Research the advantage of IRT thermal control in MEMS

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Abstract – **The spatial temperature distribution of micro-electro-mechanical systems (MEMS) is among the most important information parameter. At small scales, the processing of the great amount of data given by temperature IR images is then offering challenging opportunities to quickly and simultaneously estimate a great amount of parameters (thermophysical properties, source terms distribution).**

A convenient way is to consider a slow in-plane 2D transfer in a conductive plate at the surface of the system and to apply linear smallest square estimation principles.

Keywords – **infrared thermography, MEMS, thermal control**

I. Introduction

Micro-electronic Microsystems (MEMS) have reached enormous application in field of micro-sensors and micro-reactors. Their low fluid and/or solid mass requirements and small volumes lead to low cost manufacture. MEMS also have many unique characteristics in the field of heat transfer as high surface-volume ratio, possibility of implementing localized heat sources and high speed of the transfer/diffusive transfer. One of the main disadvantages is connected with the instrumentation of these systems. For example the implementation of small solid sensors is a difficult task for temperature measurements.

On the other hand, the main advantage of the infrared thermography (IRT) is to be non intrusive, offering possibilities of recording and processing a large amount of data related to heat transfer [1]. The main challenge is then to find out processing methods of the surface temperature field of such systems through a heat transfer model in order to estimate the largest possible amount of parameters as thermophysical properties, sources term distributions [2].

II. IRT and Parameter Estimation

For our investigation we have used an infrared (IR) focal plane array (FPA) camera FLIR P640. Each detector of the array in the IR camera is considered to be unique (distinctive offset level and distinctive calibration coefficient), independent or not from the detectors positioned in the vicinity. Several apparatus present additive devices in order to make uniform the offset level and calibration coefficient of each detector of the array. The statistical description of the measurement noise associated to the signal proportional to the temperature can traduce such assumptions. The signal T associated to a pixel will be proportional to a temperature. The processing method will consist of estimating thermophysical properties of a considered sample. The estimation problem consists of comparing a theoretical response field $T(t,x,y)$ with experimental realisations $\breve{T}(t, x, y)$.

The model in generally depending on a finite number of adjustable parameters $\alpha_1, \alpha_2,..., \alpha_m$ and of explicative variables such as time variable t, or, space variables x, y. Each experimental realisation $\breve{T}(t_i, x_j, y_k)$ (component of vector $\breve{\boldsymbol{T}}$) is related to the theoretical model $T(t_i ,x_j , y_k)$ (component of vector $\boldsymbol{T}$) by the following:

$$\breve{T}(t_i, x_j, y_k) = T(t_i, x_j, y_k) + e_{T(t_i, x_j, y_k)} \quad (1)$$

where $e_{T(t_i, x_j, y_k)}$ (component of vector: $\boldsymbol{e_T}$) is assumed to be a random variable following a gaussian or normal distribution. With FPA camera, the assumptions about the independence of these random variables depending on the time and space coordinates is questionable. Nevertheless, the assumption of independence of the pixels as a first approach allows to understand the processing methods implemented with simple expressions.

Generally the relation between parameters and temperature is non-linear, but the principle of all the optimisation methods is to describe the problems as iterative linear problems. Then, we will consider here only linear relations between parameters and temperatures such as the last step of an iterative optimisation method.

Then a summary of the simplified assumptions which will be used in the further applications is: an additive noise, a linear relation between temperature and parameters to estimate, a zero mean of the noise, a constant standard deviation σ.

The optimal estimation of parameter vector $\boldsymbol{B}$ is then obtained by:

$$\boldsymbol{B}\ (\boldsymbol{X}^t\boldsymbol{X})^{-1}\boldsymbol{X}^t\boldsymbol{T} \quad (2)$$

and the covariance matrix related to the estimation of $\boldsymbol{B}$ is:

$$cov(\boldsymbol{B}) = \sigma^2(\boldsymbol{X}^t\boldsymbol{X})^{-1} \quad (3)$$

This last expression allows the influence of the measurement noise on the parameter estimation to be studied. Expression (2) constitutes a linear transform of the data. In the case of the use of FPA, such linear transform can help to reduce the amount of information and at the same time the noise influence. For instance, if the observed signal is assumed to be stationary (the sensitivity matrix is then a unitary vector) the standard deviation of the unique parameter to be estimated is σ^2/N or σ/N (N is the number of realisations). The confidence interval of the estimation (proportional to the standard deviation) is then decreased when such a large amount of data is processed. The estimation is more difficult if the number of parameters m is larger than one. The sensitivity matrix $\boldsymbol{X}$ must be such as ($\mathbf{X}^t\mathbf{X}$) and it is inversible or well conditioned. In the case of a large amount

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of data (such IR thermography) the estimation of a large amount of parameters (smaller than the amount of data) is possible and often with a reduced noise influence, but the experimental conditions must be designed in order to dispose a favourable sensitivity analysis. Particularly, the inversion of large linear systems is cumbersome and must be considered with suitable simplifications coming from the knowledge of the physical phenomena.

III. MEMS HEAT TRANSFER CONSIDERATION

In MEMS a complete 3D transfer in heterogeneous media must be considered and the in-depth diffusion can be too fast in contrast to large objects where the lateral sizes of the sample are far larger than the thickness. One convenient solution is then to force slow in-plane heat transfer at the surface (instead of in-depth), by placing a conductive thin plate (more conductive than the substrate) in front and in contact with the micro-system. Such plate will act as a heat spreader. Generally a thin silicium wafer or a thin glass plate is used. At characteristic times larger than the in-depth diffusion time in the thin plate, the temperature field can be assumed to be 2D. Only global lateral heat losses and source terms or perturbations coming from the substrate have to be considered. The lateral heat losses are generally strong at larger scales (fin effect), but very small when a characteristic length *L* (pixel size) of the conductive plate is such as [3]:

$$L << \sqrt{\lambda e / 2h} \tag{4}$$

(with λ - thermal conductivity, h - convective losses coefficient, e - thickness of the plate).

The analysis of the surface temperature needs to consider uniform emissivity and a uniform calibration of the pixels of the array, even if the signal can be only proportional to the absolute temperature.

Unfortunately, the extension of spatial Fourier transform to heterogeneous samples is not easy and often it is difficult to take into account other phenomena as convective transport coupled with diffusion.

A local approaches have been implemented in order to estimate the local field of diffusivity or conductivity of heterogeneous thin plates with IR cameras. The main idea is to simultaneously process the whole field of temperature and to try to make each pixel sensitive to local thermophysical parameters (fig.1).

IV. CONCLUSIONS

The main advantage of such in-plane analysis of transfer at small scales is related to the very fast implementation of the experiments. Even if the first results obtained here are near to the steady-state, the stationary fields are generally obtained about a few seconds and authorizes a great number of trials (quite impossible at larger scales). The second aspect is related to the large possibilities to implement localised heat sources with external action (laser sources or heating resistors)

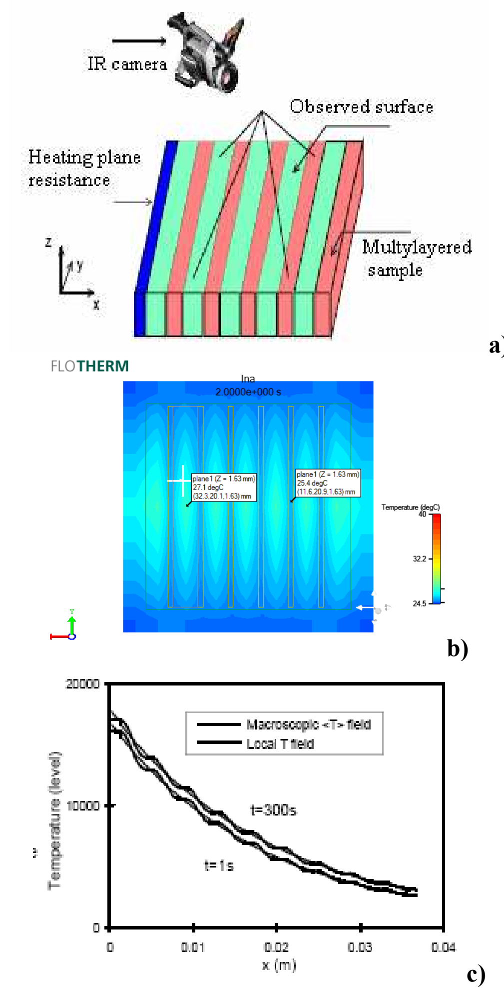

Fig.1. Scheme (a) simulation (b) and temperature profiles (3) of the experimental device with 1D heterogenous sample

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