THE THERMOGRAPHIC PHOSPHOR LABKIT

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ABSTRACT

The thermographic phosphor (TGP) lab kit is a flexible instrument for students beyond the first year and is also a useful laboratory tool for physics research and development. As to be described, it aids in teaching and demonstrating a number useful concepts and skills. Students will learn important aspects of optical physics and spectroscopy. By producing fluorescence and measuring its characteristics versus temperature, students will become familiar with atomic energy levels, lifetimes, radiative and non-radiative transitions, spectral bands and linewidth, spectral distribution, and absorption. In addition, measurements involve optics, electro-optics, and electronic instrumentation. Practice and familiarity with common laboratory and industry tools such as thermocouples, Peltier devices, and photomultiplier detectors also contribute to the educational objectives. Finally, in the course of exercising the instrument, the student will learn the practical skill of temperature measurement and control.

The labkit contains an ultraviolet light emitting diode of 365 nm that illuminates a thin phosphor layer. The phosphor adheres to a copper plate in intimate contact with a Peltier heater/cooler that covers 0 to 100 °C. A thermocouple attaches to the copper plate to monitor temperature. The lab kit allows for controlling the pulse duration of the LED and the rate of repetition.

BACKGROUND

Temperature is one of the most important attributes of physical systems, and its measurement is critical to many aspects of scientific research and development. Some situations requiring the thermographic phosphor approach include vibrating or moving surfaces, difficult to access surfaces, hazardous locations, and the like. Typical examples include centrifuges, turbine engine components, high speed motors, radioactive or very high temperature environments, or vibrating or moving production machinery. In many situations, it is also necessary to measure temperature remotely, without direct contact, because of difficulties of access, intervening heated air or other gases, or movement of the component to be measured. Such instances are covered in a number of survey articles.1,2,3,4,5,6

Phosphors are fine white or pastel colored powders commonly used for fluorescent lighting, LED lighting, X-Ray imaging, and displays. When illuminated by a proper source a phosphor efficiently converts the incident energy to its characteristic fluorescence or phosphorescence. The labkit utilizes a phosphor, La2O2S:Eu, commonly used for X-Ray applications whose emission at room temperature originates from three Eu3+ excited electronic energy levels. These are designated 5D2, 5D1 and 5D0 and the transitions terminate in any of several 7F states resulting in many emission bands from the blue to deep red. This phosphor exhibits a striking temperature dependence in this temperature range and is easily stimulated by an inexpensive ultraviolet LED. A segment of the emission is shown in Figure 1 for several temperatures, T, for 5D2 bands. The 5D1 and 5D0 bands do not exhibit significant temperature dependence in this temperature range.

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TGPs have emissions that can be measured in various ways to determine temperature. The most common method has been to measure the fluorescence intensity as a function of time following pulsed illumination and extract the characteristic lifetime, $\tau$, of the emission.

$$I(t) = I_0 \times e^{-t/\tau} + b \text{ where } t = f(T)$$

$I_0$ is the initial intensity of the luminescence at $t=0$. In practice there will be a background signal originating from any of a variety of sources including detector dark current and/or room light leakage for example. Typically, a TGP will be relatively insensitive to temperature below a certain temperature at which it "turns on," that is, begins to have other de-excitation routes competitive in probability with the photon emission. At increasing temperatures the lifetime decreases rapidly until it becomes too short to be measured with electronics involved. That range of superb temperature sensitivity is typically several hundred degrees centigrade.

**THERMOGRAPHIC PHOSPHOR LABKIT**

For calibrations near room temperature, and to clearly illustrate the phosphor thermometry (PT) method, Emerging Measurements Corporation (EMCO) has developed a Phosphor Labkit containing all the measurement components and including the basic software required to convert fluorescent signals to temperature. The resulting signal is usually recorded by a laboratory oscilloscope, the digital signal transferred to a computer for signal analysis. Figure 2 is a photograph of the Labkit and a standard laboratory oscilloscope used in the measurement system. The Labkit contains an LED interrogation source, a sample holder for a standard La$_2$O$_2$S:Eu phosphor that can be varied in temperature from about -5 C to about 100 C, a thermocouple to measure the sample temperature, narrow band filters for selecting desired wavelengths, and a photomultiplier detector to record the fluorescence signal.
The Labkit provides control of the sample temperature, pulse width and repetition rate of the interrogating light source, an internal electronic trigger output for various uses such as triggering an oscilloscope, and an external trigger input so that external devices can pulse the light source or trigger the oscilloscope.

Note that the oscilloscope pictured in Figure 2 shows two traces. The higher (yellow) one is a typical fluorescence signal as a function of time, with an input impedance of 50 ohms. The lower (blue) signal is the voltage versus time applied to a pulser which drives the LED source. During this pulse the LED emits light and when the pulse switches off the LED light switches off. Typically a series of these pulses is sent to the LED producing a repeated illumination striking the phosphor sample up to hundreds of times per second.

Figure 2. Labkit external package with digital oscilloscope displaying fluorescence and LED drive signal.

Note that the fluorescence signal begins with the onset of the pulser signal, increases to a higher value, then begins to decrease exponentially after the LED switches off. If the LED pulse width were sufficiently wide the fluorescence signal would reach a maximum value and remain there until the LED switched off. It is apparent from the two signals that the time profile of both the fluorescence increase and decrease can be used to determine the characteristic lifetime of emission. That lifetime can be used to infer temperature. The left panel of Figure 3 depicts signals from 10 to 55°C using the LabKit. The right panel plots lifetime versus temperature.

The Labkit is designed primarily for use in a laboratory environment, so that various TGP and LED sources can be evaluated for temperature response. The operation manual guides the user through the necessary aspects of its use. In addition, however, the Labkit can, in certain situations, be used for a temperature measurement application outside the laboratory. Different modifications of the system can be produced by EMCO for the special needs of the user. Typical among these modifications are: provisions for an external interrogation source such as a laser; provisions for an external detector system, such as one...
involving fiber optics; or specialized sample holders for larger or more easily exchanged phosphor samples. Software for determining lifetime is provided. However, the teacher and/or students may choose their own approach to the analysis.

Figure 3. Plots of Intensity vs Lifetime and Lifetime vs Temperature.

References


