MICRO-INTERFEROMETER FOR SMALL SCALE METROLOGY

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ABSTRACT

A micro-grating interferometer has been fabricated for use in measuring the static and dynamic performance of MEMS devices. These measurements aid in qualifying the functionality of fabricated MEMS devices, as well as improving fabrication techniques. The metrology system uses a phase sensitive diffraction grating for interferometric axial resolution and a microfabricated lens for improved lateral response. In addition, active control is applied to the system to reduce the impact of mechanical vibrations and insure a high degree of measurement sensitivity. The results generated by a single microinterferometer show good correlation with both analytic models and measurements of the MEMS devices by other metrology tools. The microinterferometer enables measurement of steady state vibration of MEMS devices as well as the development of surface vibration profiles. A deformable grating interferometer has also been fabricated using microfabrication techniques and tested to show proper range of actuation under DC bias. This deformable diffraction grating further enhances the sensor's capabilities through array implementation.

INTRODUCTION

Significant part of MEMS research has so far concentrated on developing process technology and optimizing individual device performance. However, as the technology and market potential are being realized, a sophisticated MEMS quality control scheme needs to be developed. This requires metrology throughout the design, fabrication, wafer level test, post-package test and reliability testing processes.[1]

In this paper, a microfabricated position sensing grating interferometer (μPSGI) is presented for dynamic MEMS metrology. The proposed micro interferometer measures distance using a reflective diffraction grating on a transparent substrate and a microlens fabricated using a photoresist reflow technique on the same substrate. This structure forms a phase sensitive diffraction grating to have interferometric sensitivity, while adding the capability of better lateral resolution by focusing. Figure 1 shows the schematic of a μPSGI with a photodetector. Depending on the distance between diffraction grating and target surface, diffraction pattern at the detector plane is changed. By monitoring the intensity of the certain diffraction order on the detector, the profile change of the target surface can be mapped. Detailed diffraction models of the microinterferometer have been developed to predict the device response and the location of photodetectors for integrated optoelectronics.[2] The details of the fabrication process can be found in reference 2. The structure also enables optoelectronics integration so that the interferometer with photo detectors can fit in a surface area of 1mm x 1mm. The feasibility of μPSGI was demonstrated for measurement of moving microstructures [3] and a similar structure was also integrated to acoustic transducers for displacement detection.[4] Figure 2 shows a typical design of a flexible grating used for the μPSGI, and Figure 3 shows the actual grating.

EXPERIMENTAL SET-UP AND RESULTS

An experimental set-up was implemented to test the microinterferometer on MEMS devices as shown in Figure 4. The membrane that was used in this paper has a diameter of 190 μm of diameter, a thickness of 1 μm and a 2.5 μm gap between its electrodes.[4] In this particular case, the microlens has 200μm diameter and 0.3mm focal length. The light source was HeNe laser. The membrane is shown in Figure 5, and a DC scan of the membrane is shown in

Figure 6. It should be noted that the actual shape of the membrane is not perfect as can be seen in Figure 6. To reduce the vibration noise in the signal, the experimental set-up has been improved to include a phase sensitive detector (lock-in amplifier).

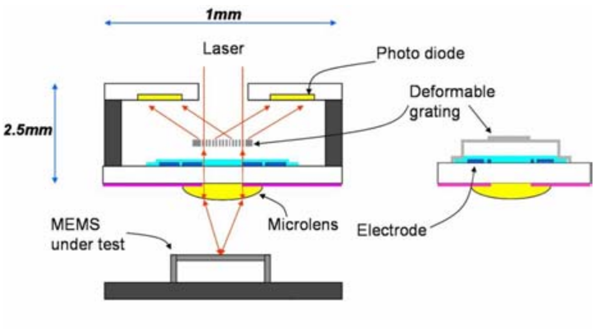

Figure 1: Schematic of a μPSGI.

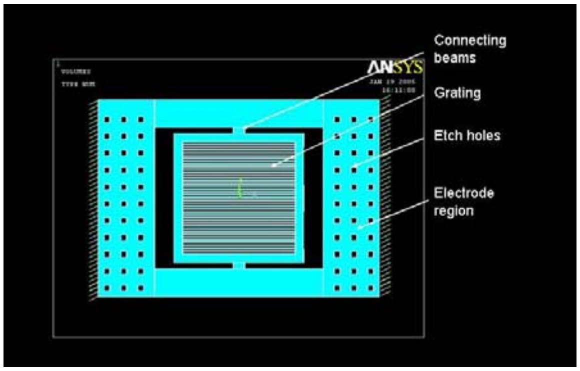

Figure 2: μPSGI Flexible Grating Design.

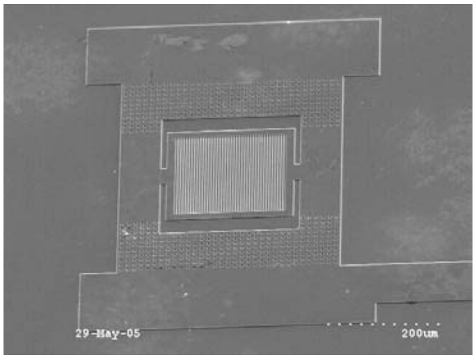

Figure 3: Actual Grating.

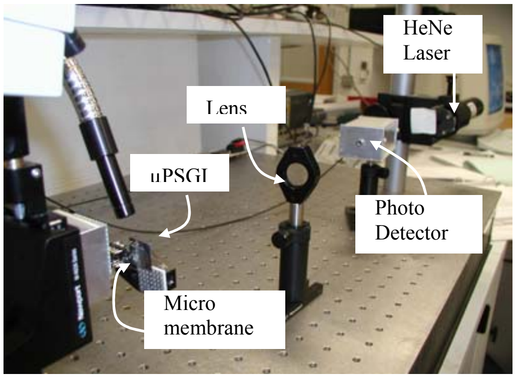

Figure 4: Experimental Set-Up.

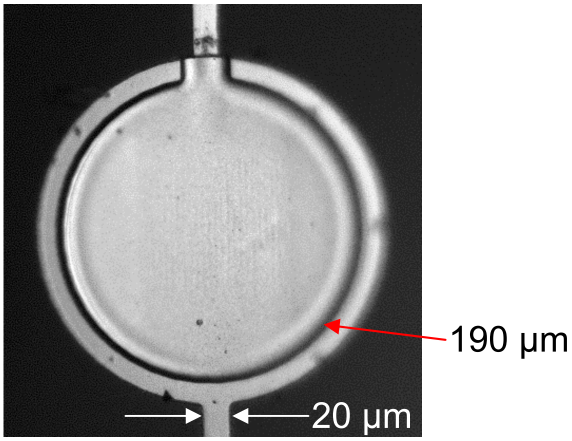

Figure 5: Thin Film Membrane to be Scanned.

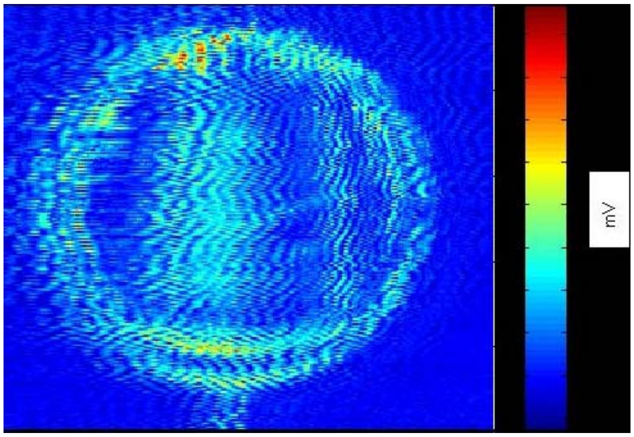

Figure 6: DC Shape of Thin Film Membrane.

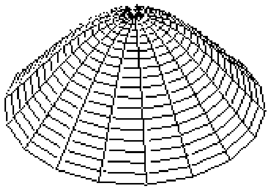

Figure 7: Theoretical 1st Mode Shape (560 kHz).

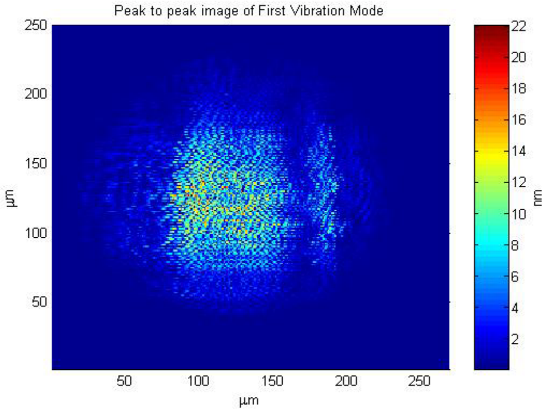

Figure 8: Measured 1st Mode Shape (560 kHz).

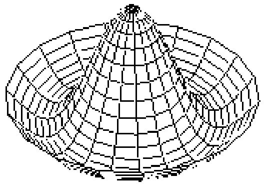

Figure 9: Theoretical 2nd Mode Shape (1.25 MHz).

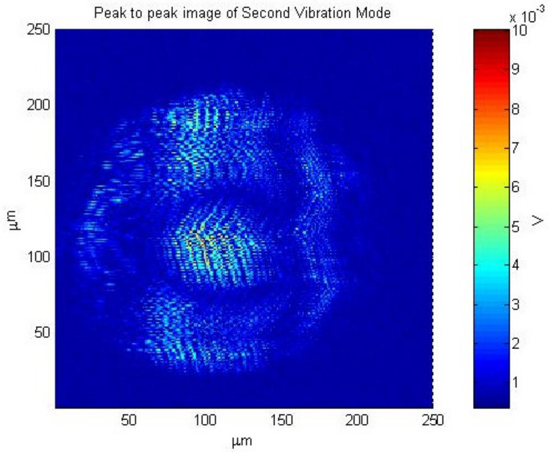

Figure 10: Measured 2nd Mode Shape (1.25 MHz).

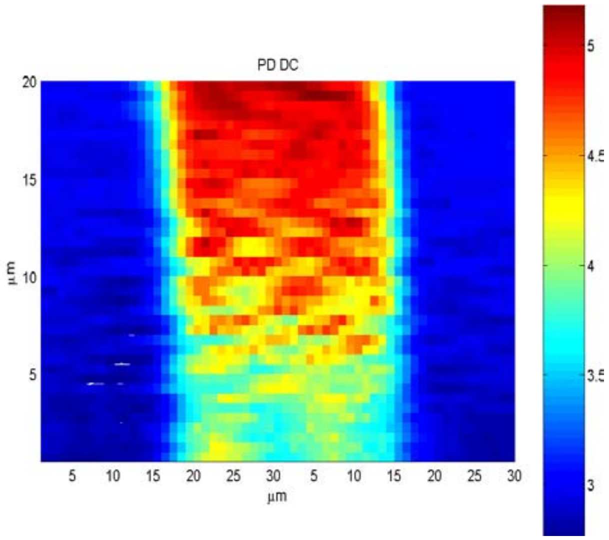

Figure 11: Scan of Lead without Control.

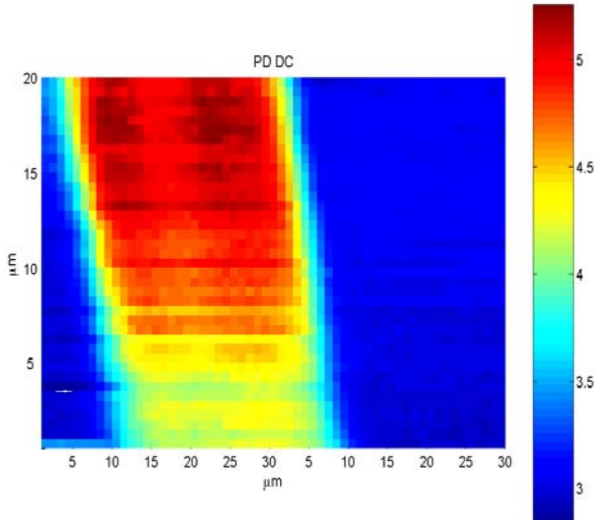

Figure 12: Scan of Lead with Control.

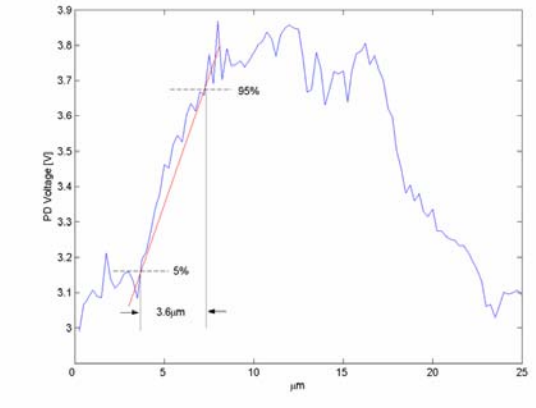

Figure 13: Cross Section of Lead Scan..

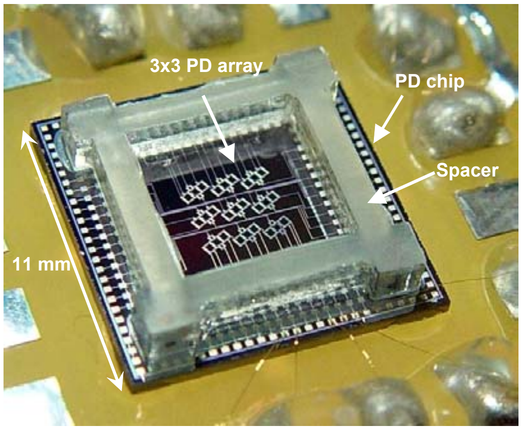

Figure 14: Sensor Array with Integrated Electronics.

To demonstrate the dynamic measuring capabilities of the µPSGI the membrane was actuated at its first and second modes (560 kHZ and 1.25 MHz, respectively). Figure 7 is the model of the membrane's first mode, and Figure 8 is the measured first mode of the membrane using the µPSGI. Similarly, Figure 9 is the model of the membrane's second mode and Figure 10 is the actual measured response. It should be noted that the measured responses do not exactly match the predicted responses. In fact, it can be clearly seen that the DC geometric error (non-flatness) of the membrane is superimposed on the first and second mode responses of Figures 8 and 10, respectively.

Figures 11 and 12 show scans of the membrane's electrical lead with the flexible grating deactivated and activated, respectively. With the flexible grating active, it can be seen that the mechanical noise experienced by the system is significantly reduced. Furthermore, by taking a cross section of Figure 12 (see Figure 13), the lateral resolution of the sensor in its current implementation can be determined. From Figure 13, the lateral resolution of the sensor is approximately 3.5 µm. This resolution is currently limited by the quality of the sensor's lens which determines the spot size of the laser on the target surface. Figure 14 shows an array implementation of the sensor that permits scanning of larger surfaces.

SUMMARY

The sensor described in this abstract is a micro-laser interferometer. It has a size of 1mm x 1mm x 2.5mm, is manufactured standard silicon processing techniques. It has a resolution 0.5 nm (vertical) and 3.5 µm (lateral). It is currently capable of measuring at rates up to 2 MHz, limited by the speed of the photodetector used in this design. The next generation design will employ a photodetector set with a bandwidth of 30 MHz, greatly increasing the sensor's bandwidth. Finally, it has the potential to be produced in an array for fast inspection of entire wafers.

REFERENCES

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3. N.A. Hall and F.L. Degertekin, "Integrated optical interferometric detection method for micromachined capacitive acoustic transducers," *Applied Physics Letters*, Vol. 80, pp. 3859-61 2002.