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Optical Characterization Method for MEMS

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Abstract

We present different optical techniques to characterize Micro-Electro-Mechanical Systems (MEMS) components. The temperature, topography and displacement of a MEMS related to its mechanical characteristics can be extracted using optical reflections. The MEMS under consideration in this paper is microheater composed of a loop-shaped resistor (heater) in phosphorus doped polysilicon.

1 Introduction

In recent years, MEMS and specially thin-films microheaters, have emerged as a topic of considerable interest for a wide range of applications (gas sensors, IR sources, etc.). One major challenge involved in the design of such structure is the need for high thermal uniformity. Optical techniques are good tools to analyze structures because they are non contact, non invasive and non destructive [1-2].

When an electrical current flows through an electronic device, some thermal waves are generated by thermoelectric effects which submit the device to a thermo-mechanical stress. This produces a surface displacement and a surface temperature variation. Indeed, a study of the topography, the surface displacement and the temperature variation of the sample is necessary for a failure analysis and to improve devices. This article presents different techniques to measure these parameters.

2 Experimental set-up

The set-up presented in Figure 1 is based on a Michelson interferometer [1-3]. Two types of light source can be used for two types of measurements. A light emitting diode (LED) is used for cartography measurements and a laser for punctual measurements. The choice of the light source is done by the mobile mirror M_L.

For cartography measurements, LED light goes through lens L_1 to limit the light diverging. An interferometric filter (IF, 633 nm) restricts LED spectrum and light is polarized thanks to polarizer P_1. The Michelson interferometer is composed of the polarizing beam splitter PBS separating light in two parts. The reference arm of the interferometer is ended by a reference mirror M_2 whereas the object arm is ended by the sample (MEMS in our case). As measurements require power supply, a generator is linked to the sample. In each arm of the interferometer, a quarter delay plate (λ) and a microscope objective (O_1 and O_2) are inserted, the first one allowing light to be detected in the detection arm and the second one allowing to focus light on the sample. The detection arm is ended by a CCD camera linked to a computer. Before detection, the light goes through polarizer P_2, that has a double function. When its axis is adjusted at 45° from PBS axis, it can be used for interferometric measurements, permitting interferences between object and reference waves coming from interferometer. When its axis is adjusted along object wave, then it can be used for reflection measurements. The L_2 lens allows to make the sample image onto the CCD camera.

For punctual measurements, the description of the set-up is quite similar excepting in the detection arm where a mirror is placed before L_2 in order to detect the light by a photodiode (Ph).

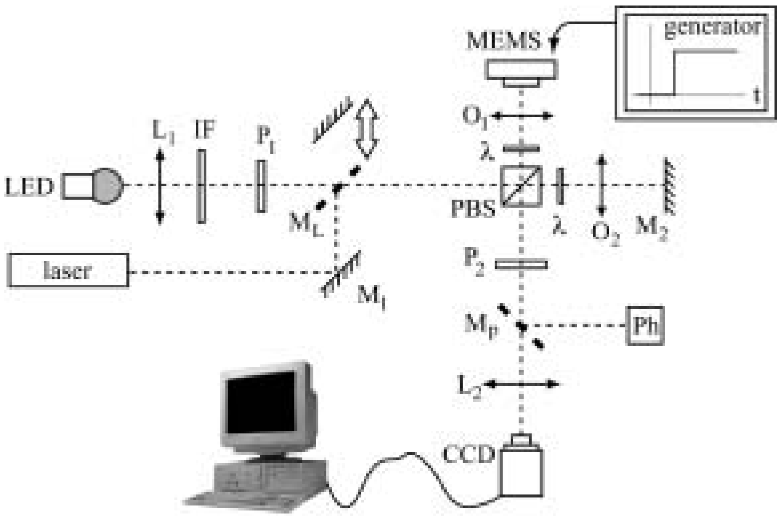

Figure 1: Experimental set-up.

3 Optical analyses

Optical analyses are common way to study small objects. By this technique, lateral resolution is limited by diffraction at few micrometer. Moreover, these techniques are non contact, non invasive, non destructive and permit analysis *in situ*. Therefore it is well adapted for microelectronics and so for MEMS analysis. Now, we will describe more precisely interferometric and reflectometric techniques.

3.1 Interferometric measurements

The set-up we have built allows measuring topography or surface displacements of the sample. As described in experimental set-up, it is based on a Michelson interferometer. When the sample is in standby, the light detected can be written:

$$I_d = \frac{I_0}{2}\left[1 + V\cos\left(\phi_0\right)\right]$$

where I_0 is the intensity of the light source, V is the contrast of interferences and ϕ_0 is the phase corresponding to the path difference between reference and object arms.

For cartography, this equation is (x, y) dependent but for simplification we will not write further this dependence. When laser is used as a light source, the method becomes well-known technique called ESPI (Electronic Speckle Pattern Interferometry) [4]-[5]. It is generally used to cartography the out-of-plane surface displacement but can also be used for in-plane surface displacements or gradient surface displacements [5]. Nevertheless, ESPI techniques cannot be used for topography measurements because of the coherence of the light which produces dots called speckle covering the sample image due to the roughness of the surface sample. This implies that ϕ_0 is a random parameter.

This is the reason why we have imagined to use a LED as a light source. This kind of source prevents speckle and is cheaper than laser. In this case, ϕ_0 represents directly the path difference between the reference and the object arms. Furthermore, a LED has a coherence length of ten micrometers that leads to set the interferometer to the zero (same length of the reference and object arm). As the roughness of the reference mirror is flat at $\lambda/100$, the interferometric measurement of the sample in standby is the measurement of its topography:

$$\phi_0 = \frac{4\pi}{\lambda}\Delta z$$

where Δz represents the topography and λ the wavelength of the light source.

In addition, the method using a LED can also be used for surface displacement mapping. The detected intensity when the sample is supplied by a current can be written:

$$I'_d = \frac{I_0}{2}\left[1 + V\cos\left(\phi_0 + \phi_d\right)\right]$$

where ϕ_d is the phase shift due to deformation linking the surface displacement Δd by the equation:

$$\phi_d = \frac{4\pi}{\lambda}\Delta d$$

The technique to extract ϕ_d is similar to ESPI techniques [5]-[6].

In punctual analysis, the light source is a laser and the detector a photodiode. It is used to study out of plane surface displacement. Sensitivity of this technique is 10^{-15} m. We will not consider it in this paper.

3.2 Reflectometric measurements

Reflectometry is a non-contact method to measure temperature variation. The intensity variations ΔI measured by the detector depend on the sample reflectivity variations ΔR. This last one is linked proportionally to the temperature variations ΔT by:

$$\frac{\Delta I}{I_0}=\frac{\Delta R}{R_0}=\kappa.\Delta T$$

where I_0 and R_0 are, respectively, the detected intensity and the reflectivity of the sample in standby. κ is the proportionality coefficient called thermo-reflectance coefficient. Assuming the knowledge of this coefficient, we can obtain a thermal mapping of the sample.

This technique is valid for both cartography and punctual techniques. In the case of cartography, this equation should be (x, y) dependent but for simplification we voluntary ignore this dependence.

The technique consists in measuring the reflected intensity I_0 and I_1 of the sample at two differents states: the first one (I_0) corresponding to the sample in standby and the second one corresponding to the supplied sample. The relative variation of the reflectivity can be written:

$$\frac{\Delta R}{R}=\frac{I_1-I_0}{I_0}$$

4 Results

The different described techniques have been applied to study MEMS. Figure 2 represents the picture of the sample. It is a microheater fabricated in Microelectronics Laboratory of UCL (Louvain-la-Neuve – Belgium) [7]. This microheater is composed of a loop-shaped resistor (heater) in phosphorus doped polysilicon.

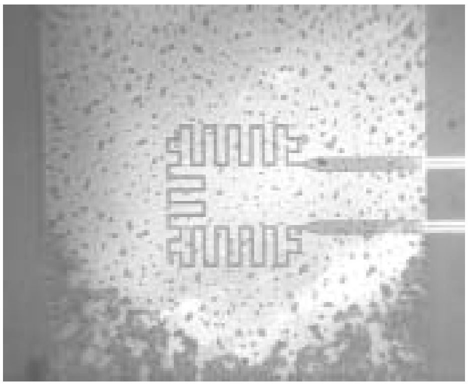

Figure 2: Image of the sample.

The resistor is supported by a thin dielectric membrane (i.e. thickness < 1 µm). For operation at temperatures up to 450°C, a membrane size of 640x640 μm^2 is used for an active heated area of 240x240 μm^2. The value of the resistor is 13.3 kΩ. The membrane consists of three stacked dielectric layers: SiO_2 (400 nm LPCVD), Si_3N_4 (300 nm LPCVD), SiO_2 (290 nm PECVD). Performance of the heater can be judged in terms of power consumption vs.

temperature elevation. The active area can be heated up to working temperatures of 400°C with less than 20 mW. These results outperform most recent realizations showing better thermal uniformity over the membrane, at much lower cost, since only standard CMOS materials are used. These excellent results are mainly related to the comparatively small total thickness of the membrane, which heads to extremely high thermal insulation (about 20.000°C/W) from the bulk, and to the novel loop shape of the polysilicon microheater.

Figure 3 represents results obtained by interferometric techniques. Figure 3-a is the topography of the sample whereas Figure 3-b represents the surface displacement. The topography shows the bending of the resistor on the membrane. It can be explained by the fact that membrane is free in air and do not collapse in its center. We can estimate the height of the resistor around 50 nm and the difference in height between the highest and lowest membrane points of around 150 nm. The numerous peaks visible in Figure 2 are due to silicon residues on the membrane after etching.

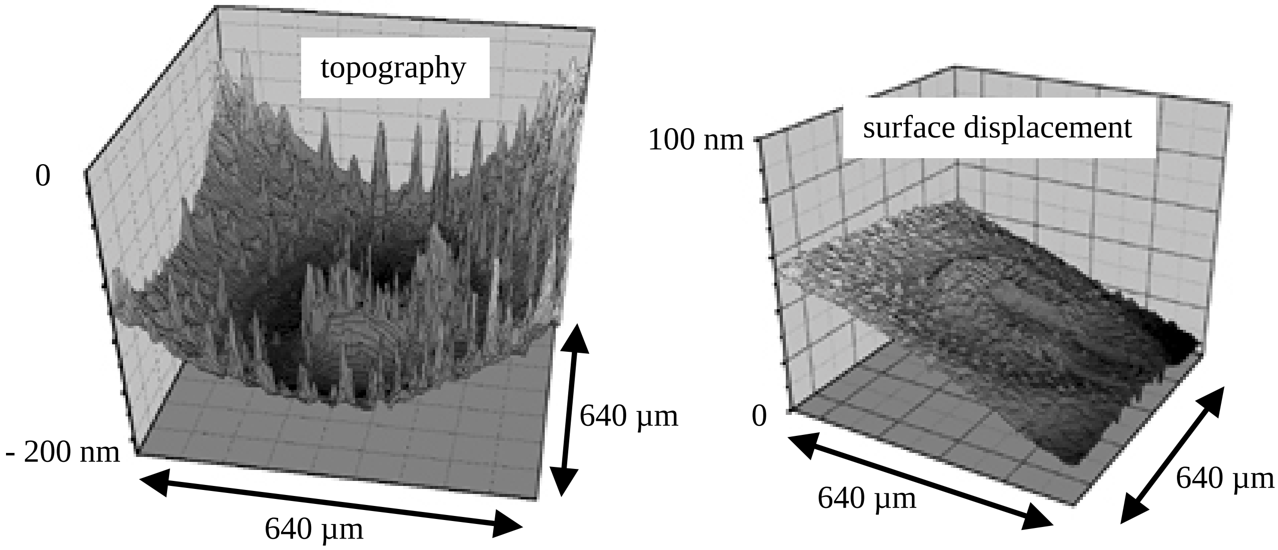

Figure 3: interferometric measurements.
3-a: topography, 3-b surface displacement.

Then, the resistor has been supplied with a transient current of 400 µA corresponding to a dissipated Joule power of 2 mW. The purpose is to analyze how the membrane has moved. We have measured a surface displacement of about 50 nm on the whole membrane and 10 nm on the resistor

At last, we have used the bench as a reflectometer. Figure 4 represents an image of the $\frac{\Delta R}{R_0}$ ratio for a dissipated power of 2 mW. The mean value measured on the resistor is 8.9×10^{-2}. A calibration of the value of the resistor in an oven enables to obtain the mean temperature variation of the resistor. The knowledge of the resistor value as a function of the temperature variation allows to extract the temperature variation at the working current if we know the applied voltage. It is therefore easy to extract the resistor value at the working current which corresponds to a mean temperature variation of 45 K.

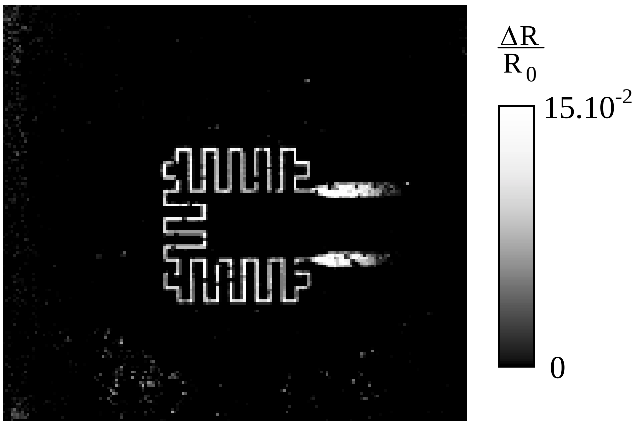

Figure 4: thermoreflectivity cartography.

Some few checks have been done to confirm our results. First, we have made different pictures in thermoreflectance for several values of the transient supplying current. We have noted that the $\frac{\Delta R}{R_0}$ ratio varies in quadratic with the current value which is significant of Joule effect.

We have also compared our results to ones obtained by simulation in [7]. The value measured for the increase of temperature on the membrane is in the region of 420 degrees for a dissipated power of 20 mW to be compared with 45 degrees for 2 mW obtained by thermoreflectance.

Finally, we have studied this microheater on a punctual laser reflectometer. The dissipated power is still 2 mW; the measured value of the ΔR/R ratio on the resistor is 8.4×10^{-2}, in good agreement with the value measured by the imaging technique.

5 Conclusion

In this paper, we present optical techniques to characterize MEMS developed at UCL in Louvain-la-Neuve. Topography, surface displacement and temperature variation of the sample are measured. Results are in good agreement with simulations and electrical measurements. Therefore, these techniques valid theoretical models and are good tools to study such components.

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