

Digital Holographic Microscopy (DHM) for metrology and dynamic characterization of MEMS and MOEMS

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ABSTRACT

Digital Holographic Microscopes (DHM) enable recording of the whole information necessary to provide 3D phase measurements with a nanometer vertical resolution with a single image acquisition. The use of fast acquisition camera or stroboscopic acquisition mode makes these new systems ideal tools for investigating the topography and dynamical behavior of MEMS and MOEMS. This is illustrated by the investigation of resonant frequencies of a dual axis micro-mirror. This enables the definition of the linear, non linear, and modal resonance zones of its dynamical response.

Keywords: Digital Holography Microscopy, MEMS, MOEMS, real time 3D optical topography

1. INTRODUCTION

MEMS and MOEMS developments require both their static and dynamical characterization with an interferometric resolution. From the resonant frequencies analysis of structures, such as cantilevers, flexure joints, microbridges or membranes, one can evaluate for instance the geometrical factor effects, the Young's modulus, the mean residual stress, the effect of air damping, or the study of microsystems aging. When developing MEMS and MOEMS, there is a constant need to efficiently compare numerical simulations to real micro devices movements and to adapt the production process by modifying geometrical characteristics.

Optical measurement of the movements of micro systems is a commonly used method for the characterization of the mechanical properties of micro-systems [1]. A single frequency spectrum is generally not sufficient to assess their dynamical behaviour. Until recently, most ex situ vibrometry measurements were performed by laser deflection, by fiber optic interferometry or with single beam laser Doppler vibrometers. These techniques provide only a point measurement of the out-of-plane vibrations. A time consuming mechanical translation of the sample or a scan of the laser beam is then needed to obtain the vibration amplitudes on several locations of the micro device. This makes also the measurement very sensitive to the vibrations. For these reasons, it is highly desirable to develop techniques which allow a full-field measurement of the out-of-plane vibrations.

Dynamic measurements can also be achieved by stroboscopic systems using phase shifting interferometry (PSI) [1] or Fast Fourier Transform (FFT) analysis of interferograms [1]. These systems offer full-field capabilities, but their speed is limited and they are sensitive to vibrations as information from several interferograms taken successively over a relatively long period of time need to be combined.

We present measurements performed with a Digital Holographic Microscope (DHM). Such instrument enables to retrieve the full three dimensional information from a single image acquisition, more precisely from a single hologram.

2. DHM AND MICRO SYSTEMS CHARACTERIZATION

Light interaction with a sample modifies both intensity and phase of the illuminating wave. Any available supports for image recording are sensitive only to intensity. Denis Gabor invented in 1948 a way to encode the phase as an intensity variation: the “hologram” [2]. Digital Holographic Microscopy (DHM) implements digitally this powerful concept of holography. With the present performances of computers and the developments of digital cameras, holograms can be numerically interpreted within a tenth of second to provide simultaneously: (1) the phase information, which reveals object surface with vertical resolution below 1° of the wave phase (the nanometer scale for homogeneous samples), and (2) intensity images, as obtained by conventional optical microscope. Both images are defined with a diffraction limited resolution in the transverse (Oxy) plane and are “reconstructed” from the hologram in real time (more than 15 reconstructions per second for 512×512 holograms).

The strength of DHM lies in particular on the use of the so-called off-axis configuration [3], which enables to retrieve the 3D phase and intensity images of the observed object by numerical reconstruction of a single hologram, which comprises the whole information, and which can be acquired within a few microseconds only.

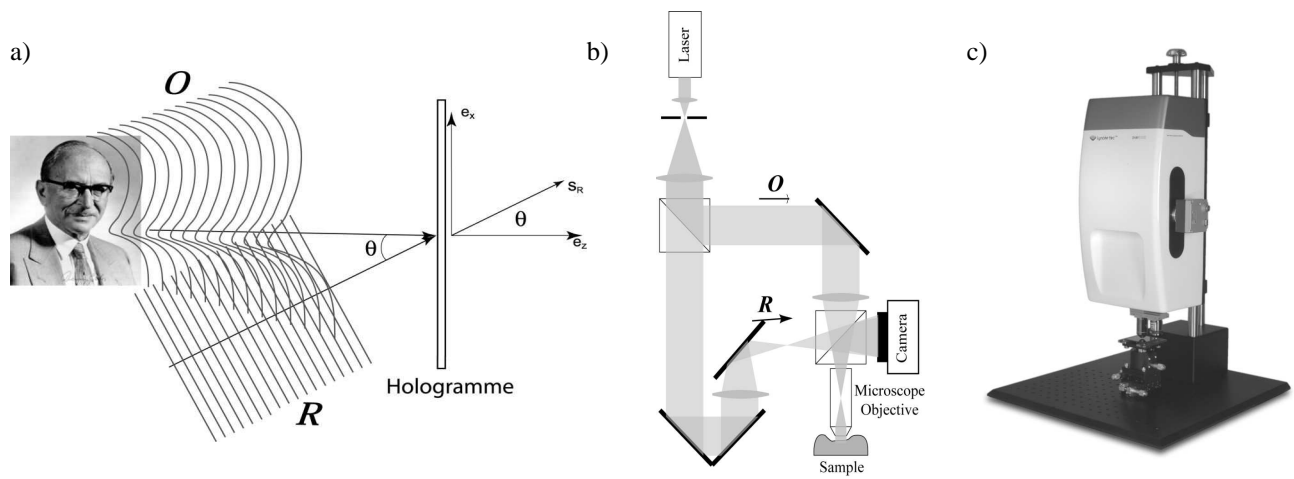


Figure 1. (a) Recording principle of off axis holograms. There are a few degrees (angle θ) between the reference (R) and the object beams (O). This enables to reconstruct the information using a single hologram acquisition. On-axis holography (i.e. $\theta=0$) requires acquisition of several holograms. The portrait is the one of Dennis Gabor, Nobel Price of physics for its discovery of Holography. (b) Optical set up for reflection DHM: the source beam is first separated into two parts: a reference beam and an object beam. The object beam illuminates the sample. The light diffracted by the sample is collected by the microscope objective and is combined with the reference beam to form a hologram on the camera. In this paper, the wavelength of the laser is 658 nanometers, and (c) The reflection DHM used for this study.

This important feature makes out of DHM a unique tool for MEMS and MOEMS characterization as:

1. Acquisition time can be reduce to a few microseconds with standard cameras and even much less using pulsed sources. Such extremely short acquisition time makes DHM systems insensitive to vibrations. Using references areas, digital procedures enable to correct for any vertical movement or tilt of the sample associated with ambient vibrations between two measurements. DHM can operate without vibration insulation means, making them a cost effective solution for R&D and for implementation on production lines.

2. Real time measurements can be achieved up to about fifteen frames per second using standard camera or as high as $100'000$ frames per second using fast cameras. Reconstruction of intensity and phase images can be performed either in real time up to fifteen measurements per second for 512×512 holograms or postponed, in a second step, for higher acquisition frequencies or higher hologram sizes.

3. Up to 100 kHz excitation frequencies, stroboscopic mode can be performed by synchronizing the camera acquisition with the micro device driving signal to recover the optical topography along the whole movement cycle of the micro device. Standard camera has exposure time down to 1 μ s. At 100 kHz, this corresponds to a duty cycle of 10%. For higher acquisition rates, the source needs to be pulsed to achieve MHz movements characterization.

3. MICRO-SYSTEM DESCRIPTION AND MOVEMENT CHARACTERIZATION

The MOEMS characterized here is composed of ten dual-axis micro mirrors array. It can be used for various applications such as optical switches, 2D scanning and image projection. Each micro mirror consists of a silicon plate of 1.5x2.0 mm², held by flexures suspended over four control electrodes. A thin gold layer is deposited over the silicon die to create the reflective surface and the bonding pads. It is shown on Fig.2a.

The aim of this paper is to investigate the combined effect of different resonant frequencies along both axis. The investigated sample is a prototype on which the geometrical parameters of the flexures have been changed for the aim of this study. It has a resonant frequency between 100 and 200 Hz. Such operating frequencies are low with respect to the capacity of DHM.

Three dimensional measurements contain a lot of information. For any micro-system under investigation, a specific measurement protocol needs to be defined. For the present micro-mirrors, measurement of the vertical displacement of five different areas has been carried out. Each area is 6x6 μ m². Fig 2a shows the location of these areas. There is one on the center and two on each extremity of both rotation axis of the mirrors. This choice enables to discriminate the characteristics of each axis. Fig 2b shows the relative displacement of these areas for a sinusoidal driving voltage ranging between a minimum of 3V and a peak value V=30V, at an excitation frequency ν =60Hz. The resulting movement is a deflection of the mirror around an axis bisecting both axis: areas 3 and 5 go down, and areas 2 and 4 up. Area 1 should remain at the same level. Note that deflection angle along both axis of the mirror can be directly calculated from this measurements and the XY coordinates of the areas.

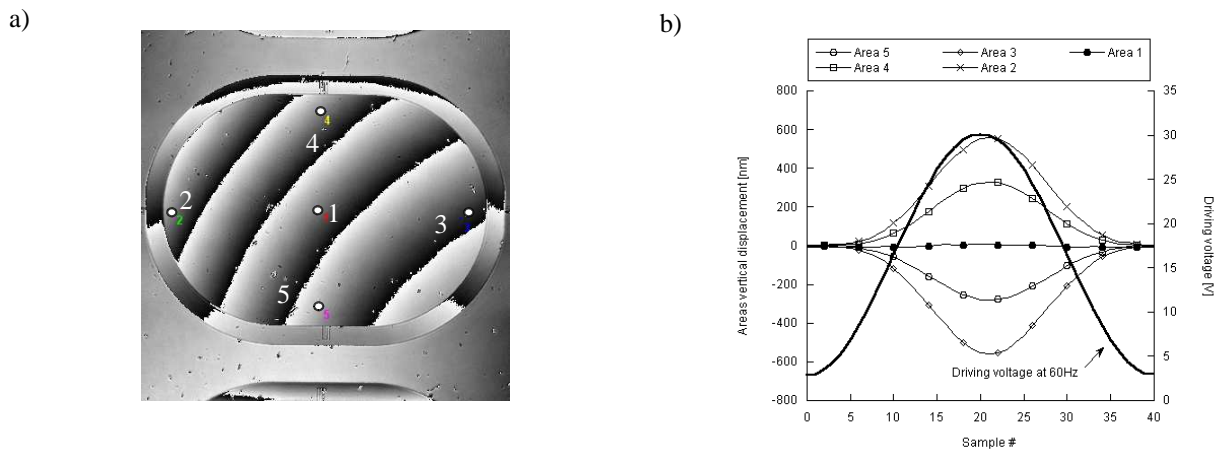


Figure 2: (a) DHM phase image of a 2-axis micro mirror by Colibrys. The two flexures of the long rotation axis are located at 6h and 12h, on the outer moving frame, and the flexures of the short axis are on the silicon frame at 3h and 9h. There are dusts on the surface. Area 1 is located on the center of the mirror, area 2 and 3 close to each extremity of the long axis, and area 4 and 5 along the short axis. b) Vertical displacement of the areas (left Y-scale) for a sinusoidal driving voltage (right Y-scale) with a peak V=30V at an excitation frequency ν =60Hz.

3. MEASUREMENTS

Although measurements have been carried out on the five areas, measurements are shown in this chapter only for area 3 for shake of simplicity. The measurements for each other areas lead to the same conclusions. Fig. 3 shows the vertical displacement of area 3 for a sinusoidal driving voltage ranging between 3 and 30V, and for frequencies ranging from

10Hz to 240Hz. One can distinguish three distinct zones. In the first one, for frequencies smaller than 60Hz (Fig 3a and 4), the correspondence between the driving voltage and the vertical displacement of the area is linear and can be easily predetermined. While the frequency increases, the dynamical behavior remains very similar, except for a slight increase of the amplitude oscillation. For frequencies ranging between 60Hz and 120Hz, the amplitude of the oscillation increase with the driving signal frequency. The displacement remains nevertheless periodic and predictable, but the oscillation dynamical curve changes when increasing the frequencies. The dynamical behavior shows clearly more complex features. The micro system can be used providing that the deviation remains within the specification of the micro system. Calibration is possible but difficult.

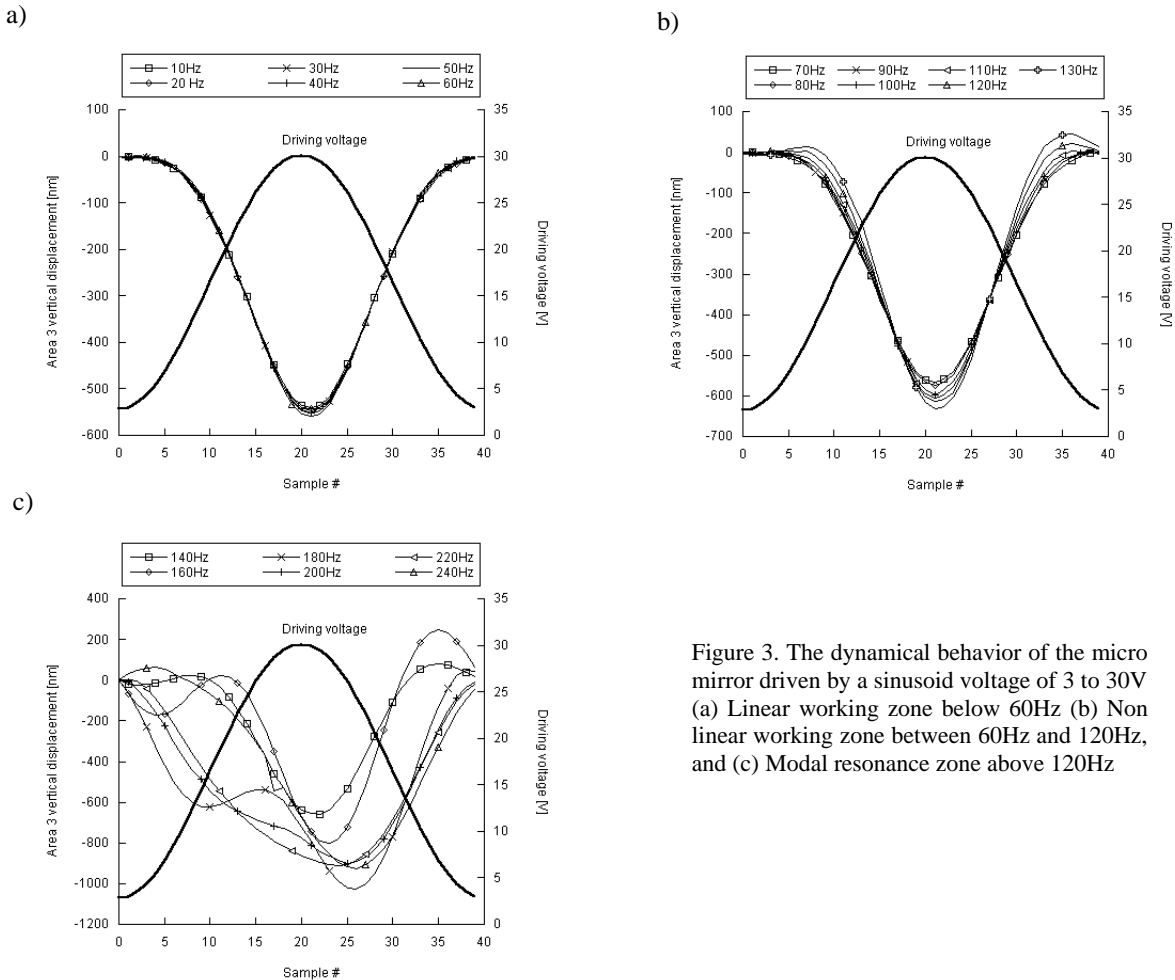


Figure 3. The dynamical behavior of the micro mirror driven by a sinusoid voltage of 3 to 30V (a) Linear working zone below 60Hz (b) Non linear working zone between 60Hz and 120Hz, and (c) Modal resonance zone above 120Hz

For frequencies higher than 120Hz, development of resonant modes is observed. These modes are asymmetric. This is probably due to a difference of elasticity parameters of both rotation axis: they do not vibrate simultaneously. This time gap results in a dephasing of both axis vibration and then in a rotational modes of the micro-mirror. These movements are observed directly on the three dimensional phase measurements of the sample. The micro mirror can hardly be used with such driving parameters, corresponding to the modal resonance zone of the micro system. DHM measurements show clearly the limitation of the driving parameters in relation with the dynamical behavior of the system. This is illustrated also in Fig 4.

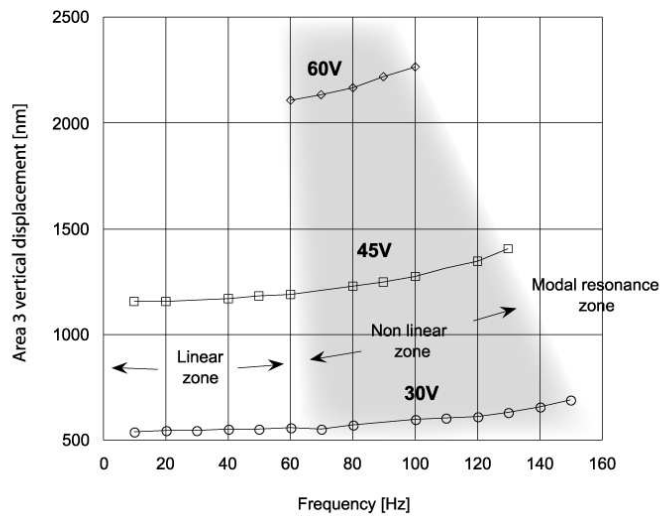


Figure 4. The dynamic response of the micro-mirror enables to distinguish the linear, non linear and Modal resonance zone of the micro-system.

The same study has been performed for sinusoidal peak voltage $V=45V$ and $60V$. Results are summarized on Fig 4 which shows the amplitude of the displacement as a function of the excitation frequencies. Such dynamical response analysis enables to determine the utilization parameters of the micro device.

4. CONCLUSION

DHM used in conjunction with a high frequency acquisition camera or in stroboscopic acquisition mode enable in a very fast and efficient way to investigate the dynamics of micro systems. It has been shown how the resonant frequencies of a dual axis micro mirror can be measured and can help to characterize the dynamical response of the micro system. Resonance modes have been analyzed, but DHM enables also to measure the deformation of the mirror as a function of both driving voltage and vibration frequency.

By providing topography and dynamical behavior of MEMS and MOEMS, DHM enable efficient R&D and production process engineering. It enables also quality control in production line of the functionality of micro systems.

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6. REFERENCES

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