Device Characterization at the Wafer Level via Optical Actuation and Detection

J. Hedley*, J. S. Burdess*, A. J. Harris* and B. J. Gallacher*

*Institute for Nanoscale Science and Technology, Newcastle University,
Newcastle upon Tyne, NE1 7RU, England.
John.Hedley@ncl.ac.uk, J.S.Burdess@ncl.ac.uk, Alun.J.Harris@ncl.ac.uk, B.J.Gallacher@ncl.ac.uk

ABSTRACT

This paper investigates the technique of optical actuation of MEMS. It is shown that a device can be driven into all of its vibrational modes simply and non-destructively by a laser pulse, making this an ideal actuation methodology for device characterization at the wafer level. This actuation method is shown to be comparable to a mechanical impulse actuation.

Keywords: optical, actuation, MEMS, characterization

1 INTRODUCTION

It has become a routine operation to perform static and dynamic measurements on micromechanical structures [1] however the problem still exists of actuating these devices prior to the packaging stage. One solution is to mechanical shake the devices with a piezoelectric disk. Although effective, the mechanism by which the device is firmly attached to the piezo disk renders the device unusable after characterisation. An alternative method to actuate devices is optically.

The method of optical actuation has been investigated by several authors. Theoretical analysis has been performed by Fatah [2]. In this work, the heating effect of an intensity modulated laser spot on the centre of a micromechanical beam resonator was considered. It was assumed the laser produced a uniform temperature across the beam's cross-section with a temperature gradient along its length. Solving the one-dimensional heat-flow equation for this system led to a value for the beam's expansion and thus its resonating amplitude.

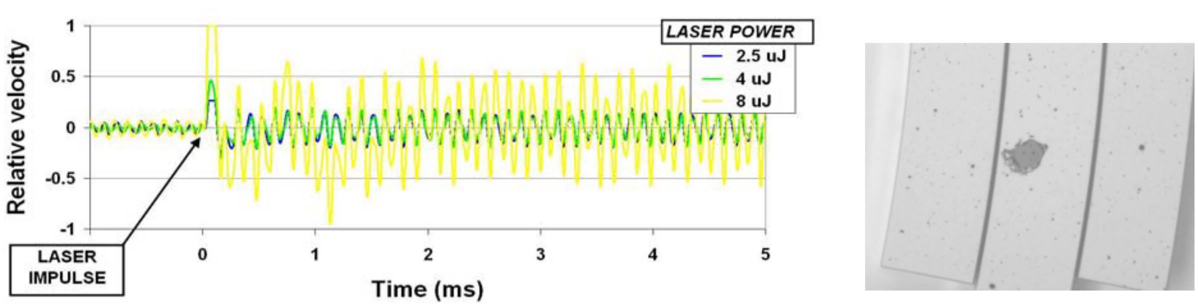
Experimental results have been obtained on a variety of structures [2-6]. In all these experiments, the actuating light beam was intensity modulated over the frequency range of interest. Although successful, this technique can be time consuming if a narrow bandwidth is being searched for over a large frequency range as is the case of locating a resonance condition with a high Q.

A quicker method is to use an impulse of light which drives all modes into resonance. An impulse response was investigated by Zhang et al [7] to optically drive and sense a micromechanical silicon bridge resonator. The bridge was excited and measured with a focused semiconductor laser which required that the bridge was coated with a metal film thus limiting this approach to general application.

In this work, a pulsed laser is used to excite an uncoated device and a laser vibrometer system used to measure the corresponding vibrations.

2 EXPERIMENTAL PROCEDURE

To actuate the devices, a frequency doubled (532 nm) Nd:YAG laser, pulse width of 4 ns with a 20 Hz repetition rate, was used. The resulting vibrations were detected with a Polytec OFV 501 laser vibrometer whose operational wavelength was 632 nm. The beams were merged with a Nd:YAG second harmonic mirror which reflected all the 532 nm light whilst allowing partial transmission of the vibrometer beam. A red filter was used to account for any stray light which may have damaged the vibrometer system. The signal from the vibrometer was digitized and collected on a computer, the trigger for this collection coming from a light dependent resistor incorporated into the system.



(a) (b)

Figure 1: Focused optical impulses produce actuation (a) but resulted in device damage (b).

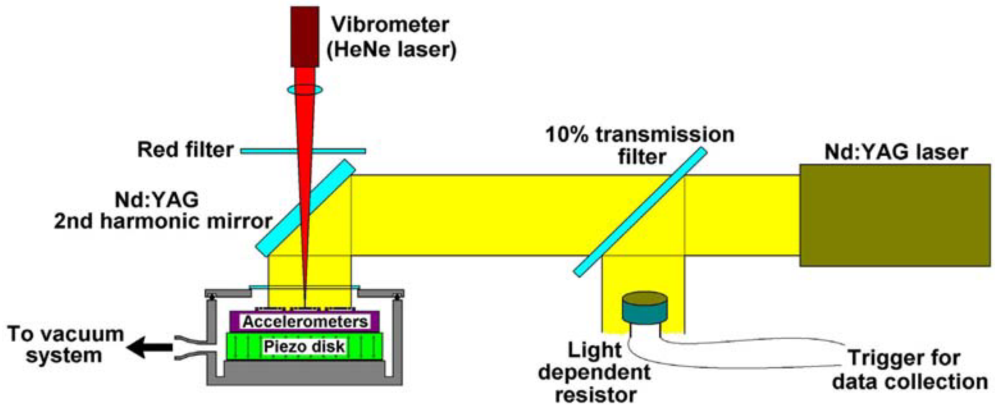


Figure 2: The setup used to optically actuate and measure a device.

In the initial experimental setup, both actuation and sensing beams were focused. The resulting traces for various actuation powers on a vibratory ring gyroscope (under a vacuum of <20 μbar) is given in figure 1(a). Although the device could clearly be seen to be resonating as a result of the impulse, the high power of the Nd:YAG laser resulted in device damage, as can be seen in figure 1(b). The beams were slightly defocused however this problem still persisted. It was concluded that the device was being driven through a conservation of momentum mechanism due to mass ejection rather than a heating effect.

The experimental arrangement was reconfigured so that only the vibrometer beam was focused; this configuration is shown in figure 2. Although this required a much larger working distance for the vibrometer beam, the actuation beam did not damage the device under test. This configuration allows for a much greater actuation power.

3 RESULTS AND DISCUSSION

The unfocused Nd:YAG beam was used to actuate a 300μm × 300μm × 3μm polysilicon accelerometer, see figure 3, the results of which are given in figure 4. The data is an average of 10 traces. As a comparison, the device was attached to a piezo disk and actuated mechanically with a 20 Hz saw-tooth waveform; this simulates the optical impulse drive. The results are also shown in figure 4. The natural frequencies of the device are clearly visible with both actuation methods. A closer inspection of the peaks reveal that there is a 20 Hz modulation superimposed onto the resonances, this is a consequence of the 20 Hz drive frequency of the impulse.

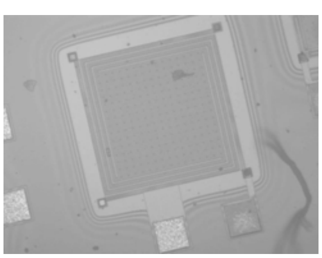


Figure 3: The polysilicon accelerometer used in the experiment.

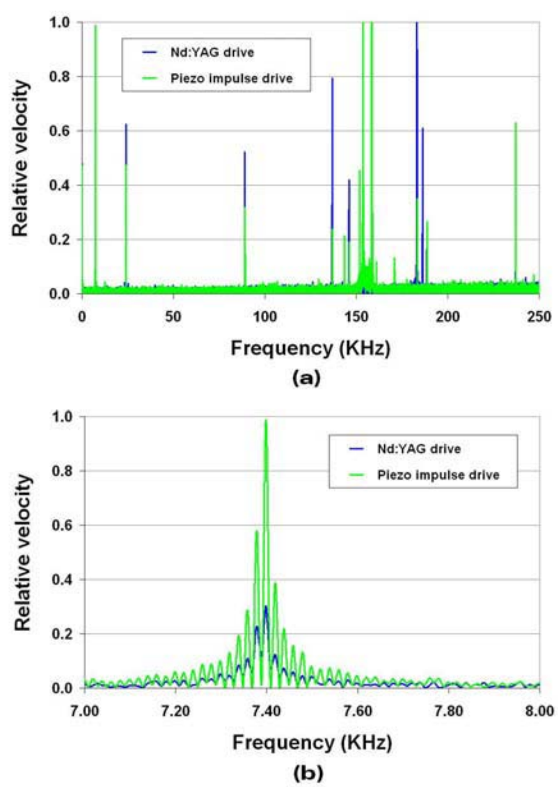


Figure 4: (a) The frequency response of a polysilicon accelerometer excited with mechanical and optical stimuli. The data is an average of 10 traces. (b) The 20 Hz repetition rate of the drive is superimposed onto the data.

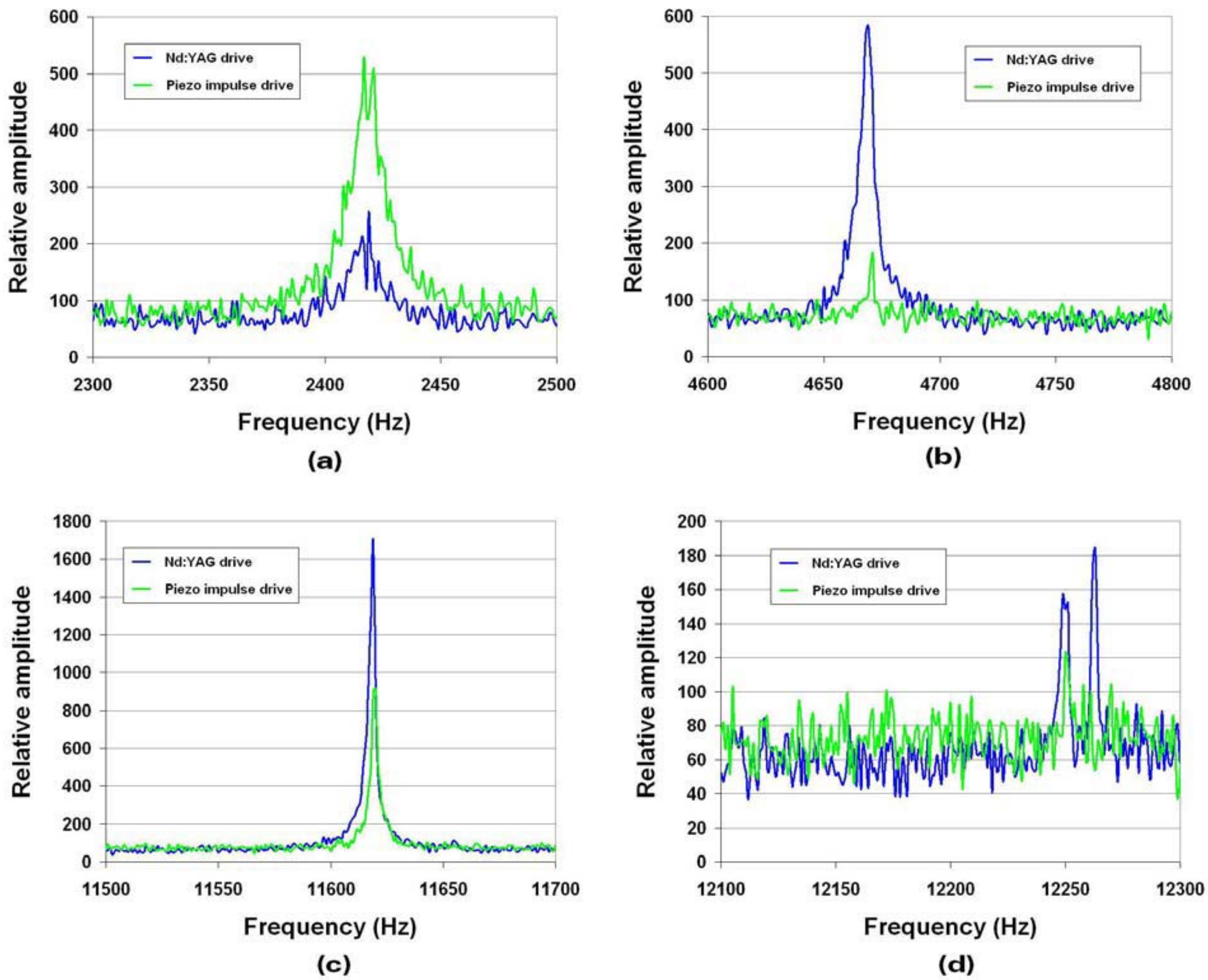


Figure 5: A comparison of accelerometer response to an optical and mechanical actuation (first four modes shown).

The measurements were repeated with another accelerometer at a repetition rate of 0.9 Hz, data collection beginning immediately after the impulse. This has resolved the modulation issue; the data for the first four modes is shown in figure 5. It is noteworthy that the optical and mechanical actuations produce different relative amplitudes between the various modes of vibration. Indeed both of the degenerate modes in figure 6(d) are visible with the optical actuation but not with the piezo drive. This difference in effective actuation is believed to be due to the non-uniform intensity of the light falling onto the device, this will tend to drive degenerate modes (i.e. rocking modes) more efficiently than the piezo whereas the uniform nature of the piezo drive should drive non-degenerate modes (i.e. the bounce mode) more effectively. This work is on-going.

4 CONCLUSIONS

Actuation of devices by a high energy nanosecond pulse has been demonstrated as a practical methodology in the dynamic characterization of MEMS at the wafer level. Being a non-contact technique, the method is both simplistic and non-destructive allowing for rapid testing. This technique has been shown to give comparable response data to currently used actuation techniques.

5 ACKNOWLEDGEMENTS

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