Mitteilung

Fachgruppe: Experimentelle Aerodynamik

Characterization of a Phosphor-Based Temperature-Sensitive Paint for High-Temperature Applications

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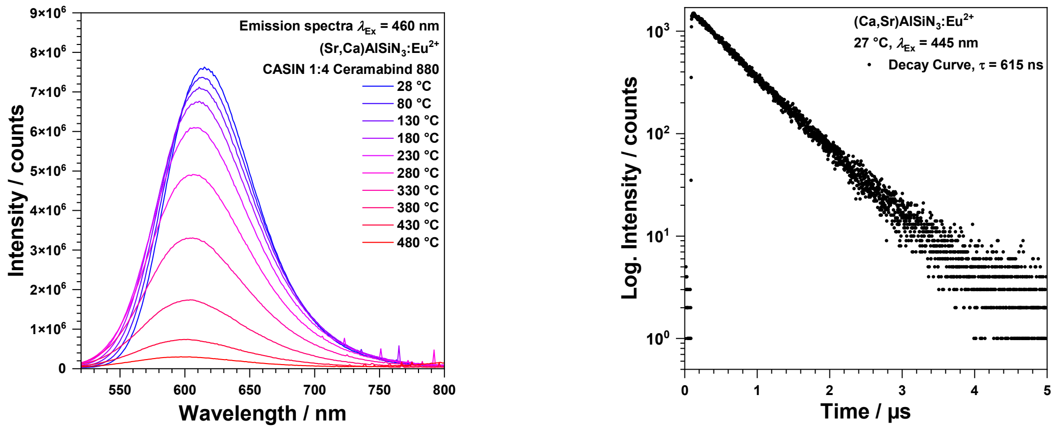
Introduction

Research into the fundamental flow physics of hypersonic regimes, such as shock–shock interactions and vortex dynamics, has increased in recent years. Understanding these flow phenomena is crucial for the development of hypersonic vehicles. However, hypersonic flow conditions pose unique challenges for experimental measurements, for example when extracting surface temperature data with high spatial and temporal resolution from the investigated vehicle. Conventional point-wise methods, such as thermocouples, have been successfully integrated into hypersonic test articles. Nevertheless, it is of great interest to obtain image-based temperature data with both high spatial and temporal resolution on such vehicles, due to their increasingly complex geometries prohibiting point-wise sensor integration into these test articles. Temperature-sensitive paints (TSP) have been employed to measure surface temperatures, and for high-temperature conditions (> 100 °C), phosphor-based TSP can be used [1, 2].

Experimental methods and results

In this study, a complete characterization of a phosphor-based TSP is presented. This TSP enables surface temperature measurements in hypersonic flow conditions up to 500 °C using the intensity method. For such a TSP, it is necessary to combine the phosphor with a binder, forming a suspension that can be applied to the test object with a spray gun. The phosphor, $(Sr_{1-x}Ca_x)AlSiN_3{:}Eu^{2+}$ [3], provided by the FH Münster, was suspended in different binder materials, all selected for their high heat resistance. In this work, only the results obtained with the so-called Ceramabind 880 [4] binder are reported. The phosphor–binder suspension was coated onto an aluminum plate, resulting in a TSP layer thickness of approximately 50 µm. The temperature-dependent emission spectra of the coated plate are shown in Figure 1 a). The decay behavior (luminescence lifetime) of the phosphor powder is shown in Figure 1 b), respectively. With a measured photoluminescence lifetime of τ = 614 ns, this TSP is in principle capable of resolving temperature fluctuations in the kHz range, extending into the upper-tens-of-kHz regime.

For further temperature calibration tests, an electrically operated muffle furnace [5], which is equipped with an optical window in its front-loading door will be employed. The TSP will be excited with a 405 nm near UV-LED, and the luminescence of the phosphor will be recorded using a 12-bit CMOS camera. Both the LED and the camera is equipped with appropriate bandpass filters. A schematic of the calibration setup is shown in Figure 2. To analyze the thermal stability of the TSP investigated here, the calibration measurements will be carried out during both the heating and cooling processes. This procedure allows possible aging effects or hysteresis of the TSP to be quantified. Such behavior would be unsuitable for later use of the TSP under hypersonic conditions when applying the intensity method. First tests were performed using a temperature-controlled sample holder inside a spectrometer with the coated aluminum plate attached to it, the resulting temperature calibration is presented in Figure 3 a). To further examine potential interactions of the phosphor with oxygen (O_2 quenching), the phosphor was also tested in nitrogen and oxygen environments. No dependence on oxygen was observed, as confirmed by the emission spectra in Figure 3 b). In the next step, the TSP developed here will be tested in the described setup in Figure 2 and applied to further investigations on a heated cylinder in hypersonic flows.



a) Temperature-dependent emission spectra of the coated aluminum plate under 460 nm excitation

b) Decay curve of $(Sr_{1-x}Ca_x)AlSiN_3:Eu^{2+}$ powder under pulsed 445 nm excitation

Figure 1 Temperature-dependent emission intensity and lifetime (at room temp.) of the investigated TSP.

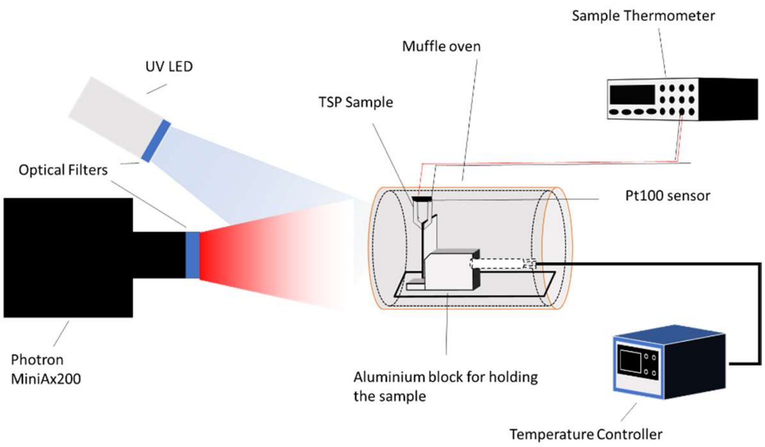
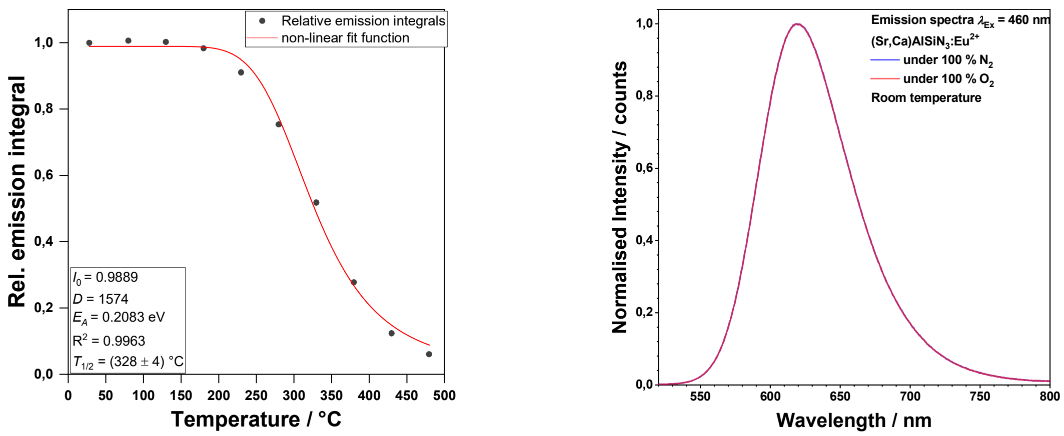


Figure 2 Schematic of the calibration setup, by Aleksandro Budina and Lorenzo Menghini, ITS Umbria.



a) Relative emission integrals of the coated aluminum plate over the temp. range of 30 - 480 °C

b) Emission spectra in oxygen or nitrogen atmospheres

Figure 3 TSP temperature calibration and emission spectra in oxygen and nitrogen atmospheres.

References

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[4] Commercially available from Aremco Products, Inc.

[5] Provided by Karsten Pfeiffer, DLR-AS, Göttingen.