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

PI: Seetha Raghavan, Co-PI: Ranajay Ghosh
University of Central Florida

Background & Motivation

Leading edge research in the field of aviation- and land-based gas turbines' high-temperature material systems has been driven by extreme hot gas path environments in power generation and propulsion.

Thermal barrier coatings (TBCs) are designed to sustain a high thermal gradient through their thickness, to protect the underlying load-bearing material. This enables higher temperatures at the turbine inlet, increasing efficiency, and extends the lifetime of the coated parts.

Processes that limit the durability of TBCs, including oxidation, creep, and thermo-mechanical fatigue of hot section materials, are activation-energy-barrier controlled. This means that a small increase in temperature can have significant effects on the remaining life, especially when materials are operated near some high temperature limit.

Accurate temperature sensing of these coatings in operation is critical to achieving the optimal balance between engine efficiency and component life. Direct strain measurements are equally valuable and less easily achieved. Both of these critical measurement parameters have the potential to be accurately obtained with the development of optical measurement techniques.

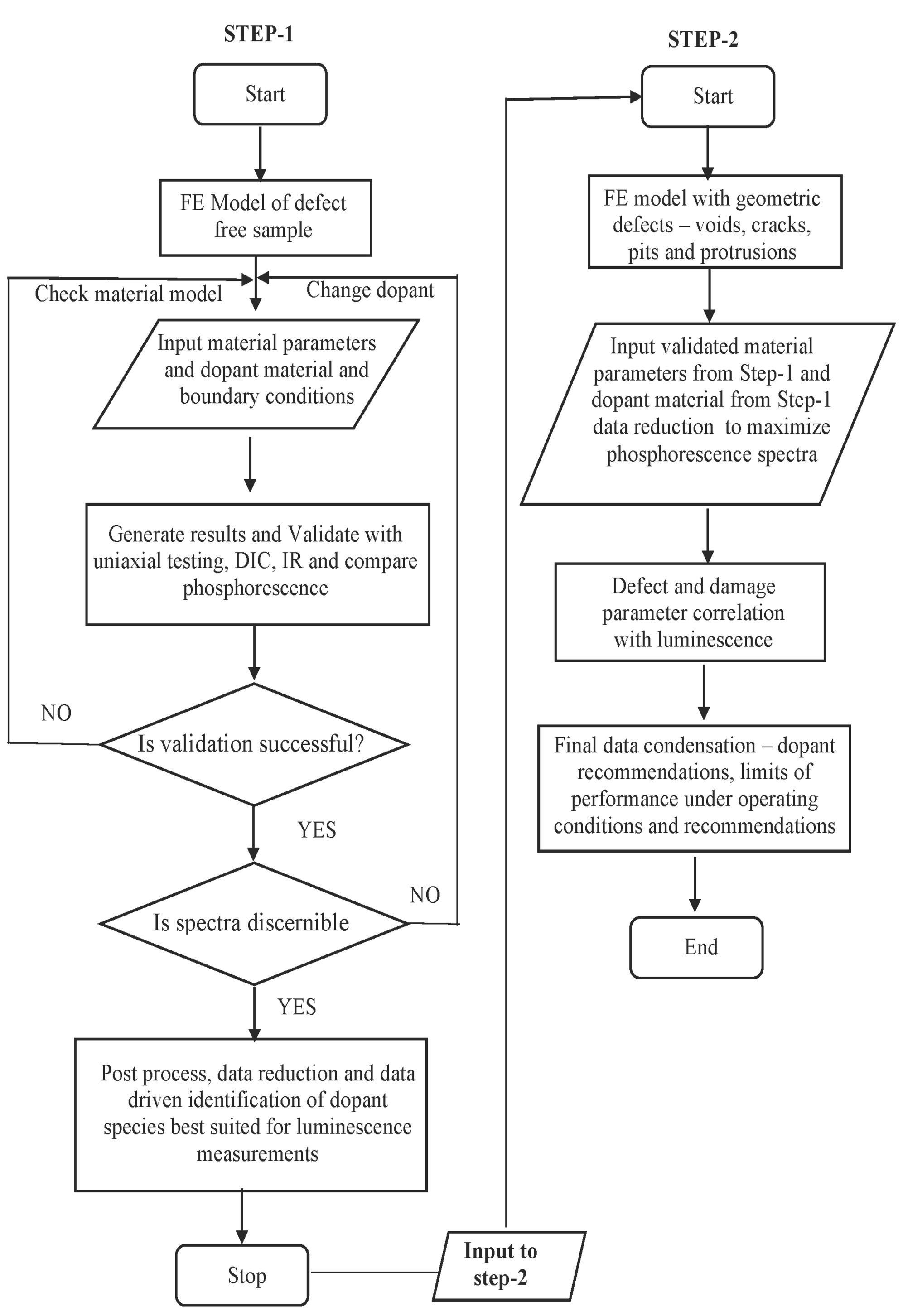
Objectives

Overall goal: Develop a suite of advanced optical technologies for enhanced monitoring of gas turbine thermal barrier coatings (TBCs), and demonstrate at the laboratory scale.

Objectives:

- Define, design, and produce the sensor configuration
  - Select dopant material, considering sensing properties, manufacturing configuration, and testing configuration.
  - Use nonlinear finite element (FE) models to predict the temperature profiles on the surface of doped material with no surface defects.
- Establish the sensing properties of the luminescence-based sensor
  - Test candidate samples at high temperature to determine the relationship between temperature and luminescence lifetime, in conjunction with well-established measurement techniques.
  - Conduct real-time strain measurements through the coating's thickness under thermal cycling, using an advanced photon source.
  - Add surface defects to FE model and compute temperature profile for selected dopants.
- Perform non-intrusive benchmarking measurements of surface temperature and strain
  - Develop a metric to quantify temperature measurement inaccuracies; evaluate methods of monitoring hot coated parts.
  - Develop an advanced digital image correlation (DIC) system to perform high speed imaging concurrently with the luminescence measurements.
- Integrate the optical sensors into one laboratory-scale instrumentation package.

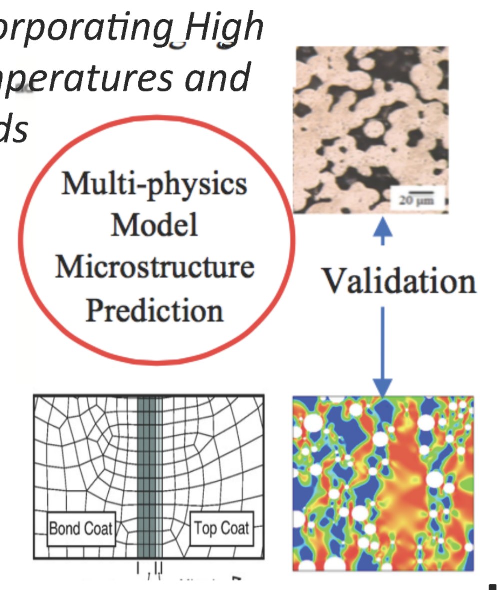
Simulation



Approach

Multi-physics modeling to define sensing material configuration
R.Ghosh

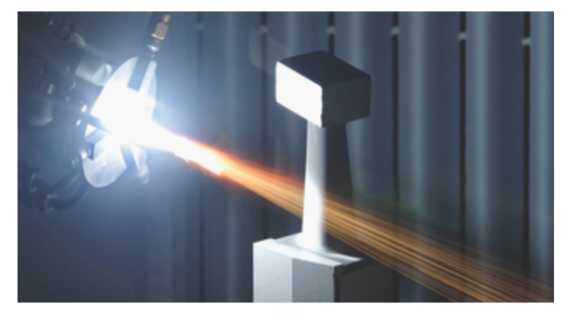
Incorporating High temperatures and loads



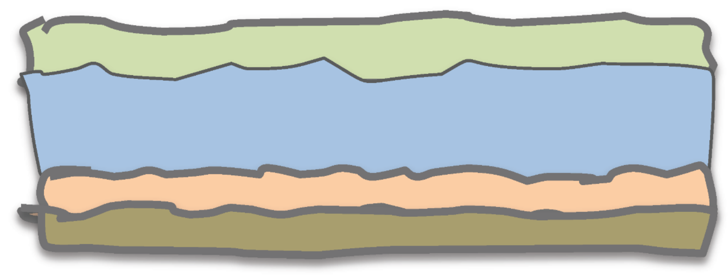
Simulation of sensing coating systems will use FE analysis to analyze configuration effect on durability eg. for TBCs shown

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

Integration of sensing configuration in thermal spray process



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



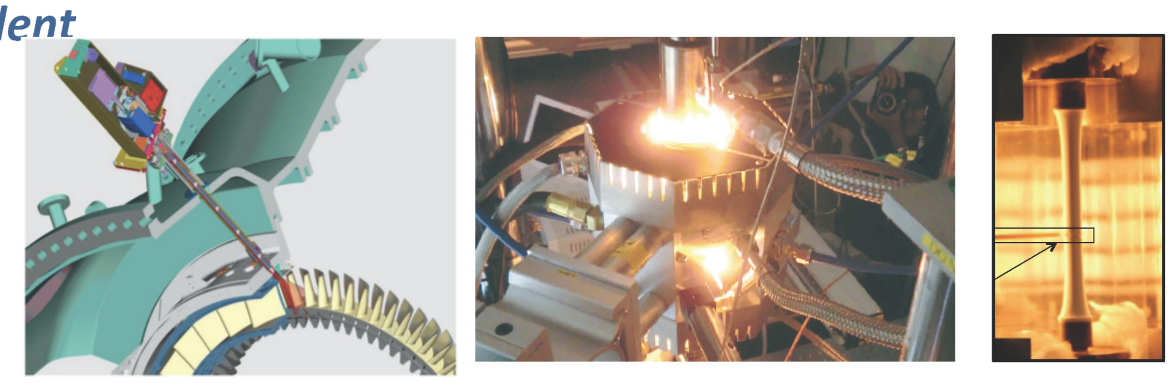
Material property data fed back to refine model (eg. conductivity measurements, time and temperature dependent phase stability

In-situ monitoring of manufactured configurations
S. Raghavan

In situ mechanics, Synchrotron studies

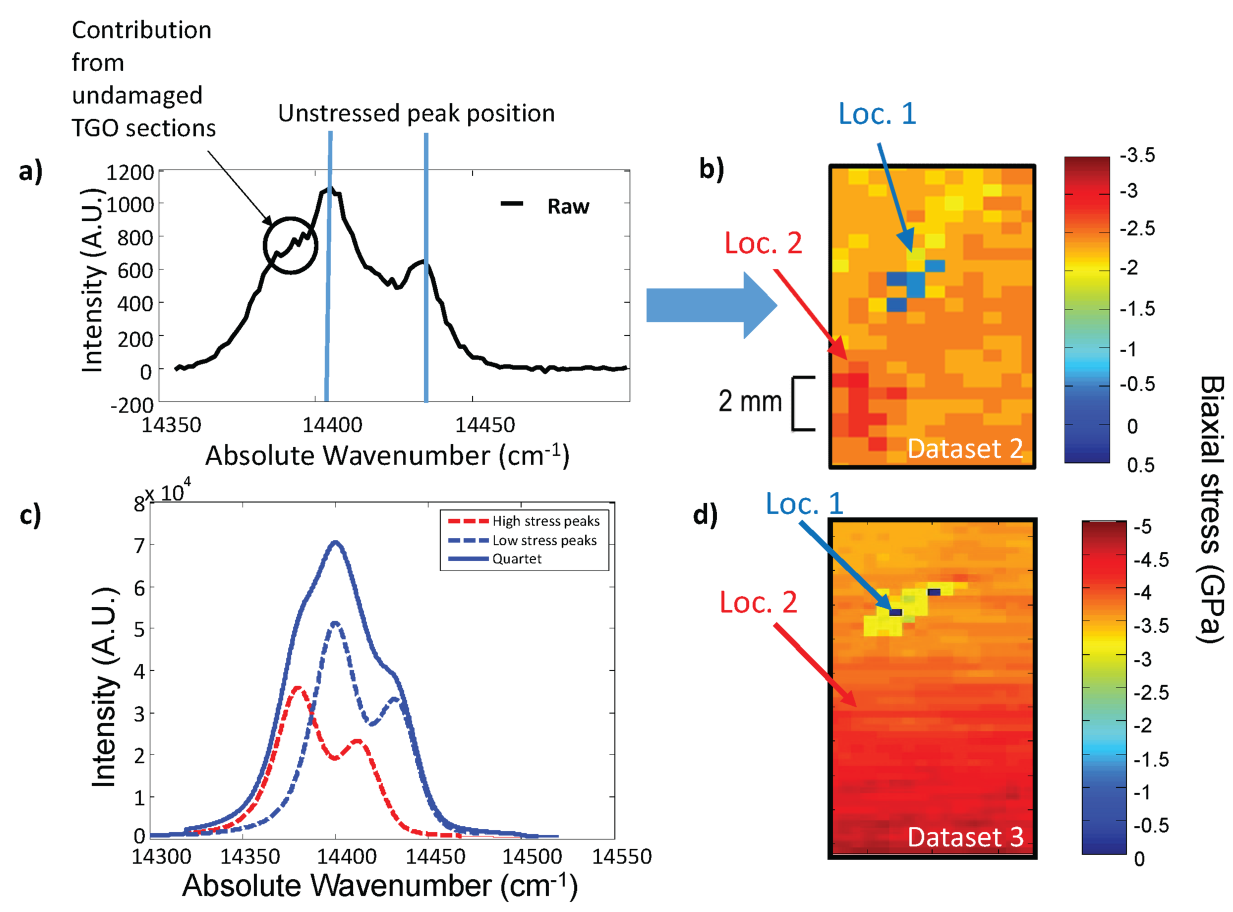
Test rig demo in collaboration with industry

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



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

Luminescence-based Sensing



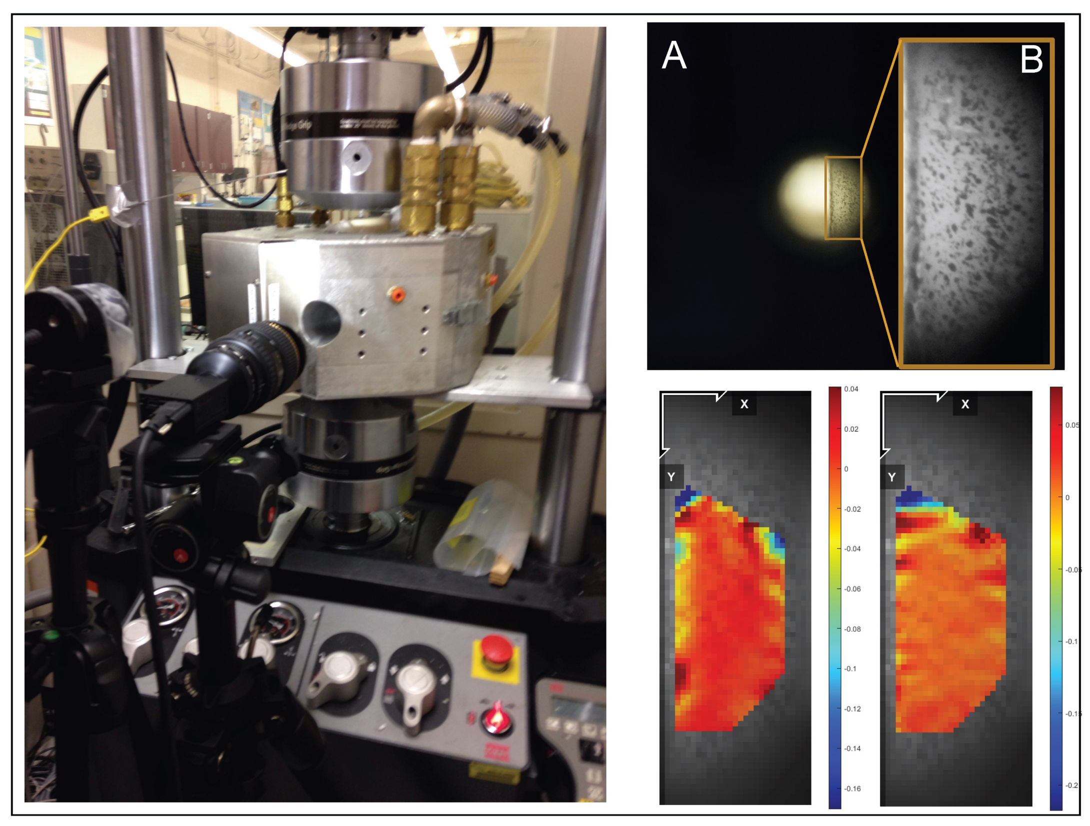
Background:

- Certain dopants among the rare earth elements and transition metals emit photons of characteristic wavelength when excited with a laser.
- The luminescence lifetime is a function of temperature.
- The wavelength emitted is a function of the strain imposed on the dopant.
- These materials therefore act as temperature- and stress-sensors.

Goals:

- Test candidate samples in situ to establish their luminescence response at high temperatures.
- Determine optimal dopant for coatings.

Digital Image Correlation-based Sensing



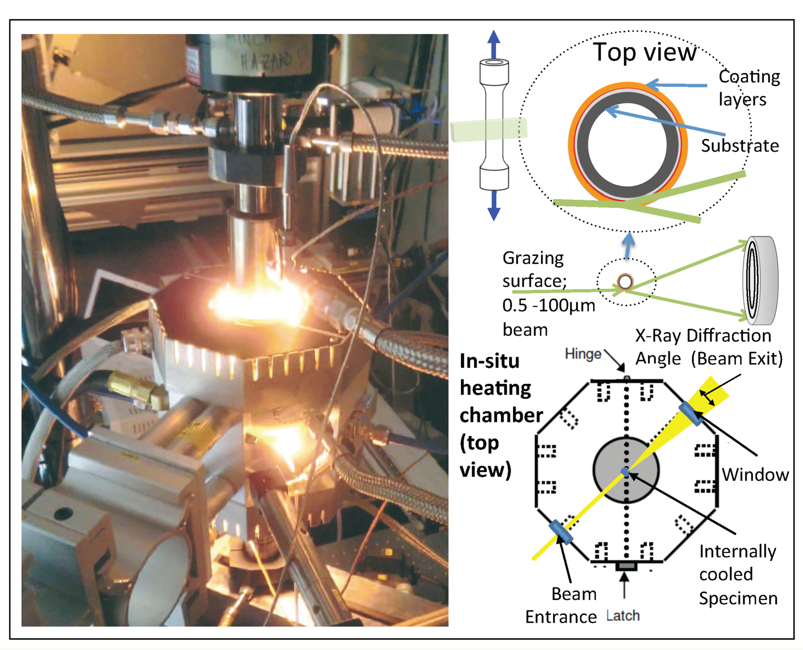
Background:

- Digital image correlation (DIC) is a well-established optical measurement technique.
- A speckle pattern is applied to the sample, which is then photographed before and during thermal and mechanical loading. Software tracks the displacement of the speckles to calculate strain.

Goals:

- Advance DIC techniques to achieve:
  - high speed imaging;
  - at high temperatures;
  - simultaneously with luminescence-based sensing.

Synchrotron X-ray Diffraction



Background:

- X-rays are diffracted by the material's crystal structure in accordance to Bragg's law, providing information on the material's microstructure and stress state.
- Synchrotron x-ray sources have sufficient energy to achieve measurements in the bulk material.

Goals:

- Obtain real-time strain measurements of the doped coating while subjecting it to thermal cycling conditions.

Acknowledgements

This research is supported by the Department of Energy, DE-FE0031282, PM-Dr Sydni Credle.