Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Procedia Chemistry 1 (2009) 405–408
Procedia Chemistry
www.elsevier.com/locate/procedia

Proceedings of the Eurosensors XXIII conference

Electrostatic actuators for misalignment compensation in multi-layered microsystem devices

P. Srinivasan[a], C. O. Gollasch[b] and M. Kraft[a]*

[a]*School of Electronics and Computer Science, University of Southampton, Highfield, Southampton, SO171BJ, UK*
[b]*Polymervision, Southampton, UK*

Abstract

Electrostatic actuation is a promising approach to compensate for misalignment of bonded, multi-layered microsystem devices. The present work discusses the performance of electrostatic actuators used for in-plane misalignment compensation in an atom chip comprising an optical cavity. Experimental investigation revealed that the central frame suspending the mirrors can be moved between 3-5 μm in the in-plane direction for the applied DC voltage of 90 volts. Future work involves characterizing the mirror displacement for optical tuning function.

Keywods: Actuators, Alignment, Micromirrors and Optical tuning

---

1. Introduction

Micromachining technology is becoming more matured by realizing three dimensional Microelectromechanical systems (MEMS) devices in layered architecture. The alignment and bonding of different layers are critical to the function of most devices. We have proposed an electrostatic actuation scheme to compensate for misalignment in a multilayered MEMS device namely, the atom chips. Atom chips are microfabricated devices capable of manipulating atoms by the application of electric and magnetic fields [1, 2]. Over the past few years, the basic functions [3, 4] were demonstrated in the laboratory experiments. However, realizing a chip with integrated functionality has been a long standing challenge from micromachining standpoint. Such an integrated chip is very promising for applications such as quantum information processing, ultra-sensitive inertial sensor, and atomic clocks.

Integrating different functions of an atom chip can be accomplished only by realizing a three dimensional MEMS device in the form of stacked layers. With the advancement of micromachining technology, it is possible to realize such devices provided the processing challenges are appropriately addressed [5, 6]. The present work is built on our previous studies focused on the design and analysis of electrostatic actuators for tunable optical micro cavities [7]

---

* Corresponding author. Tel.: +44(0)238 0593169; fax: +44(0)238 0593029
E-mail address: mk1@ecs.soton.ac.uk.

doi:10.1016/j.proche.2009.07.101

which are critical for monitoring atoms in an integrated atom chip. The objective of the present work is to discuss the performance of electrostatic actuators used for compensating the misalignment in the stacked layers. The results presented here will serve as a useful baseline for realizing three dimensional tunable optical microcavities.

This paper is organized as follows. Section 2 explains the device configuration considered for the present study. Section 3 discusses steady state DC response of the device for misalignment compensation. Section 4 discusses the performance of the device against its functional requirements. Section 5 draws key concluding remarks from this study.

2. Device configuration

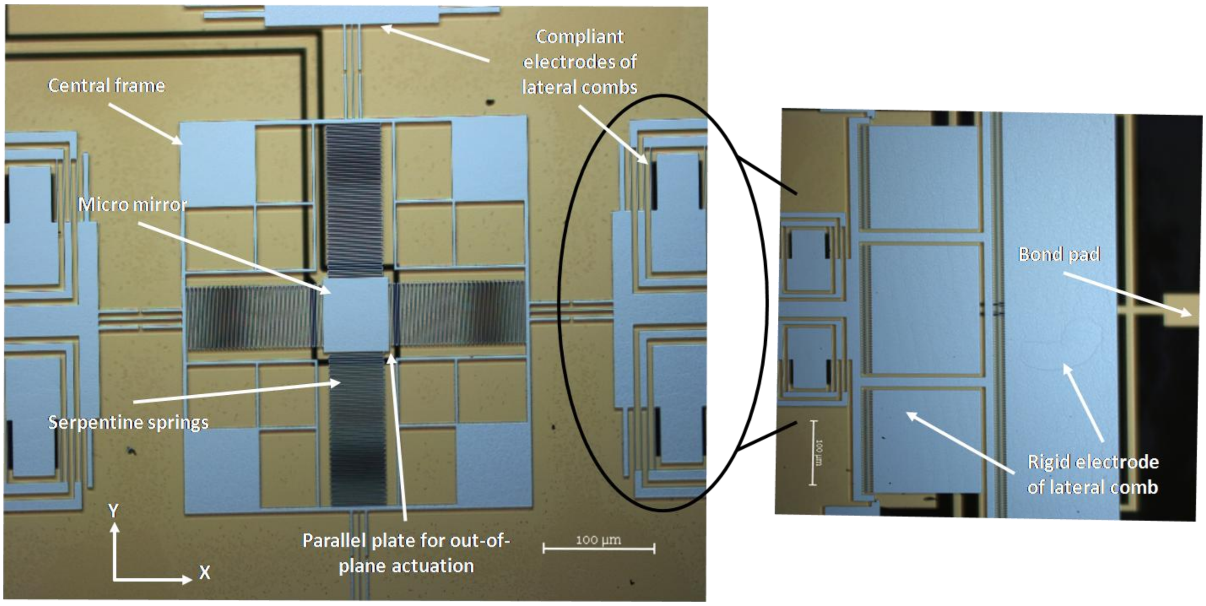
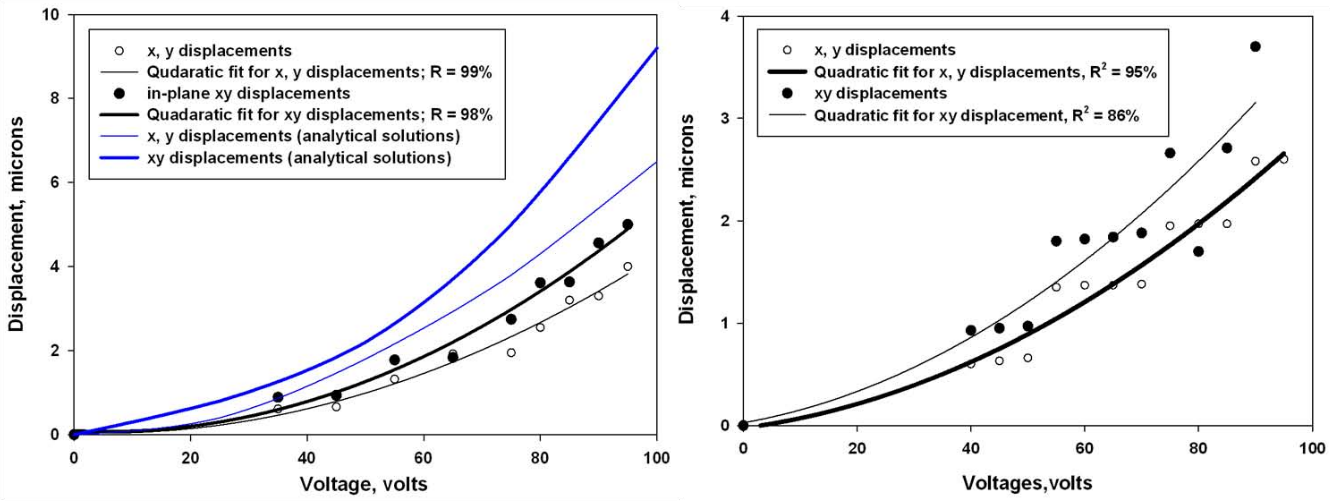


Fig. 1. Microscopic image of in-plane lateral combs and out-of-plane parallel plates for misalignment compensation and optical tuning respectively

A detailed description of different critical features of the device which was considered for experimental study was provided elsewhere [7]. Figure 1 shows the microscopic image of the key features of the device. The device consists of bonded silicon and glass substrates with device features and its electrical contacts on the silicon (60 µm thick) and glass layers respectively. The device layer is symmetric about X and Y axes and comprises a planar micro mirror suspended on serpentine flexures which are held to a central frame. The central frame can be actuated in the in-plane directions by four lateral comb drives in north, south, east and west directions. The electrodes actuating the central frame were made more compliant compared to their mating combs by defining flexures at the anchor locations. This allows in-plane motion of the central frame to compensate the inadvertent misalignments in the stacked device layers.

3. Steady state in-plane dc response

The device was tested in a probe station by applying DC voltage across the electrodes. The in-plane displacement was obtained by locating the position of a reference pixel on the central frame captured by a CCD camera before and after applying the DC voltage. The in-plane displacements towards north (+y) and east (+x) directions were obtained by separately driving the lateral comb drives in north and east ends respectively. The in-plane displacement towards north eastern direction (xy) is obtained by simultaneously driving the lateral comb drives in the north and east ends.



(a) **(b)**

Fig. 2. Steady state dc response of the central frame for applied dc voltages in north and north/east ends. (a) central frame without serpentine springs (b) central frame with serpentine springs

Figure 2a shows in-plane displacements of the central frame without serpentine springs for the applied dc voltages. The experimentally obtained in-plane displacement at 100V along the principal directions (+x, +y) were found to be less than the theoretically estimated (analytical and numerical) solution [7] by 20%. This is attributed to the unaccountability of processing pre-stress effects, in-plane twisting stiffnesses of beams connecting electrodes and the central frame, compliant conditions at the anchors, bending and in-plane twisting stiffnesses of the central frame members in the theoretical solutions. Fig. 2b shows similar such result for a central frame with serpentine springs. The drop in the displacement magnitude shown in Fig. 2b compared to that of Fig. 2a clearly manifests the influence of the serpentine springs on the in-plane displacement of the frame. An empirical relationship between the applied voltage and the in-plane displacement was obtained by fitting the experimental data with a second degree polynomial with more than 90% confidence level.

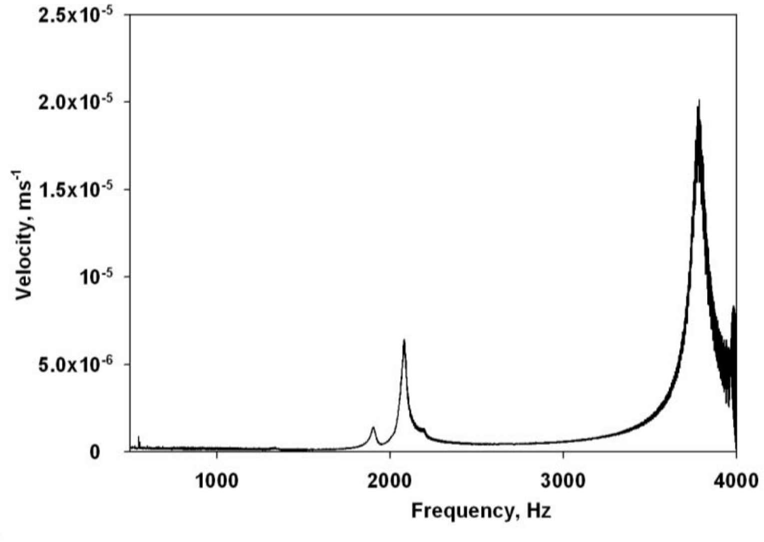


Fig. 3. Frequency response of the device for a periodic chirp signal

The device is intended to be stable against stray low frequency mechanical noise which might excite the structure thereby affecting its performance. Hence the dynamic performance of the device was characterized by experimentally evaluating its first few resonant frequencies. Fig. 3 shows the frequency response function of the device obtained using polytec Microsystems analyser (MSA-400). The device was excited using a periodic chirp signal of 1 volt and the out-of-plane velocity was measured using laser Doppler velocimetry. Previous studies based on finite element modeling predicted an out-of-plane deformation mode of the mirror at 725 Hz when the frames were fixed. However, experimental investigation revealed that frequencies close to 725 Hz were completely damped due to squeeze film damping effects. It is evident from the spectrum shown in Fig. 3 that the mirrors will not be excited by any stray excitation at frequencies < 2 kHz.

4. Performance characteristics of the device

One of the feasible and promising configurations for realizing integrated atom chip is by stacking of a few layers which consist of micromachined features critical to the device functions such as trapping, guiding, characterizing and detecting ultra cold atoms. The ability to move the micro mirrors in the in-plane directions to about 3-5 μm at 90 V makes this strategy of alignment compensation promising for stacked layers in the atom chips considering the inadvertent deviations caused during lithographic alignment, bonding and processing pre-stress.

The present work has left some design challenges which need to be addressed. The ability to achieve out-of-plane motion of the mirror by a few microns was restricted thereby affecting the optical tuning. This is attributed to the large gap (~ 20 μm) between the parallel plates besides high flexural stiffness of the serpentine springs (aspect ratio < 10) for out-of-plane displacements thereby necessitating high actuation voltage. These issues can be circumvented either by reducing the thickness of the serpentine flexures and parallel plate gaps or by defining more complaint spring structures such as hexagonal honey combs.

Although measurement of in-plane displacements based on relative position of the frame edge obtained using a CCD camera was limited by the pixel resolution (pixel size ~ 600 nm) and the ability to identify the same pixel, the accuracy of the measurement is sufficient enough to measure distances of a few microns. Future work involves characterizing the alignment compensation and tuning position of the mirror for one dimensional optical tuning of micro cavity.

5. Conclusions

A strategy for compensating the misalignments in stacked multi-layered MEMS devices is proposed. Experimental investigation revealed misalignments up to 5μm can be compensated using lateral comb drives by applying 100 V which is sufficient for atom chips. The alignment tolerance and the ability to drive the mirrors out-of-plane for optical tuning can be further improved by replacing the serpentine spring by a more compliant honey comb structure and by reducing the parallel plate gap. The design guidelines drawn from the present study will serve as a useful baseline for realizing such devices with improved performance for atom chip applications.

References

1. R. Folman, et al., Microscopic atom optics: From wires to atom chips, *Adv. At. Mol. Opt. Phys*; **48**:263, 2002
2. J. Fortagh, et al., Towards atom chips, *Science*, **307**:860, 2005
3. J. Reichel, et al., Atomic manipulation with magnetic surface traps,*Phys. Rev. Lett*., **83:**3398**,** 1999
4. W. Hansel, et al., Trapped-atom interferometer in magnetic microtrap, *Phys. Rev. A*, **64**:063607, 2001
5. G. Lewis, et al. Fabrication of magneto-optical atom traps on a chip, *IEEE J. Microelectromech. Sys.*, **18**:347, 2009
6. E. Koukharenko, et al. Microfabrication of gold wires for atom guides, *Sens. and Act. A*, **115**: 600, 2004
7. C. O. Gollasch, et al. A three dimensional electrostatic actuator with a locking mechanism for microcavities on atom chip. *J. Micromech. Microengg.*, **15:**S39, 2005