800 ºC Silicon Carbide (SiC) Pressure Sensors for Engine Ground Testing

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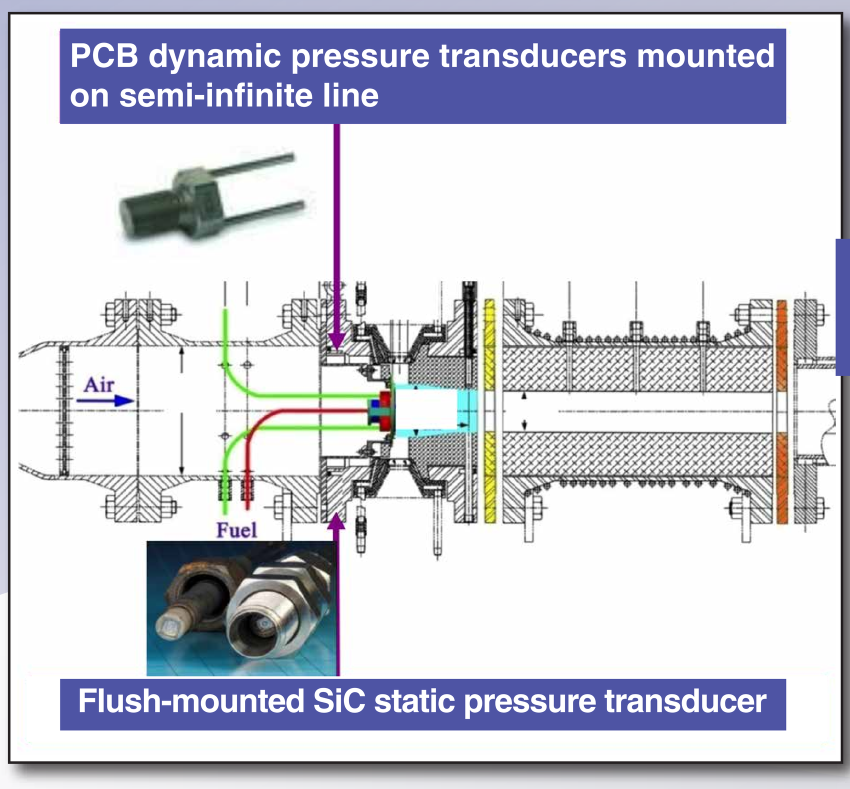
ABSTRACT

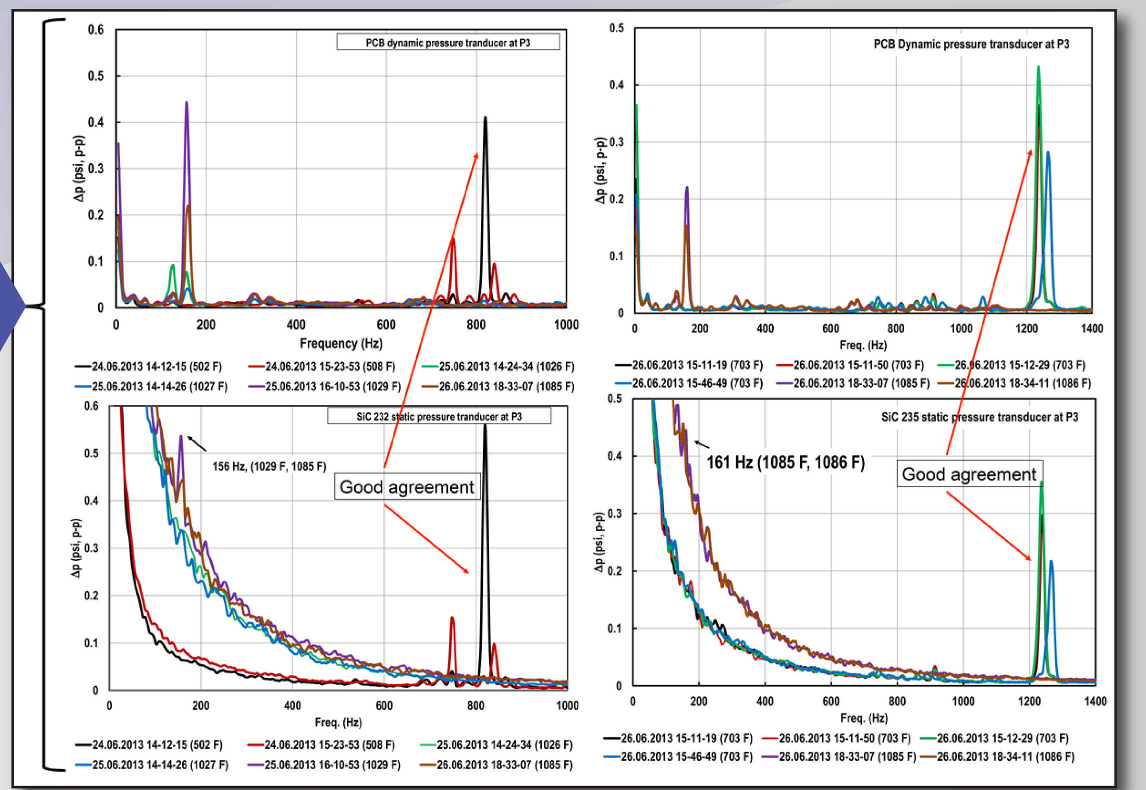
MEMS-based 4H-SiC piezoresistive pressure sensors have been demonstrated at 800 ºC, leading to the discovery of strain sensitivity recovery with increasing temperatures above 400 ºC, eventually achieving up to, or near, 100% recovery of the room temperature values at 800 ºC. This result will allow the insertion of highly sensitive pressure sensors closer to jet, rocket, and hypersonic engine combustion chambers to improve the quantification accuracy of combustor dynamics and performance and increase safety margin. Also, by operating at higher temperature and locating closer to the combustion chamber, reduction of the length (weight) of pressure tubes that are currently used will be achieved. This will result in reduced cost/lb to access space.

MOTIVATION

Lower emissions (LE) jet-engines are critically dependent on lean-burning (LB) operation. LB/LE combustors are susceptible to thermoacoustic instabilities, producing large pressure oscillations that can reduce component life and potentially cause engine failure. Existing instability prediction models have high uncertainties. Hence, robust pressure sensors are needed for accurate model validation. Conventional sensors placed at a distance from the test article limits frequency bandwidth; water cooling adds "vortex noise" to corrupt signal. Sensors are needed to perform at >500 ºC.

COMBUSTOR RIG TESTS AT NASA GLENN RESEARCH CENTER



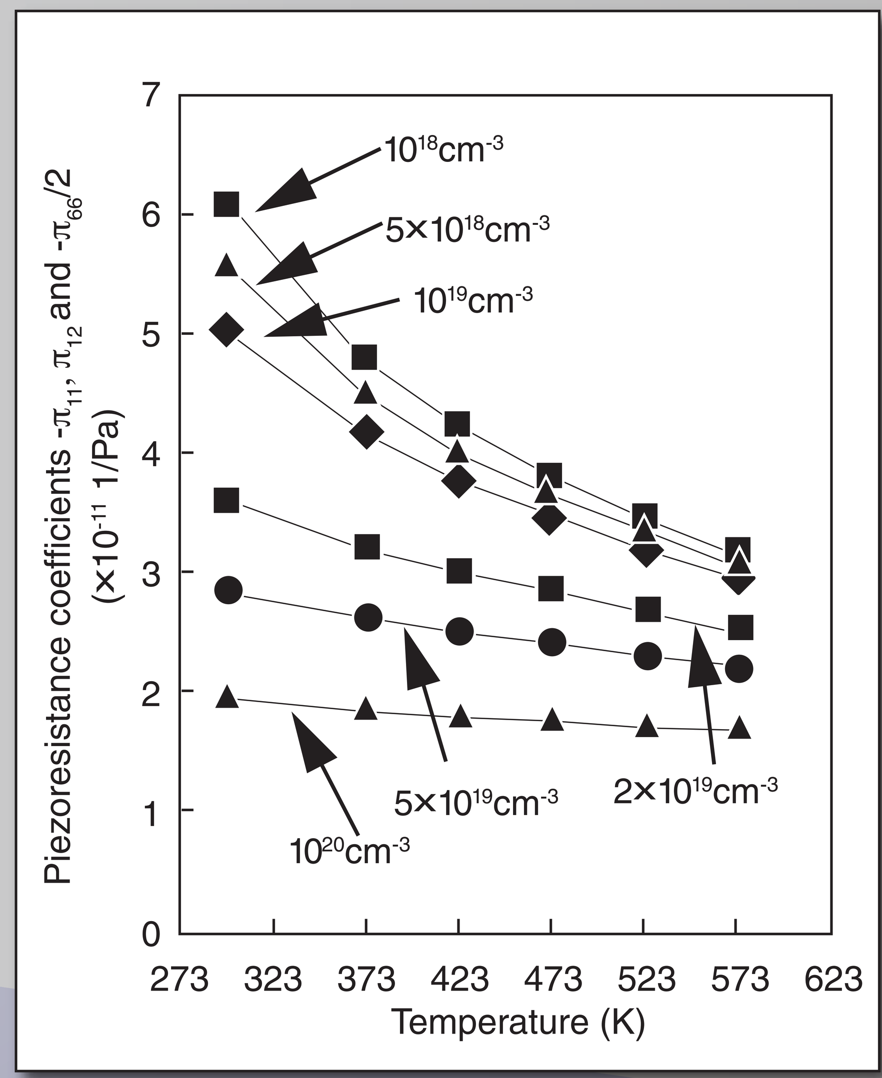


Amplitude spectral density for the water-cooled piezoceramic pressure sensor (top) and the unoptimized static SiC pressure sensor (bottom) both axially co-located at the P3 section of the combustor rig. They both detected thermoacoustic instabilities across various test conditions.

NOTE

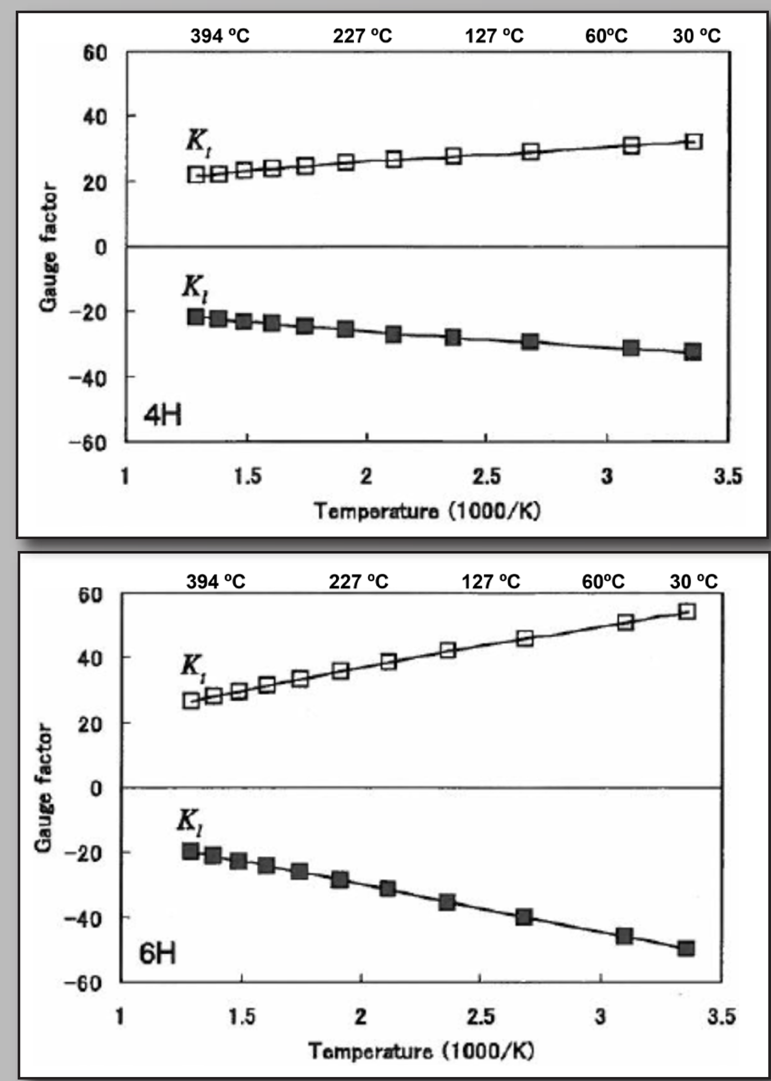
The uncooled SiC pressure sensor is a static sensor that is not optimized for dynamic sensing. However, reduced data from experiments in NASA Glenn CE5 combustor facility compared well against reduced data from water-cooled PCB dynamic sensor. The SiC pressure sensor was exposed to 550 ºC flow field while the PCB dynamic sensors were located several inches away to prevent damage. Low frequency noise (<500 Hz) suppressed the SiC sensor output at high temperature, since sensor was not optimized for low frequency sensing at high temperature. Efforts underway to develop SiC dynamic pressure sensors with higher sensitivity to increase signal to noise ratio.

LIMIT OF CURRENT THEORETICAL PREDICTIONS AND EXPERIMENTAL RESULTS



Toriyama, T., and Sugiyama, S., 12th International Conference on Solid State Sensors, Actuators, and Microsystems, Boston, vol.1, Page(s): 758 – 761 (2003).

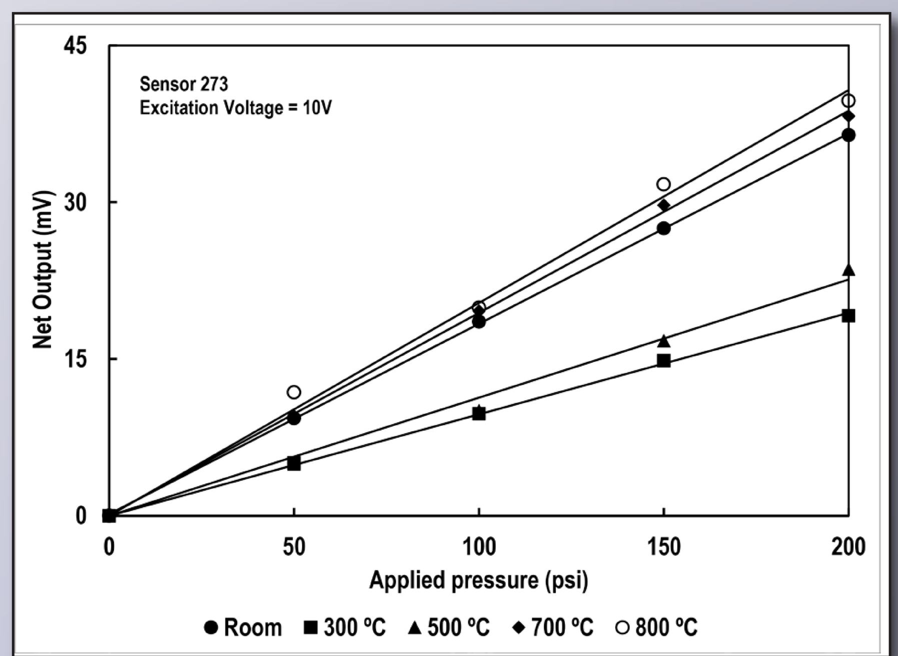
Theoretical calculation projects to lower values with increasing temperature.



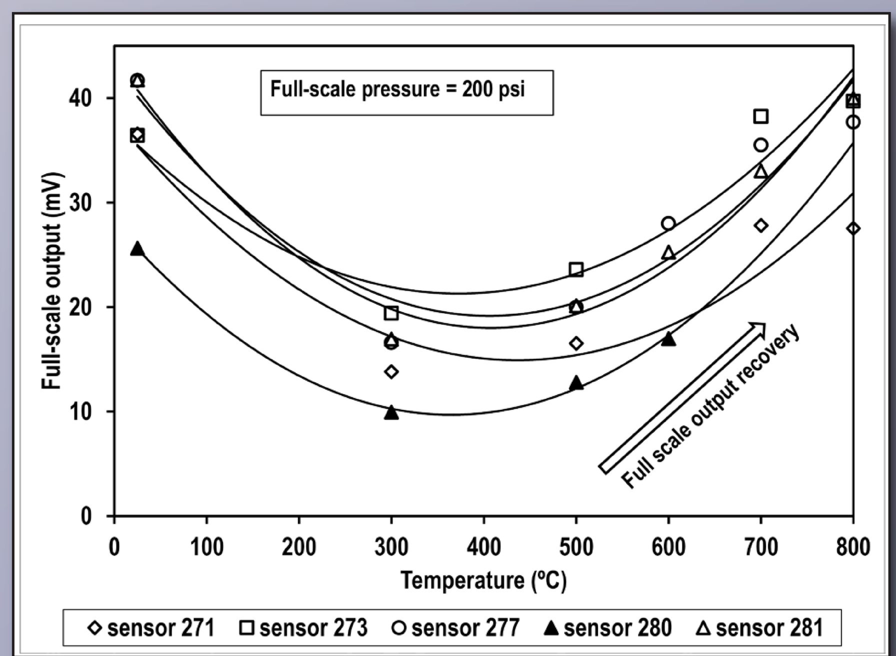
K. Nakamura et al., Jap. Jnl. Appl. Phys. (50), 06GE05. 2011.

Decrease in gauge factors with increasing temperature projects even lower values beyond 500 °C.

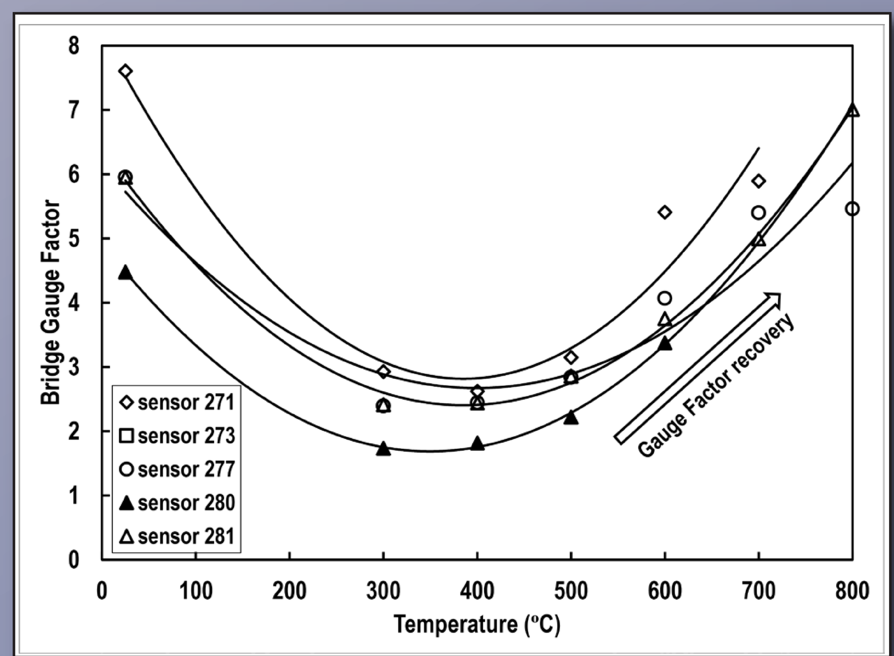
TESTING OF SiC PRESSURE SENSORS UP TO 800 ºC AT NASA GLENN RESEARCH CENTER



Net output versus temperature shows increase output at 800 ºC.

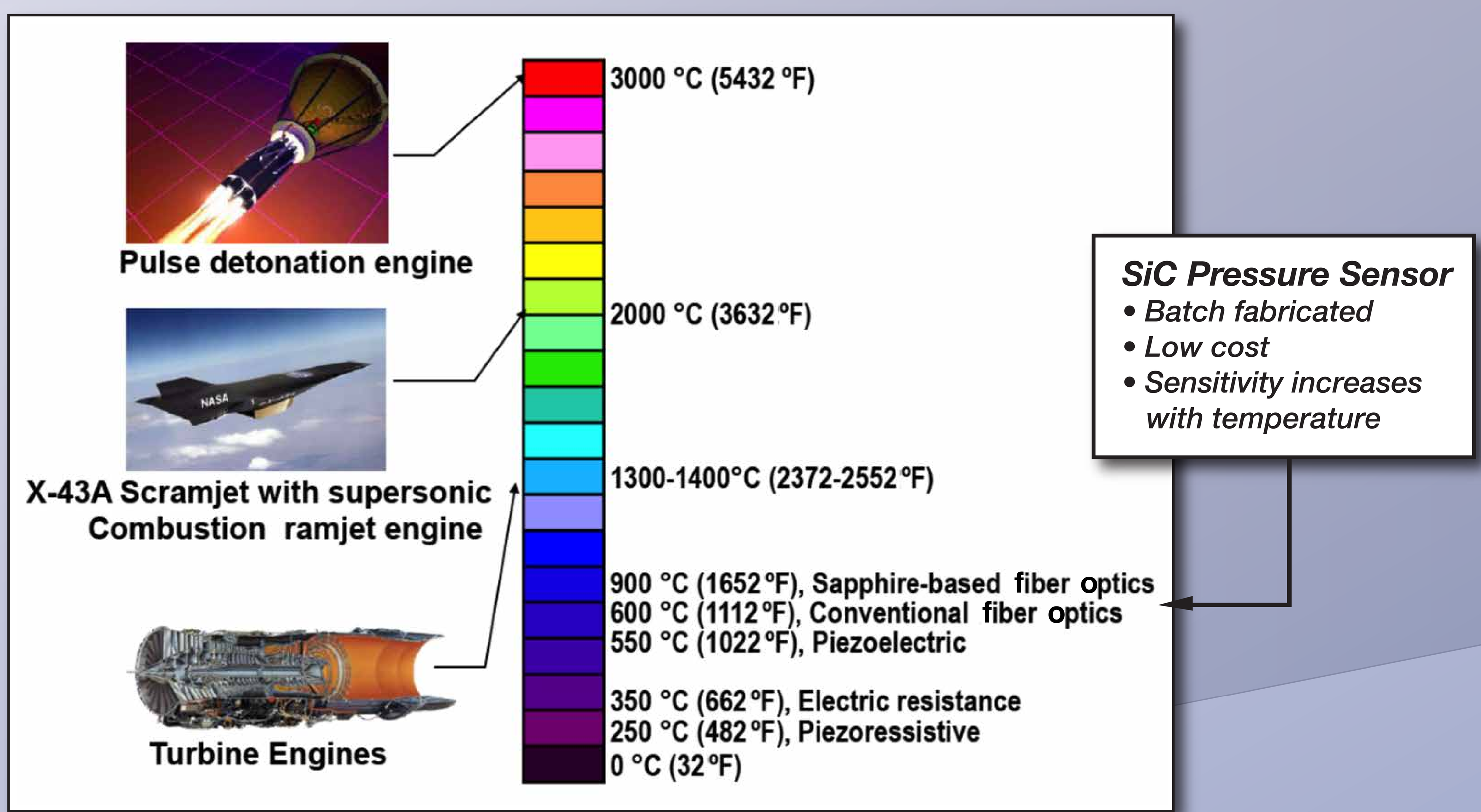


Full-scale (200 psi) output versus temperature shows increasing output from 400 ºC.



Bridge Gauge Factor versus temperature.

IMPACT OF FINDING ON TEST PROGRAMS



Alireza Behbahani and Kenneth Semega, "Sensing challenges for controls and PHM in the hostile operating conditions of modern turbine engine." AFRL-RZ-WP-TP-2008-2184, 2008.

CONCLUSION

The demonstration of 4H-SiC piezoresistive pressure sensors at 800 ºC is reported for the first time, to the best of our knowledge, [Okojie et al., IEEE Electron Device Letters, vol. 36, issue 2, 2015]. The characteristic sensitivity recovery beyond 400 ºC reached values that are nearly equal to the room temperature values at 800 ºC. It offers the promise of delivering the room-temperature-level sensitivity at the highest operating temperature, thereby making it possible to insert the sensors further into higher temperature sections of the test article without the need for cooling. The mechanism responsible for this phenomenon and the hypotheses proposed are being investigated.

SPONSOR

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