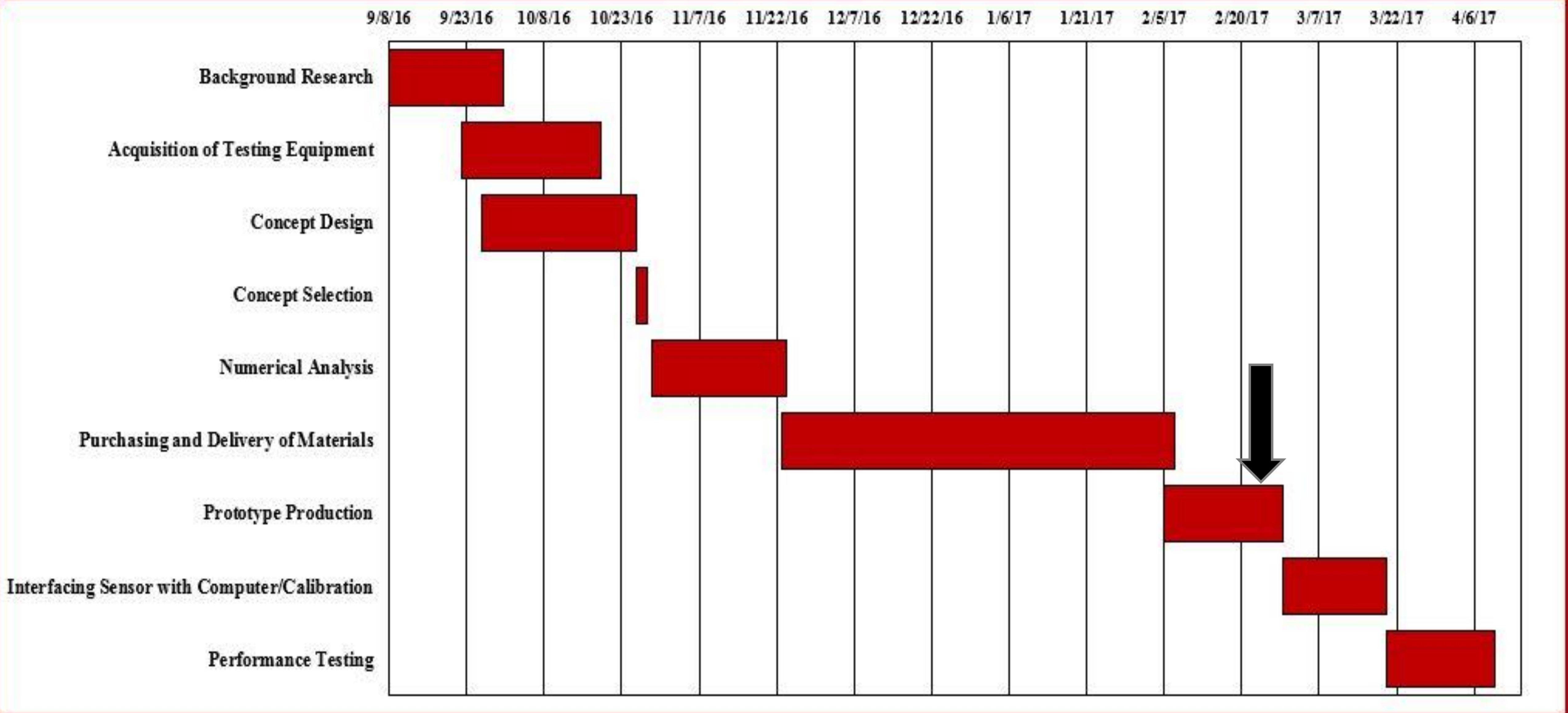


Figure 11 Grey represents epoxy base plate being created with mold

Figure 9 3D printed HIPS mold

Figure 10 Mold dissolving in D-Limonene

Modified Gantt Chart



Future Work

- Use a Network Analyzer to determine the capacitor diagram thickness and bypass creating a circuit to read capacitance.

- Interfacing Sensor with Computer

- Sensor Calibration with a commercial sensor

- Find an epoxy that is capable of withstanding low temperatures

- Start performance testing
  - Room-temperature tests
    - Decreasing temperature with each trial

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