Calibration of Infrared Signals by the Photoacoustic Effect

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Abstract – A new technique for the determination of the IR optical properties, namely the emissivity ε and the absorption coefficient, has been developed. A relies on thermal wave excitation by intensity-modulated heating in the visible spectrum and on simultaneous detection of the thermal wave response by means of IR radiometry and photoacoustics (PA). The method can be applied in the temperature range between room temperature and 1000 K.

1. Introduction

The IR detection of electromagnetic waves emitted by a heated body has become an important diagnostic tool in material science and in medical applications. A problem commonly faced when using IR cameras or simple IR detectors to determine the sample temperature is concerned with the unknown infrared optical properties of the material under study. Application of conventional optical absorption or reflection spectroscopy mostly require destructive procedures and do not provide locally resolved information. In this contribution we demonstrate the high potential of thermal waves, detected simultaneously by the photoacoustic effect and by photothermal radiometry (PTR).

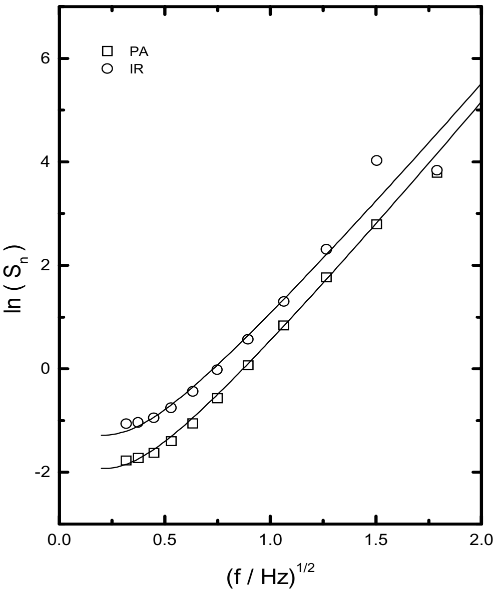

Fig. 1: Emissivity effect on the IR- and PA-signals, measured for a carbon fibre composite (Normalized amplitudes after calibration with signals measured for a common reference).

2. Combination of thermal wave techniques

In the transmission configuration of thermal waves, which means that modulated heating takes place at the front surface and that the thermal wave response is detected at the rear surface of a sample of finite thickness, information on the integral thermal properties, namely the thermal diffusivity $\alpha = k/(\rho\ c)$ and the effusivity $e = (k\ \rho\ c)^{1/2}$ is obtained from frequency-dependent measurements of the amplitude and the phase retardation of the thermal wave [1]. Here k, ρ, and c are the thermal conductivity, mass density, and specific heat capacity. The amplitude detected by IR radiometry additionally depends on the emissivity ε whereas the photoacoustic amplitude is mostly independent of ε (Figure 1).

In order to eliminate the different frequency characteristics of modulated photothermal radiometry and photoacoustics, which are due to the detection equipment and the different signal generation mechanisms – in photoacoustics the signal is proportional to the modulated heat flux from the solid surface to the adjacent gas region and in PTR the signal is directly proportional to the temperature oscillations of the solid surface – the measured signals first are calibrated with the help of signals measured by the two detection techniques for a common reference sample.

In the reflection configuration of thermal waves, where the thermal wave signals are excited and detected at the same sample surface, the absorption coefficients in the visible β_{VIS} and infrared spectrum β_{IR} can additionally be determined from the phase signals. Since the phase of the photoacoustic signal only depends on the thermal diffusivity α and the absorption coefficient in the visible β_{VIS} and since the phase detected by IR radiometry additionally depends on the absorption coefficient in the infrared spectrum β_{IR}, the two absorption coefficients can be separated (Figure 2).

Thus by combining the two detection techniques, IR radiometry and photoacoustics, and by combining the two geometrical configurations, thermal waves in transmission and in reflection, a complete opto-thermal characterization of materials is possible, which are partially transparent, both in the visible spectrum and in the infrared spectrum.

The information on the emissivity is obtained from the low-frequency limit of the signal amplitudes, while the information on the absorption coefficients is obtained from the high-frequency limit of the phases, which – in the case of photo-acoustic detection – is limited by the acoustic resonance of the cell, as can be seen in Figure 2. In the case of modulated IR radiometry, the detection is only limited by the background fluctuations at much higher frequencies [2].

In order to reduce minor effects of the emissivity on the photoacoustic signal, the secondary photo-acoustic signals generated at the window and walls of the cell, can be minimized [3].

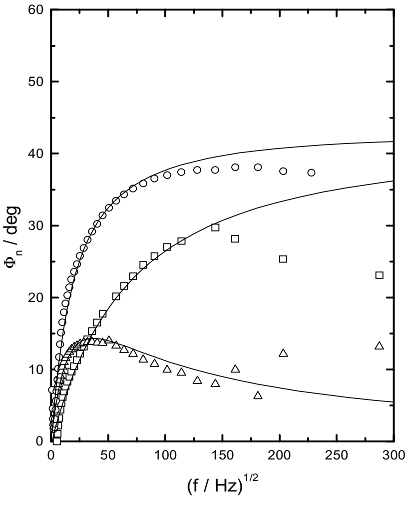

Fig. 2: Normalized phases, measured for a carbon fibre composite by IR radiometry (**o**) and photoacoustics (□), and phases difference (**Δ**), in comparison with theoretical approximations.

3. Application potential

This technique to measure the emissivity, has been applied to carbon fibre composites, tested with respect to their temperature stability. In dynamic temperature-dependent heat absorption processes, both the emissivity and the absorptivity of carbon fibre composites can change with temperature and time, e.g. due to phase transitions, oxidation, and thermal erosion. For the quantitative interpretation of thermographical measurements based on an IR camera [4], the evolution of the emissivity ε is then an important parameter, which has to be measured as function of temperature and time, before and after the erosion effects occurred. The emissivity data obtained by combining IR radiometry and photoacoustic detection are wavelength-averaged effective data and can be used for the calibration of the signal of the IR camera, once the detectors used for IR radiometry and for the camera are the same.

The measurement of the wavelength-averaged effective IR absorption coefficient by comparing the phases detected by photoacoustics and by IR radiometry can also be used to improve the interpretation of thermal wave measurements on diamond-like carbon coatings. The slight IR transparence of such coatings can lead to an overestimate of the both the thickness and the effusivity of the coating.

[1] J. Gibkes, B.K. Bein, D. Krüger, J. Pelzl, *Thermophysical Characterization of Fine-grain Graphites Based on Thermal Waves*, Carbon 31 (1993), 801-807.

[2] J. Bolte, J.H. Gu, B.K. Bein, *Background Fluctuation Limit of IR Detection of Thermal Waves at High Temperatures*, High Temp. - High Pressures 29 (1997), 567-580.

[3] S. Krüger, R. Kordecki, J. Pelzl, B.K. Bein, *Stray-light correction in photoacoustic measurements of solid samples,* J. Appl. Phys. 62 (1987), 55-61.

[4] J.Gibkes, J.L.N. Fotsing, J. Pelzl, B.K. Bein, *Identification and quantification of heat sources and sinks, based on IR thermography and inverse solutions of the heat diffusion equation*, to be published, 2002.