Fabrication process of a 7-DOF parallel micro-manipulator

Foldable Micro-robot	Main process: 1. 'Gravure moule' par DRIE 2. Moulage de joints flexibles en PDMS) 3. Gravure de la structure du robot par DRIE	Abstract : *(goal, application,…)* The need for developing new generations of micro−assembling technology which can be used to handle and manipulate with 6DOF micro−nano−objects is increasing and requiring more precision. In this project, we propose a new robotic structure able simultaneously of grasping and manipulation of a micro−nano−objects with 6−DOF without using an additional gripper. In the current research, a compliant parallel mechanism is designed for micro-nano-metric precision applications using a PDMS flexible joints to ensure a wide range of movement.

Keywords: Gravure DRIE, Moulage de PDMS.

1. Introduction and context

1.1 Purpose:

Semiconductors, dielectrics and metals are traditional materials used in the fabrication of MEMS. MEMS processes provide for small feature sizes, batch processing and good integration with microactuators. While these materials and processes have proven to be extremely successful in devices such as inertial sensors, inkjet printer heads and micromirrors for display systems, they are not well-suited for all MEMS devices including those that require compliant elastic materials.

1.2 Application and state-of-the-art:

Polymer materials such as polyimide, parylene and SU- 8 have been integrated with MEMS devices in an attempt to fill the void left by traditional materials. These polymers are attractive because of their mechanical properties, particularly a lower Young's modulus and increased elasticity. The most prevalent example of these materials is poly(dimethylsiloxane) (PDMS), which is used widely in microfluidics and imprint lithography. PDMS is not widely accepted as a mechanical material in MEMS devices, mainly because integration with semiconductor processing can be difficult. Lotters used PDMS as a mechanical material to demonstrate triaxial accelerometers using a patchwork process that required manual assembly of each sensor, resulting in variations in the acceleration sensitivity [1]. Gerratt [2] presented the characterization and implementation of the first microfabrication process to incorporate high aspect ratio compliant polymer structures in-plane with traditional silicon microelectromechanical systems (MEMS).

[1] J. C. Lotters,W. Olthuis, P. H. Veltink, and P. Bergveld. Design, realization and characterization of a symmetrical triaxial capacitive accelerometer for medical applications. Sensors and Actuators.

[2] Gerratt, A. (2013). Silicon and Polymer Components for Microrobots.

1.3 Major challenges:

Conventional parallel structures suffer from errors such as friction, hysteresis and backlash of the joints and the geometric and dimensional errors of the components. This situation leads to the development of compliant micro motion joints which can overcome these difficulties. The main problem during this process concerns the incorporation of compliant elastomers 'PDMS' into the robot structure (made of a silicon Wafer) to ensure a wide range of movement. This process examines the integration of PDMS into batch silicon microfabrication and focuses on the integration of PDMS and silicon mechanical components for microrobots.

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2. Process development

2.1 Initial Wafer:

Matière	Fournisseur	Type	dimensions	Prix	Rq		
Wafer Si		Si N ou P	4" 400µm				

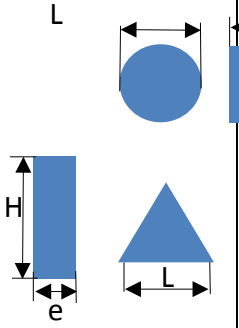
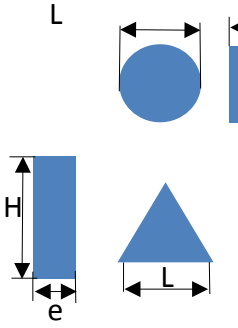
2.2 Mask definition:

- Mask A: 1st DRIE trenches formed the mold for the elastomer 'PDMS' features.
- Mask B: 2nd DRIE through the entire thickness of the Wafer to obtain the robot structure.

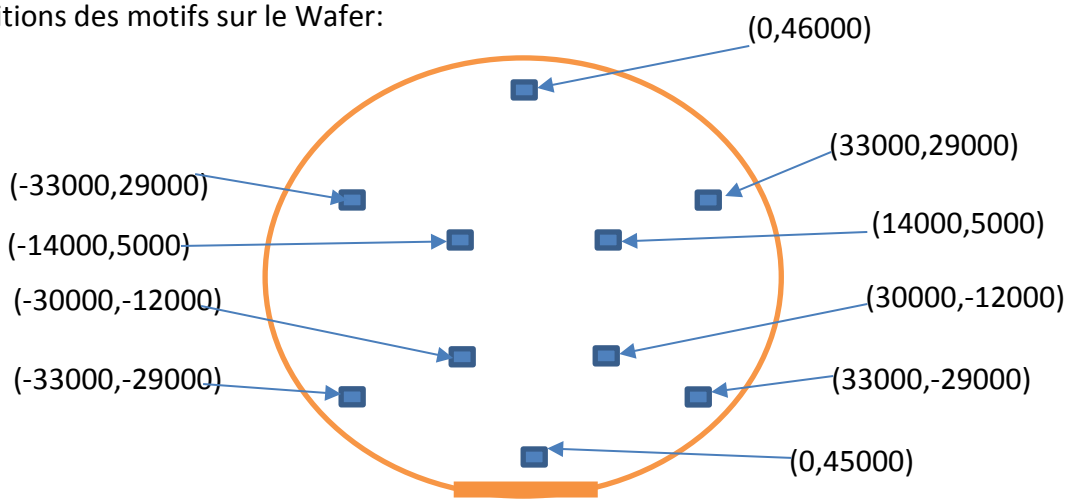
2.3 Specific test patterns

Some test patterns are made in the same wafer to verify the depth and the form of the etched parts.
These test patterns are only used when all the process is finished, removed from the wafer at the same time as the structures.
Protocol:

- Measure the dimensions of the finally processed cantilever beams with optical microscope of MEB.
- Verify the penetration of the PDMS in the etched forms.

1ère gravure		2ème gravure	
	Quatre formes différentes ont été pour quatre dimensions où : = 20, H=40, e=10. - L= 40, H=80, e=20. - L= 100, H=120, e=60. - L= 200, H=250, e=100. 		Quatre formes différentes ont été pour quatre dimensions où : L= 20, H=40, e=10. - L= 40, H=80, e=20. - L= 100, H=120, e=60. - L= 200, H=250, e=100.

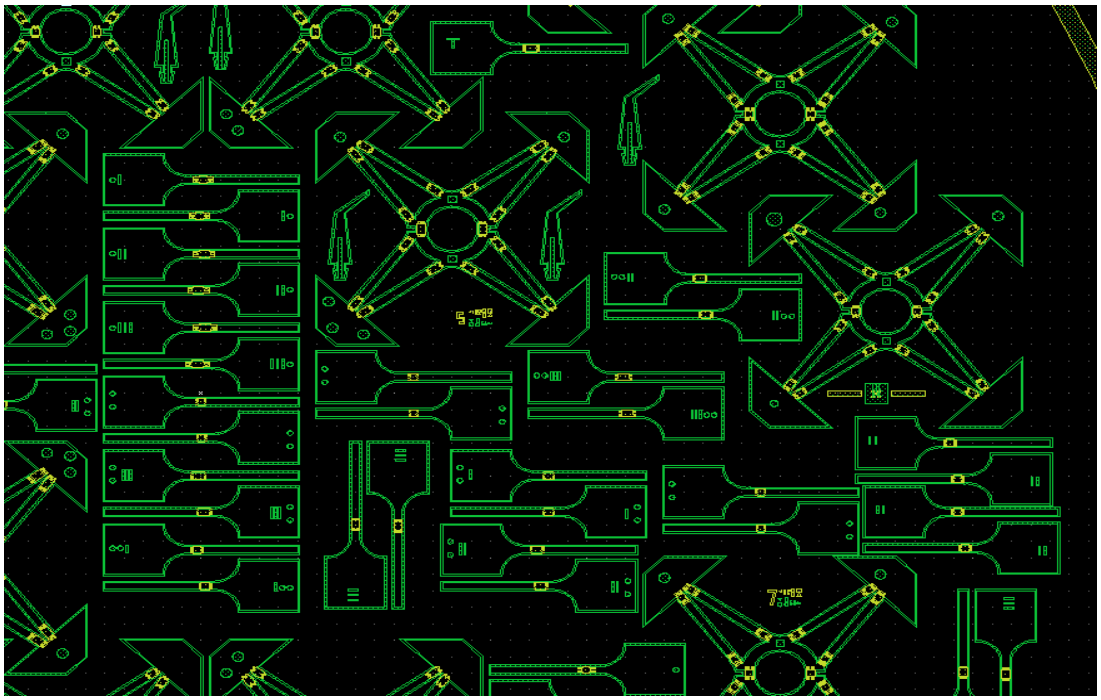
Positions des motifs sur le Wafer:



2.4 Samples organization:

Afin d'organiser et de distinguer les différents robots, nous avons choisi d'intégrer des formes spéciales, développées dans le tableau ci-dessous, dans chaque base de robot. De même pour les liaisons, des formes spéciales ont été conçu sur les bases.

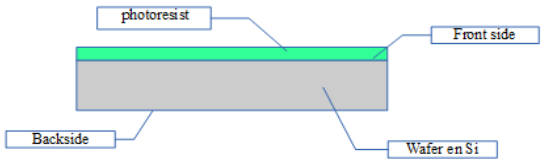
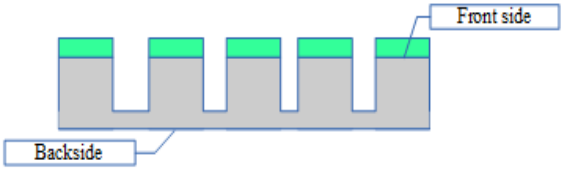
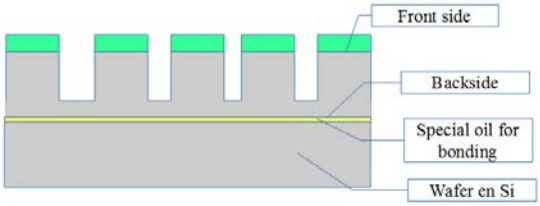
Longueur	Robot C	Robot CL	Robot R	Robot U	Liaison 1	Liaison2	Liaison 3	Liaison 4
300								
400								
500								
600								

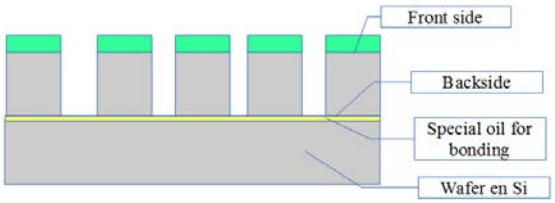
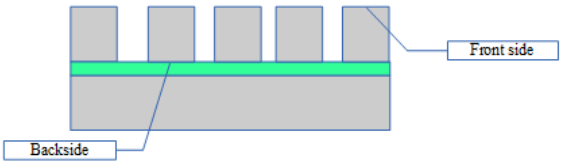
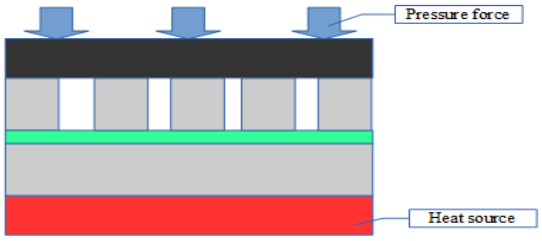
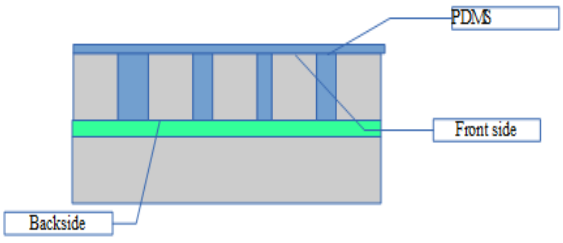


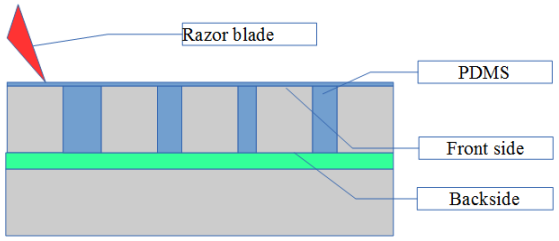
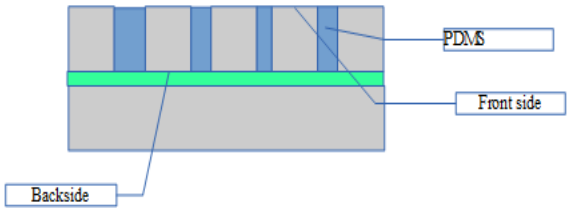
2.4 Process details:

"Device name" flow-chart – V1.0

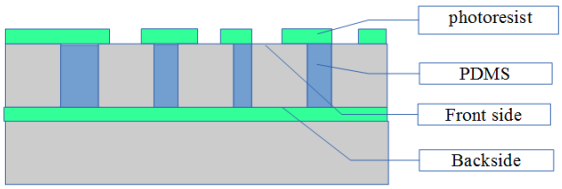
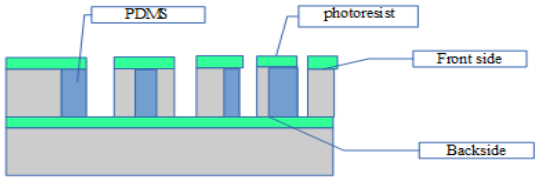
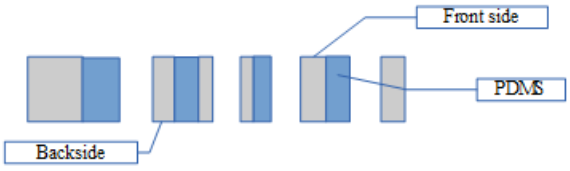
La procédure de fabrication commence par un dépôt de 15µm d'épaisseur de résine photosensible sur la face supérieure du Wafer (étape 11). Cette couche est un masque de protection pour la première gravure de DRIE 'gravure ionique réactive profonde'.
Ensuite, une gravure DRIE devra être réalisée sur le ¾ (300µm) d'épaisseur du Wafer (étape 12). Afin d'avoir des cavités débouchant, le wafer devra être collé sur un autre wafer support en utilisant une couche d'huile spéciale (étape 13 et 14). Après la gravure, un délaquage (O2 plasma) est nécessaire pour nettoyer les traces de la gravure (étape 15 et 16).
Avant le dépôt de PDMS, le Wafer devra être collé sur un autre Wafer support avec une couche de résine photosensible chauffée à une température T1 pendant t1 (étape 21). Les deux wafers doivent être légèrement pressés avec une masse pendant le recuit afin d'amélioré le collage ainsi que la planéité (étape 22).
Après cette phase de collage, le PDMS devra être préparé en ajoutant un ratio de 10:1 d'élément de durcissement. Le PDMS devra être ensuite déposé sur la face supérieure du Wafer à T2 (environ 40°C). Pour s'assurer que l'élastomère pénètre dans les fossés gravés, le Wafer devra être mis sous vide pendant t2 (environ 10 minutes). L'élastomère devra ensuite être durci à T3 (environ 90°C) pendant t3 (environ 2h) (étape 23).
Après le durcissement de l'élastomère, un rasage sur la surface supérieure du Wafer devra être réalisé pour enlever l'excès de PDMS (étape 24). Pour avoir une surface supérieure propre pour la 2ème gravure, les résidus doivent être éliminés avec un rinçage à priori d'une minute, à l'aide d'un mélange de 3:1 de n-methylpyrrolidone et tetrabutylammoniumfluoride (étape 25) (La vérification de la propreté de la surface avant et après le nettoyage au microscope est nécessaire).
Après le nettoyage de la face supérieure, une couche de résine photosensible devra être déposée pour la deuxième gravure DRIE (étape 31). La gravure DRIE devra être réalisée sur toute l'épaisseur du Wafer avec un temps d'attente de 5 minutes à chaque 100µm d'épaisseur gravé (étape 32) pour éviter la surchauffe de la résine.
La dernière étape est la libération du Wafer, en le trempant dans de l'acétone (étape 33).

10. Gravure moule par DRIE					
Step N°	Step name	Means	Parameters	Notes and results	Drawing and pictures
11	Photoresist on the front side of 15µm				
12	Perform a DRIE through ¾ (300-> 350µm) of the wafer				
13	Bond a wafer support with a special oil				

14	Perform a DRIE through the rest of the wafer				
15	stripping in acetone				
16	Stripping (RIE Nanoplat) O2 plasma				
20. Moulage des joints flexibles en PDMS					
Step N°	Step name	Means	Parameters	Notes and results	Drawing and pictures
21	Bond the wafer with photoresist (5µm / 6 µm)				
22	Annealing the two wafers using a small pressure on the surface.				
23	Refill with the elastomer at T1°C and cure the elastomer for t hours at T2°C				

24	running a razor blade across the surface of the wafer				
25	Planarize the elastomer to the surface	minute rinse in a 3:1 mixture of n-methylpyrrolidone and tetrabutylammonium fluorid			

30. gravure de la structure du micro-robot

Step N°	Step name	Means	Parameters	Notes and results	Drawing and pictures
31	Photoresist on the front side of 15µm				
31	Perform a DRIE through the wafer		5 minutes is the waiting time every 50-100µm thick etched for thermalization		
32	Release in acetone				

[1]

Process history:

(The process table in the previous section relates the "up-to-date" flow-chart. Write down every process changes and why it was necessary to change or adapt the process… ; write in particular the date, the concerned step(s), the observed problems and the proposed new solution and any information to do not try a solution already explored !)