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Journal of Luminescence 113 (2005) 151–155
JOURNAL OF LUMINESCENCE
www.elsevier.com/locate/jlumin

Laser-fiberoptic non-contact controlled heating of samples for thermoluminescence measurements

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Received 25 March 2004; received in revised form 12 July 2004; accepted 29 July 2004
Available online 23 November 2004

Abstract

Thermoluminescence (TL) measurements are based on exciting a sample and measuring the light emitted from the sample while it is being heated. The exact heating scheme is difficult to control or to change by a standard heater. We have developed a novel laser-fiberoptic system for heating a spot on the surface of a sample and monitor the TL signal emitted from this spot. With this system it is very simple to control the heating rate (e.g. linear heating, exponential heating), to measure samples in remote locations and to measure several spots on the surface of one sample. The laser-fiberoptic system would be particularly useful for thermoluminescence dosimetry (TLD) measurements.

PACS: 78.60.Kn; 44.40.+a

Keywords: Thermoluminescence; Thermal radiation; Infrared radiometry

1. Introduction

Thermoluminescense (TL) has been widely studied for almost 100 years and it has been used in thermoluminescence dosimetry (TLD) for medical and archeological applications. The exposure of a thermoluminescent material to radiation (e.g. UV, X-rays or gamma rays) causes trapping of electrons in defect sites. Heating the material afterwards causes the release of carriers from the trap which is followed by a recombination of electron–hole pairs and results in photon emission. A TL measurement, therefore, includes the means of heating a sample and measuring the light emitted during the heating until the trapped levels are emptied. The variation of the intensity of the emitted light as a function of the sample temperature T is called a “glow curve”. The overall intensity of the glow and the temperature T_m at which the glow curve exhibits a peak depends on the sample material, the dose of radiation to which the sample has been exposed to and on the heating

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doi:10.1016/j.jlumin.2004.07.010

rate. In order to conduct consistent TL measurements (for dosimetry or other applications), a controlled and reproducible heating is required. In most cases, a constant heating rate is applied, from some low temperature (e.g. room temperature or liquid nitrogen temperature) to some higher temperature (e.g. several hundred degrees Centigrade.) The commonly used heating scheme is linear, so that the temperature rise is of the form $T(t) = T_0 + \beta t$, where the heating rate β is constant [1].

Most of the heating techniques in TLD systems are based on physical contact of the sample with a heater or with a gas flow. The temperature T of the sample is continuously measured by placing temperature sensor (e.g. thermocouple) in the sample or between the sample and the heater. The accuracy of these techniques is limited since both heating and temperature measurement depend on heat conduction or heat convection, which are slow. Therefore, deviations may occur between the desired and real sample's heating profile [2,3]. Another limitation of these techniques results from the fact that the sample is heated as a whole, and while the TL light emission is measured from the surface of the sample (normally with a photomultiplier), tracing differences in luminescence intensity on different locations of the same sample is not possible. Furthermore, after irradiation of the sample, one can carry out only one measurement during heating.

In recent years laser heating techniques have been developed, which offer high heating rates and reproducibility [4]. These methods, however, have some of the disadvantages mentioned above, since they do not enable precisely to determine the temperature of the sample during the heating process.

In this paper, we present a new heating technique that would be useful for both TL and for TLD measurements. The idea is to use lasers and optical fibers for both the controlled heating of a spot on the surface of a sample and for measuring the light emitted from this spot. This scheme promises to provide a non-contact measurement, a controllable heating rate and the possibility of carrying out multiple measurements on one sample (even if the sample is in a remote location).

2. Experimental setup

Fig. 1 shows the laser-fiberoptic TL measurement system. Its description is divided into: (a) fiberoptic temperature measurements, (b) controlled heating process, and (c) TL measurement.

2.1. Fiberoptic radiometry for non-contact temperature measurements

The temperature T of an object can be determined by measuring the infrared radiation emitted from its surface. The intensity I of the radiation emitted from a surface area A is given by the expression $I = A\varepsilon\sigma T^4$, where ε is the emissivity of the object and σ is the Stephan–Boltzmann constant.

The spectral distribution of thermal radiation is derived from Planck's black-body theory. The dependence of the wavelengh at which a black body emits at maximum intensity on its temperature is known as Wien's displacement law $\lambda_{\max} T = 2898\,\mu\mathrm{m\,K}$. Therefore, most of the thermal radiation of a body near room temperature ($T \approx 300\,^\circ\mathrm{K}$) is in the middle infrared spectral range 5–10 μm. This radiation could be easily measured by infrared detectors such as pyroelectric detectors or cooled photonic detectors (e.g. HgCdTe).

Infrared radiation can be carried through infrared transmitting optical fibers. Only few optical fibers are transparent in the mid-infrared spectral range (2–20 μm). Optical fibers made of silver halide $\mathrm{AgCl}_x\mathrm{Br}_{1-x}$ ($0<x<1$) are among the best candidates for that purpose. They are highly transparent in the mid-infrared, with losses of about 0.2 dB/m at 10 μm. The fibers used in this work are core-only polycrystalline fibers, 0.9 mm diameter, made by extrusion of single crystal of $\mathrm{AgCl}_{0.5}\mathrm{Br}_{0.5}$ composition. They are used in various applications, such as infrared radiometry, laser power transmission, and spectroscopy.

2.2. Controlled heating

The laser chosen to heat a spot on the surface of a sample is CO_2 laser whose radiation ($\lambda = 10.6\,\mu\mathrm{m}$) is highly absorbed by most materials,