Assembly of 3D Reconfigurable Hybrid MOEMS through Microrobotic Approach

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Abstract Micro-assembly has been identified to be a critical technology in the microsystems technology and nanotechnology. Increasing needs of MOEMS (Micro-Opto-Electro- Mechanical Systems) for microsystems conducts to development of new concepts and skilled micro-assembly stations. This paper presents a 3D micro-assembly station used for the reconfigurable free space micro-optical benches (RFS-MOB) which are a promising type of MOEMS. Designed parts of RFS-MOB are assembled by using the developed micro-assembly station. The flexibility of the micro-assembly station provides the possibility to manipulate a variety of micro-components. The RFS-MOB design enables to reduce adhesion forces effects during releasing operations. Experimental results are shown and validate the effectiveness of the micro-assembly station and micro-assembly strategies.

1 Introduction

Over the last few years the request for miniature objects and devices has continuously increased. So the need for MEMS (Micro Electro Mechanical Systems) and MOEMS (Micro Opto Electro Mechanical Systems) in the field of telecommunication and sensor technology [16] has become more and more important. Miniaturization of optical components and the assembly of various components constitute the principal challenge in hybrid MOEMS manufacture. For fabricating MOEMS, Free-Space Micro-Optical Benches (FS-MOB) represent a very promising solution. They consist in the mounting of several different micro-optical components coming

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from various sectors of manufacturing on a same substrate. The relative position of these components with the alignment of optical path enables the fabrication of complex hybrid products. Indeed, optical components (lenses, mirrors, fiber holders, detectors, beam splitters) are microfabricated using ”simple”, well known and reliable processes [10, 17]. These components are then assembled together permitting the fabrication of complex 3D microstructures [15, 5, 11, 9]. The understanding of the microworld phenomena [6, 13] and the automation of the micro-assembly tasks are currently under investigation. Recent results in the field of multiscale assembly, especially serial precise assembly demonstrate the validity of a new approach for fabricating complex 3D MOEMS based on micro-assembly [3, 4]. These results are accompanied by the development of micro-assembly stations which integrate flexibility, modularity, precision and repeatability. High yield assembly of micro-objects depends on the compatibility of tolerances between micro-assembly station and micro-object dimensions. The micro-assembly station bring an interesting solution for fabricating 3D MOEMS which integrate some RFS-MOB and enable the design of 3D complex optical path. Due to the microfabrication tolerances and the inaccuracy of optical parameters coming from technological processes, the development of new micro-assembly station able to compensate them through the assembly of reconfigurable free space micro-optical benches (RFS-MOB) is proposed. This station enables the manipulation of generic components of RFS-MOB using active microgripper associated to a robotic micro-assembly system. Active gripping ensures reversible locking systems (which are not possible with passive gripping) and a fine control of tasks like [14]. For the precise control of position and the alignment of optical path, the 3D micro-assembly station comprises of 8 degrees of freedom (DOF) arranged into 2 manipulators with a vision system. In this paper we propose an original micro-assembly station equipped with an active microgripper. In the following, the concept of RFS-MOB is detailed in Section I. Section II describes the robotic micro-assembly system. Section III presents the experimental results. Finally, Section IV provides some conclusions.

2 The concept of RFS-MOB

The concept of RFS-MOB is composed of two bulk-micromachined silicon parts: a non-movable substrate (base), and a removable MOEMS chip (holder) with desired optical component (see Figure 1, 2). The hybrid free-space optical system can be built on the substrate by the assembly of the individual holders equipped with optical function on the precisely formed rails using an active microgripper . The substrate is a reference part for the others parts of the optical system and allows their alignment on micromachined rails, along the optical axis. The substrate can be designed for the simplest configuration with one straight rail or the complex form (two or three perpendicular rails). It is composed of two anisotropically etched V-grooves (guiding of movement) and a central runner with two vertical V-grooves (see Figure 4). Such a construction of the rail ensures the well defined surfaces of reference for the other parts of MOB. This surface permits the optical path alignment in Z direction which improve the performance of the optical bench (reduction of optical loss).

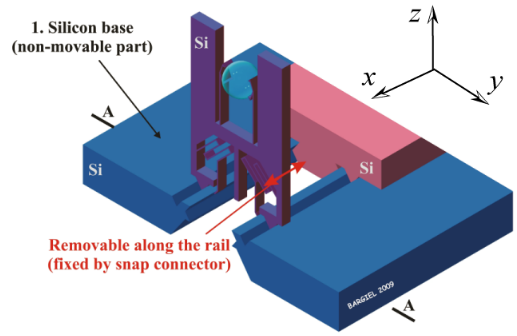

Fig. 1 RFS-MOB concept: general view.

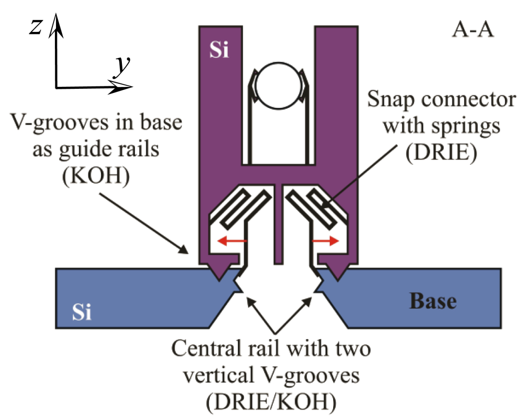

Fig. 2 RFS-MOB concept: Holder assembled on the substrate.

The holder with appropriate optical component can be assembled on such a rail using a microgripper, accurately positioned by a 3D micro-assembly station. In such a configuration, the holder contacts with the rail by two protruding grooves with triangular cross-section, compatible to the guiding V-grooves. In order to fasten the holder in a chosen position onto the rail, it contains a mechanical snap connector with two folded springs, which shape is adjusted at the end to the shape of the vertical V-grooves (see Figure 1). Once the springs are pressed by the microgripper (see Figure 3), the holder can be inserted directly into the rail, adjusted to the optical setup, and then fastened by the release of the springs.

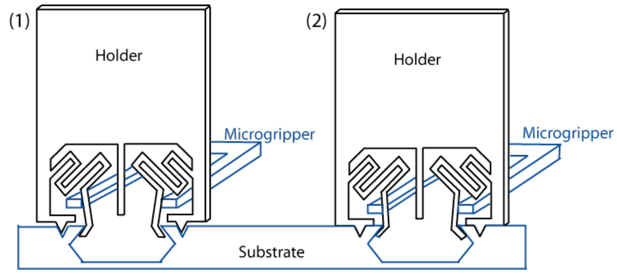

Fig. 3 (1) Gripping principle of the holder by the microgripper and (2) releasing in the groove.

The mechanical contact of the holder with the substrate occurs between its two protruding rails and the V-grooves on the base. The snap connector is also in contact to a rhomboid-shaped runner formed on the carrier's back side and they ensures the lock in Z direction (see Figure 2). Hence, once the adjustment of the all holders is finished, UV-curable glue can be used to definitely preserve their positions on the rail.

The dimensions of the bench is 2.5 *cm* x 1 *cm*. The dimensions of the holder is 800 μm x 1350 μm x 50 μm, and the cross section of the spring is 10 μm x 50 μm.

The results of fabricated rails are shown in Figure 4. The substrate is obtained after the following microfabrication process:

1. thermal oxidation of the double side wafer with 1.4 μm,
2. photolitography 1 of the back side and SiO_2 etching in BHF,
3. KOH etching in back side for forming 100 μm membrane,
4. thermal oxidation of the back side with 1.0 μm,
5. photolitography 2 of the top side and SiO_2 etching in BHF,
6. photolitography 3 of the top side and DRIE etching of 100 μm membrane,
7. after stripping and cleaning, silicon etching in KOH,
8. SiO_2 stripping in HF.

The results of fabricated holders are shown in the Figure 5. The available components are mirror, lens holder, and circular aperture. The substrate is obtained after the following microfabrication process:

1. thermal oxidation of the double side wafer with 1.2 μm,
2. photolitography 1 of the back side and photolitography 2 of the top side,
3. SiO_2 etching in BHF and photoresist stripping,
4. DRIE etching of the top side,
5. silicon etching in KOH by protected the top side by a chuck,
6. SiO_2 stripping in BHF.

More details about the design and the microfabrication process are available in [1]. At the end of the process, the holders are maintained by a tether designed in [8]. The lens holder receives a special design for integrating a lens grip. A lens grip is two flexible cantilever equipped at the end by double hooks (see Figure 5).

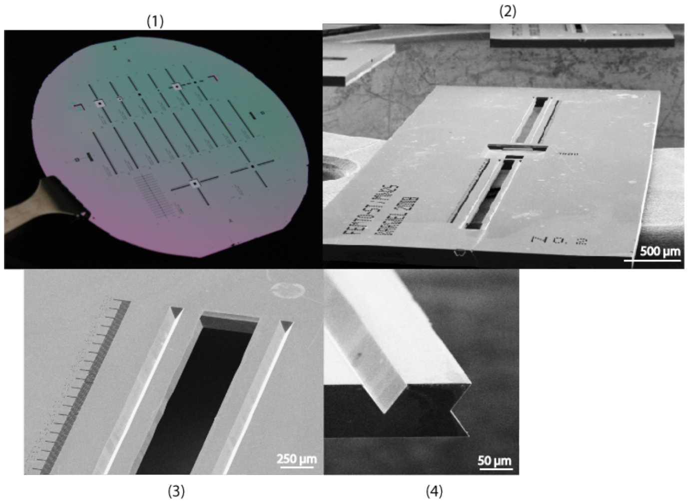

Fig. 4 Microfabricated substrate using DRIE and KOH etching: (1) general view of the wafer, (2) bench with straight rail after dicing, (3) the rail with a ruler, and (4) view of V-groove and the vertical V-groove.

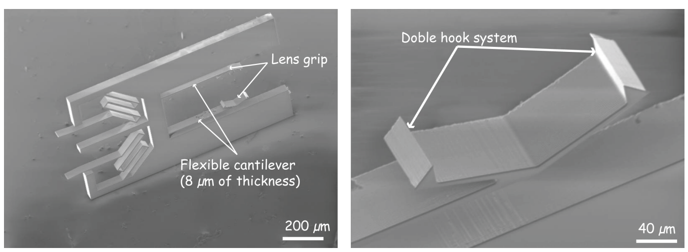

Fig. 5 SEM pictures of the designed lens holder

From a micro-assembly point of view, the RFS-MOB concept helps to reduce adhesion effects during releasing the holder. When the holder is locked into the rail (see Fig. 6), protruding rail and V-grooves are in contact, like the leg and the vertical V-grooves. These contacts are blocking the lateral movement of the holder during the releasing which occurs when the adhesion force is not dominated by another forces. In this sense, the RFS-MOB design constitutes an interesting strategy to overcome adhesion forces during releasing tasks.

An attractive feature of the presented MOB technology is the ability to adjust the position of every optical part by active way. Thus, the inaccuracy of the optical parameters coming from technological processes, e.g. shift in a focal length of microlens, can be compensated. This feature makes the MOB an reconfigurable tool to build the optical systems at different level of complexity.

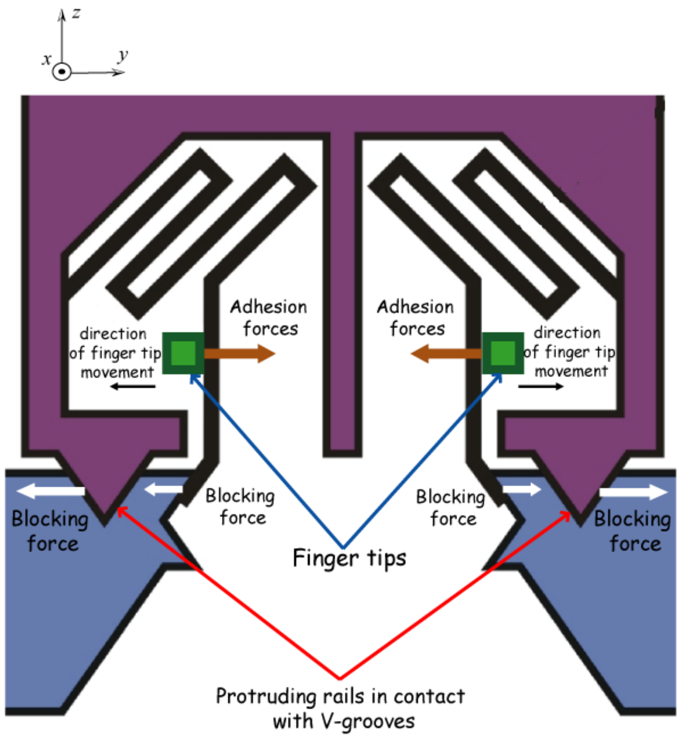

Fig. 6 Effect of blocking during releasing the holder

3 Micro-assembly Challenge and Micro-assembly System

3.1 Micro-assembly Challenge

The micro-assembly of micro-optical benches needs a precise and an adapted micro-assembly station. In addition, the features of this station must match the required DOF for micro-optical bench assembly. For these reasons, the developed micro-assembly station integrates:

1. coarse and fine positioning stages. The ability of the micro-assembly station for positioning the holder along the rail depends on the range of the stage. The fine positioning is used for compensating positioning errors from of the coarse manipulator,
2. two rotation stages (pitch and yaw) for micro-object orientation on the bench (rolling is not necessary because of the design of the components),
3. views of assembly sequence (top view and side view) to enable teleoperated assembly,

4. adapted end-effector of the microgripper which have a suitable dimension for the holder and ball lens gripping,
5. reduction of the effects of adhesion forces during micro-assembly.

3.2 Micro-assembly system

3.2.1 Description of the workcell

In order to perform serial assembly, the workcell comprises a robotic structure, vision system, and a microgripper. The proposed 3D microrobotic assembly system is a structure with eight DOF motorized stages arranged into two robotic manipulators. The kinetic scheme of this robotic structure is presented in Figure 7.

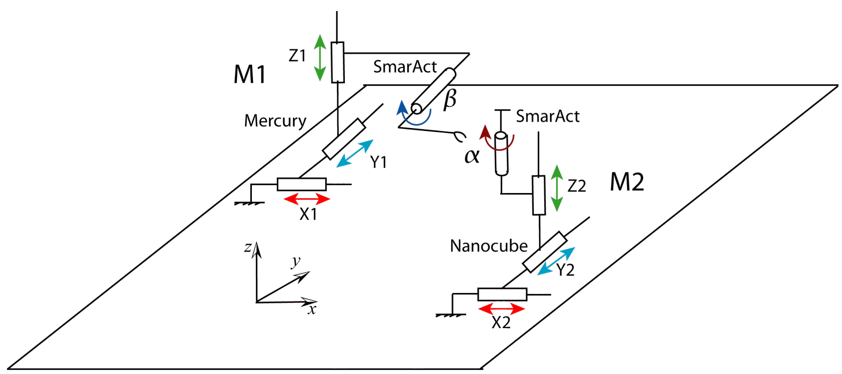

Fig. 7 The kinematic sheme of the microrobotic structure.

The manipulator M1 is a large space positioning robot with four DOF. It is composed of linear coarse positioning stages from Physik Instrumente - M112.1 DG (with 25 mm of travel range) and a rotation stage SmarAct - SR-3610-S (with 1.1 μ° of resolution). This robot permits to manipulate holder (break tether, pick, move, align to the groove and guide the holder) and other optical components. The manipulator M2 constitutes a support of the substrate and is composed of fine positioning robot with four DOF based on P-611.3 NanoCube XYZ Piezo Stage with nanometric resolution (with 100 μm of travel range) and a rotation stage SmarAct -SR-3610-S. This robot carries the substrate during the assembly process and corrects the trajectory during the guiding operation. All of these stages are closed loop controlled. The robotic configuration is shown in Figure 8.

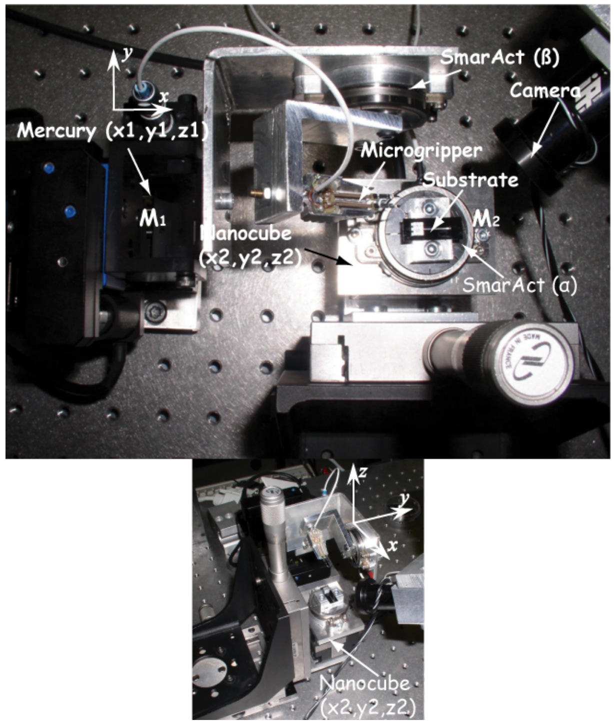

Fig. 8 Developed micro-assembly station for micro-optical benches.

3.2.2 High voltage piezogripper

For gripping holders, ball lenses,.. and ensuring reconfigurability, actuated micro-gripper which is the MMOC (Micromanipulator-Microrobot-On-Chip) piezogripper developed in FEMTO-ST Institute [12] was chosen. It has two active fingers and two DOF for each finger. Both fingers of the microgripper can independently move along Y and Z. It permits a stroke of 320 μm in open-close motion(Y) and 400 μm in up-down motion (Z). The resolution of the piezo actuator can attain 1.6 $\mu m/V$ consequently submicrometric accurate motions are achievable. In reference to [2], [7], the modularity of this microgripper is largely proved. Appropriate finger tips (tools) are chosen and installed on the MMOC. The microgripper is mounted at the end of manipulator M1 (see Figure 8). The grasping is done on the flexible part of the holder shown in Figure 3. This microgripper has to provide enough gripping forces during micro-assembly. The blocking forces is up to 100 mN in Y direction and 15 mN in Z direction for 100 V.

3.2.3 Control system of the micro-assembly station

The micro-assembly station is also equipped with a visualization system. It helps the alignment for entering in the groove, guiding, and supervising the whole assembly process (teleoperated mode in these works). This micro-assembly station is controlled via AP2M (French acronym of “Application for Controlling the Micro-Manipulation”), a home made software based on Borland C++ Bulder 6.0. AP2M is a software which makes a link between human (operator) and movable parts of the station. The modularity of this software enables the rapid development of the station. An AP2M module is developed for each element of the micro-assembly station (stages, microgripper,...).
It enables teleoperated assembly by a joystick and automated pick and place tasks. Due to the flexibility of the AP2M, the integration of new devices (force sensor, position sensor, camera) is simplified.

3.3 Micro-assembly sequence

3.3.1 General assembly sequence

The general assembly sequence gives a global view of tasks done after microfabrication of microparts. For holders, there are made by using a 4 Inches SOI wafer and at the end of the microfabrication process, each holder is maintained by the tether on the wafer. Substrates are done on 4 Inches wafer and separated by dicing. The substrate is firstly brought on the M2 robot and is used like a workplane during the holder assembly (Figure 9-1). Tethers are broken and the holder is picked and put on the holder storage (Figure 9-2). After that, the holder storage is put on the substrate and the assembly of the holder on the substrate is following (Figure 9-3).

3.3.2 Detailed assembly sequence

Micro-assembly process is the sequence of tasks to operate for obtaining complex heterogeneous devices. The sequence of tasks takes into account the specificities of the parts. The substrate is the reference part during assembly process of RFS-MOB. Holders are sequentially assembled on it and a precise position control is very important for ensuring the optical features of the assembled systems. Each holder assembled to the substrate goes through six steps, which are: (1) the holder is picked by a microgripper, (2) the holder is removed from the chip wafer, (3) the holder is moved and rotated, (4) the holder is aligned to the groove and inserted on input port of the guiding rail, (5) the holder is guided on the rail, and (6) the holder is released.
During the guiding, two strategies can be employed:
- The contact between protruding rails and V-grooves is maintained. The overshoot of the contact force has to be controlled to avoid the sliding of the micro-parts be-

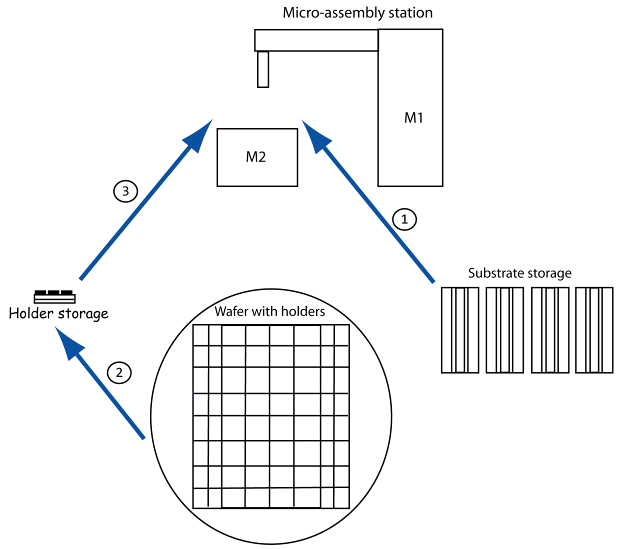

Fig. 9 Description of the general assembly sequence.

tween the microgripper and the breaking of the flexible part.
- The contact is avoided and control laws which take into account forces during micromanipulation are developing. In this sense, force feedback during the guiding task is investigating.
For the teleoperated mode, the operator manages the guiding task using views of cameras.

4 Experimental results

4.1 Holder assembly

The assembly sequence is tested on the micro-assembly station. This experiment is done by teleoperated mode by using the joystick. The assembly sequence is followed and first results of assembly are shown in the Figure 10. During the releasing of the holder, the effectiveness of the blocking force for reducing the adhesion force is observed. The Z-lock rail and two folded springs ensure the fastening of the assembled holder.

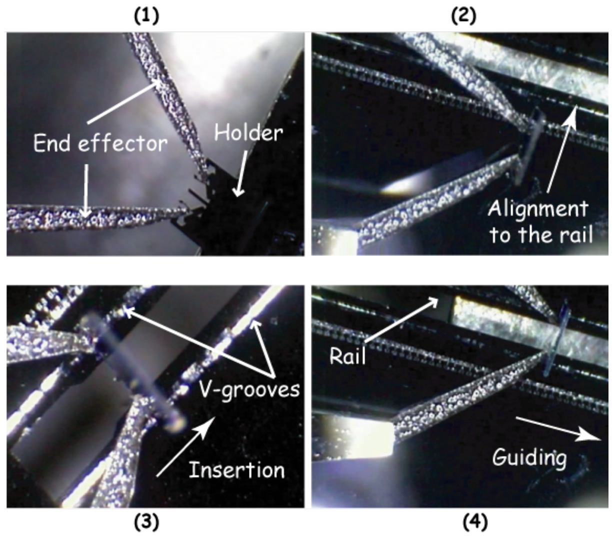

Fig. 10 Assembly sequence for holder micro-assembly: (1) Pick of the mirror on the flexible part (springs), (2) Move on space after rotation, (3) Guide in the groove, (4) Release.

4.2 Ball lens assembly

The ball lens has to be inserted on the lens holder designed with the ball lens grip. The diameter of the ball lens is about 254 μm. Two strategies can be used for the ball lens assembly:
- the ball lens is previously put on the lens holder and after that the lens holder is assembled on the substrate
- the ball lens is put on the lens holder when this one is assembled on the substrate.

This second strategy is chosen because the right position of the holder in the substrate enables a good accessibility on the lens grip. For assembling the ball lens in the lens holder, the ball lens is picked by the microgripper and inserted into the lens grip. The ball lens is correctly maintained when it is gripped on the center. The sequence of ball lens insertion in the lens grip is shown in Figure 11.

4.3 Assembled demonstrator

First results conduct to the fabrication of a demonstrator. The assembled demonstrator is composed of a mirror and a lens holder. The ball lens is put on the lens holder after the assembly of the holder on the substrate. This demonstrator can be used for testing the focal length of the ball lens by changing the distance between the mirror and the lens holder. The distance which minimizes the spot size form the fiber

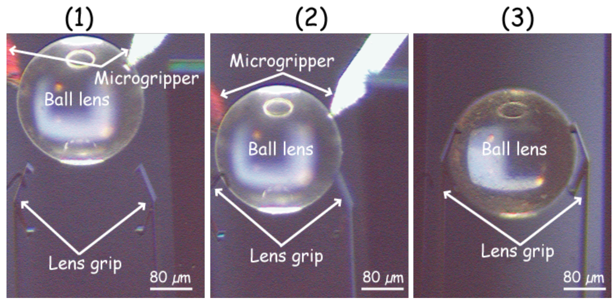

Fig. 11 Assembly sequence of ball lens using a microgripper: (1) the ball lens is gripped by the microgripper and align to the lens grip, (2) the ball lens is inserted to the lens grip, and (3) the ball lens is released and maintained into the lens grip.

laser source corresponds to the focal length. The complete view of the RFS-MOB demonstrator is shown in Figure 12.

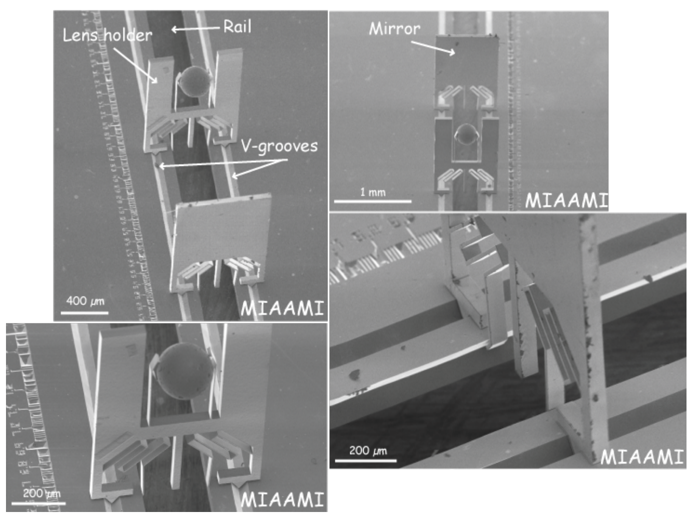

Fig. 12 SEM pictures of the assembled demonstrator.

4.4 Positioning accuracy

Positioning accuracy of components is an important criteria which influences optical microbenches. The developed micro-assembly station enables 1 nm resolution along x, y, and z and 3 μ° in α and β. Fine positioning of components can be done by active positioning, in other words, optimized position corresponds to a minimal optical loss. The reversible locking enables to perform this step.

4.5 Observed difficulties during micro-assembly

During the micro-assembly of the demonstrator, the principal difficulties concern the control of the guiding task. Indeed the contact appears between V-grooves of the substrate and protruding grooves of the holder. During the contact, the overtaking friction can break the flexible part of the holder. The use of force control can reduce the risk of breaking. In this case, the integration of force sensors in the micro-assembly station constitutes a future works. Additionally, the microscale forces like electrostatic, and pull-off force (included van der Waals, and capillary force) have to be taken into account and conducts to the development of microscale hybrid force position control for precise control of interactions.

5 Conclusion

In this paper, we have proposed a micro-assembly station which permits the assembly of 3D MOEMS. The RFS-MOB is introduced to bring a response to a new generation of complex assembled MOEMS. Indeed the microfabrication of elementary optical components uses ”simple”, well known and reliable processes. This station enables the assembly of new micro-optical systems based on the micro-assembly of holders with optical features and the substrate. The use of active microgripper is a proposed solution for ensuring the reconfigurability of micro-benches. The micro-assembly system is developed and an eight DOF robotic configuration with nanometric resolution ensures the precise positioning of components. The principle is validated through successful assembly sequence of holders on the substrate in tele-operated mode. A demonstrator MOEMS with a mirror and a lens holder is assembled. Other type of optical components can be designed like diffractive lens, beam splitter, and others, which can also be assembled with the same micro-assembly station. At the end, complete MOEMS like microspectrometer, 3D confocal miniaturized microscope, and miniaturized goniometer can be obtained. The main advantage of the RFS-MOB concept is the reconfigurability and the use of generic optical components for obtaining rapidly complex and new hybrid microsystems. According to the reconfigurability of RFS-MOB, it can also be used like a tool for characterizing new optical components. Due to the compliance of the micro-objects, the use of the force sensor constitutes a promising solution for automated tasks like pick and place, insertion, guiding. The integration of force sensor in the workcell and hybrid force/position control law are in current investigation. The characterization of the assembled micro-bench should complete the project and future work will focus on that.

Acknowledgements This work has partially been supported by the Franche-Comté region under the MIAAMI Project and NEMO/Marie-Curie. The authors would like to thank David Hériban for discussions and his help.

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