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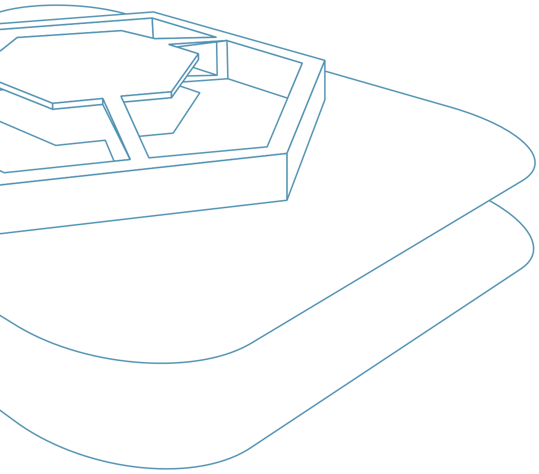
DIGITAL HOLOGRAPHIC MICROSCOPY

DHM™ R1000



Stroboscopic in-plane and out-of-plane characterization of MEMS and MOEMS

Digital Holographic Microscope (DHM™) is an ideal tool to investigate MEMS and MOEMS. In particular periodic samples can be investigated using the DHM stroboscopic mode for:

- **3D in-plane and out-of-plane topography**
- **Dynamic measurements on periodic samples**
- **Analysis of the behavior during the complete cycle**
- **Frequency and amplitude response characterization**

It is illustrated by the investigation of the rotation amplitude, vertical displacements and tilt of a variable capacitor.

Development, process optimization and quality control of MEMS and MOEMS require not only the characterization of their shape, but also an analysis of their dynamic movement with interferometric resolutions. If static measurements may provide information on geometric factor effects, mean residual stress ... dynamic ones allow the study of the sample's frequency and amplitude response, deformation during the movement, ageing comportment and more.

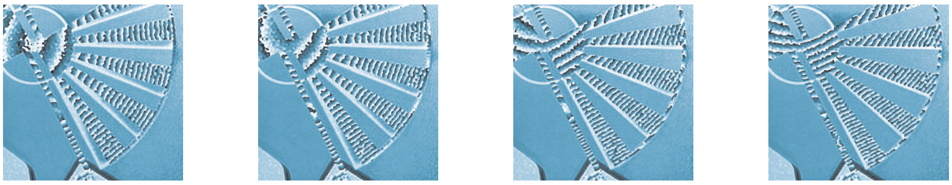
The main difficulty for measuring in-plane and out-of-plane movements of fast moving objects is that the complete information has to be acquired simultaneously in a very short time lapse to avoid blurring. Scanning techniques such as white light scanning interferometry (WLSI) are thus not appropriate techniques as time consuming mechanical scanning is needed. Other techniques provide only a point measurement for out-of-plane movements and a mechanical translation of the sample or scanning of the beam is needed to obtain measurements on other parts of the sample. The existing techniques that provide full field information, such as phase shifting interferometry (PSI) or Fast Fourier Transform (FFT) analysis of interferogram mostly need the combining of several acquisitions and are therefore limited in speed and highly sensitive to external vibrations.

Digital Holographic Microscopes (DHM™ R1000) allows the acquisition of the full three dimensional information with a nanometric vertical resolution in a single image acquisition. DHM™ systems can thus operate in real-time with up to 15 images per seconds using standard cameras and higher with fast cameras and postponed reconstructions.

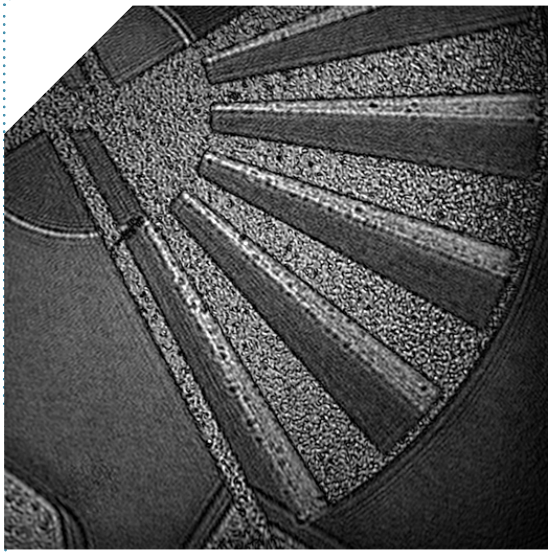
This unique feature allows DHM™ to be a powerful tool for stroboscopic measurements of MEMS and MOEMS which permits high frequency phenomena observation. It elegantly resolves the problem of standard PSI systems. In contrary to those instruments, DHM does not need the acquisition of several interferograms for a 3D image. It thus does not need any displacement of the sample or mirror. The DHM's stroboscopic mode is therefore not limited in frequency by the vibrations of the sample itself or of the microscope head resulting from the phase shifting, which clearly limits the frequency range in which the sample can be investigated.

Some important features of the DHM™ stroboscopic mode are:

- Synchronization of the of the image acquisition with external hardware or software.
- Sample driving signal provided by the DHM™ system. Driving signals up to 100kHz with amplitudes of $200V_{rms}$ (400V peak to peak) with user-defined shapes.
- The short acquisition time (a few microseconds) makes DHM™ systems insensitive to the sample's motion in that time lapse.
- In-plane and out-of-plane measurements along the complete cycle of the sample.
- Digital and analog inputs can be received by the DHM™ system for external even synchronization.



Sequence obtained with DHM™ R1000:
Half cycle of a variable capacitor motion. The upper electrode rotates which changes the capacitance. The rotation amplitude could be measured as well as an undesired vertical displacement and tilt.



Packaged rotating variable capacitor by LEG - EPFL.

Stroboscopic measurements

The stroboscopic mode is driven by an electronic module composed of an independent microprocessor, developed internally. It enables to trig the camera and includes a waveform generator. It ensures a perfect synchronization of the acquisition of the images and of the generated output signal. The monitoring of the sample over its complete cycle is achieved by the acquisition of several holograms (up to 500) over several cycles of the sample, each one being taken at a different position in the cycle (Figure 1). The fact that a single hologram taken in one shot contains the complete 3D information ensures the needed robustness for stroboscopic investigations.

Measurements

The characterized MEMS is a variable capacitor with fragmented electrodes using arms electro-thermal actuation. It is made of two fragmented electrodes: (i) a bottom fixed electrode and (ii) a top rotating electrode suspended over a 1.4µm air gap. Two arms connected on each part of the small central disk structure are used to rotate the top electrode and change the capacitance. When a current passes through the arms, the injected power induces a net thermal expansion of the arm that creates a moment rotating the entire structure. The capacity of the micro device is in particular function of the relative distance between the fixed and the moving electrode. It is mainly characterized by 3 geometrical parameters: (1) the rotating angle, (2) the vertical displacement and (3) the possible tilt of the suspended structure. Those three parameters have been measured by a DHM™ R1000 operating in stroboscopic mode to sample 50 measurements along the sinusoidal excitation period. The measurements presented here have been performed with a signal at 50Hz and voltages from 1 to 1.8 Volts. The complete study also investigated the frequency response of the sample in the 1Hz to 100kHz range.

To investigate changes in height of the suspended structure, a profile from a point having a fixed height (point A on Figure 2a) to an extreme point of the structure (point C), passing through the center of the structure (point B) was extracted.

Figure 2b shows six profiles, over the 50 measured for the full sinus period, for driving signal amplitude of 1.785V. Figure 2c shows the minimum and maximum height difference between the fixed point A and the point B for four different sinus amplitudes.

The rotation angle of the structure can be characterized on both DHM phase and intensity. The movement is characterized comparing to the fixed electrode. The tilt of the structure has been determined by extracting phase profiles perpendicular to the symmetric axis of the fingers (Figure 2a).

Figure 2d and 2e reports the maximum and minimum values of respectively the angles of rotation and tilt for the four driving amplitudes.

The three investigated geometrical parameters show that for driving voltages above 1.5V, the sample does no more return to its equilibrium position. The capacity has thus lost its linear response to excitation. The complete analysis enables a good understanding of the capacity's mechanical behavior and thermal dissipation issue. Relaxation time of the capacity and aging are also interesting features to be investigated.

Conclusion

The DHM™ R1000 used in conjunction with a stroboscopic acquisition mode enables a very fast and efficient investigation of the dynamics of micro-systems. The technique permits a 3D characterization of in-plane and out-of-plane movements of the MEMS capacitor.

References

F.Montfort et al., "Process engineering and failure analysis of MEMS and MOEMS by Digital Holographic Microscopy (DHM)", SPIE Proceeding San Jose 2007

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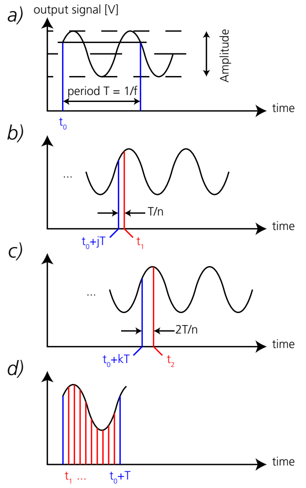
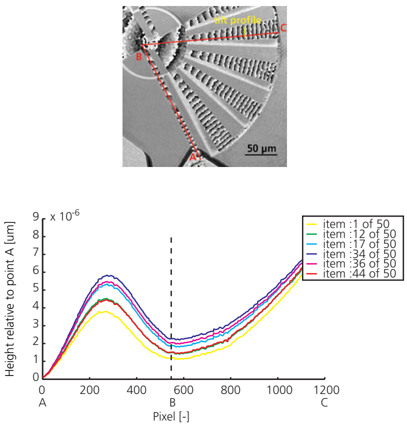


Figure 1: *Stroboscopic mode principle. (a) A first hologram is acquired at time t_0. New holograms are acquired at times t_0+jT+T/N (b) and t_0+kT+2T/N (c), and so on. Finally a complete period is reconstructed, sampled by N holograms.*



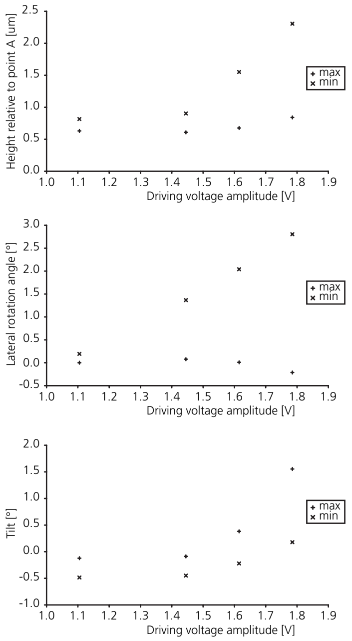


Figure 2: *Dynamic measurements: (a) phase image with profile lines for vertical displacement and tilt. (b) 6 out of 50 profiles extracted over one cycle. Max & min values over one cycle for (c) vertical displacement, (d) rotation and (e) tilt.*