A method for the measurement of the thermal, dielectric, and pyroelectric properties of thin pyroelectric films and their applications for integrated heat sensors

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A method is described that enables the simultaneous or consecutive determination of the specific heat, the thermal diffusivity, the dielectric constant, and the pyroelectric coefficient of thin pyroelectric films. The sample is heated by the absorption of intensity modulated light at one surface. The pyroelectric current and the transient temperatures of the sample surfaces are recorded as a function of the modulation frequency of the chopped light. The transient temperature recording is performed via thin-film bolometers. Analysis procedures for the determination of the specific heat, the thermal diffusivity, and the spatially varying pyroelectric coefficient are introduced and discussed. A simulation of the performance of integrated pyroelectric ir sensors on silicon chips is performed by a coupling of the pyroelectric material to a heat sink. It is shown that the response of pyroelectric ir sensors integrated on silicon chips is influenced by heat wave interference effects. Experimental results are given using thin pyroelectric PVDF films. It is shown that the use of pyroelectric polymers for integrated pyroelectric sensors is a good choice, due to their low thermal conductivity.

I. INTRODUCTION

Pyroelectric materials have found many applications recently.[1] Examples are pyroelectric ir sensors and sensor arrays,[2] as well as pyroelectric thin-film calorimeters.[3] A detailed knowledge of the specific heat, the thermal diffusivity, the dielectric constant, and the pyroelectric coefficient is of importance for these applications. Therefore, an arrangement that enables the simultaneous or consecutive measurement of these properties on the same sample is of interest. Transient methods for the determination of the thermal or pyroelectric properties of thin films, by heating the film with intensity modulated light, are quite common; see Handler, Mapother, and Rayl for the determination of the specific heat,[4] Hirschmann *et al.* for the thermal diffusivity,[5] Chynoweth for the determination of the ratio of the pyroelectric coefficient and the specific heat,[6] and Glass for the simultaneous determination of specific heat and pyroelectric coefficient.[7] In the method developed by Glass,[7] wire thermocouples were used for the determination of the transient sample temperature. Because of their thermal capacity, the method is applicable to rather thick films only. In the present paper, this method is further developed. The temperature recording is performed via thin-film bolometers of negligible heat capacity. Thus, the method can be used for thin pyroelectric films, e.g., pyroelectric polymers. Results are presented for the pyroelectric polymer PVDF. The experimental arrangement allows the investigation of pyroelectric materials on a substrate. The motivation is given by the recently introduced techniques to integrate pyroelectric materials with silicon chips.[8-10] It is shown that pyroelectric polymers are attractive for the development of integrated pyroelectric sensor arrays.

II. SAMPLE PREPARATION AND EXPERIMENTAL ARRANGEMENT

The experiments are performed using 9- and 25-μm-thick pyroelectric PVDF films from Solvay. The films are metallized with 40-nm-thick aluminium electrodes on both sample surfaces. Structured electrodes are prepared by a photolithographic technique. To improve the absorption of the metal electrodes 18-nm-thick bismuth films are evaporated. The sample is mounted in a cryostat, which allows an accurate control of the sample temperature within the range 100–400 K. Reflectance measurements have shown that the reflectance, and thus the absorptance of the electrode arrangement, is temperature independent within the given temperature range. The thermal excitation of the sample is performed via the absorption of intensity modulated light within the sample electrode. A laser diode with a wavelength of 856 nm is used as the light source. By monitoring the light intensity of the laser diode and by appropriate regulation of the current through the diode the intensity of the laser light is given by $j = j_0 + j_\sim \cos(\omega t)$, with $j_\sim \approx j_0$. The transient temperature of the sample surface is recorded via the resistance of the metal electrode. The resistance of the electrode is measured by the van der Pauw method. Simultaneously, or consecutively, the pyroelectric current is measured. Figure 1 shows schematically the experimental arrangement for the transient temperature and the pyroelectric measurements.

III. DETERMINATION OF THE THERMAL PROPERTIES

A. Transient temperature distribution within the film

The radius of the sample electrode is chosen much larger than the sample thickness, thus a one-dimensional treat-

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