Configurations for Luminescence-based Temperature Sensing Thermal Barrier Coatings

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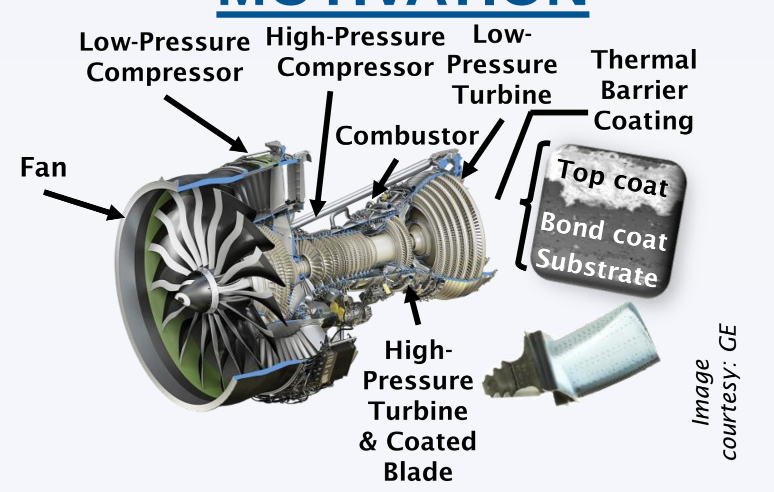
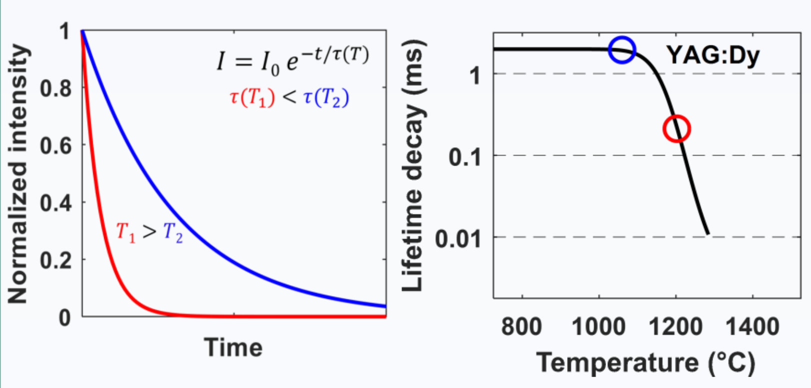
BACKGROUND & MOTIVATION



Thermal barrier coatings (TBCs) are used to protect turbine components from the extremely hot gas flow, which may be above the component materials melting point. Accurate temperature measurements enable precise lifetime predictions, which favor safety and efficiency. In-situ monitoring of in-service turbine components is ideal; a promising method is Phosphor Thermometry which uses the luminescence decay of doped coatings stimulated by a pulsed laser. There are various configurations of candidate phosphors and host materials, but it is crucial to ensure both sensing and integrity needs are met.

METHOD : LUMINESCENCE DECAY



OBJECTIVES

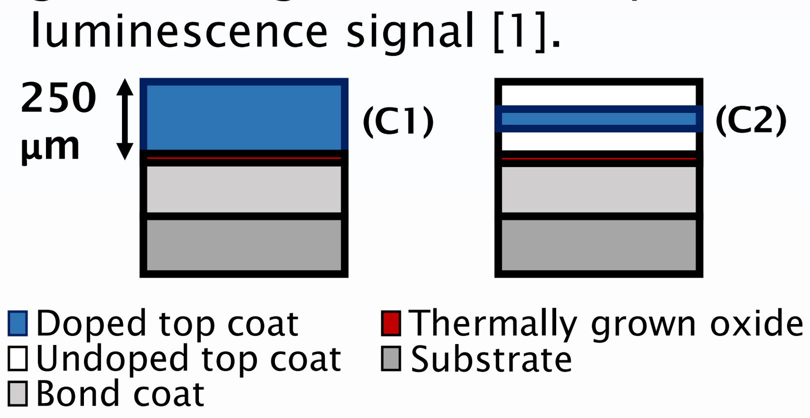
➡ Quantify the luminescence intensity for any TBC configuration.

➡ Predict the location into the TBC of the Phosphor Thermometry temperature output.

DOPED LAYER TBC CONFIGURATIONS

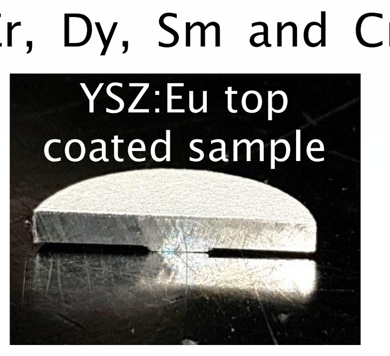
Sensing TBC configurations have been separated into two categories:

(C1) is easier to manufacture, does not add any extra interface and provides higher luminescence intensities. **(C2)** gives higher accuracy of luminescence signal [1].



MATERIALS

YSZ:Eu (1% Eu_2O_3, 8% Y_2O_3, 91% ZrO_2) TBC coupons were prepared by Air Plasma Spray at the Florida Institute of Technology to validate initial results of Kubelka-Munk based models. Er, Dy, Sm and Cr are other dopants that will be made for Phosphor Thermometry.

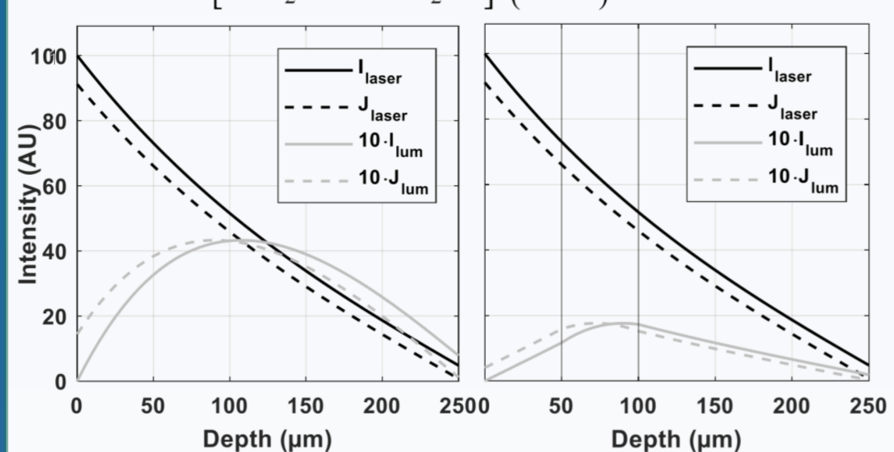


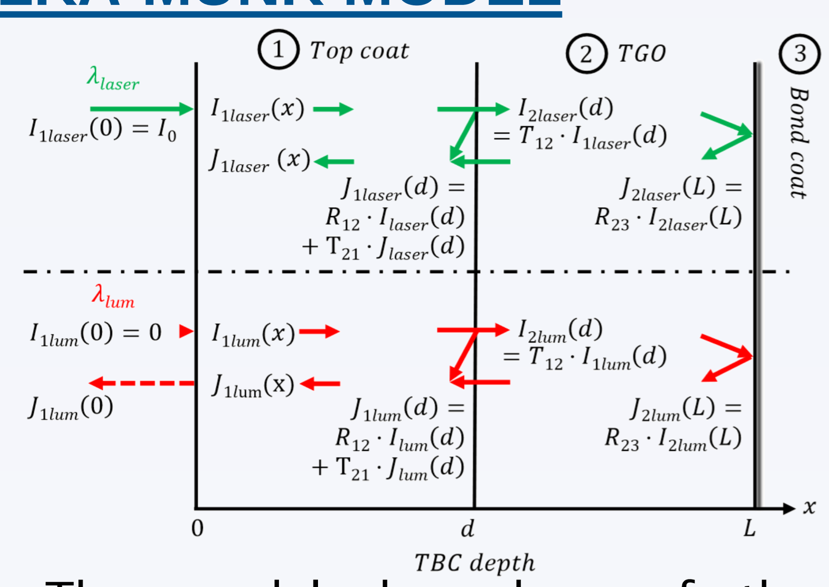
MODELING COLLECTABLE LUMINESCENCE USING FOUR-FLUX KUBELKA-MUNK MODEL

The challenge with modeling Thermal Barrier Coating optical properties is to account for the significant amount of scattering that occurs due to the intrinsic inhomogeneities of porous ceramic materials that are used to lower thermal conductivities. In addition, it is necessary to consider absorption of light as it travels through the coating. A well-known model that combines both factors is the Kubelka-Munk model. The following equations are describing the distribution of intensities of excitation and emission lights as the laser beam penetrates TBC that contains luminescent dopants [2]:

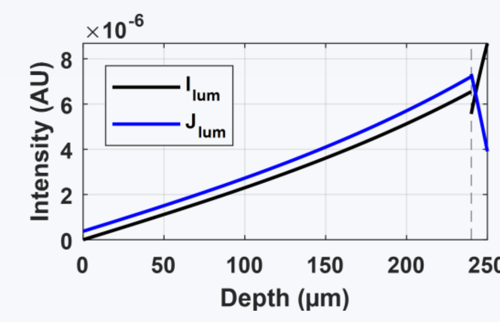
$$\begin{Bmatrix} I'_{laser} \\ J'_{laser} \end{Bmatrix} = \begin{bmatrix} -(K_{laser}+S_{laser}) & S_{laser} \\ -S_{laser} & K_{laser}+S_{laser} \end{bmatrix} \begin{Bmatrix} I_{laser} \\ J_{laser} \end{Bmatrix}$$

$$\begin{Bmatrix} I'_{lum} \\ J'_{lum} \end{Bmatrix} = \begin{bmatrix} -(K_{lum}+S_{lum}) & S_{lum} \\ -S_{lum} & K_{lum}+S_{lum} \end{bmatrix} \begin{Bmatrix} I_{lum} \\ J_{lum} \end{Bmatrix} + \begin{bmatrix} \frac{qK_{laser}}{2} & \frac{qK_{laser}}{2} \\ -\frac{qK_{laser}}{2} & -\frac{qK_{laser}}{2} \end{bmatrix} \begin{Bmatrix} I_{laser} \\ J_{laser} \end{Bmatrix}$$



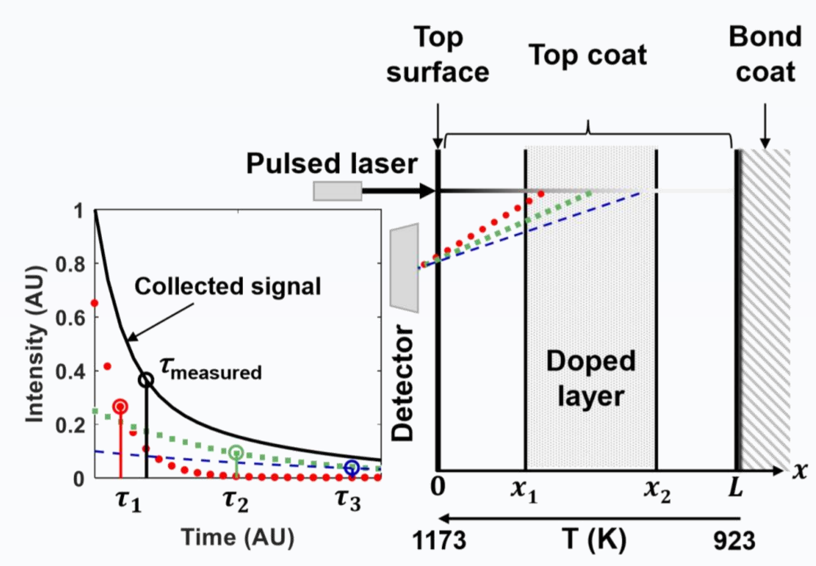


The model has been further extended to predict the luminescence coming from the thermally grown oxide (TGO) that forms when aging the material:



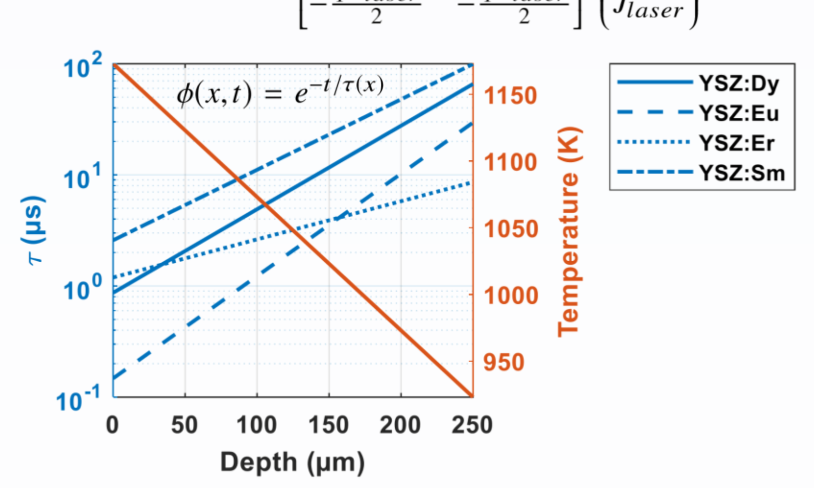
Innovative specimens including dopant in the bond coat that diffuses to the thermally grown oxide are currently being prepared for temperature measurements at the top coat - bond coat interface. The monitoring of temperature at this key location can help controlling the degradation mechanisms occurring in operating conditions on turbine blades and allow for more efficient engines.

INTEGRATION OF DECAY TIME



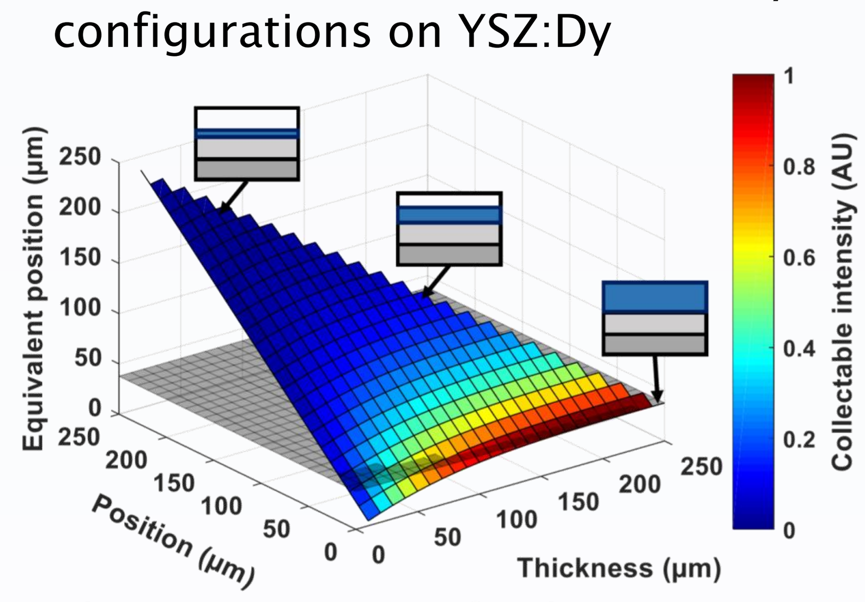
One of the main work on this model is the integration of decay time for numerical predictions of the collectable $J_{lum}(0,t)$, in presence of a gradient of temperature based on the following equation:

$$\begin{Bmatrix} I'_{lum} \\ J'_{lum} \end{Bmatrix} = \begin{bmatrix} -(K_{lum}+S_{lum}) & S_{lum} \\ -S_{lum} & K_{lum}+S_{lum} \end{bmatrix} \begin{Bmatrix} I_{lum} \\ J_{lum} \end{Bmatrix} + \phi(x,t) \begin{bmatrix} \frac{qK_{laser}}{2} & \frac{qK_{laser}}{2} \\ -\frac{qK_{laser}}{2} & -\frac{qK_{laser}}{2} \end{bmatrix} \begin{Bmatrix} I_{laser} \\ J_{laser} \end{Bmatrix}$$

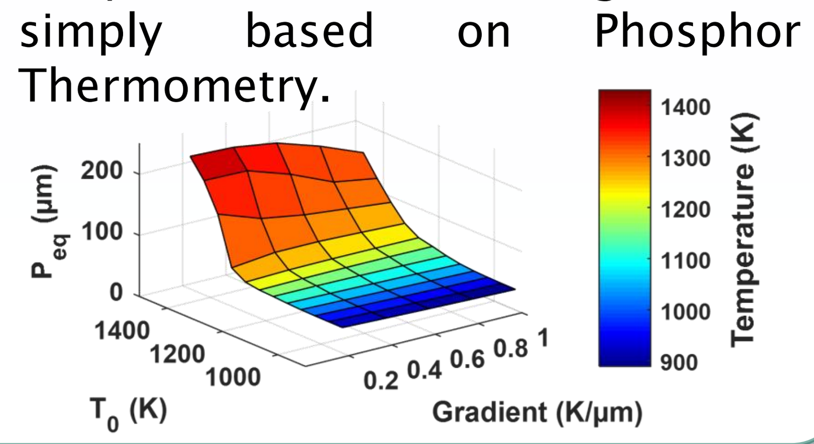


The equation includes the exponential decay that is characteristic of luminescence. The latter equation is providing very promising results to correlate temperature readings obtained with decay time phosphor thermometry and its accurate position in the coating, allowing for reduction of errors in the evaluation of the temperature distribution. Based on this results, a reverse model has been constructed to predict temperature at any point in the TBC using a single point measurement.

The plot presented below show the results of equivalent position for the temperature measurement and collectable intensity using the model for 325 TBC layer configurations on YSZ:Dy



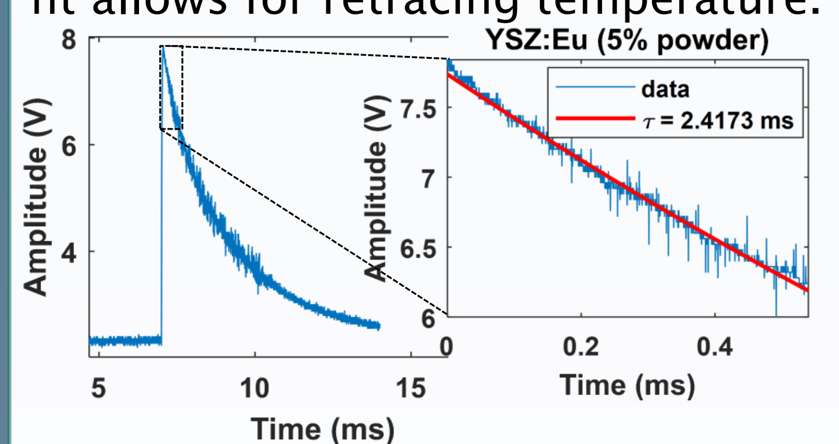
The precision of the previous results is to be related to the effects of the input gradient of temperature on the model. The sensitivity of the model to the input surface temperature and internal gradient for the configuration **(C1)** for YSZ:Dy is shown below. It has been found that for the usable range of temperature of this material (800K-1450K) the equivalent position remains constant (±8K error) which allows to retrace temperature and internal gradients simply based on Phosphor Thermometry.



INSTRUMENTATION

The Phosphor Thermometry instrumentation at the University of Central Florida has been constructed in collaboration with Dr. Heeg at *Lumium*, The Netherlands, and is composed of a switchable 355 nm / 532 nm wavelength pulsed laser that excites doped specimens. Neutral density and bandpass filters are used to collect the luminescence. A photomultiplier tube is used to convert the photons into a detectable electric signal. The data collection is then processed through MATLAB. The sensitivity of the temperature measurement is proper to each configuration and based on the variation of decay time with temperature. The equipment has been designed so it is adaptable to the sample positioning and portable.

This instrument is combined with an infrared heater (model E4 from *Precise Control Systems Inc*, MN, USA) that is capable of heating the specimens up to 1300˚C to reproduce TBC real service conditions. Measurements have been taken on YSZ:Eu powder and a fit allows for retracing temperature.



FUTURE WORK

➡ Data collection through doped TBCs at high temperature.

➡ Addition of a PMT with a different bandpass configuration for the combination of the decay and the intensity ratio methods.

➡ Specimen fabrication and residual strain characterization of the doped TBCs to ensure the mechanical integrity of the specimens.

REFERENCES & ACKNOWLEDGMENTS

[1] Fouliard, Q. P., Jahan S. A., Rossman L., Warren P., Ghosh R., Raghavan S., Configurations for Temperature Sensing of Thermal Barrier Coatings, *International Conference on Phosphor Thermometry*, 25-27 July, 2018, Glasgow, UK

[2] Fouliard, Q. S. Haldar, R. Ghosh, S. Raghavan, Modeling Luminescence Behavior for Phosphor Thermometry Applied to Doped Thermal Barrier Coating Configurations, *Applied Optics* (2019) - Submitted

[3] Pilgrim, C. C., J. P. Feist, and A. L. Heyes. "On the effect of temperature gradients and coating translucence on the accuracy of phosphor thermometry." *Measurement Science and Technology* 24.10 (2013): 105201.

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