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Temperature Distribution in a Film heated with a Laser Spot: Theory and Measurement

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Abstract. For the measurement of the thermal capacity and the thermal conductivity of films, the thermal excitation of the sample is commonly performed by the absorption of light. This results in a spatial and temporal temperature distribution within the film. With a variety of methods static or dynamic temperature recordings are performed.

Two problems with these methods are discussed, the calculation of the temperature distribution in the film and the measurement of the mean surface temperature of the film. An analytical solution of the heat conduction problem for a cylindrical geometry with any radial distribution of the absorbed light is given. Resistive bolometers are introduced for the measurement of the mean surface temperature of the film within a circular area. Experiments with a 25 μm thick PVDF film give excellent agreement with the theoretical calculations within the modulation frequency range 10^{-3} Hz to 10^{3} Hz, thus allowing a determination of various thermal parameters of the investigated film.

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The measurement of the thermal properties of films, such as specific heat and thermal conductivity is of great importance for numerous technical applications of the films [1]. As examples one might notice pyroelectric sensor arrays [2], especially hybrid sensor arrays on silicon [3–5] and pyroelectric sensors for thermal diffusivity measurements [6] and microcalorimeters for specific heat measurements [7]. The knowledge of the thermal properties of the materials of these devices is essential for a calculation of the pyroelectric response and in sensor arrays of the thermal crosstalk between adjacent sensor elements [2]. Another application is given by the measurement of charge and polarisation distributions within polymer films with the thermal wave method [8, 9], as for the data analysis a knowledge of the thermal properties of the polymer film is a necessary condition.

For the measurement of the thermal properties of films, the thermal excitation of the sample is usually performed by the absorption of laser light. This results in a spatial and temporal temperature distribution within the film. A knowledge of this temperature distribution is essential for the evaluation of the thermal parameters and, of course, for the investigation of phase transitions, as the phase transition region is broadened if the temperature distribution in the film is nonuniform.

However, the measurement of the thermal properties of films represents a difficult problem due to theoretical problems to calculate the spatial and temporal temperature distribution within the film and due to experimental problems to measure the temperature distribution.

The purpose of the following paper is twofold. First, an analytical solution to the heat conduction problem shown in Fig. 1 is given for any arbitrary radial distribution of the laser light. These calculations show that the heating of the film results in a strongly nonuniform temperature distribution within the film, thus the properties of the thermometer used must be known precisely. As an example, an evaporated thermocouple would give a measurement of the lowest temperature within the contact area.

The second purpose is the introduction of a temperature sensor, which is able to measure, with a high precision, the average temperature of the heated area. This temperature sensor is a resistive bolometer. Resistive bolometers were in-

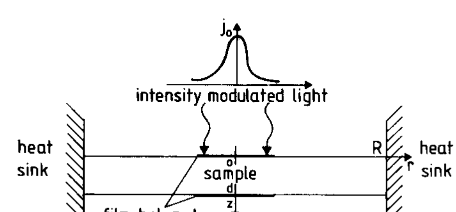

Fig. 1. Schematic view of the sample geometry. The sample consists of a film of thickness d, which is coupled to a heat sink at radius R. It is heated by the absorption of intensity modulated laser light having an arbitrary radial profile