PIEZORESISTIVE METAL RUBBER™ SENSORS FOR THE HEALTH MONITORING OF PACKER MATERIALS FOR GEOTHERMAL WELLS

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INTRODUCTION

A typical packer assembly incorporates a means of securing the packer against the well casing or liner wall, such as a slip arrangement, and a means of creating a reliable hydraulic seal to isolate the annulus, usually by means of an expandable elastomeric packer element.
Over time, and especially in the high temperature and high-pressure environment of geothermal wells, packer materials may degrade, fail, damage the completion design, and disrupt or stop production. Instrumentation is needed to understand when these failures may occur.

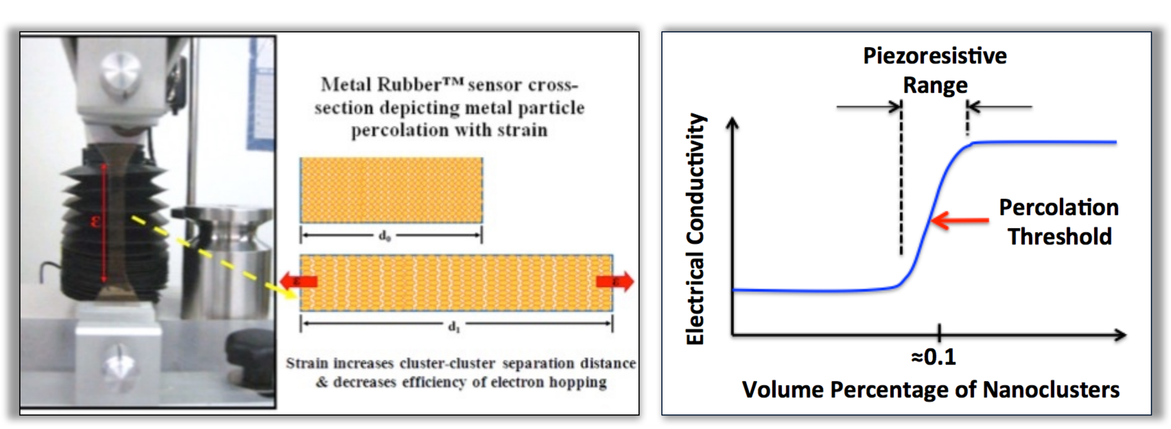
PROGRAM OBJECTIVE

The objective of the Phase I effort is to develop and demonstrate materials and laboratory-scale test articles, and work to envision means to incorporate Metal Rubber instrumentation into packer constructions.

- Demonstrate the feasibility of matching the sensor modulus to that of the packer
- Demonstrate internal strain field mapping in nitrile butyl rubber (NBR) or similar packer materials
- Develop an analytical model to relate internal strain to sensor output signal
- Demonstrate sensor performance for operational environment
- Consider practical data acquisition possibilities

SENSOR TECHNOLOGY

Metal Rubber materials exhibit a change in electrical resistance as a function of the change in strain in the material, and are an ideal candidate for the non-destructive measurement of large strains and creep.



Metal Rubber Sensor performance is controlled via molecular-level properties
- Percolation
- Modulus of polymer
- Type / size of nanoclusters
- Volume % of conductive nanoclusters

Metal Rubber is produced as a freestanding sheet that is assembled at the molecular level using alternating layers of conductive gold nanoparticles and polymeric materials.

TESTING

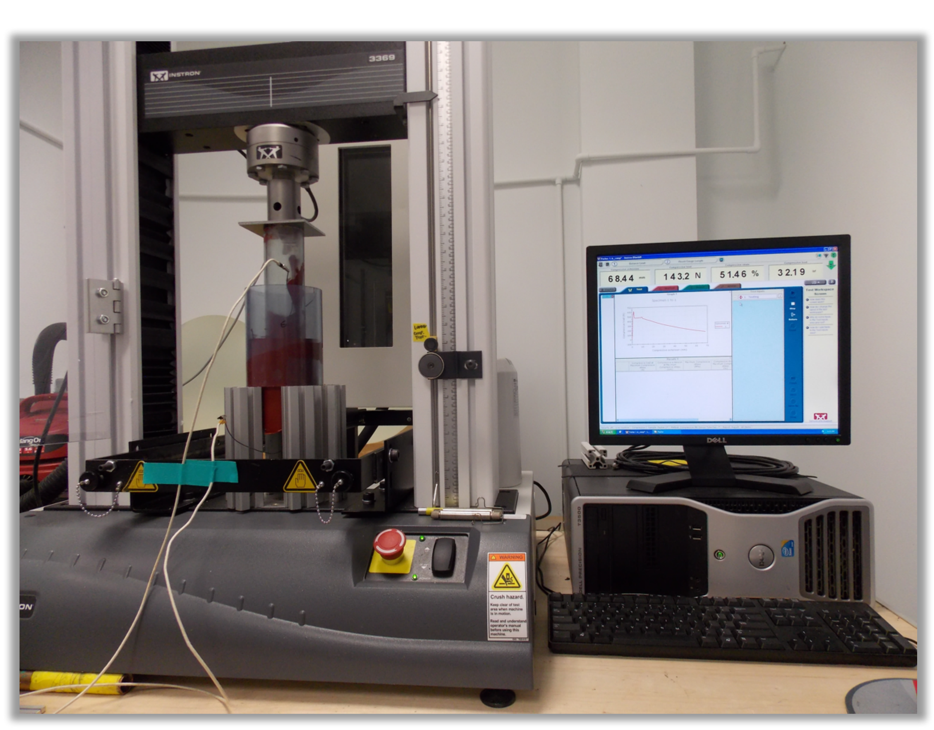
	Standard Metal Rubber (start)	Low conductive Standard Matrix	Medium conductive Standard Matrix	Modified Modulus (Black)	Med. Conductive; High Modulus Matrix
Modulus	9.8 MPa	16 MPa	16 MPa	16 MPa	138 MPa
Resistance (0 to 16 % strain)	12Ω to 120Ω	Too high	10Ω to 89Ω	N/A	8.4Ω to 62Ω
Comment	inconsistent 'R' at low % strain	'R' outside of TA range	little response in 'R' at low % strain	polymer only - no conductive material	good response at low % strain

A matrix of Metal Rubber sensor materials were evaluated for modulus and electrical conductivity, based on polymer molecular weight, cross-linking and gold nanoparticle volume percentage.

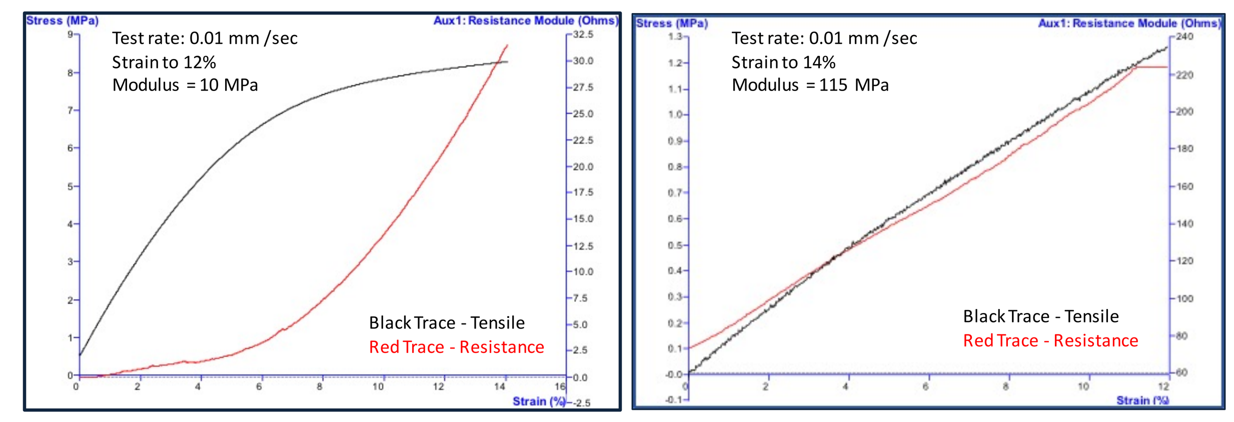
Metal Rubber sensors were evaluated for material compatibility in a high-temperature molding compound used as a packer prototype material. Resistance values before and after sensor integration were similar; approximately 35 Ohms.

SENSOR DEMONSTRATION

Packer prototype with embedded sensors connected to a multimeter were subjected to initial compression tests using an hydraulic press to approximate stress. Packer prototypes are currently being measured for mechanical stress in tandem with change in sensor conductivity.

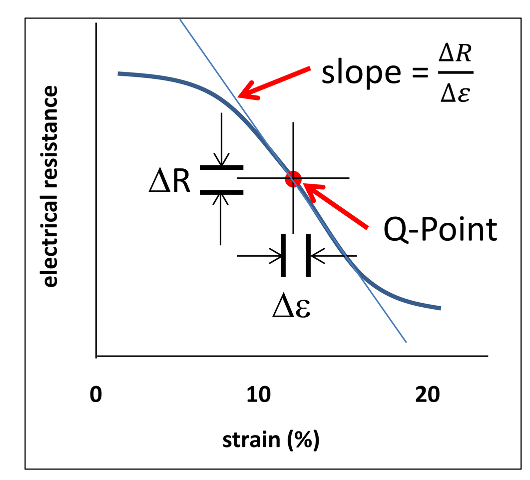


RESULTS



Metal Rubber sensor materials exhibit:
- Low modulus
- Electrical response at low strain
- Yield stress > 10%

Metal Rubber sensors embedded in packer prototype exhibit:
- Consistent electrical response after fabrication/molding process
- Change in resistance under preliminary compression test: 15Ω to 60Ω
- Typical prototype packer material under instrumented compression experiences 2% to 7% strain



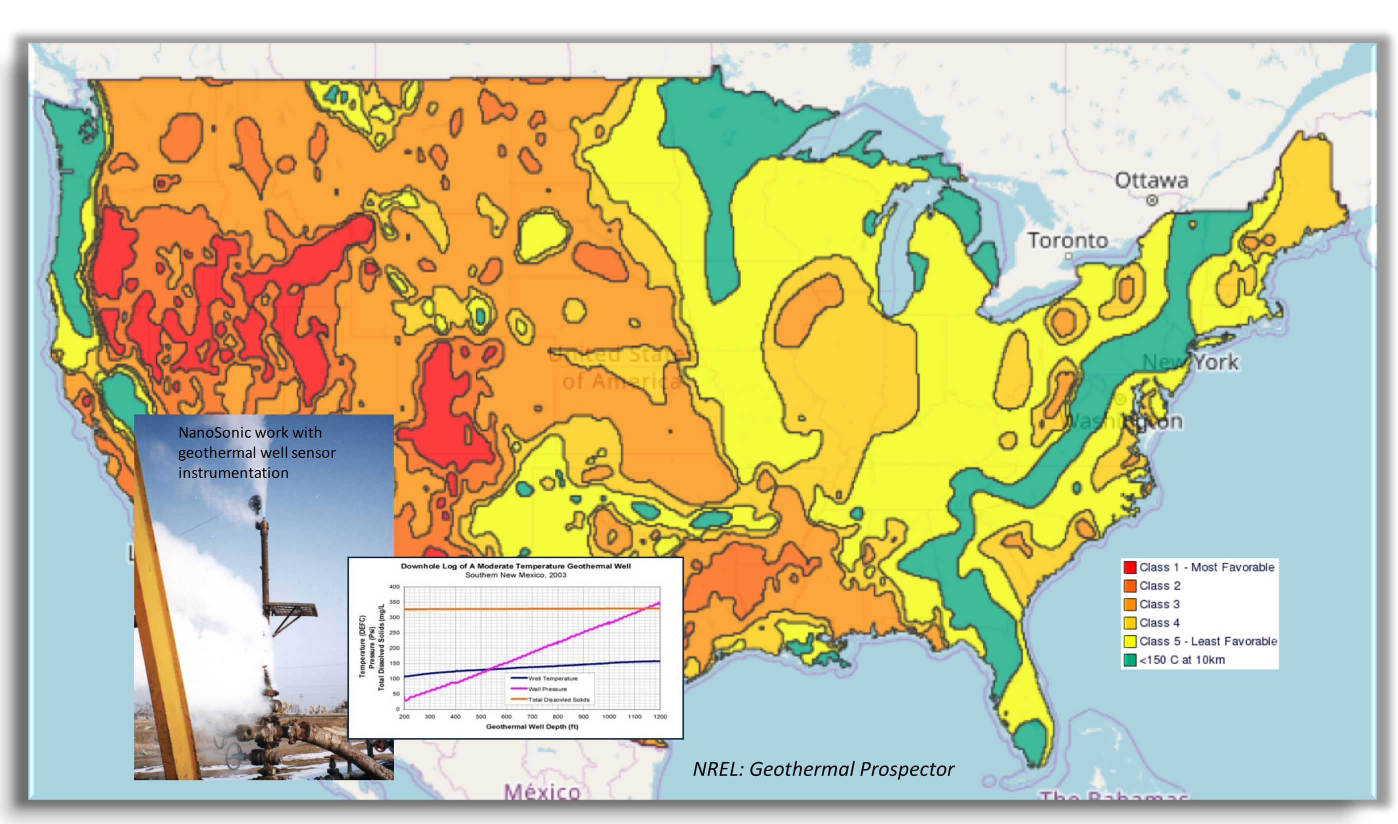
$$\frac{\Delta R}{\Delta \sigma} = \frac{\Delta R}{\Delta \varepsilon}\left(\frac{\Delta \varepsilon}{\Delta \sigma}\right) = \frac{\Delta R}{\Delta \varepsilon}\left(\frac{1}{E}\right)$$

SUMMARY

- NanoSonic fabricated Metal Rubber sensor materials with a wide range of modulus and resistance values
- Increasing the yield stress of the sensor material reduces risk of sensor failure due to material hysteresis
- Select formulations were successfully embedded in a high-temperature molding material used to fabricate a prototype packer for demonstration purposes
- Sensors embedded in the prototype packer can be instrumented and measured for resistance response as a function of compression

FUTURE WORK

- Evaluate sensor performance at elevated temperatures
- Determine long-term performance of sensor materials through thermal analysis and Time Temperature Superpositioning (TTS)
- Demonstrate strain field mapping and determine operational limits of sensor
- Work with Phase I partner to investigate practical alternatives for strain data acquisition from embedded sensors



NREL: Geothermal Prospector

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