

PI: Seetha Raghavan, Associate Professor

- Mechanics of Aerospace Materials and Structures
- High temperature materials, Sensing materials
- Expertise in characterization of mechanical behavior using piezospectroscopy; synchrotron x-ray diffraction

Co-PI: Ranajay Ghosh, Assistant Professor

- Mechanics of Solids, Biomimetic materials
- Expertise in Computational Mechanics, Multi-scale and multi-physics materials design

- Laboratory facilities:
 Unique in-situ equipment coupling micro-raman with mechanical testing;
 AFM-Raman system for spectroscopy characterization at the nano-scale.
- Access to synchrotron facilities at the Advanced Photon Source and Center of Nanoscale Materials, Argonne National Laboratory through active user proposals.



Background

In-situ optical monitoring of gas turbine blade coatings under operational extreme environments

Overall Goals

Develop and demonstrate at the laboratory scale an advanced optical suite of instrumentation technologies for enhanced monitoring of gas turbine thermal barrier coatings (TBCs).

Specific goals are to improve the accuracy and effectiveness of temperature and strain measurements made on high temperature gas turbine blades



Project Objectives

- Achieve intelligent sensing that leverages intrinsic properties of coatings and dopants through optical emission and absorption characteristics while ensuring coating integrity and durability goals are concurrently met.
- Achieve accurate diagnostics of turbine blade coatings under operating environments through calibration and correlation of measurements with direct and indirect parameters.
- Achieve advances in benchmarked optical measurement technologies of infrared imaging, pyrometer (IR) measurements and digital image correlation (DIC) in existing laboratory replicated environments.

Project Tasks

- Task 1: Project Management & Planning
- Task 2: Define and manufacture sensor configuration
- Task 3: Establish Sensing Properties and Characterize Coating Response for Luminescence Based Sensor
- Task 4: Perform Non-Intrusive Benchmarking Measurements of Surface Temperature and Strain
- Task 5: Develop and Test Laboratory Scale Sensor Instrumentation Package



Project Overview

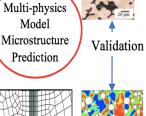
Multi-physics modeling to define sensing material configuration

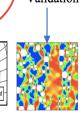
Manufacturing and processing of sensing coating architectures S. Raghavan in collaboration with industry

Incorporating High temperatures and loads

Validation

R.Ghosh





Simulation of sensing coating systems will use FE analysis to analyze configuration effect on durability eq. for TBCs shown

Integration of sensing configuration in thermal spray process



Novel sensing coatings with multi-layered and/or hybrid configurations identified and selected for manufacturing



In-situ monitoring of manufactured configurations

S. Raghavan

In situ mechanics, Synchrotron studies Test rig demo in collaboration with industry

In-situ property data fed back to refine simulation (eg. depth resolved modulus, creep constants, oxidation growth data)

(eq. conductivity measurements, time and temperature dependent phase stability

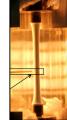
Material property data

fed back to refine model









Synchrotron x-rays provide validation and calibration measurement parameters in extreme thermo-mechanical environments to capture material and mechanics evolution

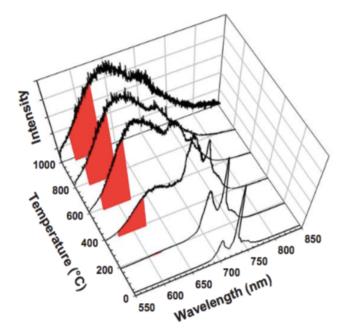
Task 2: Luminescence-based sensing using intrinsic properties of coatings and dopants

- Use of RE based dopants within coatings that provide sufficient emission for luminescence lifetime measurements to be made at temperatures above 1000 deg C
- Phosphor thermometry has been limited due to low emission or low thermal quenching temperatures
- Improve configurations for higher energy barrier to non-radiative relaxation (suppressing thermal quenching to higher temperatures (initial results with Cr:GAP)

Advantages of Luminescence-based sensing:

- Non-contact, no attachment issues
- No issues with stray radiation/unknown emissivity
- Simple instrumentation, ease of integration with operating environment
- Works well with current IR imaging can provide improved accuracy of temperature measurements

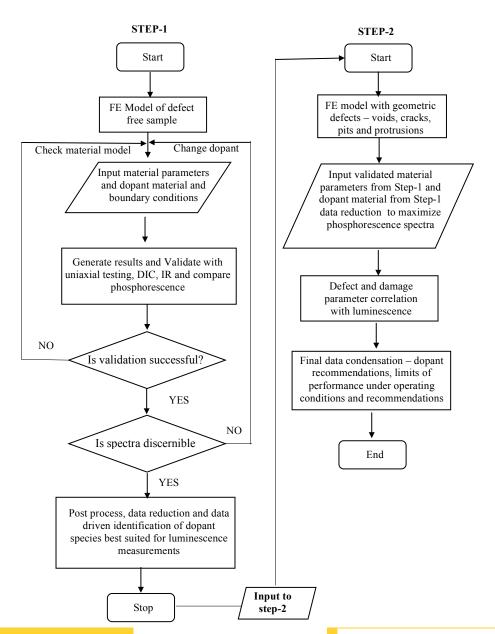
Below: Spin-allowed emission centered at 640nm gets more prominent with temperature



Eldridge et al. NASA/TM—2014-218418



Task 2 & 3 Simulation Efforts



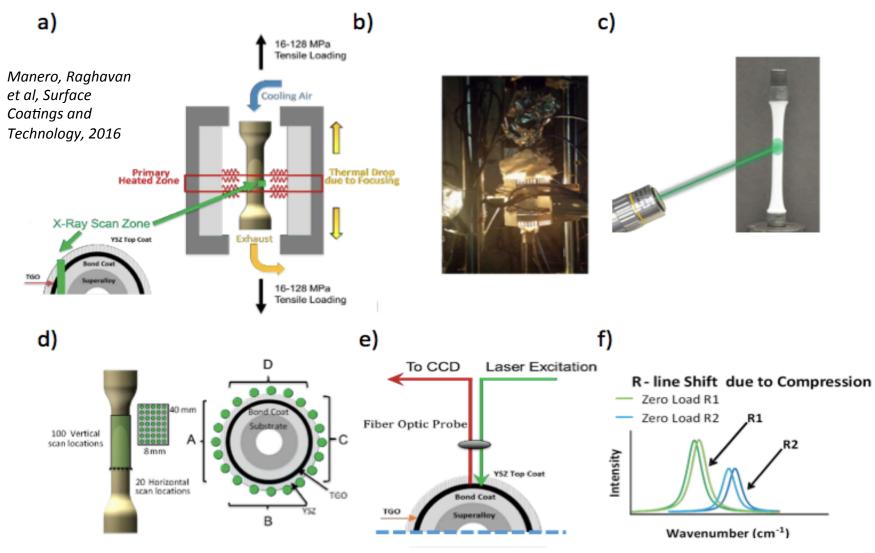
Goal: developing a computational paradigm for luminescence based non-intrusive monitoring technique.

Step 1: Multi-scale continuum models to predict the temperature profiles on the surface of doped material with no surface defects using nonlinear finite element (FE) models.

Effect of dopant on the continuum behavior will be addressed in the material model

Step 2: Surface defects will be introduced in out FE model and temperature profiles computed for select group of dopants

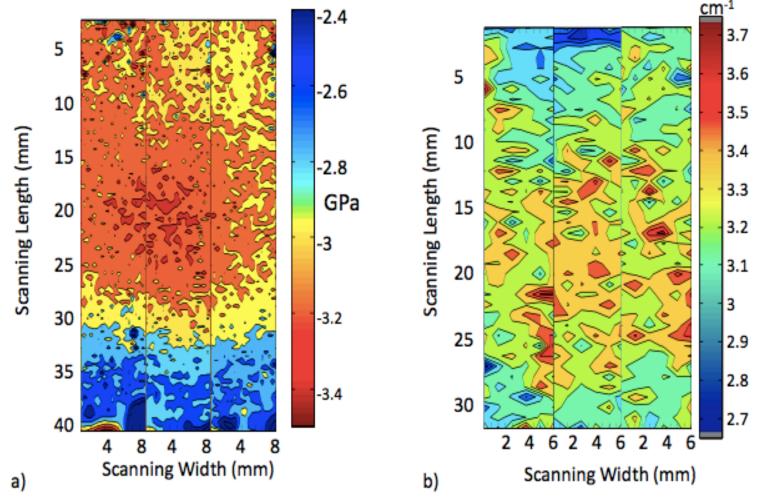
Task 3: Establish Sensing Properties and Characterize Coating Response



Motivation: Verification of stresses induced by thermal gradient cycling in cylindrical TBC coated samples using piezospectroscopy



Task 3: Establish Sensing Properties and Characterize Coating Response

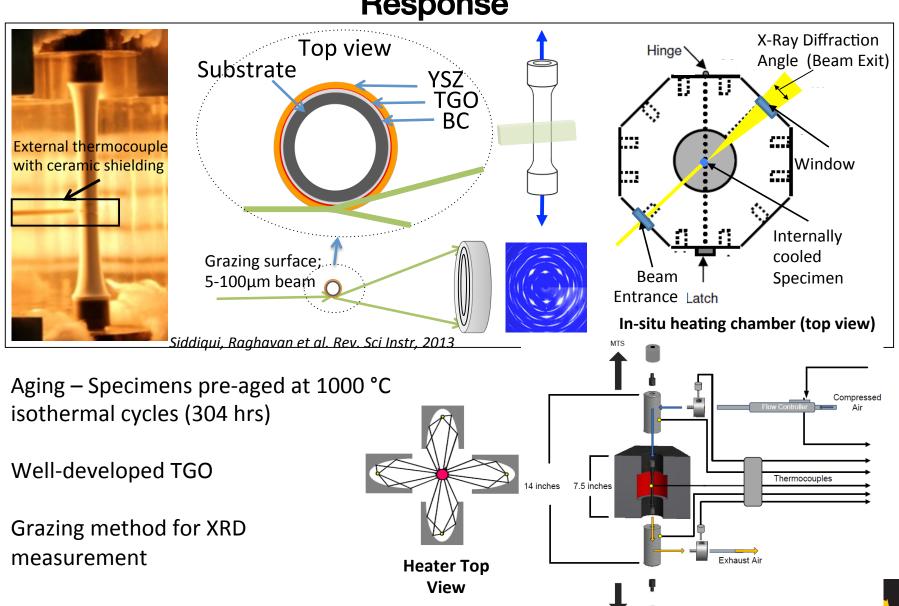


Piezospectroscopic maps for cylindrical TBC specimen a) TGO stress b) YSZ peakshift

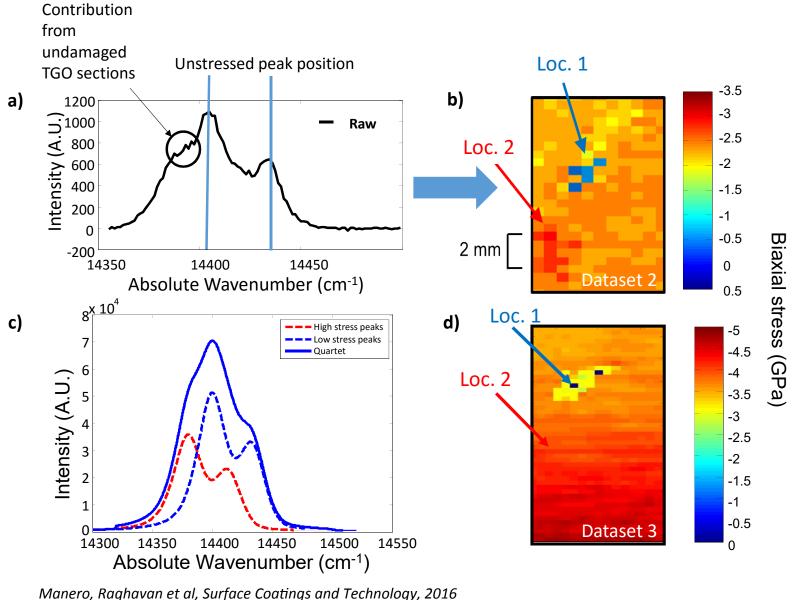
Manero, Raghavan et al, Surface Coatings and Technology, 2016



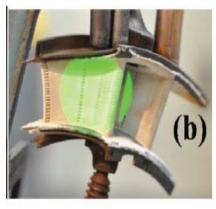
Task 3: Establish Sensing Properties and Characterize Coating Response

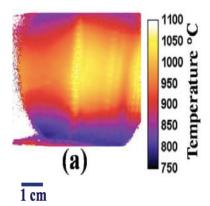


Task 3: Establish Sensing Properties and Characterize Coating Response



Task 3: Establish Sensing Properties and Characterize Coating Response







Lifetime measurements with surface tempeature Eldridge et al. NASA/TM—2014-218418

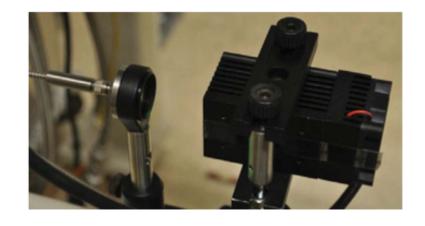
Measurements
Luminescence lifetime –
correlates with
temperature and

therefore indirectly with coating health.

Instrumentation:

Low Power pulsed laser 532nm Coupled with fiber probe PMT

Concurrent instrumentation – pyrometer





Task 4: Perform Non-Intrusive Benchmarking Measurements of Surface Temperature and Strain

Goal: Benchmark technologies will be enhanced in the proposed work while providing validation comparison with the more recent luminescence-based TBC sensing measurement technique

To make improvements in the measurement capabilities and accuracy of benchmark temperature and strain measurement technologies by focusing on reducing the uncertainties in the benchmark measurement methods.

The following 2 subtasks are defined.

Subtask 4.1. Improve Temperature Measurement Capability

Subtask 4.2. Improve Strain Measurement Capability

Focus techniques: Emission pyrometers and infrared imaging (IR Imaging) for temperature measurements and digital image correlation (DIC) for strain measurements



Task 4: Subtask 4.1. Improve Temperature Measurement Capability

- For monitoring temperature in hot-sections of gas turbines, emission pyrometers and infrared (IR) imaging methods are typically chosen because of their relative simplicity of use and high sensitivity.
- Advantages of IR imaging: allows for imaging of high speed transient events inside a gas-turbine; passive technique, no contact with the substrate providing simplicity for online measurements.
- Disadvantages of IR imaging: inaccuracy due to uncertainty in the emissivity of the TBC, which can change during engine use; TBCs are semi-transparent at mid infrared wavelengths, so the measurement temperature from the instrument is an average temperature of a path of unknown depth into the TBC coating instead of the direct surface temperature.



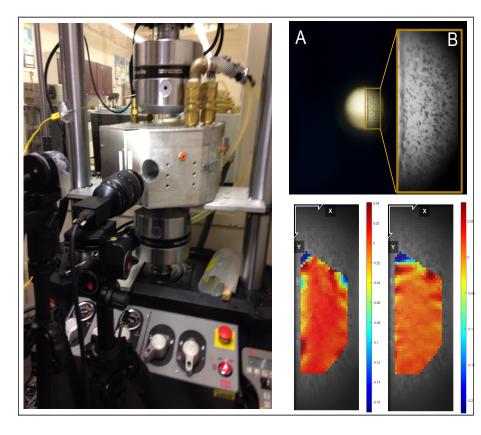
Task 4: Subtask 4.1. Improve Temperature Measurement Capability

- Identifying sources of errors and methods of quantifying errors: Eg. IR imaging
 is subject to errors due to stray reflections, combustion gas emission and
 contamination of the optical ports,
- Focusing on reducing the uncertainties systematic approach on reducing errors eg. take measurements at multiple wavelengths and using additional active optical emissivity sensors, emissivity dependencies to be ascertained and accounted for.
- Resulting complex system measurements should be accompanied by reduced uncertainty



Task 4: Subtask 4.2. . Improve Strain Measurement Capability

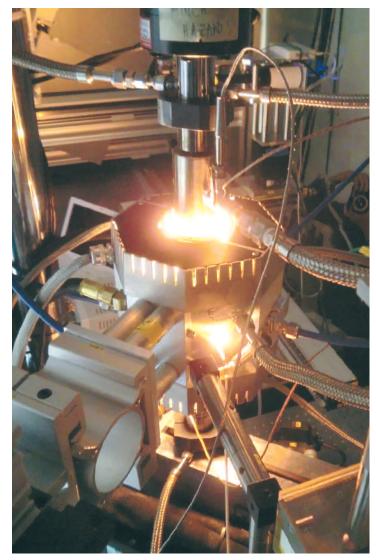
- Digital image correlation (DIC) is a commonly used non-contact method for obtaining full-field deformation measurements of materials under load.
- High temperature DIC is non-trivial and an area of interest for development.
- In previous work, high temperature DIC capability was developed that was successful in obtaining usable DIC images on a sample in an infrared heater through remote operation, while simultaneously obtaining synchrotron XRD measurements
- High temperature DIC will be developed in order to be able to incorporate strain measurements concurrently with temperature from the luminescence studies.



Mounting of custom heater with loading frame coupled with Digital image correlation device at UCF (left) and results on a loaded sample at high temperature (bottom, right); A: Image taken by camera; B: Same image, cropped and adjusted

Task 5: Lab-scale Instrumentation

- Lab-scale Instrumentation will utilize existing high temperature furnaces (up to 1800 deg C & coupled with mechanical testing systems) with some access to sample probing with non-invasive methods.
- Pulsed laser will be used to capture the luminescence data from the location of interest using appropriate lenses which will focus it into a multimode fiber coupled to a filtered PMT.
- Techniques to integrate existing environmental systems with newly introduced measurements will be developed as part of this task.
- The set up will serve as the prototype laboratoryscale test rig for the demonstration of in-situ luminescence sensing under extreme thermal and/or thermo-mechanical conditions



Raghavan et al. ACerS Bulletin, 2015



Project Timeline

Tasks	FY18				FY19				FY20			
Task 1	10/1 - 12/31	1/1-3/31	4/1 -6/30	7/1-9/30	10/1-12/31	1/1 - 3/31	4/1-6/30	7/1-9/30	10/1-12/31	1/1 - 3/31	4/1-6/30	7/1-9/30
Project Management and Planning												
Task 2												
Defining and manufacturing the 'sensor" configuration												
2.1 Identify and Select Materials												
2.2 Perform Simulations												
Task 3												
Establishing sensing properties and characterizing coating										/		
response for luminescence-based sensing												
3.1 Correlate Materials & Measurement Properties												
3.2 Simulations - Surface Defects on Temperature Profiles												
Task 4												
Non-intrusive and well-benchmarked measurements of										/		
surface temperature and coating strain										\		
4.2 Improve Temperature Measurement Capability												
4.3 Improve Strain Measurement Capability												
Task 5												
Laboratory scale instrumentation development												



Completion of all tasks



Testing of temperature measurements complete



Laboratory scale tests complete



Coating configurations selected



Validation of benchmark tests complete



