FABRICATION AND MICROMECHANICAL TESTING OF POLYMER MICRO-GRIPPERS WITH COMPLIANT FORCE SENSING

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Introduction

Micro-gripping of small scale constructs <50μm is a considerable challenge. Small scale tissues not only respond to chemical and electrical signals but also mechanical forces [1]. Mechanical characterisation of tissues and cells will help scientists to understand fundamental physiology. A number of research groups have concentrated on capturing cells/tissues and others investigate mechanical properties of the samples. Few systems bring together cell trapping and mechanical testing of samples on a single chip. This paper discusses the fabrication of electro-thermally operated polymer SU-8 micro-grippers and micro mechanical calibration of compliant folded flexures and gripping stiffness [2]. Displacement of folded flexures is measured off chip via optic fibre using the micro-mirror (Fig. 1).

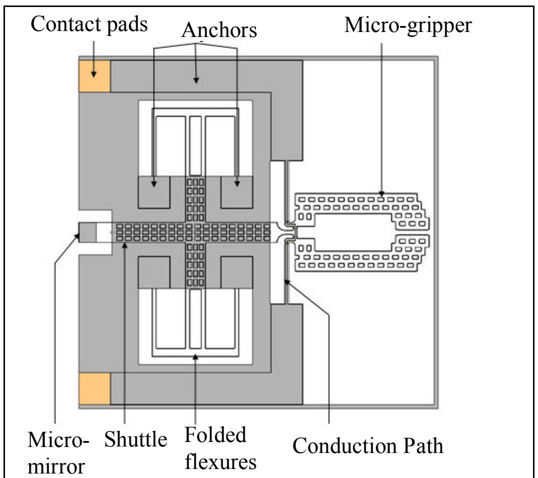

Fig.1 Design concept of SU-8 micro-gripper with compliant folded flexures for force sensing.

Fabrication

A novel fabrication method was developed and is shown in Fig. 2. Aluminium sacrificial layer is evaporated using Edward's 306 evaporator from tungsten coils. Anchors were patterned using Shipley S1813 was spin coated to a thickness of 1.2μm and baked at 125^{0}C. An OAI J500 photo-aligner was used to pattern the anchor points, S1813 was exposed with 80mJ/cm^2. The wafer is developed in a bath of 1MF351+5DI H_2O for 20s.

Al etchant $16H_3PO_4$+$1HNO_3$+$1CH_3COOH$ is heated to 50^{0}C. Wafers are immersed in Al etchant for 40 seconds, rinsed in DI H_2O for 10 minutes and dried with N_2. Wafers are then rinsed in acetone to remove photoresist and dried in N_2. The same process is adopted for patterning the conduction path, however UV light dose is reduced to 48mJ/cm^2. Cr is etched using Transene 1020 for 1m30s. SU-8 2007 is spun onto the wafer at 510 rpm for 4 seconds, 1170 rpm for 30 seconds and finally ramped up to 1910 rpm for 4 seconds to remove the edge bead. Soft baking is carried out for 1m at 65^{0}C and 5m at 95^{0}C on a hotplate to ensure removal of solvent. SU-8 was cooled for 10 minutes to lower stresses in structures. The sample is exposed for 300mJ/cm^2. Post exposure bake cures exposed SU-8; PEB parameters are equivalent to soft bake parameters. EC solvent was used to develop structures for 3m. Finally the SU-8 structure was rinsed with IPA and dried with N_2. SU-8 thickness is 24μm.

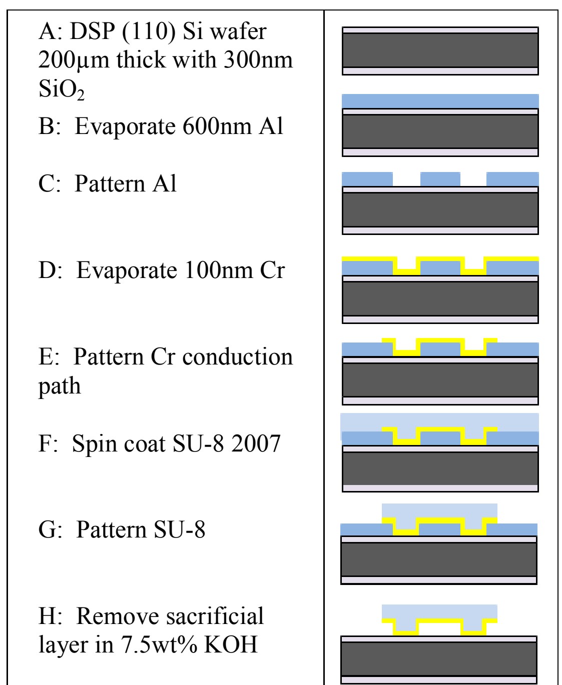

Fig 2. Process Flow for fabrication of SU-8 micro-grippers with and folded flexures.

Mechanical Testing

Micro-mechanical testing was carried out using two techniques; folded flexures for tensile tests of samples were calibrated using Tinius Olsen H5K-S UTM whilst gripping stiffness was examined using Kleindiek FMS using Si cantilever beam (Fig. 3) [3].

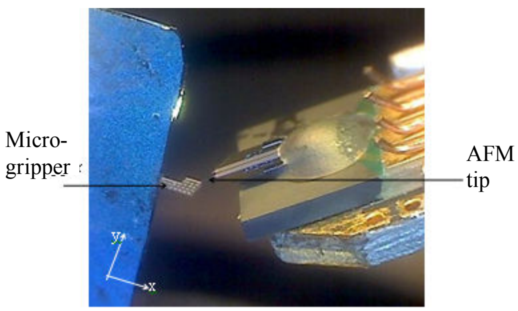

Fig.3 Kleindiek micro-manipulator and manipulating AFM tip to align with x-plane for in plane gripping tests

Tensile tests of flexure springs were carried out until failure of the system occurred. Three thickness of micro-gripper were tested. All tests conducted showed linear stiffness up to a specific point, i.e. 1.67mN for 38µm sample; the material then undergoes plastic deformation which varied widely from sample to sample (Fig. 4a). Calibration curves were taken from the linear part of the stiffness curve where elastic deformation is occurring. Average stiffness for the three thicknesses were calculated by taking the gradient of the force-displacement graph, this was 172.3N/m for the 38µm sample. Microgripper failure occurred at the joint between gripper arm and hot central beam. Micro-gripper arms were displaced by 1.8µm in the gripping plane over 3 cycles in each run. Samples showed a linear relationship between applied force and displacement. Ten samples of 24µm were tested and all showed similar results with low standard deviation (Fig 4b). Other thicknesses were also tested and showed increasing stiffness with increasing thickness as expected.

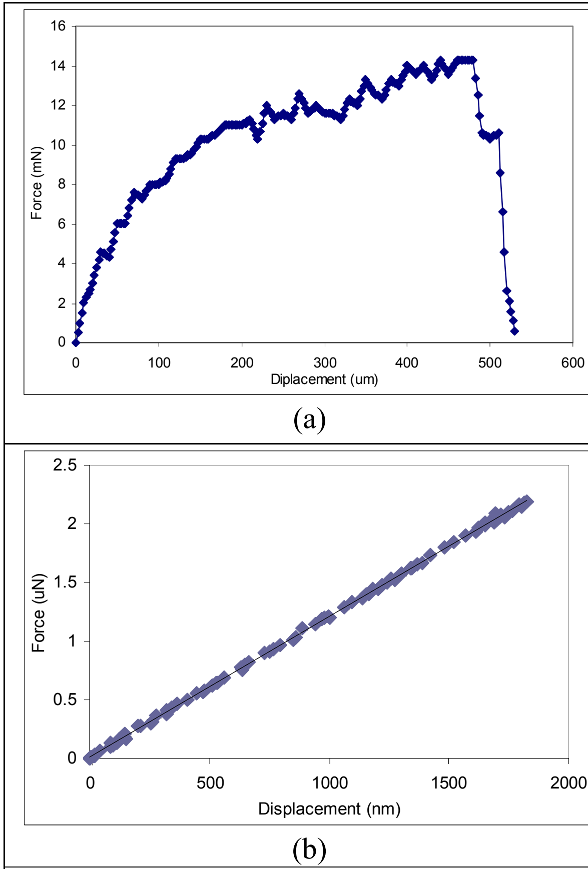

Fig. 4 (a) Force displacement curve for folded flexures for 38µm thickness; (b) micro-gripper stiffness of tips for holding sample, stiffness of single arm 24µm thickness is 1.2N/m.

Maximum gripping force tested systems was between 240-430µN for maximum stroke of 220µm.

Conclusions

A repeatable, low cost fabrication method has been developed for producing micro-grippers with compliant force sensor. Micro-mechanical testing showed stiffness results for both folded flexure and gripping stiffness which correlated with finite element results. Minimum force resolution of the system is 33µN with envisaged Philtec D6 displacement sensor. Gripping force can be varied by changing the gripping stroke of the actuated arms

1. Suresh S., (2007) Biomechanics and biophysics of cancer cells, *Acta Biomaterialia* Vol. 3 No., 4 pp.413-438

2. Mackay R.E., Le H.R., Keatch R.P. (2011) Design optimisation and fabrication of SU-8 based electro-thermal micro-grippers, *Journal of Micro - Nano Mechatronics* Vol.6 No.1 pp.13-22

3. D.J. Bell et al. (2006) Three-dimensional nanosprings for electromechanical sensors, *Sensors and Actuators A: Physical* Vol. 130-131 pp54-61.