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Design and fabrication of a novel centimeter scale three dimensional silicon tip, tilt and piston mirror mechanism

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Abstract

A novel centimetre scale tip tilt piston mirror mechanism has been designed in silicon. The mirror consists of three identical mechanism parts and one mirror part. The fabrication of the parts was done with photolithography and Deep Reactive Ion Etching and they are presently being assembled. The originality of the proposed concept resides in breaking down of the kinematic structure into three identical planar flexure-based monolithic structures and the isostatic alignment concepts used to assemble these planar structures into a three dimensional structure.

1 Introduction

The up scaling of silicon Micro Electro Mechanical Systems (MEMS) to millimetre and centimetre scale is a bottom-up approach of coping with the challenges between the domains of MEMS and classical metal-based precision mechanisms. Basing this approach on silicon presents several advantages such as the absence of fatigue, machining accuracy (typically one order of magnitude better than that of Wire-EDM), possible integration of sensors and actuators inside the articulated structures themselves and batch production on wafers.

However, the fact that most mature Silicon processing is planar (2D) or stacked planar (2.5D) in combination with silicon being a brittle material, prevents silicon from being widely used at the centimetre scale. The challenge of assembly has been coped with in various publications [1], [2] but typically on a micro scale. We also coped with these challenges in our previous research [3].

We characterised the effects of stress concentration, crystalline orientation and surface treatments on the fracture strength of silicon flexures. This led to a set of fabrication and design rules enabling the design and fabrication of more robust parts which are less prone to fracture.

In the same research, we also showed that, assembling centimetre scale silicon slabs in three dimensions is feasible, and can lead to the production of silicon based three dimensional mechanical systems. In this context, we designed, assembled and characterized a silicon sugar cube size delta robot as displayed in figure 1. This robot consists of three identical flexure based silicon slabs assembled together to form the architecture of a delta robot.

Figure 1: Photos of a flexure slab of the sugar cube Delta-Robot (left) and the sugar cube size Delta-Robot (right) [3]

2 The tip tilt piston mirror mechanism

In an effort to further improve our expertise in the assembly of 3D centimeter scale silicon structures comprising delicate flexure mechanisms, a novel silicon Tip, Tilt and Piston mirror mechanism (TTPmm) has been designed and produced. The originality of the proposed concept resides in the breaking down of the kinematic structure into three identical planar flexure-based monolithic structures and the isostatic alignment concepts used to assemble these planar structures into a three dimensional structure.

The achieved device has a relatively small volume compared to classical metal-based precision mechanisms while achieving large displacement ranges compared to classical MEMS.

2.1 Fabrication

The 2.5D silicon parts were micro-fabricated using photolithography and deep reactive ion etching (DRIE). For the fabrication, a Silicon On Insulator (SOI) wafer (500 µm handle layer, 2 µm buried Oxide, 45 µm device layer) was used. In addition, for the mirror surface and solder pads, a 200 nm gold layer was deposited.

2.2 Kinematics

The TTPmm consists of a total of four monolithic silicon components: three identical silicon slabs containing the kinematic structure (hereafter referred to as “the flexure slabs”) and the silicon mirror. The flexure slabs have multiple functionalities: decoupling the actuators; providing a translation of the integrated mirror frame.

The kinematics of one flexure slab is displayed in figure 2. The structure consists of a linear guide which is actuated through a silicon rod used to decouple parasitic motions of the actuator. The linear guide pushes the mirror frame with a rod in the Z direction while another rod constrains the mirror frame in X.

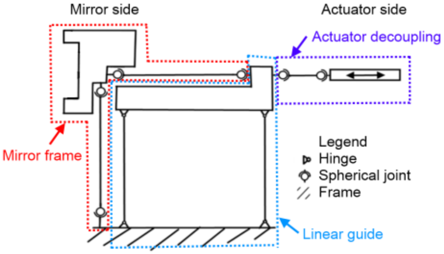

Figure 2: Kinematics of a flexure slab.

The implemented design of the TTPmm is capable of +/- 4 Deg (Tip and Tilt) rotations in the mirror plane; the (Piston) translation range out of the mirror plane is +/- 0.6 mm.

2.3 Proposed Assembly strategy

For the assembly, each of the three flexure slabs constrains the mirror in 2 Degrees of Freedom (DOFs): 1 axial and 1 azimuthal DOF. With the introduced method for alignment we achieve isostatic positioning of the mirror. The flexure slabs are fixated to a metal frame.

The entire assembly fits in a 40x40x42 mm^3 rectangular volume and is shown in figure 3. The actuators are in turn coupled to the silicon rods to provide the actuation. The flexure slabs are fixated with either gluing or soldering. To allow for soldering the flexure slabs and the mirror have a gold coating on their interfaces.

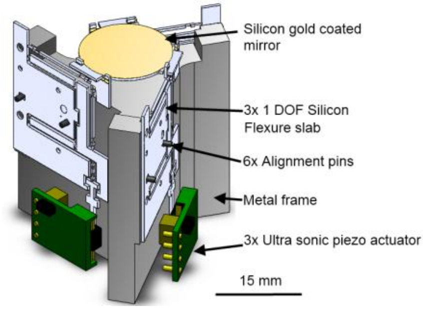

Figure 3: Tip Tilt Piston Mirror Mechanism

2.4 Actuation and sensing

Three commercial ultrasonic piezo actuators were selected to provide the forces for actuating the TTPmm. However, the design allows for various linear actuators. Although sensing functions are not directly implemented in the current design, a first approach is to use an optical measurement system based on the mirror itself to characterize its displacements.

3 Conclusion

The design demonstrates the possibilities of creating centimetre scale 3D assembled silicon mechanisms by use of parts integrating novel features both for alignment and for fixation. Presently the parts have been fabricated and we are in the process of assembling and characterizing the demonstrators.

Typical application areas of such an centimeter scale opto electro mechanical systems include laser machining, scanning Light Detection And Ranging (scanning LIDAR) systems, as well as pick off mirrors for multi object spectrometers.

References:

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