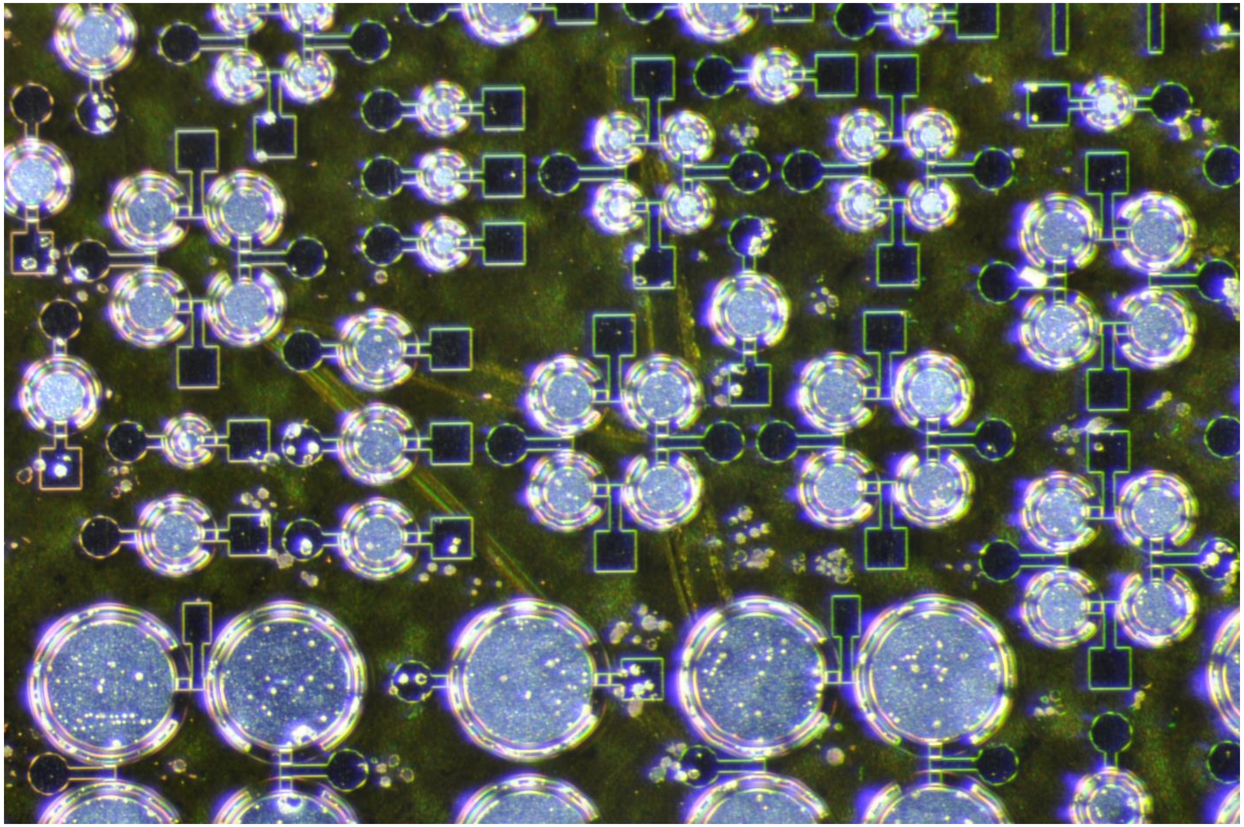

Deployment of Integrated Wide Bandgap Sensor, HT Packaging, and Data Communication System

Project Officer: Lauren Boyd
Total Project Funding: $380k
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This presentation does not contain any proprietary confidential, or otherwise restricted information.

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EGS: High Temp Tools, Drilling Systems

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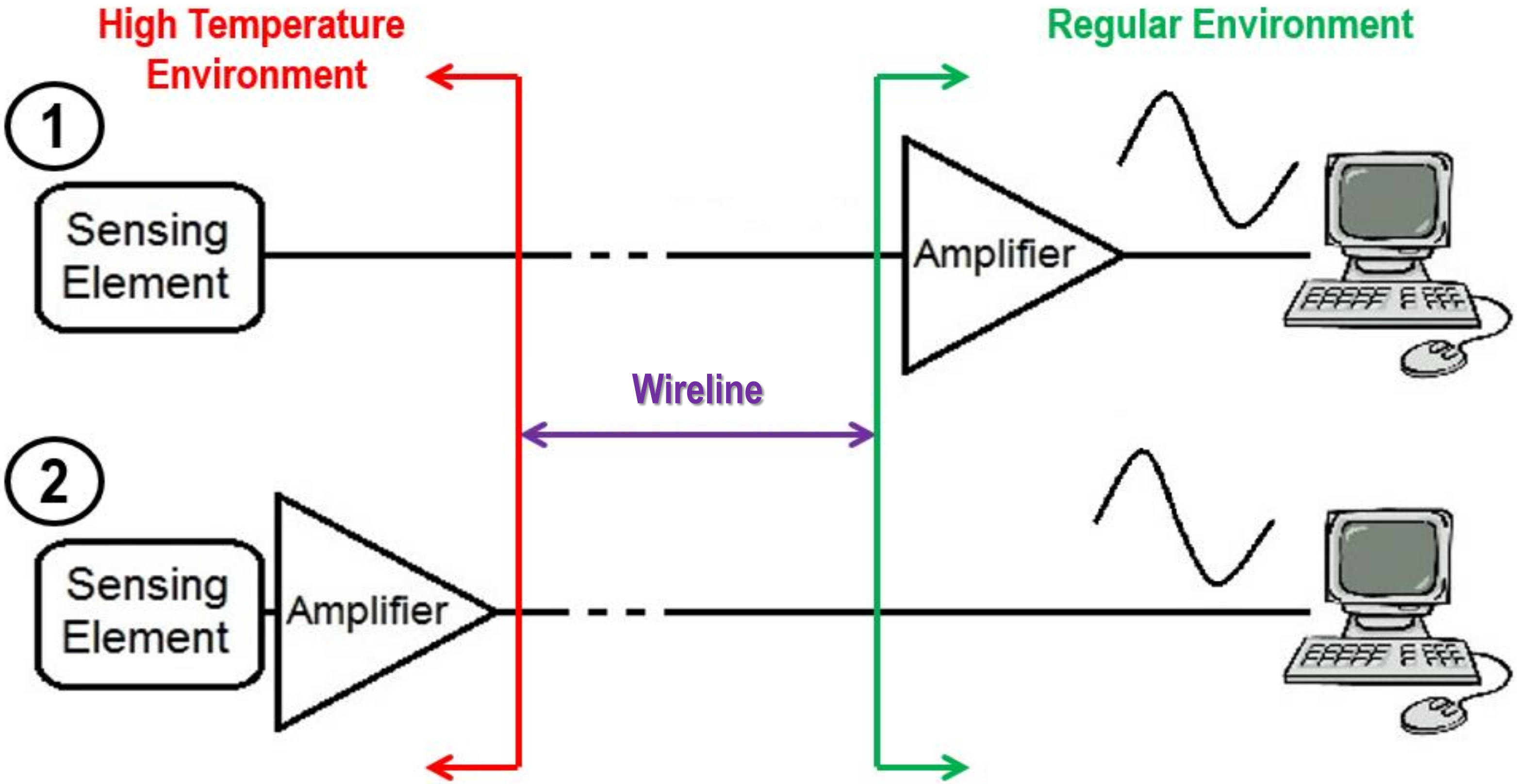
Relevance/Impact of Research

- Background
  - Need for continuous monitoring of downhole conditions in HT geothermal injection and production wells
    - Enabling technology for optimization of EGS systems
    - Improved fidelity of reservoir models
    - Maximize production and minimize the maintenance costs.
  - Lack of existing long-term monitoring solutions for very hot wells
    - SOI components cannot operate at very high temperatures indefinitely
    - Sensors deteriorate with time when exposed to extreme conditions
- Goals
  - Develop a prototype HT system featuring wide-bandgap Silicon Carbide (SiC) sensors capable of prolonged monitoring of downhole conditions
    - Temperature up to 300^{o}C (and possibly higher)
    - Pressures up to 35 GPa (5000 psi)
  - Design prototype SiC temperature and pressure sensors as well as specialized diode bridge and operational amplifier (opamp).
    - Partner with Professor Pisano’s group (UC San Diego/UC Berkeley)
    - Pave way for further sensor development

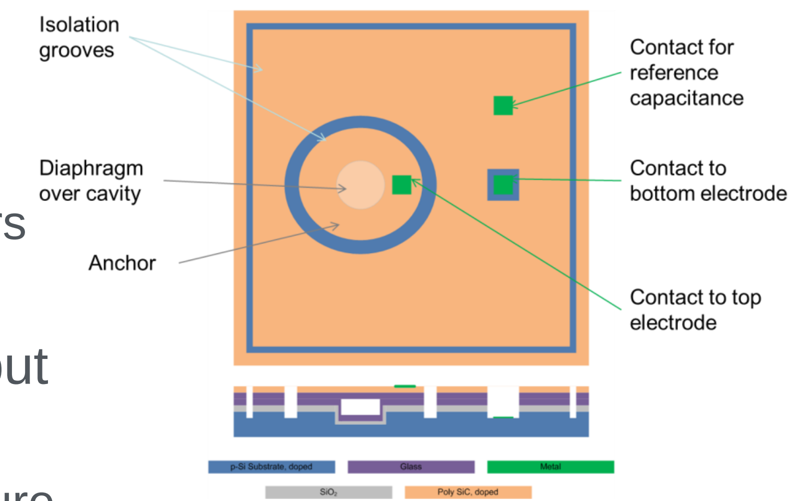
Scientific/Technical Approach

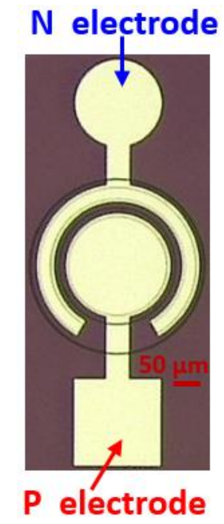
Two possible approaches to interrogating downhole HT sensors

- Differential with no downhole amplifier
- Single Ended with downhole amplifier

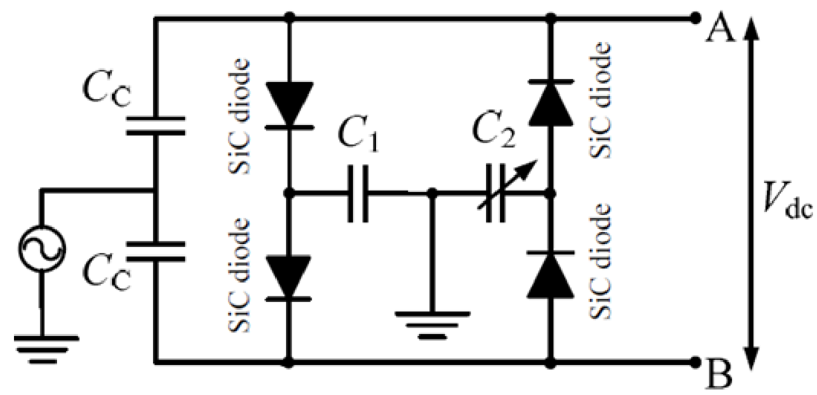


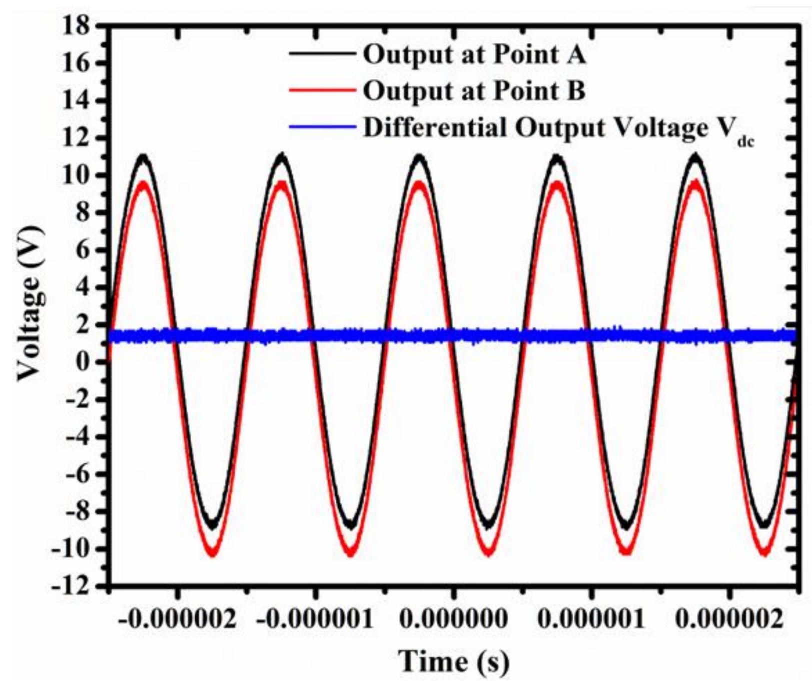
- SiC Pressure sensors; dual approach
  - Pressure Sensor with Single Output (PSSO)
    - Easier to manufacture
    - Leverage previously developed sensors
    - Requires downhole opamp
  - Pressure Sensor with Differential Output (PSDO)
    - Significantly more difficult to manufacture
    - Cutting edge technology
    - Will not require downhole opamp
  - Capacitive in nature
  - Require diode bridge for readout circuitry
- Temperature sensor
  - SiC PN diode
  - Optimized for linear response





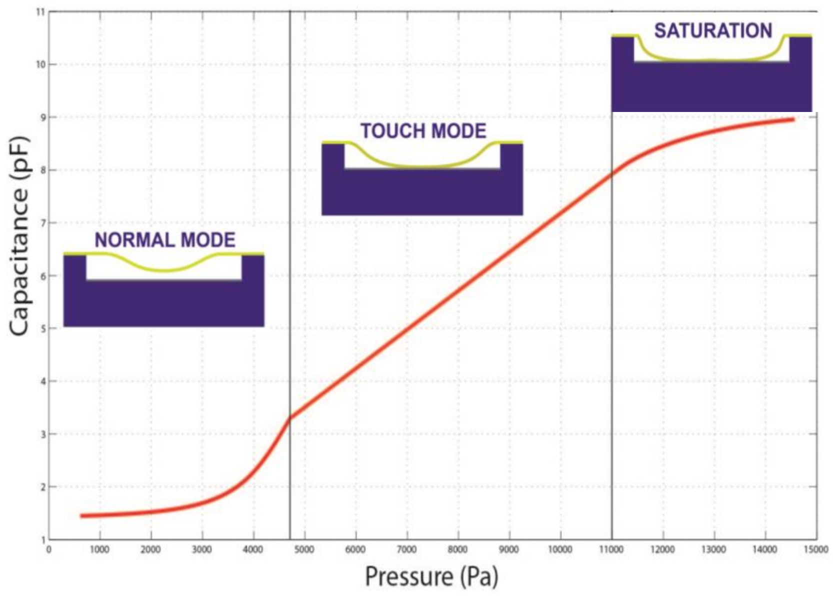
- Capacitive sensor interface – Diode bridge
  - Minimize required downhole electronics to interface with sensors
  - Eliminates common mode capacitance issues related to wireline
  - DC offset between outputs proportional to capacitance change of the sensor
  - Can be used with single and differential output sensors

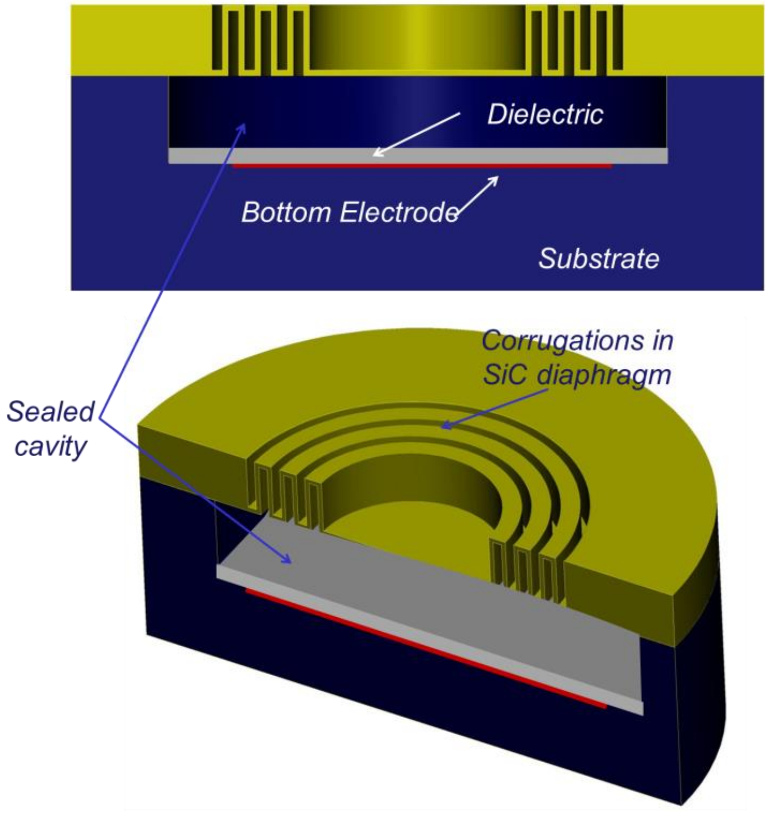




Scientific/Technical Approach

- PSSO – touch mode sensor
  - Silicon Carbide (SiC) to survive high pressure & temperature
  - Scalable design (large range)
  - High burst pressure
  - Linear at higher pressures
- Needs to be optimized to work up to 35GPa

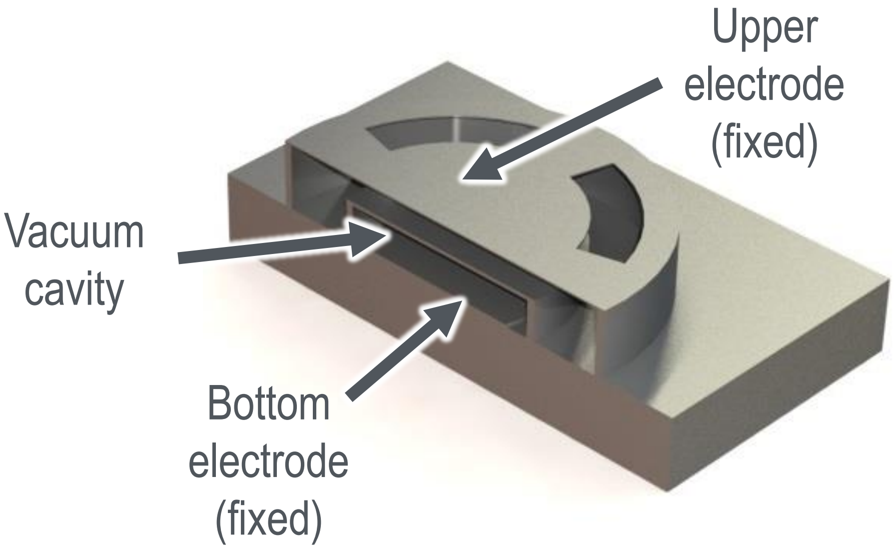




Schematic images of proposed design for capacitive pressure sensor (a) Cross-sectional view (front), (b) Isometric view of half-symmetry model.

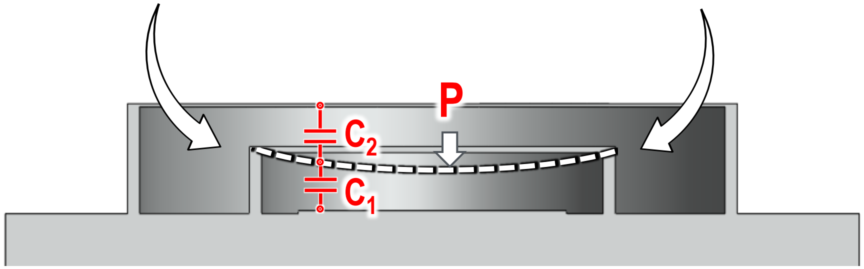
Scientific/Technical Approach

- PSDO
  - Uses two fixed electrodes with membrane in between
  - Forms two capacitors
    - As pressure changes one increases and one decreases
  - New design and construction
  - Difficult to construct due to multiple layers required
- Aims at providing better results than PSSO
  - Better linear range and sensitivity
  - Careful design and simulation is required



X-section view

Operation:

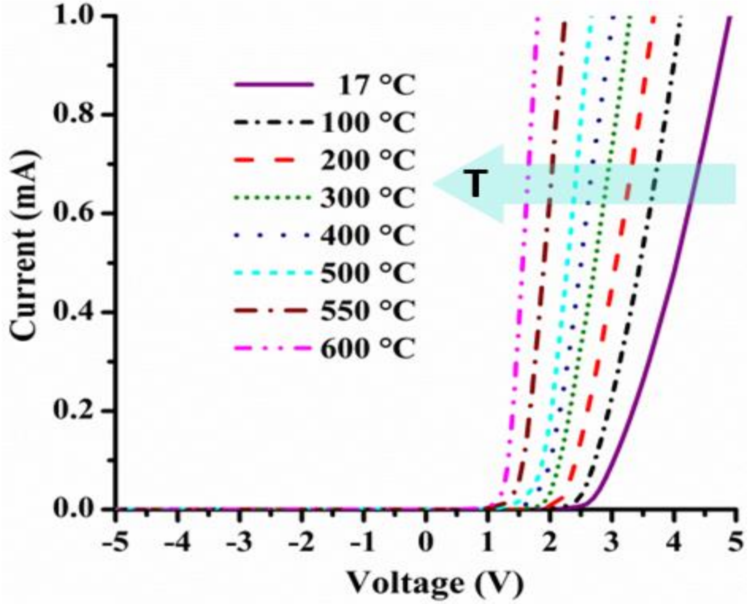


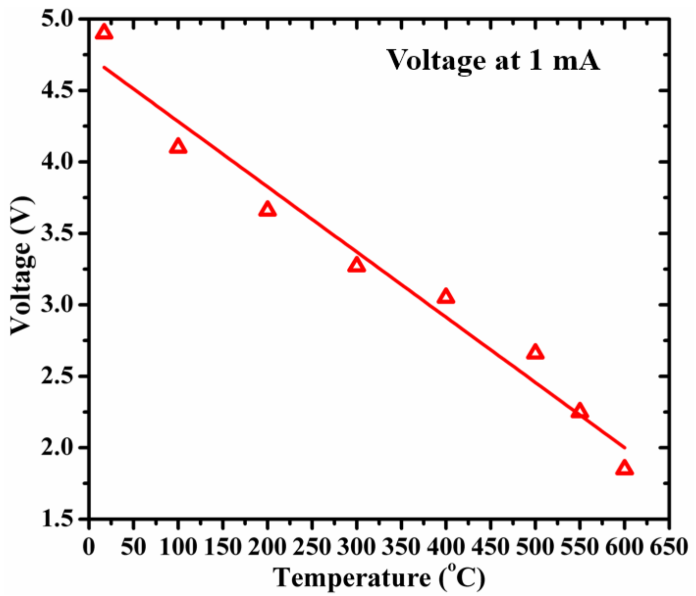
X-section view

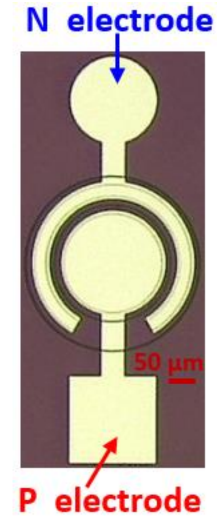
- Pressure deflects membrane
- C_1 increases and C_2 decreases

Accomplishments, Results and Progress

- Designed and manufactured PN diode temperature sensor
  - SiC diode shows very good results
  - Calibration curve may be required
  - Constant current mode (1mA)
  - Sensitivity of 4.72 mV/^{o}C (much better than thermocouples)

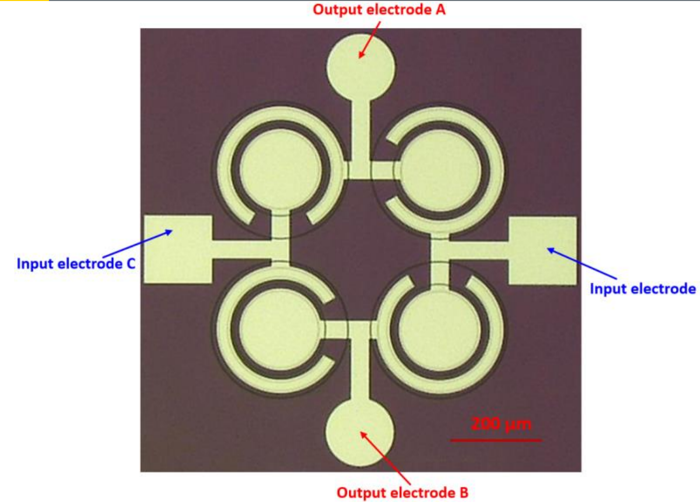


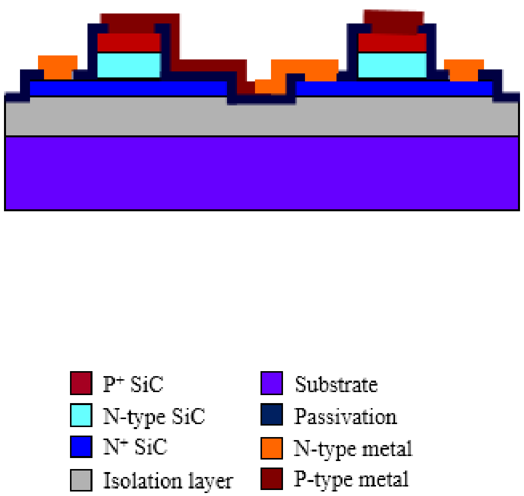


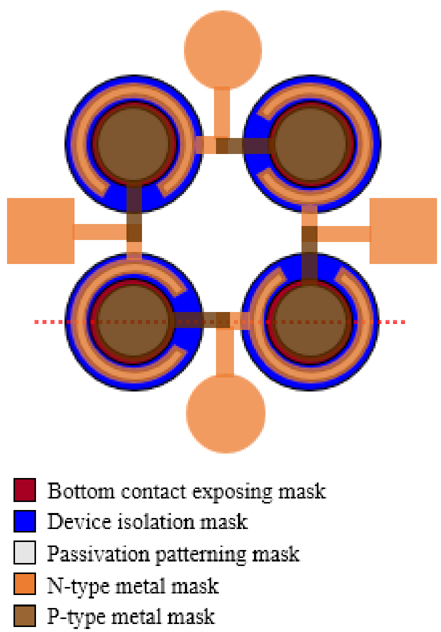


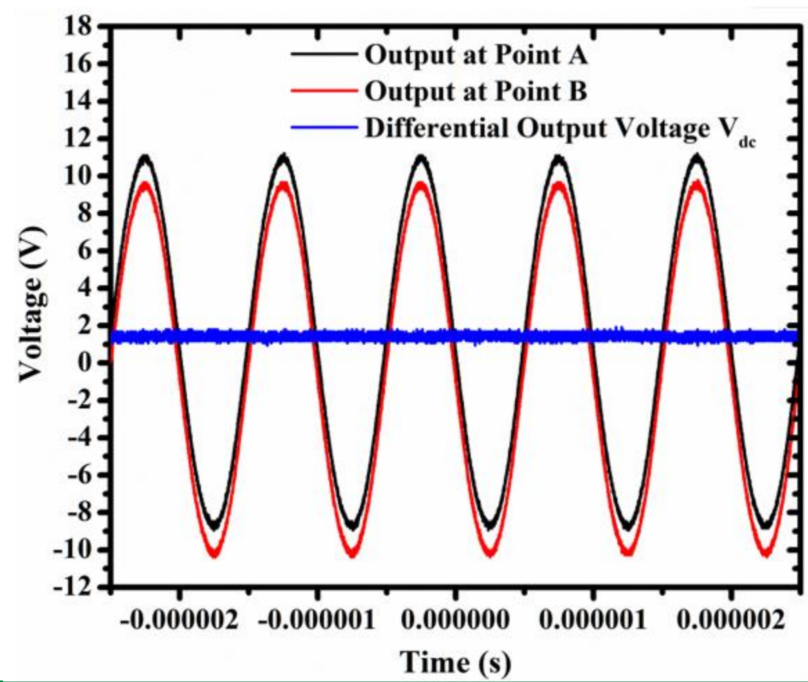
Accomplishments, Results and Progress

- Designed and manufactured diode bridge for reading out capacitive sensors
  - Calibration curve may be required
  - Excitation frequency 1MHz
  - Sensitivity of ~10mV/pF
  - Further testing ongoing at SNL



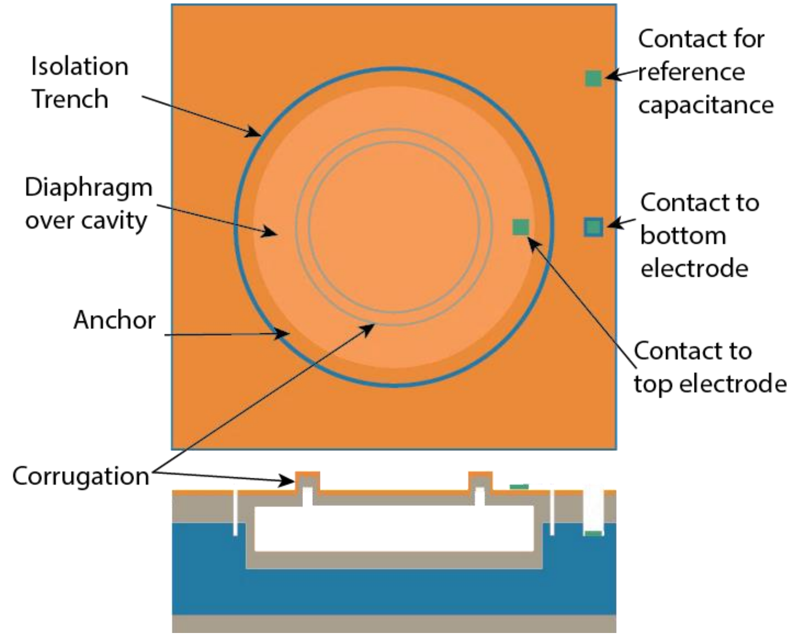


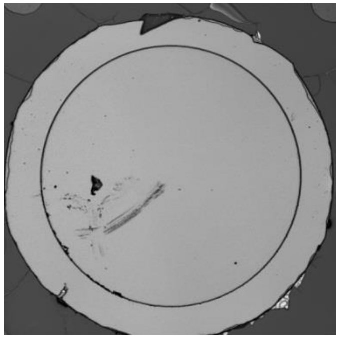


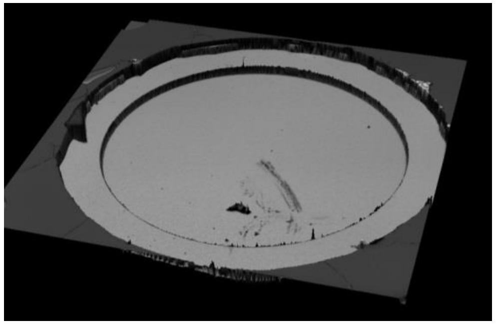


Accomplishments, Results and Progress

- Designed and fabricated an initial version of the PSSO sensor
  - Difficulty with liftoff. Only few working sensors were manufactured
  - Limited testing
    - The sensor shows good temperature stability (>300^{o}C)
  - The pressure membrane was damaged either during shipment of initial test at SNL
    - The liftoff issues are being addressed by switching to a different process.
    - Awaiting new sensors
    - Construction of pressure and temperature testing chamber in process







- Preliminary design for PDSO
  - Created finite element model coupled electrostatic model
  - Explored the design space for optimal sensor parameters to produce linear sensor
  - Continuing research and development of this sensor.
  - The fabrication will begin in FY15

Pressure ratio:

$$P_R = \frac{\Delta P_1 + \Delta P_2}{3P_{touch}}$$

Slope ratio:

$$m_R = \frac{m_1}{m_2}$$

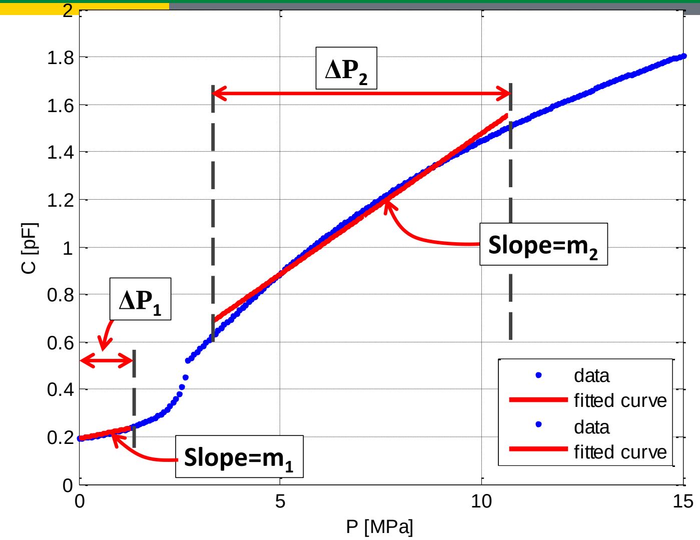
Requirements for linear sensor:

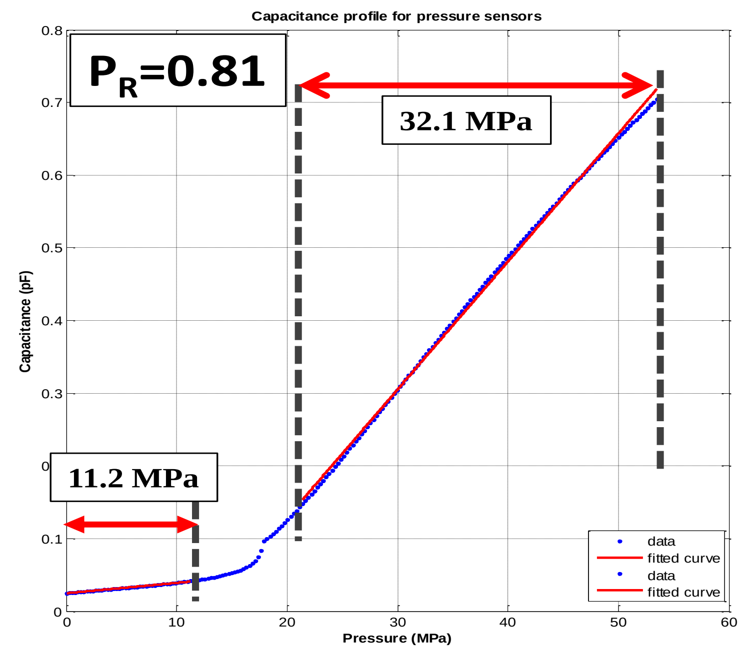
P_R & m_R → 1

Parameters used for optimization:

λ_R=R/h λ_g=g/h

R: radius, h: thickness, g:gap





Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
FY(14) Fabricate SiC downhole pressure and temperature sensor modules.	Fabricated SiC temperature sensor and diode bridge. Continuing work on pressure sensors	Ongoing – delayed start on the project. Lab relocation from UC Berkeley to UC San Diego. Contracting difficulties
FY(14) Demonstrate functionality of the entire system over a single conductor logging cable by varying the pressure and temperature at the sensor modules, and monitoring the output voltage with the uphole electronics.	Waiting for the sensors	Ongoing
FY(14) Test the system with the downhole modules at 300^{o}C and pressure to demonstrate temperature survivability and calibration curves.	Construction of test chamber underway	Ongoing
FY(15) Design a test fixture for high-temperature high-pressure testing of wide bandgap components and sensors.	Design completed awaiting components	Ongoing
FY(15) Fabricate and test first version of differential pressure sensor and opamp	Initial work started at UC San Diego	Ongoing
FY(15) Develop and test a prototype tool which will integrate the sensors developed by university partner. The SiC pressure sensor will provide 5% pressure accuracy at pressures up to 35GPa at temperatures of 300^{o}C.	Waiting for the sensors	

Future Directions

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- Continue the development and fabrication of PSDO
- Leverage previously developments to design and fabricate JFET based opamp suitable for sensor integration.
- High-pressure high-temperature testing
  - Awaiting parts to finalize construction of the chamber
  - Waiting for sensors to perform testing
- Prototype HT tool
  - Integrate the sensors
  - Test using appropriate wireline

Mandatory Summary Slide

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Need for continuous monitoring of downhole conditions in HT geothermal injection and production wells
- Begun the development of HT Silicon Carbide sensors which can be used to develop HT monitoring tool
  - SiC PN diode was fabricated and successfully tested as temperature sensor
  - SiC diode bridge was fabricated and tested for readout of capacitive pressure sensors
  - Initial version of PSSO was designed and fabricated. Limited but positive test results
  - PSDO was designed and simulated. Might offer a better alternative to PSSO.
- Continuing development of sensors and opamp.
- Acknowledgement: Professor Pisano’s group on design and development of SiC sensors and components