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Metrology, static and dynamic characterization of microstructures using acousto-optic-modulated-stroboscopic-interferometry

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ABSTRACT

Mechanical and electro-mechanical advancements to the nano-scale require comprehensive and systematic testing at the micro-scale in order to understand the underlying influences that define the micro/nano device both from a fabrication and operational point of view. In this regard, surface metrology measurements, as well as static and dynamic characteristics will become very important and need to be experimentally determined in order to describe the system fully. These integrated tests are difficult to implement at dimensions where interaction with the device can seriously impact the results obtained. Hence, a characterization method to obtain valid experimental information without interfering with the functionality of the device needs to be developed. In this work, an Acousto Optic Modulated Stroboscopic Interferometer (AOMSI) is presented and employed to obtain surface, static and dynamic properties of micro-scale structures. This method has the advantage of being a high-speed visualization technique that can provide details of surface metrology as well as static/dynamic displacements and modal profiles. In this regard, it is a non-contacting approach that can be implemented without negatively impacting structurally sensitive devices especially at the nano-scale. The experimental setup can incorporate both thermo-mechanical and electro-mechanical loading in order to quantify operational and/or environmental influences. This method has the advantage of obtaining real time vibrating shape modes when compared to single point scanning methods. This approach is applied to cantilever microstructures. Sample test results are presented and compared with theory and are in good agreement.

1. Introduction

The main concern, when testing micro-scale integrated systems, is how to carry out experimental measurements in such a manner that they will not interfere with the operation of the device, in order to extract information that reflects the operation of the device in a realistic manner. Hence, the excitation mechanism whether it is electrostatic, thermal or mechanical must be carefully considered prior to the testing. In this regard, it is possible to deduce or extract material and mechanical properties of the device from the static and dynamic investigations, which will enable designers to improve and validate the theoretical model. High-speed visualization is a tool to improve the understanding and testing of microstructures. This versatile diagnostic technique can be used for developing reliable and enhanced micro-electro-mechanical-systems (MEMS) [1,2]. The characterization tool should have the capability to measure various parameters such as displacement and vibrations in order to understand the performance of the microdevice.

Real-time measurement of surface displacement using laser Doppler vibrometry (LDV) has been used for both macro and micro-scale systems [3–5]. However, in widely

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used LDV systems, a raster-scan method is used for testing the microstructure which eliminates the major advantages of real-time measurement [6,7]. In this regard, stroboscopy can be employed as a diagnostic tool in vibrating systems, in general, and has the capability to sense in-plane and out-plane displacements [8]. Use of pulsed stroboscopic illumination has been demonstrated for MEMS characterization [7,8]. A standard charge-coupled-device (CCD) camera is employed to detect the flexural motion of the resonating microstructure. The pulsed strobing mechanism generates a sequence of temporal images from which the surface motion characteristics of the microstructure can be extracted [9].

In this paper, an acousto-optic-modulator (AOM) is employed as the strobing mechanism for the stroboscopic interferometer using transistor–transistor-logic (TTL) signals to pulse the light wave. The AOM acts as a Bragg cell creating a grating that is a function of the acoustic velocity. With this approach, zero and first order Bragg refractions of an incident coherent light source are possible. The use of AOM in other types of classical interferometers for device characterization has also been demonstrated [10].

Herein, the surface metrology and static properties of MicraGeM silicon-on-insulator (SOI) microstructures [11] and the dynamic properties of atomic force microscope (AFM) cantilevers provided by MikroMasch [12], are investigated using the AOMSI approach. The static deflections obtained for a given applied electrostatic potential and flexural mode shapes obtained experimentally are compared to those obtained with the analytical model.

2. Acousto-optic-modulated-stroboscopic-interferometer

Stroboscopy creates the illusion of slow-motion. In this regard, stroboscopy has been widely used in photography and also in industrial applications to *freeze* the motion of moving objects. The fundamental principle being that when the strobing frequency is equivalent to the frequency of the device in periodic motion, the motion appears frozen and is visualized in a still position. Hence, the strobing principle can be exploited in the freeze-frame visualization of high frequency cyclic motion and hence, applied to high frequency resonating microstructures. Through the combination of a classical interferometer platform and a strobed monochromatic light source, in-plane and out-of-plane motions of microstructures are possible.

Recently, stroboscopic interferometers were built using pulsed light emitting diodes (LED) sources on a Twyman–Green interferometer platform [7]. However, LED based systems have issues of lower stability when pulsing at high frequency [13]. Speckle pattern interferometry is also used for MEMS characterization but it limits its use on rough surfaces [8]. Using AOM as a strobing device helps in attaining higher frequencies with better stability due to low random-access-time [14–16]. With low comparable random access time and the ability to use TTL signals in the AOM, the light source can be shuttered on and off in the crystal to very high frequencies resulting in highly stable and a broad range of strobing frequencies.

In the experimental method presented here, an AOM is used as the strobing module. This setup is the first of its kind to capture the static, dynamic and surface metrology characteristics of microstructures using a single camera and a relatively simple setup.

2.1. Acousto-optic-modulator

In the setup, an AOM operating in the Bragg regime, as shown in Fig. 1, is employed to obtain the first order diffraction of the incident laser light for the experiments. In this regard, a standard 5 mW Helium–Neon (HeNe) laser source of 500 μm beam diameter and 632.8 nm wavelength is employed. By using a HeNe laser source instead of an LED source greater frequency stability is achieved.

The AOM (tellurium dioxide crystal) is excited at 85 MHz using a driver and TTL signal. A modulating capability of approximately 4 MHz can be achieved and may be enhanced further if the beam diameter is reduced. For example, with a 50 μm beam diameter on the same AOM, the light can be modulated to approximately 47 MHz. The main advantage in the implementation of an AOM is that less noise is incurred in the optical path and the modulation is stable even at high frequencies. This tool was developed for quick and accurate characterization in a self-contained experimental setup.

3. Experimental setup

In this section, the basic setup of the interferometer is described in detail. A 5 mW, 632.8 nm HeNe laser source is directed into an AOM positioned at a Bragg angle θ_B, of 0.7 mrad with respect to the laser in order to maximize the first order efficiency. The AOM is excited at 85 MHz, 85 MHz being the center frequency of the AOM, using a driver and a function generator to modulate it to a desired time delay. When the crystal in the AOM is excited it creates an acoustic grating which splits the single incident laser beam into two optical outputs, the zero and the first order Bragg diffractions. Two $\lambda/10$ mirrors are used to widen the zeroth and first order diffractions. The zeroth order Bragg diffraction is terminated and the first order diffraction is then used for the experiments. The excitation is controlled with the TTL signal of the function generator which creates the time delay to modulate the optical path. A spatial filter is used to remove the spatial error in the optical path in order to obtain a smooth Gaussian beam

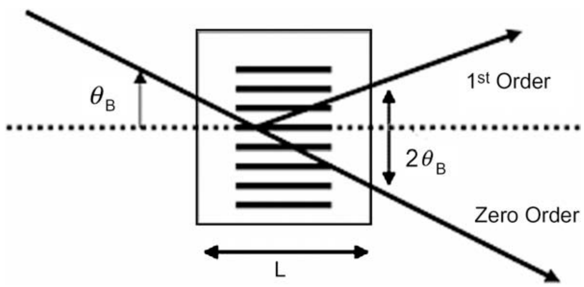

Fig. 1. Bragg regime principle. θ_B is the Bragg angle.