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Micro-motion analyzer used for dynamic MEMS characterization

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ABSTRACT

A computer-controlled micro-motion analyzer (MMA) to study the dynamic behavior of movable structures of MEMS is described in this paper. It employs two optical nondestructive methods—computer microvision for in-plane motion measurement and phase-shifting interferometry for out-of-plane motion measurement. This fully integrated system includes a high-performance imaging system, drive electronics, data acquisition and data analysis software. This system can freeze the fast motions of MEMS devices using strobed illumination and measure motions in three dimensions with nanometer accuracy. The static measurement accuracy and repeatability of the system is calibrated by a step height standard which is certified by National Institute of Standards and Technology (NIST). The capabilities of this system are illustrated with a study of the dynamic behaviors of a surface micromachined polysilicon micro-resonator.

1. Introduction

The design and fabrication of MEMS need powerful measuring tools to enable their performance consistent with the designers' intent, and provide data feedback to the process of design and fabrication in the engineering development. This data feedback should include material properties, three-dimensional (3D) structure, dynamic behavior, surface pattern, reliability evaluation and so on. To some MEMS devices with moveable components such as micro-resonator, micro gyro, micro accelerometer and optical switch, its dynamic behavior determines its fundamental performance; consequently, the measurement of its dynamic behavior plays a very important role in the MEMS developing process [1].

Efforts are now underway to develop automatic characterization tools of micro motions explicitly for MEMS dynamic performance analysis. For example, a fully automated measurement system is designed to evaluate the dynamic characteristics of micromechanical structures with laser Doppler vibrometers in the University of Newcastle by Burdess et al. [2,3]; a computer-controlled stroboscopic interferometer system for measuring out-of-plane motions and deformations of MEMS structures with nanometer accuracy was described by Hart et al. in University of California Berkeley [4]; LaVigne et al. have constructed an integrated image analysis system with a strobed light source to study the reliability of movable MEMS devices in Sandia National Laboratory [5]; Freeman and his colleagues have developed a computer microvision station for MEMS characterization at the Massachusetts Institute of Technology [6]; Burns et al. report a system for automatic electrical and optical characterization of MEMS Devices in the Air Force Research Laboratory [7]; Bosseboeuf et al. develop a strobed microscopic interferometer used in the MEMS dynamic mechanics testing, with the maximum measuring frequency of above 800 kHz and nanometer out-of-plane motion measuring accuracy in Paris XI University of France [8]; Aswendt et al. employ time-averaged ESPI and Ultraviolet ESPI to do MEMS dynamic testing in Fraunhofer Institute IWU of Germany [9,10]; Georges et al. study on the vibrating mode shape analysis in a large field using strobed illumination, digital holography and phase-shifting interferometry in Liege University of Belgium [11].

Micro-motion analyzer (MMA) is a metrological instrument based on optics and image, which provides the measurements of nanoscale motions in three dimensions and dynamic profiles of the microstructures. It employs two kinds of nondestructive methods—computer microvision for in-plane motion measurement and phase-shifting interferometry for out-of-plane motion measurement. It is a high integrated system, including high-performance imaging system, driving circuit, data acquisition and analyzing software. A micromachined polysilicon lateral resonator is tested to show the capabilities of the system.

2. System set up

The structure of MMA is shown in Fig. 1(a). MMA is equipped with several long working distance optical objectives from Zeiss in Germany, including $5\times$, $10\times$, $20\times$ and $50\times$. There are two kinds of light sources: one is a high-performance light-emitting diode (LED) (Nichia NSPG 500S LED, center wavelength is 525 nm, optical bandwidth is 40 nm) to be used in the in-plane motion measurement; the other is a LD (Hitachi HL6501MG, the power is

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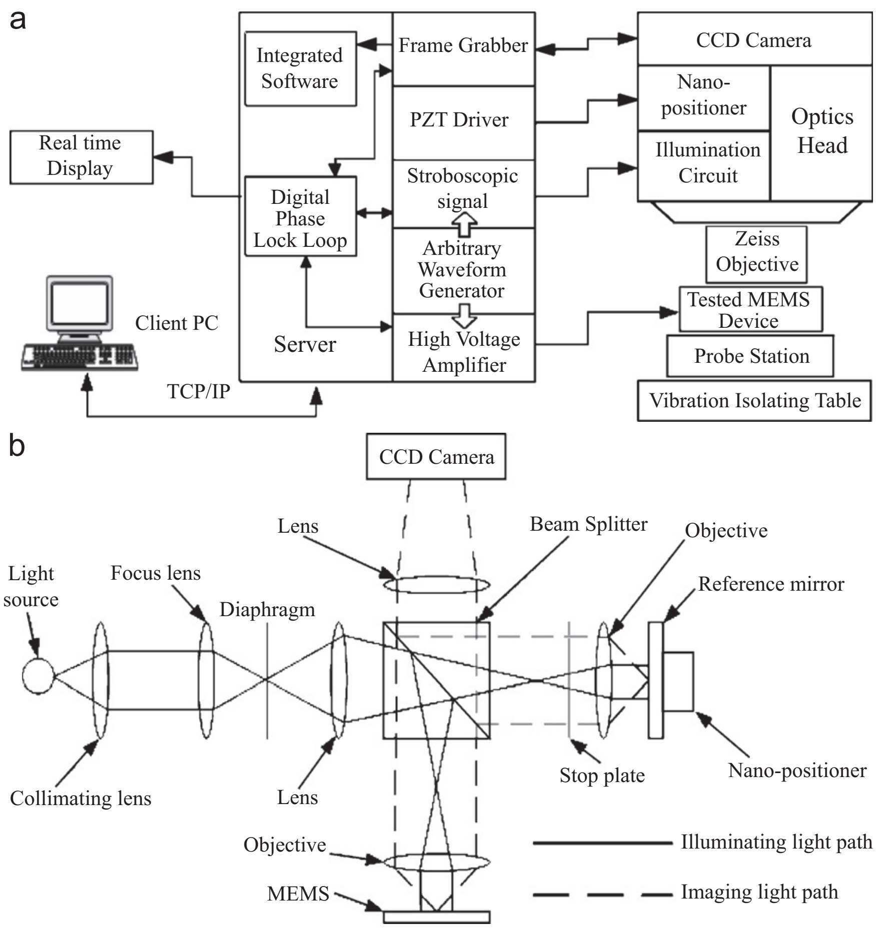

Fig. 1. Structure diagram of the MMA (a) system structure diagram and (b) optical system structure diagram.

50 mW, the wavelength is 658 nm) to be used in the out-of-plane motion measurement. A nano-positioner (PI P-721.CL, capacitor sensor feedback control in close loop) is used to change the phase of the interferogram, adjusting the optical path with sub-nanometer resolution. The optical system is described in Fig. 1(b). The bright field and interference field are switched by putting a stop plate in the reference optical path. Images are captured by a digital CCD camera (Microvision, 1280×1024 pixels, 9 μm pixel distance, 100% filling factor and 10 bits grayscale resolution), then transferred to the server to be post-processed. The user can transfer and receive commands and data through TCP/IP protocol on a client PC. The system is also equipped with a signal generating unit and a high voltage amplifying unit to output high voltage signal and stimulate the tested MEMS devices. The system is put on a vibration isolating table (TMC Laboratory table) to decrease the effect of outside vibration. The system is also equipped with a probe station (Karl Suss, Germany) to test the unpackaged MEMS devices online. Here digital phase lock loop (PLL) makes the stimulating signal, illuminating signal and the image capturing synchronized. The frequency range of AWG is from 1 Hz to 10 MHz, the sampling frequency is 40 MHz. For the $20\times$ objectives, the spatial resolution is 822.5 nm and the field of view is $0.4 \times 0.35\,mm^2$.

3. Measurement principles

The MMA is a highly integrated video microscope, using stroboscopic techniques to capture images of small, fast moving structures. The MMA uses both bright field and interference field based illumination modes combined with sophisticated machine vision algorithms to quantify motions. The MMA server and optics head combine the video microscopy with interferometry. However, successful measurements demand several characteristics in the target. The MMA needs two things: a target that can be moved in a periodic manner, and a target whose image has contrast or structure when illuminated.

3.1. *In-plane motion measurement using video microscopy*

The MMA calculates the motion of a selected region in a sequence of images using computer vision algorithms. The MMA algorithms are hybrids constructed from a broad class of algorithms (gradient based) that exploit changes in brightness (grayscale values) between images and are capable of measuring motions smaller than one pixel size.

Fast moving structures appear blurry. One way of looking at fast moving targets is to slow down their apparent motion using a strobed light source. The schematic representation in Fig. 2 shows how pulses of light can capture snapshots of object motion. These snapshots or images can then be used to reconstruct the displacement curve of the target (Fig. 4(a)). This is the case for displacements in the focal plane of the microscope or for displacements along the optical axis. It turns out that sometimes different types of images are better for measuring different types of displacements. The MMA optics module provides illumination for two types of images, both of which are acquired in a similar manner.