Embedded Optical Sensors for Thermal Barrier Coatings

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Objectives:

The overall objective is to develop a class of prototype optical sensing systems for monitoring thermal barrier coatings based on the luminescence properties of ionic dopants incorporated into the crystal structure of the coatings themselves. Concepts for different types of TBC sensors, for assessing damage, wear and temperature, will be tested. Integral to the overall objective is the demonstration of a combined optical and electronic system incorporating the embedded sensors.

Accomplishments to Date:

A variety of rare-earth ions have been substituted in to the crystal structure of the two principal thermal barrier coating materials in use today, yttria-stabilized zirconia (YSZ) and the pyrochlore zirconate, $Gd_2Zr_2O_7$ (GZO), and shown not to destabilize the structures. Investigation of the photoluminescence spectra stimulated using lasers at 248 nm, 355 nm and 532 nm, indicate that many of the rare-earth ions, such as Er, Sm, Eu, Tb, give strong and characteristic luminescence that could be used in a TBC sensor. The effect of the doping concentration has also been explored and quantified at room temperature.

To investigate the temperature dependence of the luminescence intensity and luminescence lifetime of the doped materials, a fiber-optic based system has been constructed that enables measurements to be made up to a maximum of 1200^{o}C. The excitation laser is focused directly onto a sample positioned in a furnace and the luminescence is collected with a sapphire fiber in proximity to the sample and connected, at room temperature, through a standard silica optical fiber to a grating monochromator and photomultiplier tube detector. The system operates under computer control using Labview software.

Using this system, the luminescence lifetime as a function of temperature has been measured for Er, Eu and Sm dopants in YSZ and for Eu in a variety of pyrochlore zirconates. The results indicate that each rare-earth dopant exhibits different temperature dependence and that there are two temperature regimes. One regime is at moderate temperatures, where the lifetime is relatively independent of temperature. The other is at higher temperatures where the lifetime decreases exponentially with increasing temperature. Europium-doped GZO and $Eu_2Zr_2O_7$ at this stage in the program appear to offer the highest temperature capabilities with luminescence lifetimes being measurable up to at least 1200°C for the $Eu_2Zr_2O_7$ material. Currently, the effect of doping concentration on the luminescence lifetimes of these materials is being studied in order to identify whether there is an optimum doping concentration.

Multilayers of YSZ with each layer containing a different rare-earth dopant, have been fabricated by sintering and initial data has been obtained on the absorption dependence of the luminescence lines as a function of layer thickness. Red-line sensors, consisting of doped layers interspersed at different levels in a standard coating have been fabricated by electron-beam evaporation (EB-PVD) at both UC Santa Barbara and in collaboration with Howmet Corporation. The optical and luminescence properties of these red-line sensors are being investigated and the temperature dependence of the luminescence lifetime measured. On the basis of these and related concentration dependence measurements, new red-line sensors will be fabricated by electron-beam evaporation and by plasma-spraying for thermal cycling and combustor atmosphere testing.

Future Work:

There are three major tasks remaining. Two are concerned with evaluating the stability and lifetime of the sensor coatings under realistic thermal cycling conditions to which TBCs on blades and vanes are subjected in practice and to the gaseous environment in a combustor chamber. The third is to demonstrate that a complete optical sensing system can be constructed based on integration of solid state lasers, optical fibers, sensor coating and luminescence detectors into a single system.

List of Papers Published and Presentations:

Luminescence Sensing of Temperature in Pyrochlore Zirconate Materials for Thermal Barrier Coatings, M. M. Gentleman and D. R. Clarke, Surface and Coatings Technology, in press.

Non-contact Temperature Measurements by Luminescence, International Symposium of Research Students, held at IIT Madras, Chennai, India. (Gentleman received a best paper award for her presentation). December 2004

Towards Robust TBC Sensing, National Science Foundation – European Union Workshop on Thermal Barrier Coatings, Stockholm, July 2004

Luminescence Sensing of Materials at High Temperatures, GE Global Research Center, Schenectady, NY, July 2004.

Student Supported:

Ms. Molly Gentleman, PhD Student.