**TITLE:** **Hybrid Wired-Wireless Silicon Carbide-based Optical Sensor for Extreme Sensing Environment Temperature**

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## 1. ABSTRACT

### Program Introduction: Rationale and Objective

Recent studies have shown that higher gas turbine efficiencies (> 50%) and environmentally cleaner operations can be achieved using higher temperature turbines (1000 °C to 2000 °C). Second , future combined cycle clean coal systems are expected to have high pressure values near 100 atmospheres (atm). Such operations require reliable and accurate temperature and pressure measurements throughout the power generation system. Furthermore, sensors must be able to provide accurate and reliable information from distributed locations within the plant, making smart communications and controls a necessity. This abstract deals with a research program with objectives that study single crystal Silicon Carbide (SiC) dynamical optical and mechanical properties and demonstrates its practical applications engaging these dynamics for extreme environment physical temperature and pressure sensing and design of high reliability distributed sensor networks and controls.

### Accomplishments Achieved During the Current Period of Performance

During the current period of performance, July 2007 – April 2008,

A wavelength tuned signal processing approach is proposed for enabling direct unambiguous temperature measurement in a free-space targeted single crystal Silicon Carbide (SiC) temperature sensor. The approach simultaneously exploits the 6H SiC fundamental Sellmeier equation-based wavelength sensitive refractive index change in combination with the classic temperature dependent refractive index change and the material thermal expansion path-length change to encode SiC chip temperature with wavelength. Presently, the technique is useful for fast coarse temperature measurement as demonstrated from room temperature to 1000°C using a 10-peak count wavelength tuned measurement with a 0.31 nm total wavelength change. This coarse technique can be combined with the previously presented two wavelength signal processing temperature measurement approach to simultaneously deliver a wide

temperature range and a high resolution temperature sensor. Newly conducted experiments and calculations show that the instantaneous temporal response of a 400 micron thick 1 cm x 1 cm square single crystal SiC chip when subjected to a conductive temperature step function of 90 deg-C peak value is under 1/30 seconds. Given the 1 mm diameter conductive heat tip placed on the chip, ~ 16 seconds are required to reach the steady state 90 deg-C temperature of the heat tip from the 25 deg-C room temperature setting. Approximately the same time (~ 17 seconds) is required for the chip to cool down to steady state room temperature by simply using convection cooling, indicating a reversible and repeatable heat/cool refractive index change process for the observed temperature range. Our industry partner Nuonics,Inc. provided probe assembly using single crystal SiC optics and sintered SiC packaging has been used for basic experimental studies. Observed is reflected 1550 nm infrared laser beam movement at temperatures close to 1000 deg-C when the probe is open to external air currents. On the other hand, data shows that the reflected 1550 nm infrared laser beam movement is essentially zero at temperatures close to 1000 deg-C when the probe is closed using the optical window and near vacuum-sealed. This data clearly shows that when the probe is open, the laser beam is moving around very rapidly due to convection currents in air whereas when it is closed and vacuum-sealed, the laser beam becomes stable and maintains its location for effective detection by a 2-D camera or large area point detector. Oven tests of the probe have been conducted with 30 heat/cool cycles from ~ 25 deg-C to ~1100 deg-C. The heat cycle is ~ 4.5 hours long while the natural convection cool cycle is conducted over night time (e.g., > 10 hours) in the laboratory as the oven is turned off. These tests show the probe optical and mechanical performance to be unchanged. The probe has also been tested to hold a partial vacuum of 25 inch Hg (~ 85 kpa). Initial tests show a drop to about 20 inch Hg in a 21 hours time frame, indicating the probe vacuum holding capability. During this 21 hour test period, the probe did experience one ~ 1075 deg-C thermal cycle over a 6 hour period.

### Plans for the Remaining Period of Performance

The work planned for the remaining months of Phase-I of this research program include the following tasks:

- Conduct higher speed SiC optical response experiments
- Conduct single crystal SiC temperature calibration studies
- Publish the outcome of these investigations.

## 2. LIST OF PUBLISHED JOURNAL ARTICLES, COMPLETED PRESENTATIONS AND STUDENTS RECEIVING SUPPORT FROM THE GRANT

### Conference & Journal Publications

- N. A. Riza, M. Sheikh, and F. Perez, “Design and Fabrication of an Extreme Temperature Sensing Optical Probe using Silicon Carbide Technologies,” IEEE Sensors 2007 International Conference, pp. 660-662, Atlanta, GA, Oct. 28-31, 2007.
- N. A. Riza and M. Sheikh, “Silicon Carbide-based Extreme Environment Temperature Sensor using Wavelength Tuned Signal Processing,” Optics Letters Journal, May 2008.
- M. Sheikh and N. A. Riza, “Experimental Studies of an All-Silicon Carbide Hybrid Wireless-Wired Optics Temperature Sensor for Extreme Environments in Turbines,” SPIE Conference Proc. April 2007.

### Students Supported Under this Grant

- Mumtaz Sheikh, graduate student in the CREOL-College of Optics, University of Central Florida.
- Syed Azer Reza, graduate student in the CREOL-College of Optics, University of Central Florida.