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Nanoscale surface deformation inspection using FFT and phase-shifting combined interferometry

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Abstract

In this paper, a flexible optical interferometer incorporated with both fast Fourier transform (FFT) and phase-shifting method is developed for three-dimensional (3D) testing of micro-components. Using light interference, microscopic optics, piezoelectric transducer (PZT) nanoscanning and a CCD camera, the proposed system can detect deformation and surface contour in the order of nanometers. An application of the proposed technique is demonstrated using two micro-components: a micro-beam in an accelerometer and a micromirror. The resulting interference fringes that are related to the deformation and surface contour are analyzed using FFT method or three-step phase-shifting method depending on the test surface features. Experimental results show the feasibility of the proposed method for 3D deformation and surface contour measurement of micro-components.

Keywords: Optical interferometry; Non-destructive measurement; Phase-shifting technique; Fast Fourier transform (FFT); Micro-components; Piezoelectric transducer (PZT)

1. Introduction

Currently, micro-electromechanical systems (MEMS) and micro-optoelectromechanical systems (MOEMS) are realized by the integration of electronic circuits and mechanical components through IC fabrication processes [1]. The capability in fabricating micro-components enables miniaturized devices to be used in the M(O)EMS industry which has been experiencing phenomenal growth, particularly in optical communication and sensing applications, such as micro-accelerometer [2], torsional micromirror [3,4], add-drop wavelength multiplexers [5] and tunable lasers [6]. To develop M(O)EMS micro-components for these applications, a non-invasive system for characterizing out-of-plane deformation and surface contour is essential. Furthermore, advanced testing methods for three-dimensional (3D) characterization of micro-components are necessary to develop reliable and commercial miniaturized devices as 3D testing of those components in the micro-mechanical devices can provide feedback for the further understanding of their mechanical properties [7–9]. Information of this type is beneficial to adjusting the fabrication and processing procedures in order to achieve optimal device performance. Hence, it would be beneficial to develop a system which has sufficient flexibility to make various measurements on M(O)EMS devices.

However, due to a large variety of micro-components, which vary in physical dimension, surface condition and deformation characteristics, it would be difficult to provide a universal solution. In the earlier research work, significant efforts have gone into the development of fundamental techniques for M(O)EMS measurements [10–17]. Among them, optical interferometric technique is a promising tool for full-field/3D non-contact measurement. By combining interferometric techniques with "state-of-the-art" electronics and data processing software, it is possible to perform accurate measurements on micro-components of M(O)EMS devices with surface deformation ranging from 0.1 nm to several hundreds of micrometers. In addition, interferometric techniques, which are capable of performing 3D measurements, do not

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require pointwise scanning and ensure speedy inspection. Novak et al. developed template-based software technique for accurate MEMS characterization [18]. Bosseboeuf and Potigrand applied microscopic interferometry technique in the MEMS field [19,20]. The dynamic characteristics of moving components are the key factors to realize the designated functions of MEMS devices. Therefore, the dynamic MEMS structures characterization becomes one of the important topics in MEMS stability and reliability study. Grigg et al. reported work on the dynamic characterization of MEMS and MOEMS devices using optical interference microscopy [20]. Nakano et al. also carried out work on fringe scanning interferometric imaging of small vibration using a laser diode [21].

The existing commercial interferometers, e.g., ZYGO New View 5000 and WYKO 3300 profilometer, are powerful metrological tools. However, in general, corresponding equipment is somewhat elaborate. Furthermore, it is inconvenient to modify the interferometer to be incorporated with other facilities, which are employed to apply loads (e.g., force or bias voltage loadings) onto micro-components. In this paper, a flexible optical interferometer that can be readily incorporated with the electronic probe station is described for measuring the deformation and surface contour of two types of micro-components namely a micro-beam in a micro-accelerometer and a micromirror.

2. Objective

To verify the proposed system, a polysilicon based cantilever micro-beam involved in a micro-accelerometer and a rotational micromirror were used as test specimens. A SEM photograph of a micro-accelerometer is shown in Fig. 1. The accelerometer consists of a micro-beam with a square attachment. A point load force applied at the centre of the square attachment will induce a deformation on the micro-beam. The objective of this study is to measure experimentally the out-of-plane deformation of the micro-beam so that modeling techniques may be further applied to validate the mechanical property of the micro-beam. Fig. 1(b) shows the area of interest for deformation measurements on the micro-accelerometer.

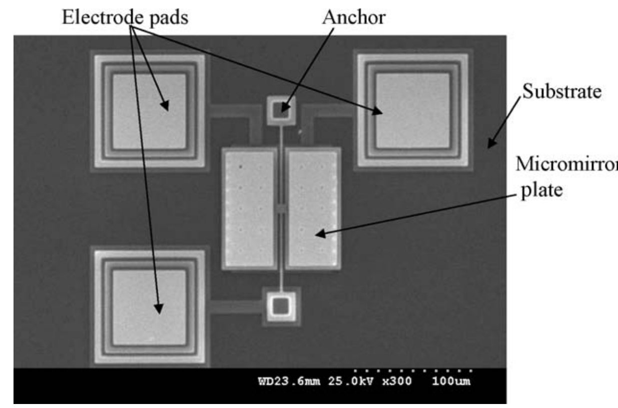

Fig. 2. SEM photograph of a micromirror.

Fig. 2 shows a SEM photograph of a micromirror. Since optical distortion could be caused by the surface curvature of the micromirror, the micromirror is required to have a reflective surface as flat as possible. The initial curvature on a micromirror is dependent on the residual stresses introduced by the fabrication process and materials used. Initial curvature measurement can thus provide feedback to the designer/manufacturer on the selection of a suitable fabrication processing and ensure a quality micromirror.

3. Method

Since the deformation of the micro-components is still large compared to the wavelength of visible light, optical interferometric techniques are applicable to their characterization. As is well known, optical interferometry is an important method in optical metrology and has been adopted in many applications in optics. There are three different types of interferometric objective [13], namely Michelson, Mirau

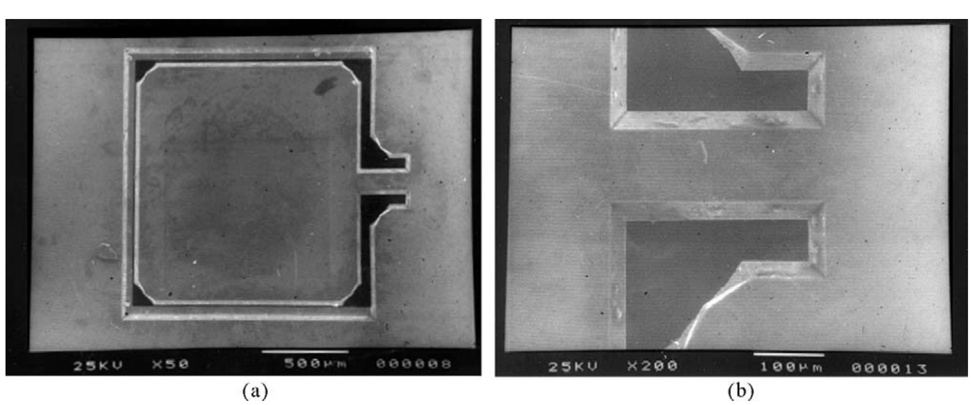

Fig. 1. SEM photographs of (a) a micro-accelerometer and (b) close-up of a micro-beam.