

MEMS Based Retroreflective Phase Modulator

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Abstract

A MEMS based retroreflective optical phase modulator requiring low-operating power is presented. The modulator was conceived as part of a remote interrogation system for optically downloading data from micro-sensor platforms. The overall device comprises a heterogeneous modulator consisting of a small section of “off-the-shelf” retroreflecting strip (1mm square) attached to an electrostatically actuated silicon MEMS platform. Results relating to device design and performance are reported.

Keywords: MEMS, optical MEMS, phase modulator, retroreflector

Introduction

There has been considerable research and development to realize autonomous multi-sensor micro-platforms with low detection signature that are designed to be scattered over large areas for the purpose of wide area covert surveillance [1]. Remote optical interrogation using lasers offers a viable technique for polling such distributed micro-platforms from a safe distance using, for example, an unmanned aerial vehicle which would act as the hub. In such interrogation, an initially unmodulated and collimated laser signal propagates from the hub towards the microplatform. Here the beam is modulated with sensor data, and is retroreflected. The retroreflection of the laser beam allows covert communication to be achieved because the modulated beam returns only to the hub. As in any optical communication system, the choice has to be made between using direct or coherent optical detection. Coherent optical systems offer higher sensitivity, but at the expense of greater complexity. At least one EMRS DTC project has studied coherent modulation using retroreflection. To extend this concept, we have aimed to demonstrate a MEMS based compact retroreflecting,

free space micro-optic modulator suitable for use in coherent optical detection systems. The heterogeneous device achieved comprised (a) a MEMS platform that could oscillate in the vertical plane (“piston” mode), (b) an optical retroreflecting film that could be fixed to the MEMS platform and (c) electrostatic actuation of the device, since this actuation mode inherently has low-power consumption.

Electrostatic MEMS platform

An electrostatically actuated MEMS platform was designed to a common overall design, but fabricated in three different sizes. The designs were fabricated at a commercial MEMS foundry, MEMSCAP Inc, using the MEMS foundry process called SOIMUMPs. The process begins with 100 mm diameter, n-type, double-side polished silicon-on-insulator (SOI) wafers. These wafers have a 10 μm silicon layer, a 1 μm oxide layer, and a 400 μm substrate layer. First, the silicon is patterned with the first mask level, “SOI”, and etched. Next, a protective material is deposited on the front face, and then patterning of the back side of the wafer is achieved using the second mask level, “TRENCH”. A deep reactive

ion etching (DRIE) step is used to etch these features completely through the substrate layer. A hydrofluoric acid releasing process follows, allowing silicon structures on top of the trench hole to be completely released since the acid removes the oxide. Finally, a metal layer, consisting of 50 nm Cr+ and 600 nm Au, is deposited and patterned using shadow masking technique. This mask layer is called “METAL”. The wafers are then diced using a scribe and break method.

Design Process

In the SOIMUMPs process, it can be seen that the structural silicon layer is nominally flat and, at first, it would appear to be impossible to create a vertical offset using this single layer of silicon on its own. However, long suspended silicon beams fabricated using this process have a curvature due to residual stress in the silicon. Moreover, if a gold-silicon bimorph beam is realised, then the curvature of the bimorph beam increases considerably because of the large differential stress. By using the curvature of the bimorph beam, it becomes possible to design an offset between the two parts of a comb drive. For the SOIMUMPs process, the vertical offset should be less than 10 μm as this is the thickness of the silicon layer in the SOIMUMPs process. In order to obtain a vertical offset of under 10 μm , the length of bimorph beam was selected to be 250 μm . The offset produced by this length of bimorph beam is 3 μm . A further length of 150 μm of pure silicon beam continues from the end of the bimorph beam giving a total beam length of 400 μm and a comb offset of 7 μm at the tip of the beam.

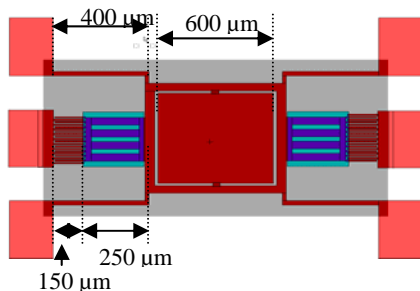


Figure 1. Dimensions and layout of 600 μm platform

The layout of the MEMS device is shown in Figure 1 – this shows one of the three different sizes designed and fabricated. The 600 μm side square platform will hold the retroreflective layer. The bimorph beams, which will eventually produce the required curvature, are connected to the platform and their free ends form part of the comb drive. The anchors are rigid and also act as the electrodes in the system. The suspension allows the platform to oscillate in and out of plane.

Resonant frequency calculation by finite element modelling

Finite element modelling was used to determine the mode shape and resonant frequencies of the MEMS devices. The theoretical resonant frequencies of the oscillating platforms were obtained as 11.5kHz (300 μm), 6.28kHz (600 μm) and 4.87kHz (900 μm).

Characterisation of retroreflective sheet

Commercially produced retroreflecting film was used in combination with the MEMS platform. The commercial film was evaluated by directing a laser beam on the film and measuring the angular dependence of the retroreflected radiation.

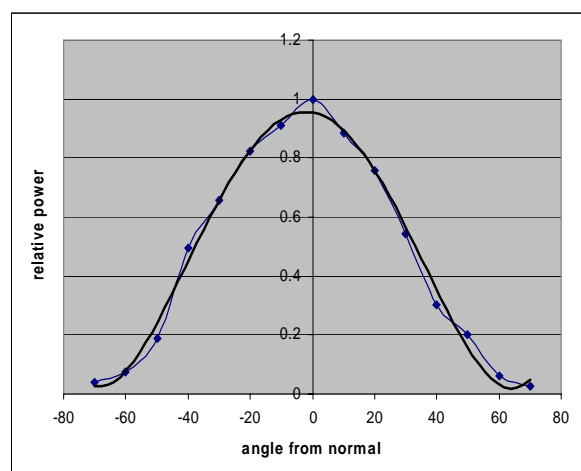


Figure 2. Angular dependence of retroreflection

The results of this experiment are shown in Figure 2. It was concluded that the retroreflective performance of the film was adequate for use with the MEMS platform to achieve a heterogeneous MEMS phase modulator.

MEMS device testing

Dynamic analysis of the MEMS device was undertaken using a Polytec laser vibrometer whose interrogating light beam was incident on the centre of the vibrating MEMS platform. An SEM of the platform is shown in Figure 3.

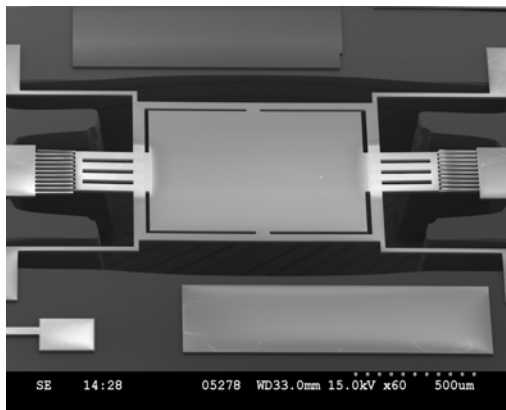


Figure 3. SEM image of 600 micron MEMS device

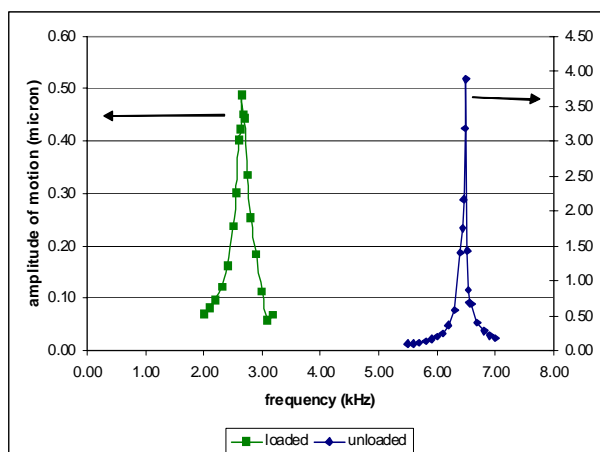


Figure 4. Response of 600 micron device. Unloaded resonant frequency 6.46 kHz. Loaded resonant frequency 2.67 kHz.

The platforms were evaluated in both “unloaded” and “loaded” states. “Loaded” refers to the attachment of a small square of the retroreflective strip onto the platform surface. Figure 4 shows the amplitude versus frequency response of the 600 μm device. The drive signal to the devices was a 30V DC bias on which is superimposed a 30 V pk-pk AC signal. It can be seen that the loading of the device results in both a reduction of resonant frequency and displacement amplitude. The displacement drops by at least one order of magnitude for the same driving voltages. The unloaded resonant frequencies were measured to be 11.1kHz (300 μm), 6.46kHz (600 μm) and 4.94kHz (900 μm). These values compare very well with the theoretical values obtained by FEM.

Testing in an optical interferometer

This section shows some of the results of testing the MEMS modulator in a Michelson interferometer. The interferometer was based on a multi-longitudinal mode helium-neon laser as source, and the aim of the experiment was to demonstrate coherent detection of an initially unmodulated optical signal which was retroreflected from the heterogeneous MEMS modulator. One arm of the interferometer had a 100% reflecting mirror which provided the reference optical signal, while the second arm of the interferometer had the retroreflective phase modulator which was driven by a signal generator. The signal generator represented the data being transmitted. The interferometer arms were about 10 cm in length. The retroreflective modulator was placed at a various angles ranging from 10-40 degrees away from the normal. In this way specular reflection from the retroreflective sheet was completely diverted away from the optical detector and only the true retroreflected signal returned to the optical detector to contribute towards the generation of the interference signal from the optical detector/photoreceiver. It was noted that the beam quality of the

retroreflected optical beam was quite poor, and for this reason good alignment between the reference and optical beams was only obtained for short path interferometers. Figure 5 shows the interference signals generated from the photoreceiver and displayed on an oscilloscope. Numerous traces similar to these figures were obtained during the experiments.

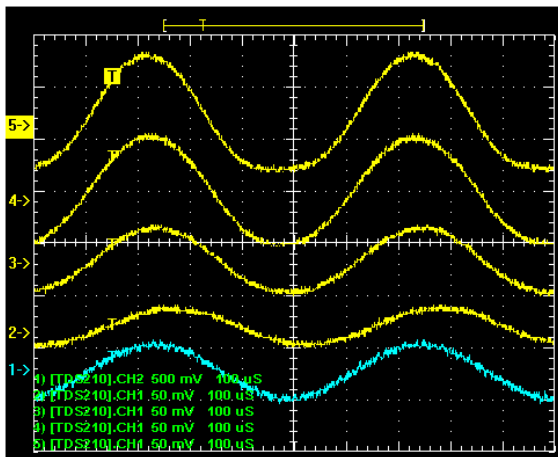


Figure 5. Oscilloscope traces of signal outputs from the photoreceiver for different modulating voltages applied to the phase modulator. DC drive voltage = 15 Volts DC. Trace 2 is output with driving voltage 2.5 V p-p. Trace 3 is output with driving voltage 5.0 V p-p. Trace 4 is output with driving voltage 7.5 V p-p. Trace 5 is output with driving voltage 10.0 V p-p. Trace 1 is input to modulator. Driving frequency is 1.96 kHz.

Conclusion

MEMS technology has been used to fabricate a heterogeneous retroreflective modulator for remote optical interrogation of micro-sensor platforms. Figure 6 shows the overall device, including the bond-wires and retroreflective film.

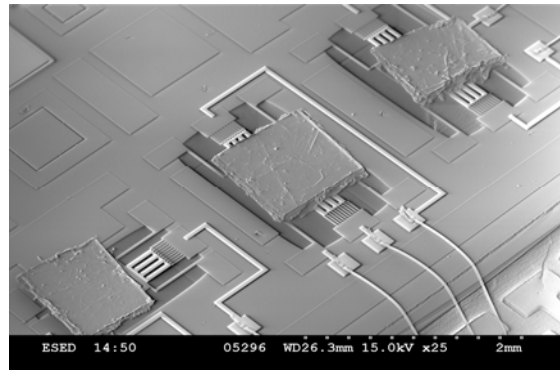


Figure 6. MEMS modulator with retroreflective film attached

Good agreement has been found between the theoretical and measured resonant frequencies of the modulator. The modulator has been successfully introduced into a Michelson optical interferometer to demonstrate retroreflective phase modulation.

References

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