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All-Silicon Carbide Hybrid Wireless-Wired Optics Temperature Sensor: Turbine Tests and Distributed Fiber Sensor Network Design

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ABSTRACT

Highlighted are results from a commercial Siemens rig test of the fabricated all-Single crystal Silicon Carbide (SiC) temperature probe. Robust probe design options are introduced. Introduced is a fiber network-based spatially distributed sensor design suitable for turbines.

Keywords: Optical sensors, temperature sensor, turbine rig, sensor network, extreme environments

1. INTRODUCTION

Greener energy generation is the focus of many advanced countries. As coal-fired power plants still dominate the world energy production, one approach to greener energy production is via the use of higher (e.g., > 1500 deg-C) combustor firing temperatures in gas turbines. This leads to higher turbine system efficiencies and hence use of less coal/fuel per Watt production leading to lower green house gas production. To achieve this higher temperature operation goal, temperature sensors for extreme temperature measurement in gas turbines are required that are robust and accurate. In addition, pressure measurements are also desired in these gas turbines. Over the last few years, progress has been reported on a new hybrid theme all-Silicon Carbide (SiC) sensor design to enable harsh environment temperature and pressure sensing [1-14]. The focus of this paper is to further report on recent progress of the proposed hybrid theme sensor for temperature sensing.

2. TURBINE RIG TEST

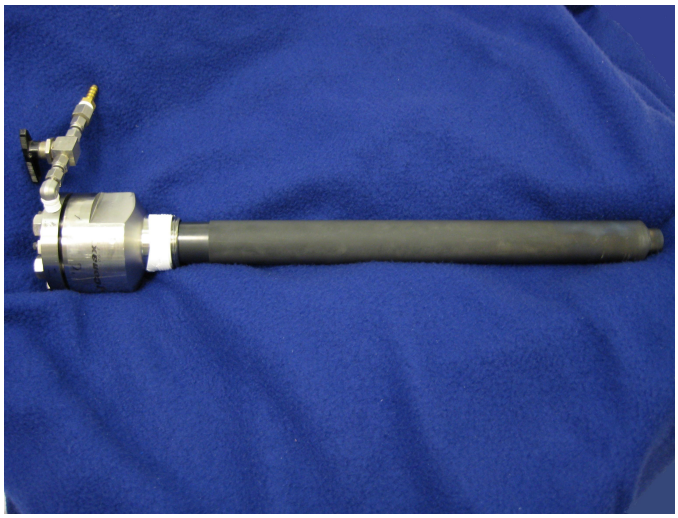


Fig.1. The novel all-SiC probe assembly with sealed pressure connector with optical window.

Our industry partner Nuonics, Inc. has recently designed and fabricated this hybrid material probe (Fig.1) and the probe has been successfully deployed and tested in a Siemens Power Generation Orlando combustion rig (Fig.2) to form a complete temperature sensing system.

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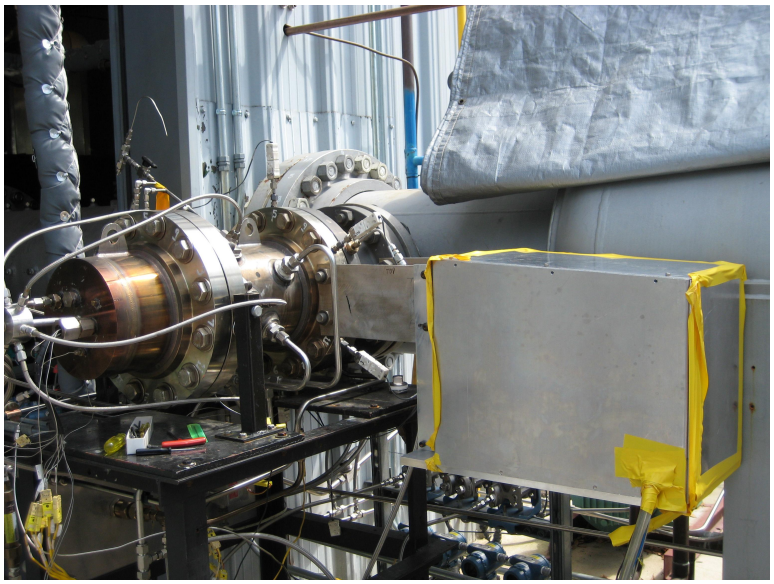


Fig.2. All-SiC temperature sensor first test at Siemens rig facility conducted recently.

Table 1: Summary of all-SiC probe test at Siemens rig.

COMBUSTION RIG FLAME ACTIVE OPERATION	6 DAYS
NO. OF TIMES PROBE EXPERIENCED FLAME LIGHT AND THERMAL SHOCK (TEMPERATURE RAMP OF 1000 DEG-C IN 3 SECONDS)	8 (1 DAY 3 FLAME LIGHTS, 5 DAYS 1 FLAME LIGHT/DAY
OPERATION WITH FLAME ON	26 HOURS
OPERATION WITH FLAME OFF AND BLOWER ON	13.5 HOURS
NUMBER OF COMBUSTION HEAT AND COOL CYCLES	8
DAYS IN EXTERNAL RIG ENVIRONMENT	28 DAYS

These Siemens test rig results with the proposed new all-SiC sensor technology are summarized in Table 1 and indicate early promising results for all-SiC probe frontend robustness. For example, the probe survived thermal up-ramps of 1000 ºC in less than 4 seconds. The probe also survived localized thermal shock and maintained mechanical integrity when subjected to an oxy-acetylene flame that produced temperatures near 1600 ºC.

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3. ROBUST ALL-SILICON CARBIDE TEMPERATURE PROBE DESIGNS

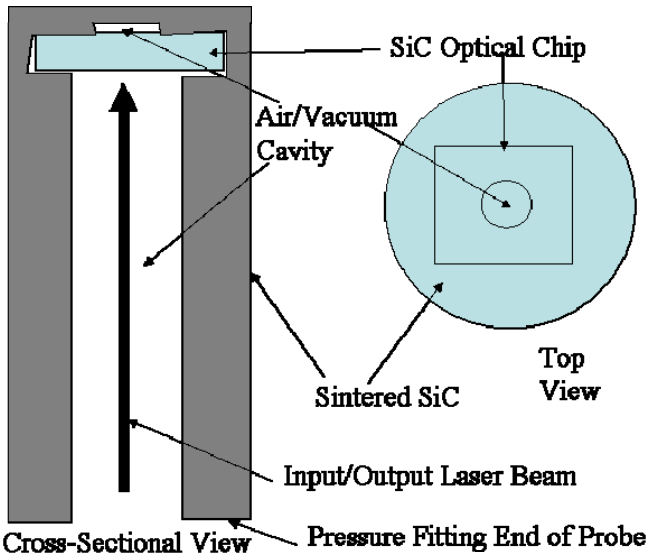


Fig.3. Proposed novel all-SiC Probe 1 frontend design optimized for temperature measurement.

Fig.3 shows a Probe 1 frontend novel probe design. This design is intended for a temperature-only measuring probe to operate over long life-times in the extreme environment of a combustor with temperatures reaching 1600 ºC. Note that the sintered SiC material is in physical contact with a large fraction of the SiC optical chip surface area, leading to fast heat transfer between outside gas temperature and optical chip via sintered SiC material with matched CTEs. The sintered SiC material cover over the chip is of small thickness (e.g., <2 mm) over the outer part of the package where conductive heat transfer takes place. The central part of the sintered SiC cover (looks black) is thinner, forming a small (e.g., <800 micron) thick air cavity that can be vacuum sealed or filled with an inert gas for convective heat transfer. The purpose of the cavity is to maintain a SiC-air interface for strong Fresnel reflection from the incident laser beam. The Fig.3 probe frontend design makes sure that the single crystal SiC chip stays completely protected inside the sintered SiC assembly and tube, thus not directly exposing the optical chip top surface to the extreme conditions of the combustor. In effect, the life-time of the optical signal is greatly enhanced as on-off optical signal modulation depth drop is protected from the harsh combustor environment. The probe 1 design is unlike protected TC designs (i.e., capped and shielded TC technology) where electrical insulator material (i.e., a high temperature ceramic like MgO) is used in the wired junction tip zone to prevent electrical shorting. As electrical insulators are also good thermal insulators, external gas temperature heat transfer to TC junction wires is slowed down. In the case of the all-SiC probe, because SiC has high thermal conductivity, heat transfer between external gas temperatures and internal SiC optical chip through sintered SiC happens efficiently.

Unlike the Probe 1 design, Probe 2 design shown in Fig.4 has direct contact with the hot gas in the combustor. In effect, the central part of the SiC optical chip is exposed to the hot gas extreme conditions while the chip side zones are protected with sintered SiC covers with small cavities. The optical chip, like the experiments on pressure conducted earlier deforms like a convex mirror with increasing relative external pressure (the inside of the probe holds a given partial vacuum level). Thus depending on the chip boundary conditions (clamped edge or simply supported or a combination), incident light on the deforming part of the chip suffers beam expansion and a CCD camera can record this image growth with pressure and deduce gas pressure. For example, the beam that hits the central gas exposed part of the chip could suffer the beam expansion given the chip is clamped around the open face of the sintered SiC cover. In this case, the central part of the beam (labeled with P in Fig.4 top view) provides the pressure measurement. Hence, the central part of the chip simply acts as a mirror where light is reflected mainly from the inner surface of the chip that is inside the probe. Thus as pressure and temperature change, the central part of the received beam grows in size (not in change of optical power) while the external ring (checkered zone labeled with T in Fig.4 top view) undergoes interferometric gray-scale optical power changes based on temperature change. Thus, monitoring the changing optical power on a localized or point level of the retro-reflected ring zone provides the temperature-only data while global size monitoring of the central zone gives the pressure-only data. In this simple model case, one assumes that due to material

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CTE matching the temperature changes cause equal expansions of the SiC optical chip and sintered SiC package assembly, thus preventing any mechanical lens-like deformation of the SiC chip, keeping pressure and temperature optical effects decoupled.

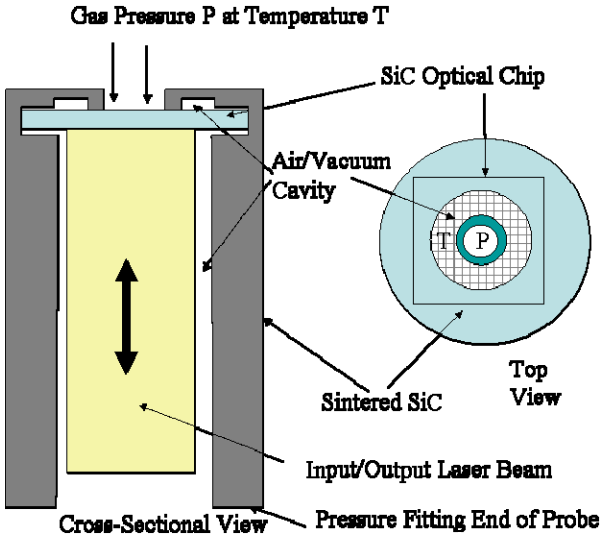


Fig.4. Proposed novel all-SiC Probe 2 frontend design optimized for simultaneous temperature and pressure measurement in a combustor.

4. SENSOR NETWORK DESIGN FOR GAS TURBINES

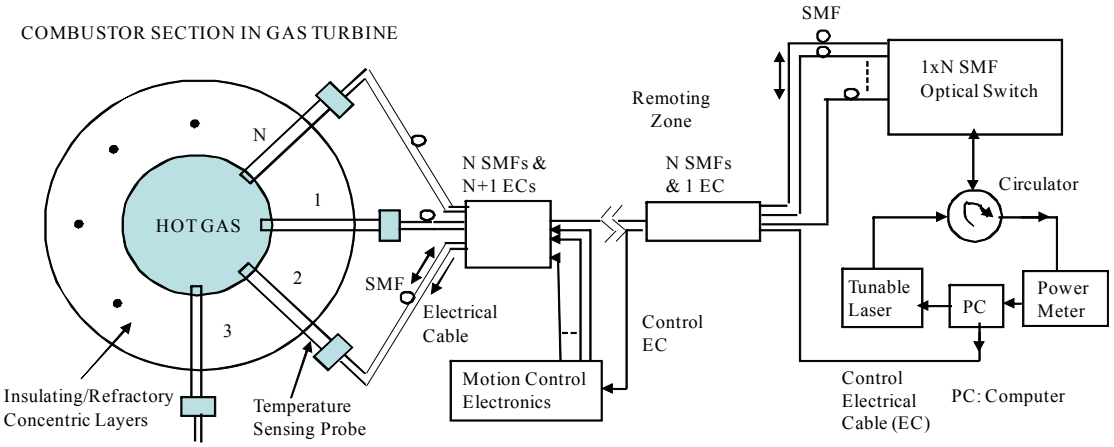


Fig.5. Proposed N temperature probes sensor network using the All-Silicon Carbide Hybrid Wireless-Wired Optics Temperature Sensors.

Fig.5 shows how the developed all-SiC temperature probes can be combined via an all-fiber network for form a discrete distributed sensor network for a gas turbine. The N probes are connected to N fibers that connect to a N x 1 optical switch for selecting the probes in a time multiplexed fashion. Note that all N probes use the same laser and detection optics and electronics, saving space, power, and cost. Key point to note is that each probe entry point has fiber lens motion mechanics for optimal light transmission and reception for temperature signal processing.

5. CONCLUSION

The continuing studies and experimental progress for the proposed SiC temperature sensing technology has been presented related to a rig test, robust probe designs, and a discrete distributed sensor network design for gas turbines. Future publications will report the details of the presented works.

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