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MICROFABRICATION OF A MICROGRIPPER DESIGNED FOR ARTIFICIAL FERTILIZATION

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Abstract

This paper presents the fabrication of monolithic compliant microgripper. The following research has mostly focused on the fabrication methods and characteristics of the microgripper. This new architecture of micro gripper enables it to apply a variable force to a wide range of handled micro objects in micro assembly, micromanipulation and also in biomedical plans as artificial fertilization. The microgripper was designed to be normally open. Two SMA (Shape Memory Alloy) actuators close the jaws. To achieve the tasks, the most proper size has been considered to be 8mm×8mm with thickness of 250μm.

PET (Polyethylene terephthalate) has been used as the structural material. It is non brittle and less shock sensitive in compare to silicon based grippers as well as les fabrication cost without losing precision.

Keywords: Microgripper, Fertilization, Fabrication, Flexible, Biocompatible

Introduction

Micromanipulation is a growing step in the process of microassembly. Efficient, reliable and flexible handling is still very challenging in micromanipulation and microassembly. The primary function of a microgripper within microassembly procedures is to provide high resolution grasping of minute parts in precision environment. The irregularities in size and structural texture of the objects add to the complexities and challenges to the developing of high accuracy and controllable grasping operation. These requirements are paramount to avoid significant damage to objects, which are known to be sensitive to external forces, a target egg for fertilization is a good example.

In 2005, Bordatchev et al. demonstrated a monolithic compliant microgripper working based on the expansion-compression of materials [1]. Houston et al. represented a polymeric compliant microgripper activated by SMA wires [2]. Dechev et al. work describes the assembly of 3D microstructures from polysilicon using passive microgrippers [3].

Enikov and Lazarov developed a microassembly system with an optically transparent gripper. It used electrostatic forces to hold metal parts [4]. Tsui et al. described robotic assembly system with a passive end-effector to assemble silicon-based connectors [5], and Beyeler et al. are developing MEMS grippers with integrated force sensing [6]. Our former work presented a compliant constant force micro gripper using Pseudo Rigid Body Model (PRBM). [7]

The review shows that researchers commonly emphasize on three major components during model development. These are namely novel microfabrication techniques [8], new actuation methodologies [9] and manipulation of different materials [8].

The microgrippers developed in literature can be systematically classified according to the source of actuation employed for the driving mechanism. In particular, there are four major actuation techniques typically utilized in micrograsping operation. These techniques are piezoelectric, electrostatic, electromagnetic and thermal actuators [8].

Some rarely used methods were also suggested for designing microgrippers such as using electromagnetic stimulation or hydraulics and pneumatics actuators which used sucking and blowing force to actuate [11]. The actuator can either be integrated as part of the unit [8] or stands as separate entity, thus enables the developer to gain more options during the developing stage [8]. Some microgrippers also incorporate sensor architectures to acquire feedback signals for the accuracy and precision enhancing during the grasping operation [8,12].

The fabrication techniques such as Electro Discharge Machining (EDM), LIGA, surface, bulk and laser micromachining, have paved a decisive breakthrough to the persisting constraints in micrograsping methodology particularly associated with the object-gripper compatibility, surface to surface interaction between the object and the gripper’s jaws and nonlinearity during operation [13,14].

Most of the microgripper published works have used silicon for their fabrication. Despite of its electrical and structural advantages, employing brittle materials like silicon will make compliant hinges less flexible and costly.

In this work, the gripper is built with PET(Polyethylene terephthalate). Besides higher flexibility, PET is easy, accurate and less expensive to fabricate in compare to silicon. PET is also biocompatible [15], which make it a suitable candidate for applications such as in vitro fertilization and laboratory cell experiments. The microgripper is designed to grasp any object in the range of 100 to 400 microns but the initial intention was to grasp eggs for in-vitro fertilization.

Figure1 is shown a schematic of gripper design and its characteristics dimensions.

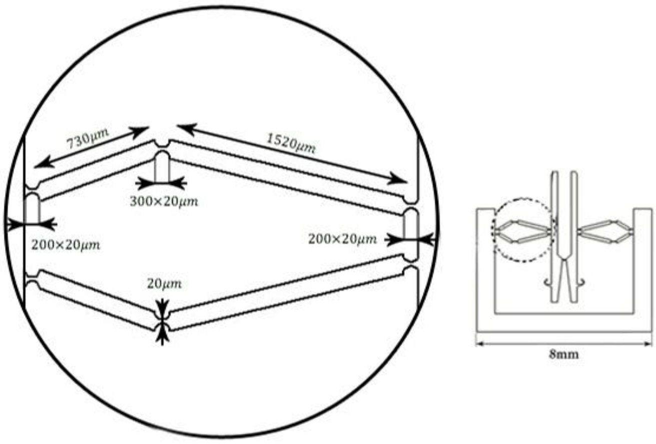

Figure 1: schematic and dimensions of compliant micro gripper with the flexural hinges thickness shown.

FEA validation of design

Finite element analysis was performed to investigate the compliant mechanism. The 3D elements are used to model the microgripper mechanism and predict the stress concentration and displacements of the microgripper. Mechanical strength and gripper performance are validated by ABAQUS software. The material properties that are used for this model are PET mechanical properties with the modulus of elasticity equal to 2800Mpa and the yield stress assumed to be 60Mpa for this material.

The load applied at the hooks designed at the bottom of the gripper's jaws with continuous load condition increase from 0mN to 1.6mN.For the contact condition a friction coefficient was assumed between the griper's jaws to prevent the jaws cross each other, if half body model analyzed this condition was not necessary.

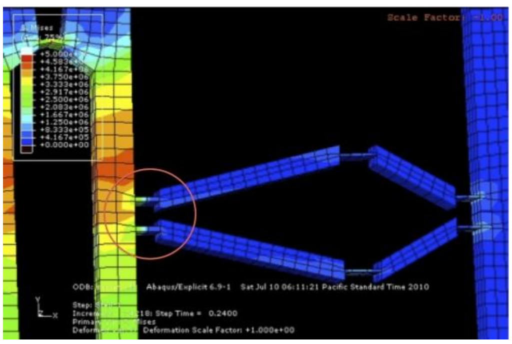

Figure2 Image of ABAQUS full body model analyze of microgripper. As shown the maximum stress occurred in design is much lower than yield stress. The critical joints determined with a circle.

The model was meshed with the ABAQUS automatic mesh and the smallest mesh had a 2μm dimension.

As the analyzed images show the stress concentration occurs at the notch hinge points as shown in Figure2. The maximum stress was found to be 4Mpa, which is much smaller than the yield stress and the elastic modulus of the material.

Fabrication process on PET wafers

Polyethylene terephthalate (PET) is a robust material and chemically resistant to many solvents. These characteristics make it a suitable choice for many large area electronic applications. Also in the following study the microgripper is fabricated form PET using a UV assisted vertical etching process [16]. The presence of the UV light promotes etching in the direction determined by the incident photons. Contrary to the etching methods of described in literature [17] where either an X-ray radiation or energetic ion bombardment is used to accelerate the etching process. In adopted fabrication method only a UV source is utilized during the chemical etching of the substrate.

In fabrication of this gripper, PET has been chosen over SU8. This selection has been made based on basic different in fabrication process of our designed gripper and experimental limitations in our fabrication lab. In SU8 grippers, normally SU8 has been spin sputtered on top of the wafer and will be followed by a LIGA process. But, in this study, gripper has been design using maximum thickness of the wafer. In other words, unwanted parts of the mask have been etched away through all substrate thickness. In addition to this fundamental difference, making such a thick SU8 or PMMA layer like the one fabricated in this paper needs hours of lithography, which was not a part of interest of authors, and was not compatible with our fabrication equipment specifications. Considering all of the above, authors decided to employ biocompatible PET to fabricate the gripper, as it's more compatible to the design and easier to fabricate .

The fabrication process used for PET in this case is general vertical etching under ultra violate beam. The gripper material was chosen to be PET because of its high deformation capability that happened during the gripper's jaws movement.

The first step was to remove the gelatin layer on the PET wafers. To remove this layer dissolved dichloromethane (DCM) was used [18].

The masking layer used in these experiments is a Si layer deposited with the Plasma Enhanced Chemical Vapor Deposition (PECVD). This mask has been found to be suitable in order to protect the PET substrate from the UV exposure as well as the solvent in the protected areas. Using photolithography desired patterns could be made in the masking layer. Setup used in this study is also equipped with a water-cooled glass container. This container is also equipped by a heater to control the temperature of the solvent during etching process [17].

The best masking layer experimented based on stickiness and flexibility are Si and SiO_2 multi layer because of the PECVD, the layers have impressive quality and low surface roughness and its possible to deposit a none cracked layer on PET, the deposition conditions for these two layer illustrates in Table.1. The basic problem with Si and SiO_2 masking layers was difficult etching processes. The masked sample was placed in the Reactive Ion Etching (RIE) device to dry-etch the silicon layer in SF_6 plasma. But SiO_2 was etched by liquid HF in this process. Because the SiO_2 is colorless, it is difficult to realize when the SiO_2 layer is finished and the etched section reaches the Si layer, so the Si selected for masking layer in this paper.

Table.1.Si and SiO_2 deposition condition applied to final sample.

	SiH_4 Sccm	RF Power. Watt	Press. mtorr	Dep. Rate A°/sec	H_2 Sccm	N_2O Sccm
Si	5	40	450	1.25	180	-
SiO_2	7	80	700	150	-	160

The microfabrication process is shown schematically in Figure3. The deposited silicon layer acts as a mask. It protects the PET surface from exposure to the UV and DMF.

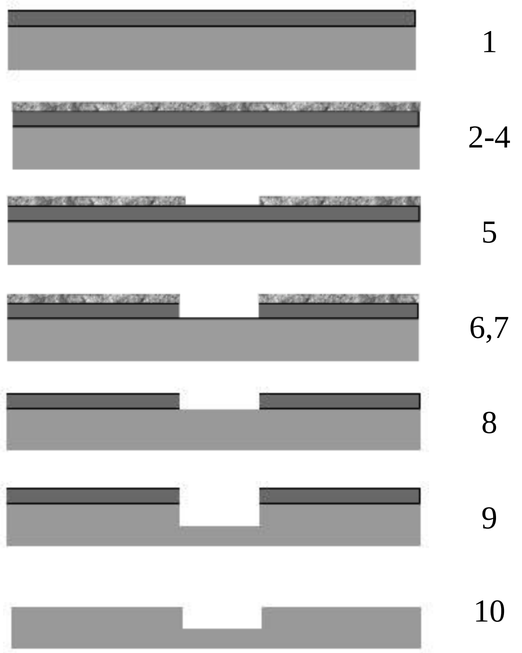

Figure 3: Process flow diagram of microgripper's fabrication steps.

Some etching defects happened during the vertical PET etching process, which are worth mentioning: under etching, eternal deformation that is the most serious defect PET etching faces and cracking during the etching process. Solving some of these problems causes a decrease in the etching rate. Finally by considering experimental results for a better PET etching process, methods like decreasing the temperature to about 60℃ to 70℃(In first experiments 130℃ used) before, using the appropriate DMF height on the sample and also adding the DCM in DMF solvent can be mentioned. By applying these methods, the etching rate increased to about 20 to 30 μm/hours. Because of the low temperature, the eternal deformation problem did not happen. The etched PET at this condition has been able to save its good flexibility and strength.

The whole fabrication process can be summarized in these 10 steps and conditions:

1. Silicon deposition on PET using PECVD.
2. Photo resist coated by use of the spin coating device with 4000 rpm for 30 second.
3. Prebaking the photo resist in the 75◦C oven for 10 minutes.
4. Photolithography for 30 seconds.
5. Parenting the photo resist.
6. Baking the photo resist in the 110◦C oven for 20 minutes.
7. Deleting the silicon layer on photo resisted section using SF6 gas in the RIE device with 100W power for 100 seconds.
8. Deleting the photo resist remains on silicon layer with Acetone.
9. Placing the sample on the holder in the etching device and letting it float under DMF solvent with 4% DCM for a height of 1mm upper than the sample surface.
10. Removing the silicon layer in RIE machine.

Fabrication Results

Figure4 and figure5 illustrates a magnified scanning electron microscopy (SEM) image of the final microgripper's structure that we have fabricated. The minimum feature size of this microgripper is the flexure hinges with the size of 20μm×100μm.

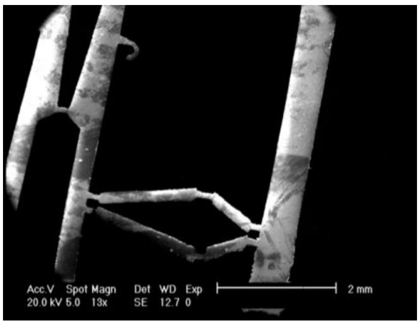

Figure 4: full body microgripper SEM shows middle joint between jaws, compliant arms and its joints with jaws and wall.

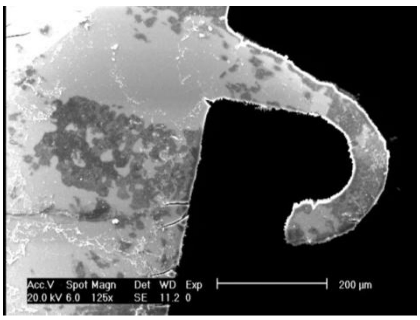

Figure 5: hook designed for SMA actuator connection.

Performance test

An experimental grasping test was performed applying the proposed microgripper device. A sugar particle with the thickness of about 150 μm was used for performance test. Figure6 shows images taken from the arms of the microgripper approaching to the sugar particle and grasping it.

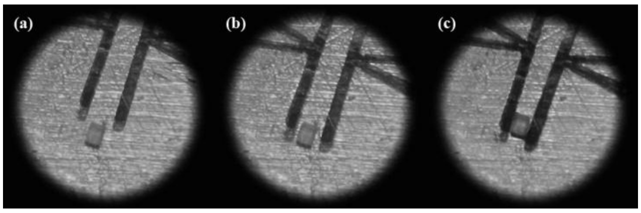

Figure 6: Grasping action of the microgripper on the sugar particle Steps a–c show grasping action.

Conclusion

In this paper the polymer based microgripper has been designed and fabricated. The fabrication method is an accurate and low cost process. The PET wafers has some advantages over other materials like low wafer price and easy etching ability. Because of its plasticity, it is not a shock sensitive device like other silicon based microgrippers and has a longer work life. This device can be specially used for biomedical usage like as fertilization. Plier design of microgripper made a wide diameter range for gripping also made it adaptive for unknown micro particle shape. Our future works focus on development of this microgripper's usage for in vitro fertilization process on caviar eggs.

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