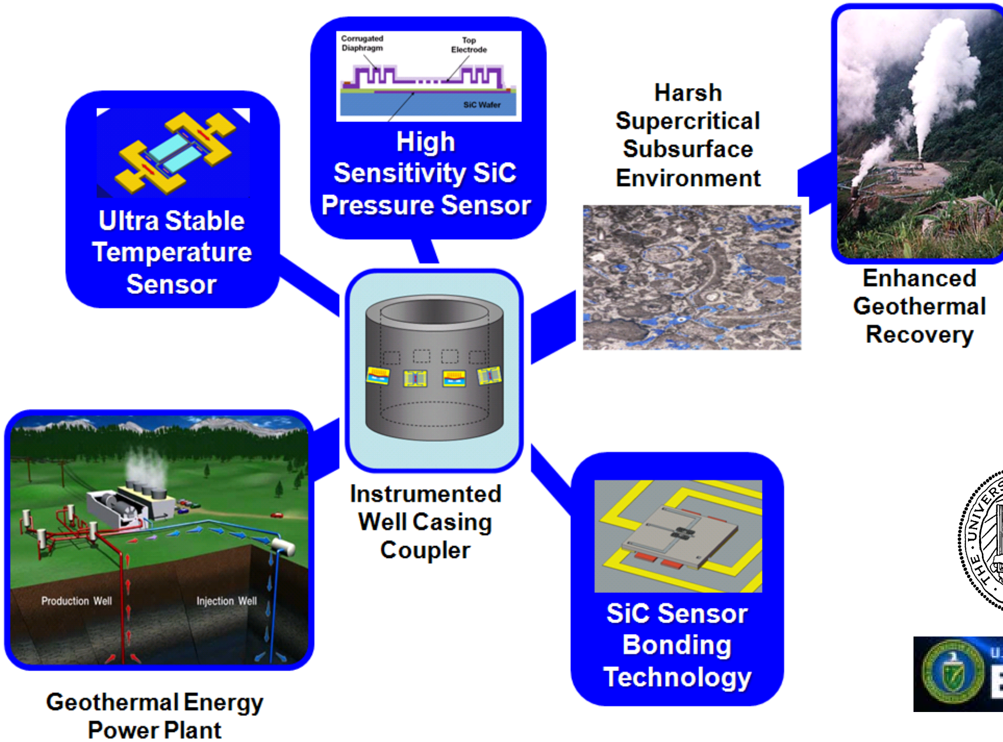
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy




# Harsh Environment Silicon Carbide Sensor Technology for Geothermal Instrumentation

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High Temperature Tools and Sensors, Down-hole Pumps and Drilling

# Mandatory Overview Slide

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- Timeline
  - Project start date: 01/29/2010
  - Project end date: 02/28/2013
  - Percent complete: 5%
- Budget
  - Total project funding: $2,222,022
  - DOE share: $1,777,617
  - Awardee share: $444,405
- Barriers
  - Development of tools and sensors capable of tolerating the extreme environment of supercritical reservoirs (374°C and 220 bar for pure water).
- Partners
  - Not Applicable

# Relevance/Impact of Research



- Project objectives:
  - Develop advanced sensor technology for the direct monitoring of geothermal reservoirs.
  - Engineer sensors to survive and operate in $H_2O$ pressures up to <u>220 bar</u> and temperatures as high as <u>374$^{o}$C</u>.
- Innovative aspects of project:
  - Utilize chemically inert and thermally stable materials (ceramic, wide-band gap materials and inert metals)
  - Utilize semiconductor manufacturing technology to create sensors
  - Develop capacitive-based sensors that can interface with simple electronics.

# Scientific/Technical Approach

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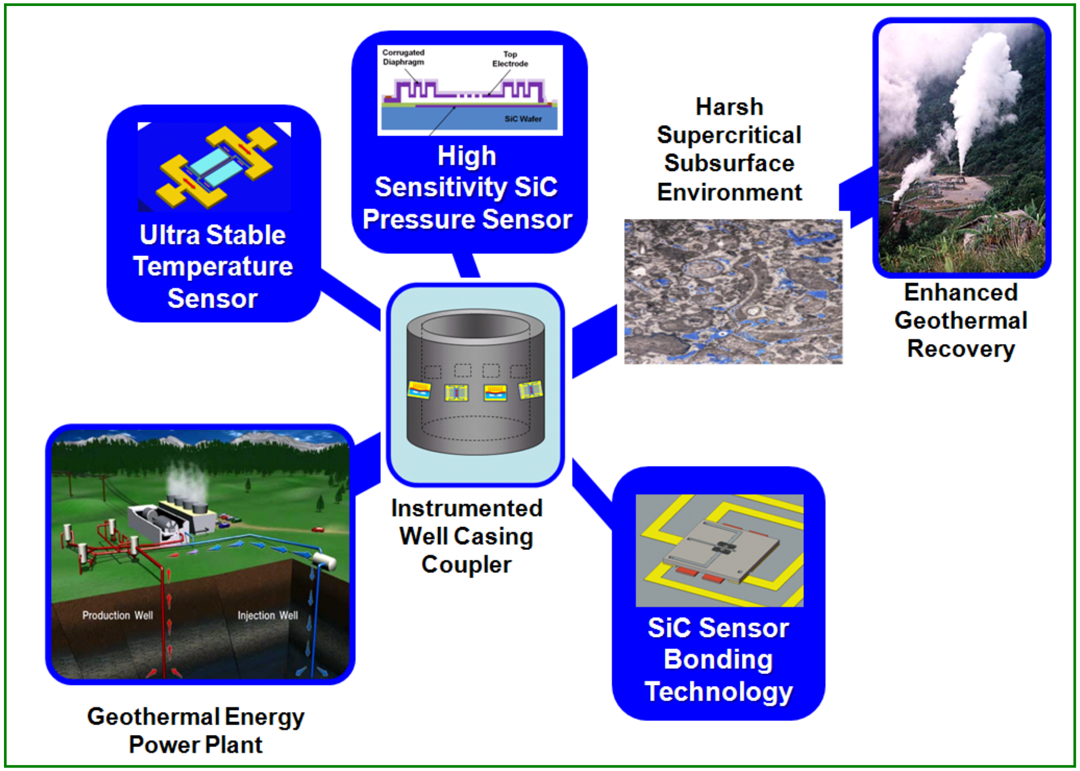
| Property | Silicon Carbide 3C-SiC (6H-SiC) | AlN | Silicon | Diamond |
|---|---|---|---|---|
| Melting Point (°C) | **2830 (2830) sublimes** | **2470** | **1420** | **4000 phase change** |
| Energy Gap (eV) | **2.4 (3.0)** | **6.2** | **1.12** | **5.6** |
| Critical Field ($\times 10^6$ V/cm) | **2.0 (2.5)** | **10** | **0.25** | **5.0** |
| Thermal Conductivity (W/cm-K) | **5.0 (5.0)** | **1.6** | **1.5** | **20** |
| Young's Modulus (GPa) | **450 (450)** | **340** | **190** | **1035** |
| Acoustic Velocity (x$10^3$ m/s) | **11.9 (11.9)** | **11.4** | **9.1** | **17.2** |
| Yield Strength (GPa) | **21 (21)** | **-** | **7** | **53** |
| Coeff. of Thermal Expansion (°C $\times 10^{-6}$ ) | **3.0 (4.5)** | **4.0** | **2.6** | **0.8** |
| Chemical Stability | **Excellent** | **Good** | **Fair** | **Fair** |

Material properties of SiC and other materials used by the semiconductor industry.

**Phase I:**

- **Task 1:** Deliver Preliminary Pressure Sensor (Design #1) for Operation in Harsh Subsurface Environments
- **Task 2:** Deliver Preliminary Temperature Sensor (Design #1) for Operation in Harsh Subsurface Environments
- **Task 3:** Develop and Complete Preliminary Characterization of the Bonding Procedure for Adhering Sensors to Casing Components
- **Task 4:** Perform Supercritical Exposure Demonstrations on Sensor Materials



# Accomplishments, Expected Outcomes and Progress

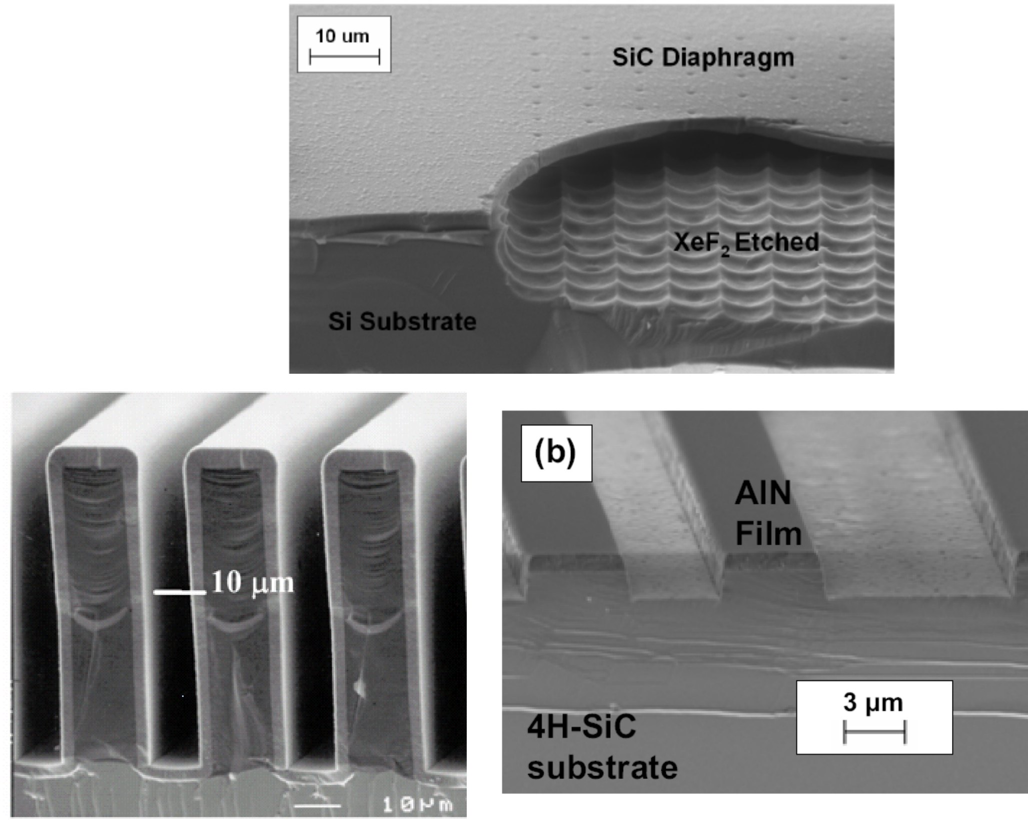


- Progress to date
  - Preliminary design algorithms for capacitive SiC temperature sensor developed
  - Fabrication process for sensors developed
  - Design of experiments for Y1 exposure tests developed
- Planned accomplishments/outcomes
  - Exposure testing of materials in supercritical environments
  - Design and fabrication of pressure and temperature sensors
  - Development of harsh environment bonding technology

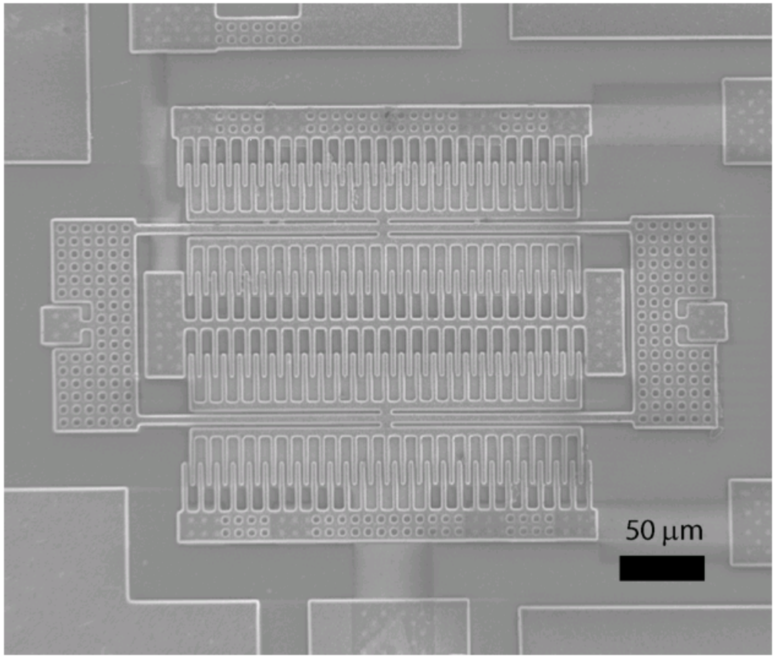

**Image of high pressure vessel (max. pressure = 3500 bars at 600°C) to be used for supercritical exposure testing.**

# Accomplishments, Expected Outcomes and Progress

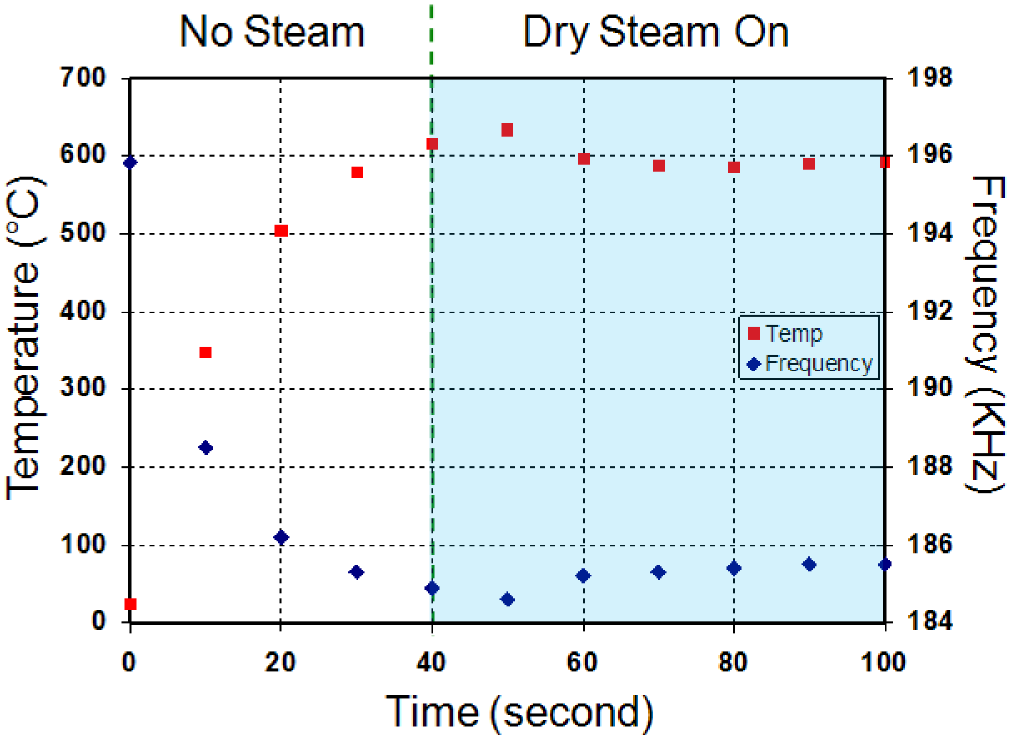
- Special process equipment available at UC Berkeley (Micro and Nano Laboratories)
  - Low pressure chemical vapor deposition (LPCVD) of polycrystalline 3C-SiC
  - Ion sputter deposition of amorphous SiC
  - Reactive sputtering of aluminum nitride (AlN)
  - Plasma etching of SiC




**Images of SiC structures fabricated at UC Berkeley by researchers in Prof. Maboudian and Prof. Pisano laboratories.**




**SEM image of polycrystalline 3C-SiC (7um thick) resonant strain sensor fabricated at UC Berkeley.**




**Results of high-temperature exposure testing of SiC strain sensor.**

D. R. Myers et al., J. Micro/Nanolith. MEMS MOEMS (2009)

# Project Management/Coordination



- Y1 Research Schedule
  - Supercritical exposure testing of materials (June 2010)
  - Design optimization of sensors (July 2010)
  - Fabrication of sensors (October 2010)
  - Experimental testing and characterization of first generation sensors (December 2010)
- Application of resources and leveraged funds/budget/spend plan
  - 1 Research specialist
  - 3 Graduate student researchers (GSRs)
  - User facilities
    - Microlaboratory (UC Berkeley)
    - Petrology laboratory (University of Hawaii)

# Future Directions



- Future research
  - Development of parametric design models of mechanical sensors (pressure and temperature)
  - In-situ exposure testing of materials and sensors in experimental supercritical environments
  - Demonstrate sensor bonding technology on casing components
- Development or deployment needs
  - Collaborations for future field testing are desired

# Mandatory Summary Slide



- Development of advanced sensor technology for in-situ geothermal reservoir monitoring is underway
- Materials will be exposed to supercritical environments for extended periods
- SiC pressure and temperature sensors will be designed to monitor the reservoir environment
- Harsh environment bonding technology will be developed to locate sensors within the harsh reservoir environment