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Averaged field analysis for infrared images processing. Application to microscale thermal characterization

by O. Fudym*, F. Sepulveda*, J.C. Batsale**, C. Pradčre**

*RAPSODEE UMR 2392 CNRS, Ecole des Mines d'Albi, 81013 Albi Cédex, France
** TREFLE, UMR 8508 CNRS, Esplanade des Arts et Métiers, 33405 Talence, France

Abstract

The focus of the present paper is devoted to the thermal conductivity measurement of microwires or microfibers inserted in an homogeneous subrstrate plate. Some steday and mainly 1D heat transfer conditions are applied to the plate. When the size of the object of interest is almost at the spatial resolution limit of the thermal imaging system, the corresponding heat transfer parameters to be measured in microscale devices can be adressed through the analysis of the deformation of a mainly one-dimensional temperature field. The small target to be analyzed can then be considered as a perturbating inclusion, yielding a two-dimensional deformation of the heat flux lines. This twodimensional field can be processed directly through a local (pixel-to-pixel) approach [1]. When heat transfer is assumed to be 2D with convective heat losses, the local governing equations are given by

$$k\Delta T + \frac{\partial k}{\partial x}\frac{\partial T}{\partial x} + \frac{\partial k}{\partial y}\frac{\partial T}{\partial y} - h(T - T_\lambda) = 0 \tag{1}$$

A direct local estimation of the pixel-to-pixel thermal conductances is then implemented, and deduced from the correlations between the Laplacian of the thermal signal and the corresponding first spatial derivatives. Unfortunately, in this case, the low signal-to-noise ratio makes the estimation procedure higlhy unstable. Moreover, estimation is only possible at the interface beween the different materials, that is through the thermal conductivity gradient.

When only two components are considered in the thermal image, such as the case where a microwire is inserted in an homogeneous substrate, an alternative method is to use an analytical Twotemperature model approach [2] - [3], involving the averaged temperature of the two components derived from a simple energy balance approach, resulting in the following equation:

$$k_1 e_1\left(\frac{d^2 < T_1 >}{dy^2} - h_1 < T_1 >\right) = -k_2 e_2\left(\frac{d^2 < T_2 >}{dy^2} - h_2 < T_2 >\right) \tag{2}$$

These solutions are also compared to a full 3D numerical simulation in order to validate the application of the Two-temperature model for the corresponding experimental bench. Edge detection filtering is implemented in order to retrieve the boundaries of the sample. Then, some direct relationships involving the averaged temperatures are obtained and used directly in a linear estimation frame based on the maximum likelihood estimator. Some examples of experimental images processing are given in order to illustrate the suitability of the proposed model applied to the thermal conductivity measurement of microwires.

In Fig. 1 is shown the 2D temperature field resulting from uniform boundary conditions (constant heat flux left ; constant temperature right ; up and down walls insulated). The small deformation of heat flux lines is due to the microwire insertion. In Fig. 2, the thermal conductivity gradient is apparent at the interface between the microwire and the substrate.

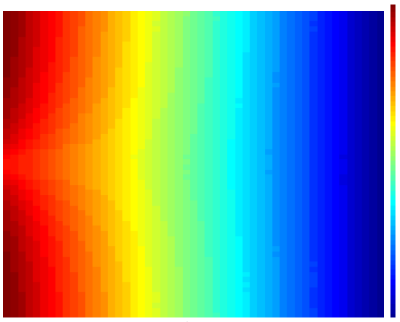

Fig. 1 *- Insertion of a microwire in a plate: 2D Temperature field*

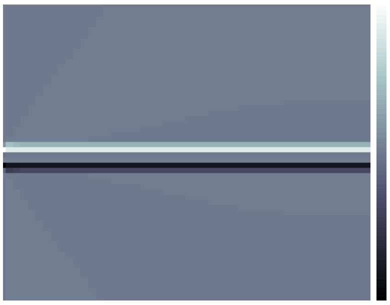

Fig. 2 *- Local Thermal conductance mapping within the plate: the microwire boundaries are apparent*

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Both approaches (local and averaged) are however highly sensitive to noise, due to the spatial derivatives of the signal, and some regularization procedures are necessary in order to stabilize the estimation.

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