Using MEMS Sensor Array to Map the Temperature of Hot Springs in Yellowstone National Park

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Abstract and Introduction:

During its exploration of Mars, the *Spirit* exploration rover uncovered areas of high concentration of silica, which was proposed by scientists to be the evidence for possible ancient hot springs that may have been similar to those that are currently present on Earth. One such analog environment on earth may be the hot springs located at Yellowstone National Park (YNP), which are teeming with thermophilic organisms, both chemosynthetic and photosynthetic. This is an important revelation because if the hot springs on Mars are at all similar to those at YNP, then they too might have been home to similar kinds of life. At the same time, there has been a goal of many researchers to understand the conditions under which life can exist in the hot springs of YNP.

Yellowstone National Park hot springs' ecological environment consists of areas where microbial communities thrive juxtaposed to areas where no life is present. The abrupt transitions between these regions happen on a millimeter-scale, rendering commercial sensors impractical for measuring the changes in the potential of hydrogen (pH), temperature, flow, and conductivity (factors which may influence the type of life found at any particular location) across these transitions. Microelectromechanical systems (MEMS) technology, enabled by the development of chemically and thermally tolerant materials, can be employed in the exploration of the microbial boundaries in the hot springs.

The focus of our research was on the fabrication and utilization of MEMS thermistor arrays to measure the temperature of the microbial boundaries in the hot springs of YNP.

Experimental Procedure:

Silicon dioxide (SiO_2) was deposited onto one side of Si wafers using plasma-enhanced chemical vapor deposition (PECVD). On top of the SiO_2, temperature-sensitive resistors (thermistors), made of titanium/platinum bi-layers, were patterned in a linear array at spatial intervals of 5 mm using photolithographic methods. Several wafers were made with varying thicknesses of the bi-layer metals to optimize the temperature coefficient of resistance (TCR).

Thermistor resistances were measured at various locations on the wafer at different temperatures in order to determine the TCR via the equation:

$$\frac{\Delta R}{R_0} = \alpha \Delta T$$

where α is the TCR, ΔR is the change in resistance, ΔT is the change in temperature from the initial set point of 30°C, and R_0 is the initial resistance at 30°C.

Photolithography and the metal deposition were employed again to produce leads of copper on chromium to connect the bond pads to the thermistors. The sensor arrays were then coated with a biocompatible, chemically inert and water-resistant polymer, Parylene-C. To enable the thermistors to be wired, the Parylene-C was etched to provide access to the bond pads. The wafers were diced producing six arrays per four-inch wafer, each with 12-15 resistors in an array configuration. The array allowed for simultaneous temperature measurements and the data could be utilized in mapping the temperature gradient. Wires were then soldered to the bond pads on the arrays and later connected to a data acquisition card (DAQ). The wire connections were coated with a commercial epoxy for increased mechanical strength.

Using the DAQ, each array was calibrated in a hot water bath between 40 and 100°C. The DAQ was programmed to measure the voltage drop across a known resistor in series with a thermistor to determine the current through the circuit following Ohm's law $I = V/R$.

This current and the resulting voltage drop across the thermistor were used to calculate the resistance of the thermistor, whose value could be paired to a specific temperature.

Results:

The results of how the varied thicknesses of metal affect the TCR are compiled in Table 1. The sensors with the best TCR were used in the field at YNP. The measurements from one of the hot springs are detailed in Figure 1. The data was taken by measuring at one spot, averaging the temperature readings across the array, and then sliding the sensor back in a straight line before taking the next measurement. At location A no life existed. At location B life existed as a green-black microbial community. At location C the life transitioned from a green microbial community to an orange/brown microbial community.

	Wafer 1	Wafer 2	Wafer 3	Wafer 4
Resistor Thickness	10nm Ti / 90nm Pt	10nm Ti / 120nm Pt	90nm Ti/ 15nm Pt	80nm Ti / 40nm Pt
Avg. R_{o-} (ohms)	496.0	456.8	2232.6	4065.4
Avg. TCR, α (K^{-1})	0.001204	0.001065	0.000338	0.00013
Avg. $\Delta R*K^{-1}$ (ohms)	0.5979	0.4868	0.7532	0.5200

Table 1: Resistor Metal Composition and TCR data. High Avg. TCR is better for thermistors.

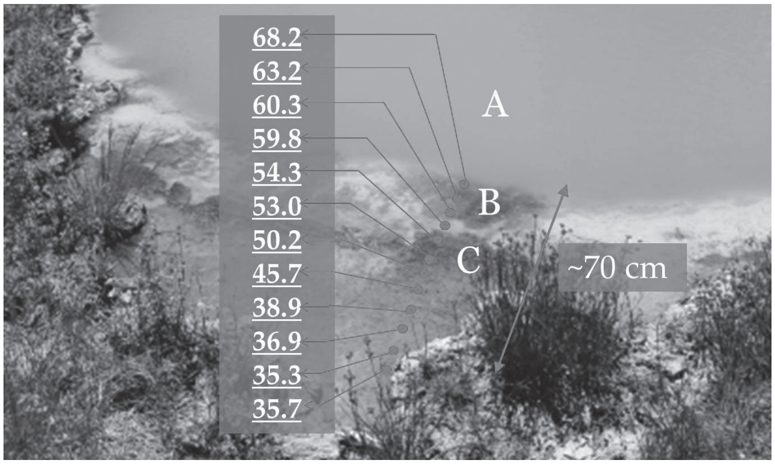

Figure 1: Surface gradient across microbial boundary of pH 6 hot spring using our MEMS temperature sensor. (See cover for full cover version.)

Conclusions:

Our MEMS temperature array was able to accurately measure the temperature across the microbial boundaries in the hot springs of YNP. Our results are shedding light on the interactions between the water temperature and the location of the different microbial communities living in the hot spring environment. This is evident by the drastic change of life with a change of temperature. Our success opens the door for new MEMS sensors arrays (such as pH, conductivity, and flow rate) to be used in small scale gradient measurements and demonstrates their versatility and practicality in research.

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