The resolution of thermal profiling techniques

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Abstract

Mathematically, the determination of a polarization profile from pyroelectric data measured by the Laser Intensity Modulation Method (LIMM) or Laser Induced Thermal Pulse (LITP) is an ill-posed problem. This means that a variety of very different polarization profiles can be found which are all consistent with the experimental data. A common rule which avoids artifacts is to choose the smoothest profile (the principle of parsimony). Thereby, however, structures can be lost which may actually be contained in the experimental data. An optimum evaluation which extracts all the structures of a polarization profile which are significantly supported by the experimental data but which avoids the creation of artifacts requires to know the resolution of the thermal profiling techniques. Starting from the propagation properties of thermal waves and using a partial deconvolution this resolution has been derived. It is given in dependence of the precision of the experimental data and the frequency range of the experiment.

Introduction

Thermal profiling has been widely used for the investigation of polarization or charge profiles in pyroelectric materials. The laser intensity modulation method (LIMM) [1] uses sinusoidally modulated light to heat one surface of a sample. The modulation frequency is varied and the pyroelectric current spectrum measured as a function of frequency. Usually a mathematical procedure is applied to calculate the pyroelectric profile from the experimental data.

The first evaluation procedures for LIMM were approximations of the pyroelectric distribution by a sum of trial functions [2]. A Fourier procedure has been implemented for the evaluation of LIMM–spectra in combination with a deconvolution procedure [3]. The Constrained Regularization Method developed by Provencher [4] has also been implemented for solving the LIMM problem [5], and the Tikhonov–regularization [6] has been adapted to the evaluation of pyroelectric spectra [7]. Recently, techniques based on the principle of parsimony, using networks and power series, have been presented [8].

Thermal Scanning Function

A different approach to the solution of the LIMM equation is the thermal scanning function technique [9]. It is based on the finding that on a logarithmic length scale the 45 degrees out-of-phase component of the temporal derivation of the temperature amplitude is a scanning function for the pyroelectric profile. An approximation $p_a(x)$ for the pyroelectric profile $p(x)$ is directly calculated from the difference of real part $\Re$ and imaginary part $\Im$ of the pyroelectric current spectrum $I_\sim(\omega)$ vs frequency f.

$$p_a(x) = \frac{c\rho d}{\eta j_\sim A} \left[(\Re - \Im) I_\sim (\mathrm{f} = D/(\pi x^2)) \right] \tag{1}$$

$D = \kappa / c\rho$ is the thermal diffusivity, κ the thermal conductivity, c the heat capacity per mass, and ρ the mass density of the dielectric material. η is the absorbance of the sample electrode, $j_\sim$ the amplitude of the modulated incident intensity, d the thickness of the sample and A the electrode area.

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