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Contactless temperature field measurements in infrared semi-transparent materials using thermotransmittance imaging.

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Abstract

Temperature field measurements need to be performed in many research areas to ensure an accurate control of numerous systems, such as in material sciences or biology. However, for infrared semi-transparent objects, like living cells or semiconductors, infrared thermography is not well-suited. To address this purpose, we used the thermal dependence of material transparency to image temperature fields. This thermotransmittance approach enables contactless and absolute temperature field measurements. This work introduces the calibration procedure of the thermotransmittance coefficient, and its use to image transient absolute temperature fields.

1. Introduction

Temperature measurements are a challenge in many fields, such as biology or microfluidic for which the goal is to study the thermal effects occurring in chemical reactions or during the interaction between living cells. Usually the temperature is probed directly and locally with a thermocouple or indirectly with emissivity measurements.

In the targeted environments, temperature monitoring shall not interfere with the reaction, thus the measurement must be contactless which discards local measurements. Moreover, these samples are semi-transparent to infrared (IR) light which complicates the data analysis. Indeed, measuring the emissivity of semi-transparent materials raises the questions of the influence of parasitic reflections, or the origin of the emitted signal.

To solve these issues, we propose a method based on the thermal dependence of the optical properties of a material. One way to exploit this thermo-optic coupling, called thermoreflectance [1], is to study intensity variations of a reflected beam on an opaque medium. Moreover, using a monochromatic incident light in the near IR, such as a laser or a spectrally filtered source, improves the spatial resolution which allows measurements at the micrometre scale with microchannels [3] for instance.

Following these works, another way well suited to study semi-transparent media is thermotransmittance [2,3], to analyse transmitted light instead of reflected. However, the thermally induced relative variation of transmitted or reflected light is low ($10^{-5}\ K^{-1}$), such that the measured signal is weak and sensitive to the environmental disturbances. To solve this issue, instead of using steady-state measurements like in many current approaches, we chose to use transient regime, with a fast infrared camera (up to 300 Hz) and average the signal.

This paper introduces and validates thermotransmittance as a new fast and reliable technique for temperature imaging.

2. Experimental setup

The experimental setup (figure 1a) is decomposed as follows. A monochromator is used to select the wavelength of light emitted by a blackbody. Planar mirrors redirect the beam from the monochromator to the sample. This latter is fixed on a temperature controlled annular resistance. An IR camera (FLIR SC7000, InSb sensor, wavelengths range 2 µm to 6 µm) collects the beam transmitted and images the sample. The transmittance is defined as the ratio between the fluxes transmitted and that incoming on the sample.

The temperature T is related to the transmittance $\Gamma(T)$ via the thermotransmittance coefficient κ_Γ according to

$$\frac{\Gamma(T)-\Gamma(T_0)}{\Gamma(T_0)} = \kappa_\Gamma(T-T_0) = \kappa_\Gamma \Delta T \qquad (1)$$

where T_0 is the ambient temperature.

In order to suppress instrumental drifts, the calibration of the thermotransmittance coefficient is performed in a transient regime which allows to average the measurement by a simple integration of equation 1 as:

$$\int_0^t \frac{\Gamma(T,t)-\Gamma(T_0,0)}{\Gamma(T_0,0)}dt = \kappa_\Gamma \int_0^t \Delta T(t)\,dt \quad (2)$$

The result of the calibration is presented in figure 1b.

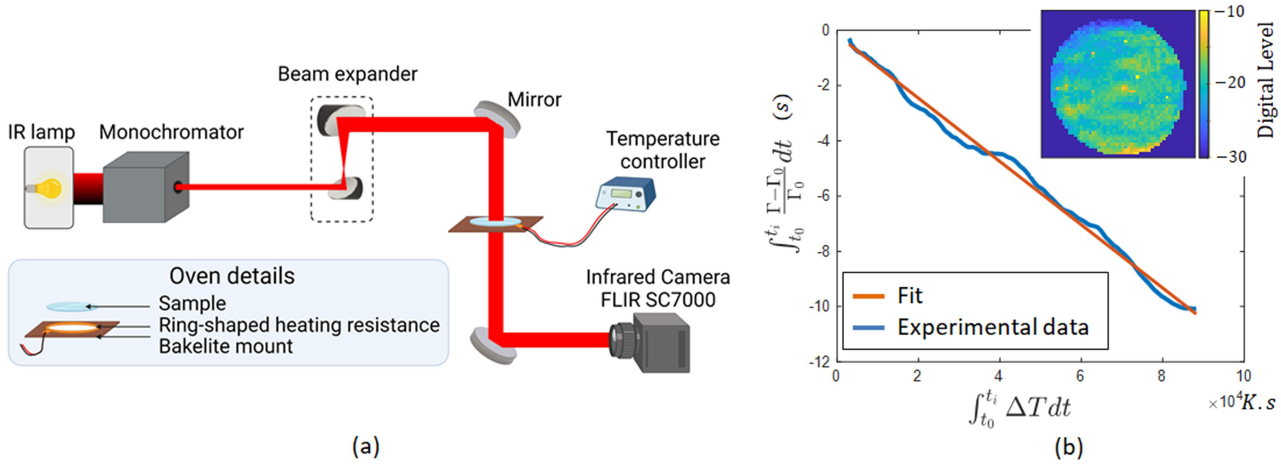

Fig. 1. *(a) Representation of the experimental setup. (b) Calibration curve of the silicon thermotransmittance coefficient at 3.9 µm: the slope of the fit corresponds to the thermotransmittance coefficient. Insert in (b): difference between the transmitted signal at t and the transmitted signal at $t = 0$.*

3. Results and discussion

The calibration of several materials (wafers of silicon and sapphire), with temperatures ranging from 20°C to 70°C and over the spectral range [2.5 µm; 5.5 µm] will be presented. Then, several temperature field measurements of these samples in the transient regime will be shown. Finally, the sensitivity and advantages of the method will be discussed. Using the thermotransmittance coefficient and the setup described (figure 1), reliable measurements of temperature fields in semi-transparent materials can be achieved.

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