Title	Digital holography for MEMS application
Author(s)	Anand, Asundi; Singh, Vijay Raj
Citation	Anand, A. & Singh, V. R. (2009). Digital Holography for MEMS Application. Digital Holography and Three-Dimensional Imaging (DH) (2009:Vancouver).
Date	2009
URL	http://hdl.handle.net/10220/7116
Rights	© 2009 Optical Society of America. This paper was published in OSA Technical Digest and is made available as an electronic reprint (preprint) with permission of Optical Society of America. The paper can be found at URL: http://www.opticsinfobase.org/abstract.cfm?uri=DH-2009-JTuA2. One print or electronic copy may be made for personal use only. Systematic or multiple reproduction, distribution to multiple locations via electronic or other means, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper is prohibited and is subject to penalties under law.

Digital Holography for MEMS Application

Anand Asundi[a] and Vijay Raj Singh[b]
[a]School of Mechanical and Aerospace Engineering, Nanyang Technological University Singapore 639798,
[b]Ngee Ann AEM Centre of Innovation (NACOI), Clementi Road, Singapore 599489
e-mail: anand.asundi@pmail.ntu.edu.sg, and vr.singh@pmail.ntu.edu.sg

Abstract: Studies on digital holographic microscopy system for full-field high resolution 3D profiling of MEMS and micro-devices are presented in this paper. Applications of the system for thickness measurements of thin film and analysis of accelerometer device are presented.

OCIS Codes: (090.1995) Digital holography, (120.5050) Phase measurement, (120.2830) Height measurement

1. Introduction:

New technologies are required for inspection and characterization of micro-devices, with the ever increasing technological development, miniaturization and increase functionality of the system. Integration of mechanical elements, electronics, sensors and actuators on a common silicon substrate by micromachining technology constitute a MicroElectroMechanical System (MEMS) [1]. Microsystems are fabricated using micro-fabrication process where control parameters in process are critical to maintain design specifications. Inspection and characterization of MEMS during different stages of fabrication is becoming increasingly important for performance, reliability and repeatability of device. The purpose of testing the device during fabrication process is to provide the feedback about the material properties, fabrication process and device behaviour and simulation process. Inspection and characterization of MEMS at early stage and static and dynamic characteristics of the finished product is a challenging task.

Digital holography (DH) is an imaging process followed by numerical reconstruction to provide quantitative information of both of the amplitude and phase of the wavefront [2]. The capabilities of DH to store full field 3D information offer new possibilities for non-invasive inspection and characterization of micro-device. The most significant advantage comes from the numerical phase information that provides nanometer range resolution in axial direction. Potential application areas include bio-imaging, measurements, and interferometry [3-5]. In this paper a digital holography microscopy system is presented for high resolution full field 3D measurement for MEMS applications.

2. Digital Holographic Microscopy System:

2.1 Optical System:

The schematic of optical geometry of reflection digital holographic microscope, based on Michelson interferometer, is shown in fig (1). A single mode fiber is coupled to a HeNe laser. The laser beam coming from the other end of the fiber is focussed using a focusing lens and split into two parts by the beam splitter (BS). The microscopic objective (MO) is placed at one side of BS and the focusing lens is adjusted such that the object beam (coming from MO) becomes collimated. The other beam also gets collimated and reflected by the mirror. The tilt screws of the mirror control the angle of reference wave (reflected by the mirror). The object beam and reference beam, after reflection, interfere (hologram) and recorded by the CCD. The advantage of the geometry is the same wavefront of the object and reference waves and thus the spherical aberration of the MO is automatically compensated.

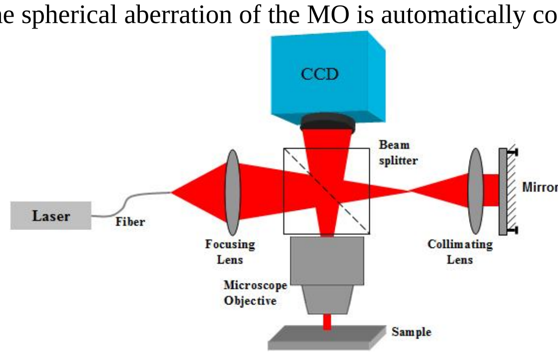

Figure 1 Reflection digital holography microscopy system design

2.2 Methodology:

Hologram is the interference of the object wave $O(\xi,\eta)$ and the reference wave $R(\xi,\eta)$. Suppose (x,y) is the object plane and (ξ,η) is the hologram plane. Then hologram can be written as,

$$H(\xi,\eta) = |O(\xi,\eta) + R(\xi,\eta)|^2 \quad (1)$$

For digital recording, a CCD is placed at the hologram plane. The recorded hologram is converted into a two-dimensional array of discrete signals using the sampling theorem [6].

For the reconstruction of object wavefield, the digital hologram is multiplied by the reconstruction wave $R'(\xi,\eta)$. The reconstructed wavefield at the image plane (x', y') at distance d' from hologram plane is given by the Fresnel diffraction equation [6]

$$U(x',y') = \frac{e^{ikd'}}{i\lambda d'} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} H(\xi,\eta) R'(\xi,\eta) \exp\left[\frac{i\pi}{\lambda d'}\{(x'-\xi)^2 + (y'-\eta)^2\}\right] d\xi d\eta \quad (2)$$

For space invariant system, this diffraction equation is represented as the convolution of the product of the hologram and reconstruction wave, and the impulse response function $g(\xi,\eta)$ [6], i.e.

$$U(x',y') = \{H(\xi,\eta)R'(\xi,\eta)\} \otimes \{g(\xi,\eta)\} \quad (3)$$

By using the convolution theorem, reconstructed wavefield can be written as,

$$U(x',y') = \Im^{-1}[\Im\{H(\xi,\eta)R'(\xi,\eta)\} \times \Im\{g(\xi,\eta)\}] \quad (4)$$

For digital reconstruction, digital reference wave and impulse response are numerically created. When the reconstructed wave is the complex conjugate of the reference wave, the real image of the object wave is formed at the reconstruction distance d which is same as the recording distance of the hologram from object (image by MO). The image intensity can be calculated by squaring the numerically reconstructed wavefield;

$$I = |U|^2 \quad (5)$$

and the phase is calculated as;

$$\phi = \arctan\{\mathrm{Im}(U)/\mathrm{Re}(U)\} \quad (6)$$

This numerically reconstructed phase information is important and can be for the study of high resolution surface topography of the sample. If n is the refractive index of the sample, than the sample height/thickness h can be written as follows:

$$h = \lambda\phi / 4n\pi \quad (7)$$

The axial resolution of the system depends on the number of gray levels that can be numerically reconstructed. In our case, hologram is recorded by the 8-bit CCD sensor and thus ideally the numerically reconstructed phase can be divided into 256 gray levels which provide the axial resolution about 2.5 nanometre. However, practically all 256 gray levels of hologram are not recorded and also imperfections in optical components of the system result as a noise which reduces the axial resolution.

3. MEMS Applications:

3.1 Thin Film Thickness Measurements:

The first application of the system is shown for quantitative measurements of deposition height of thin film. Two thin films of different thickness (100nm and 200nm) are deposited on a silicon wafer. Fig 2 shows the imaging and measurement results for 100nm film. Fig 2(a) shows the amplitude image which only shows the edges of the thin film (a sharp line), fig 2(b) is the numerical phase contrast image which provides the quantitative measurements in 3D. The line profile shown in fig 2(c) provides the height information from the phase contrast image. Phase contrast image and measurement results for 200nm thickness film are shown in fig 3.

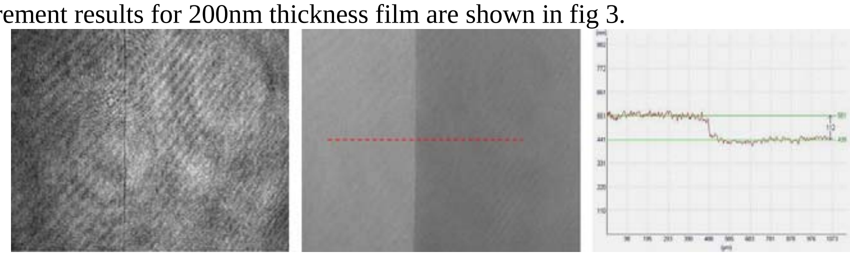

Figure 2 100nm thin film thickness measurements (a) Amplitude image, (b) Phase image, and (c) Line profile

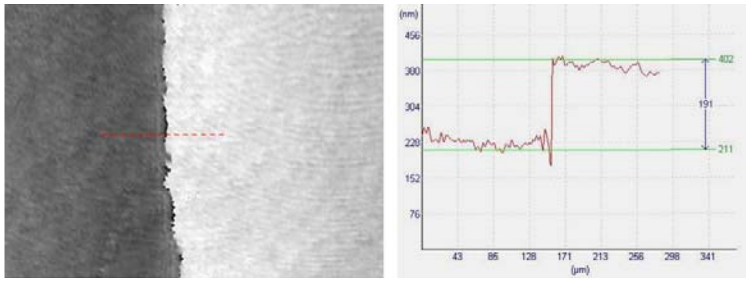

Figure 3 200nm thin film thickness measurements (a) Phase image, and (b) Line profile

3.2 Device Performance Analysis:

The performance of a MEMS accelerometer when mounted on two different substrates, ceramic and PCB is tested due to concerns of cracking at the interface of the device and the PCB substrate. The surface profile of the device after packaging is studied for both the cases and shown in fig 4. Fig 4 (a) and (b) show the phase image and its 3D map of the device when mounted on a ceramic substrate and fig 4 (c) and (d) is for PCB substrate respectively. It can be clearly seen that the 3D surface map is flat for ceramic substrate while that for the PCM substrate is warped suggesting the introduction of mechanical stress at the interface between device and substrate. This study reveals the importance of the substrate on the characteristics of the MEMS device. Indeed, the warping of the device when mounted on a PCB substrate was a possible reason for damage of this system as compared to the ceramic substrate.

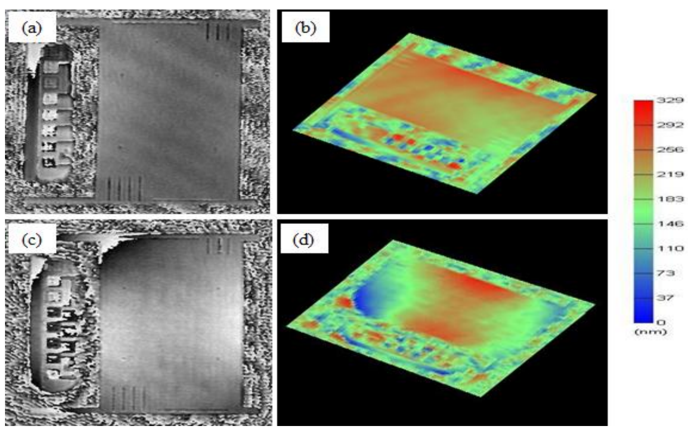

Figure 4. Accelerometer device analysis, (a) and (b) phase image and 3D profile of sensing area for ceramic substrate, and (c) and (d) phase image and 3D profile of sensing area for PCB substrate

4. Conclusions:

In this paper a digital holographic microscopy system is presented for high resolution 3D measurements for MEMS applications. The optical geometry is designed in such a way that the spherical phase aberration of the microscopic objective is automatically compensated. Two different applications of the system are presented; first application is for monitoring the thickness of the thin films deposited on silicon wafer using micro fabrication process. The measurement results for thin films of thicknesses 100nm and 200nm are presented. The second application is presented for accelerometer device performance analysis. Two devices are fabricated using different substrates and the 3D profiling of the sensing part of the device is shows as an indication of the final device performance.

References:

[1] N. Maluf, "An Introduction to Microelectromechanical Systems", Boston: Artech House (2000).

[2] U. Schnars, and W. Juptner, "Digital recording and numerical reconstruction of holograms", Meas. Sci. Technol. **13**, R85-101 (2002).

[3] P. Marquet, B. Rappaz, J. Magistretti, E. Chuche, Y. Emery, T. Colomb, C. Depeursinge, "Digital holographic microscopy: a noninvasive contrast imaging allowing quantitative visualization of living cells with subwavelength axial accuracy", Opt. Lett., **30**, 468-470 (2005).

[4] V.R. Singh, O.C. Chee, E. Sim, and A. Asundi, "Characterisation of laser marks using digital holographic microscopy", Proc. SPIE, 7155, 715509 (2008)

[5] A. Asundi, and V.R. Singh, "Time-averaged in-line digital holographic interferometry for vibration analysis", Appl. Opt. **45**, 2391-2395 (2006).

[6] J.W. Goodman, "Introduction to Fourier Optics", McGraw-Hill Companies, Inc., New York (1996).