# Measuring Shape and Surfaces down to the Nanometer and Nanosecond scales by Digital Holographic Microscopy

Christian Depeursinge[1], Isabelle Bergoënd[1], Nicolas Pavillon[1], Jonas Kühn[1], Tristan Colomb[2], Frédéric Montfort[2], Etienne Cuche[2], Yves Emery[2],
[1]Ecole Polytechnique Fédérale de Lausanne (EPFL), Advanced Photonics Laboratory, CH-1015 Lausanne, Switzerland
[2]Lyncée Tec, SA, PSE A, CH-1015 Lausanne, Switzerland

## 1 Introduction

Digital Holographic Microscopy (DHM) is an imaging technique that allows measuring quantitatively the wavefront transmitted through or reflected by a microscopic specimen. A hologram, composed by the interference of the wave scattered by the object with a generated reference wave, is recorded with a digital camera and then numerically processed to extract both the amplitude and the phase the wavefront with a very high accuracy. When evaluated in the spatial and / or in the time domain, the phase of the reflected wavefront yields the topography of the specimen with an accuracy around one nanometre. This ultra-high accuracy can be preserved in the measurement of dynamic phenomena by exploiting the capability to acquire a single hologram in a very short period of time defined either by the acquisition time of the camera which can be as low as a few microseconds and / or by the recourse to a pulsed source which can be as short as a few nanoseconds or even less with femtosecond lasers. Indeed, a single hologram taken in the off-axis configuration permits to reconstruct the complex wavefront and therefore to measure the phase, perfectly resolved in time. The applicability of DHM to metrology is also facilitated by the remarkably high measurement stability and robustness of DHM.

## 2 Measuring technique

In order to demonstrate the ultrahigh accuracy of time and space dependence of the specimen topography, measurements were made on a cantilever with a reflection DHM set-up, based on a modified Michelson

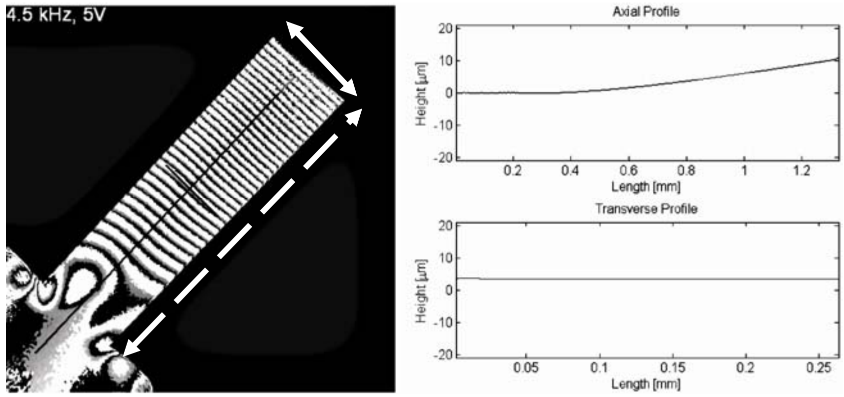



**Fig. 1.** Wrapped phase image of a cantilever excited at 4.5 kHz. The diagrams of the right part of the figure show the axial and transverse profile of the cantilever displacement after phase unwrapping

interferometer. As a bright field technique, DHM permits a high acquisition rate only limited by the performance of the camera, which can reach several tens of thousand holograms per second, and therefore permits fast, non-repetitive dynamics to be measured: transients can be measured with a few tens of microseconds resolution. In the case of a repetitive process, such as a vibration or an oscillation, stroboscopic mode can be used to image deformations for up to several tens of MHz excitation frequencies: 25 MHz in our case, by synchronizing the camera acquisition and / or the illuminating source with the micro-device driving signal.

The optical topography can be captured along the whole movement cycle of the micro-device. The retrieval of the full three-dimensional information with a nanometre vertical resolution is therefore possible with very high temporal resolution, ranging down to the nanosecond scale.

## 3 Experimental results

The example of a cantilever is given, illuminated with a laser diode ($\lambda$ = 682 nm), the image being recorded in the Fresnel zone with a charge-coupled device (CCD) camera with 20x magnification,. The hologram was reconstructed with spatial filtering method. The complex wavefront was digitally propagated into focus with a numerical implementation of the Fresnel integral [1, 2].

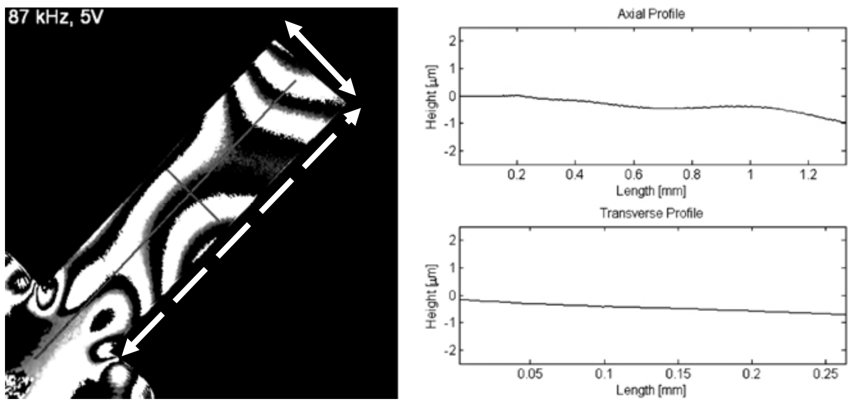
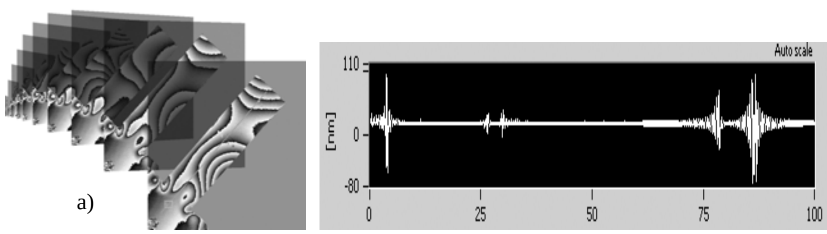



**Fig. 2.** Wrapped phase image of a cantilever excited at 87 kHz. The diagrams of the right part of the figure show, after phase unwrapping, the axial and transverse profiles of the cantilever displacement




b) Frequency (kHz)

**Fig. 3.** a) Synthetic phase images of the cantilever at various excitation frequencies. b) Amplitude response as a function of excitation frequency

The topography of the cantilever at the time of maximum extension is illustrated on Fig. 1: the axial and transversal profile show the monomodal character of the vibration. Fig. 2. shows the same axial and transversal profile of the cantilever vibrating at 87 kHz: the complex shape reveals a complex multimodal regime.

The analysis of the resonant frequencies and modal decomposition of the cantilever deformation can be achieved by a frequency scan of the exciting signal. This is illustrated on Fig. 3: the different resonances appear on the amplitude signal as a function of the frequency.

The particularities of the cantilever topography at 87 kHz are presented in Fig. 4. The coupling between different modes is visible from the quantitative measurement of the topography.

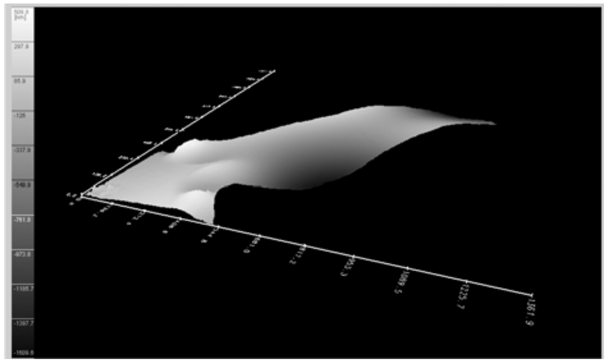


**Fig.4.** 3D representation of the topography of the cantilever at 87 kHz

## 4 Conclusion

By the analysis of the resonant frequencies of micro-structures like cantilevers, flexure joints, micro-bridges or membranes, one can evaluate the geometrical factor effects, the Young's modulus, the mean residual stresses, and some particular effects such as the effect of air damping, or the study of micro-systems ageing. The calibration of displacement is simple: vertical calibration only depends on the wavelength, which ensures an accuracy that is intrinsically not limited by the precision of the mechanical control of moving parts. When developing MEMS and MOEMS, there is a constant need to efficiently compare numerical simulations to the real micro-device movements and to adapt the production process by modifying geometric characteristics. The method can be applied to the observation of the movement of a micromechanical system: MEMS, MOEMS: oscillating micro-mirrors for example. The method can be also applied to the observation of the mechanical wave propagation in a medium.

## Acknowledgements

Part of this work has been supported by the European Project Real 3D. The authors would like to thank their colleagues in the MVD Group and in Lyncee Tec SA (www.lynceetec.com) for their cooperation and several fruitful discussions.

## References

1. Depeursinge, C (2006) Digital Holography applied to Microscopy, in Digital Holography and Three-Dimensional Display: Principles and Applications. S.S.B. Media, TC Poon Editor., Springer Science+Business Media: New York.
2. Cuche, E, Marquet, P, Depeursinge, C (1999) Simultaneous amplitude-contrast and quantitative phase-contrast microscopy by numerical reconstruction of Fresnel off-axis holograms. Applied Optics 38:6994-7001