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Technology platform for hybrid integration of MOEMS on reconfigurable silicon micro-optical table

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Abstract

This work presents a novel approach to the development of MOEMS devices by robotic micro-assembly of individual micro-optical components onto reconfigurable free-space micro-optical table (RFS-MOT). Various micro-optical elements (e.g. microlenses, micromirrors) are integrated within a generic structure of silicon holders. The holders are manipulated by 3D micro-assembly station with active microgripper, then aligned with nanometer precision within the guiding rails of silicon baseplate, and finally fixed by release of integrated mechanical snap connector. The fabrication of RFS-MOT components involves bulk micromachining of standard silicon wafer (baseplate) or SOI wafer (holders). The design and technology of RFS-MOT is presented. The successful micro-assembly of holders is demonstrated as an experimental validation of the proposed approach. The new method for measuring of position of assembled holder, based on laser triangulation displacement sensor, is described.

Keywords: MOEMS; micro-assembly; micro-optical table; hybrid integration; microgripper, silicon micromachining; SOI, displacement sensor

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1. Introduction

Hybrid integration of heterogeneous micro-optical components on a single micromachined silicon substrate constitutes a promising solution for manufacturing of new type of micro-opto-electro-mechanical systems (MOEMS). Recent works in this field demonstrate the validity of this approach by fabrication of complex structures, e.g. microspectrometer [1] or imaging system [2], in which an optical signal is transmitted in plane of the substrate through vertically positioned micro-optical elements, inserted into dedicated mounting slots as individual chips. The position of each chip on the substrate is well defined in the layout of photolithography mask of mounting slots whereas silicon springs, created inside the slots, provide blocking force to stabilize the position of assembled elements.

One of the principal challenges of this integration strategy is the effective assembly of small (mm-sized) and fragile micromachined parts. This is a delicate operation which becomes tiresome, time-consuming and causes lots of losses when performed manually by human operator using a high magnification microscope and microtweezers.

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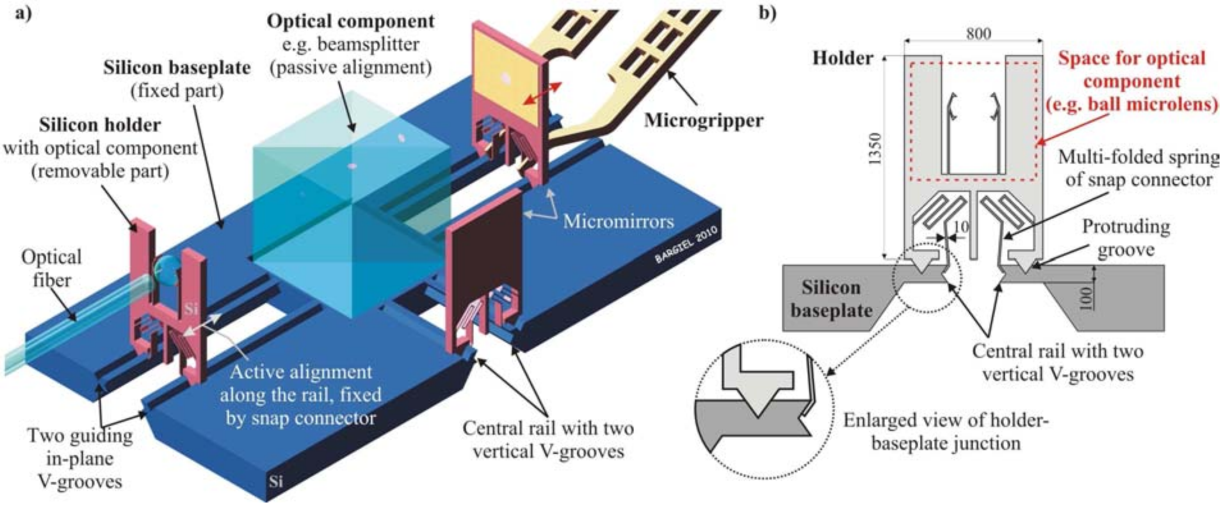

Fig. 1. Reconfigurable silicon free-space micro-optical table (RFS-MOT): a) assembly concept of individual optical components, integrated with removable holders, b) details of holder construction.

Therefore, robotized and computer-controlled micro-assembly stations, intensively developed during the last few years, have to be employed to increase the efficiency of assembly tasks, to improve the yield and reliability, and consequently reduce the cost of MOEMS. In addition, passive alignment of micro-optical parts in the predefined slots is sensitive to inaccuracy in optical parameters, commonly observed due to variation of technological process. Compensation of this inaccuracy may require precise displacement of an element along optical axis which can be achieved to only limited extent in passively aligned system by moving the element to adjoining mounting slots.

In this paper we present technological platform to build MOEMS devices on reconfigurable silicon free-space micro-optical table (RFS-MOT) using a robotic micro-assembly technique. In reference to our previous paper [3], the first results of characterization of micro-assembly experiments are described.

2. Concept of RFS-MOT and basic silicon components

The concept of RFS-MOT is based on robotic micro-assembly of various micro-optical elements, integrated with removable silicon parts (holders), on a bulk-micromachined universal silicon substrate (baseplate). The baseplate constitutes rigid and stress-free mechanical support, characterized by excellent surface quality and equipped with a set of two-directional micro-mechanical rails (Fig. 1a). The holder permits the optical element to be hybrid or monolithically integrated within its structure and then to be assembled on the rail in arbitrarily chosen place. Using a newly developed 3D micro-assembly station, the holder can be actively aligned with nanometer precision along the rails and finally fixed by releasing of the mechanical locking system (snap connector). Further adjusting of holder position or replacement of a damaged holder is possible, ensuring reconfigurability of optical system. Thus, variation of the optical parameters, e.g. focal length of microlens etc., can by precisely compensated.

The fine control of holder position on the rail is of great importance to ensure the usefulness of the RFS-MOT. In order to achieve this goal, a set of compatible V-grooves is produced both in baseplate and holders by anisotropic etching of silicon. Two standard in-plane V-grooves and two “vertical” ones are formed in baseplate. In-plane V-grooves creates guiding rails as well defined surfaces of reference for other microparts of RFS-MOB. For instance, the holder is in contact with these rails through two protrusions with matched triangular cross-section, formed by DRIE. Whereas “vertical” V-grooves enable mechanical fastening of the holder onto the baseplate. Figure 1b shows detailed view of the snap connector, integrated within the structure of each holder. It is composed of two 10-μm-thick silicon multi-folded springs, which are adjusted at the very end to the shape of central rail of the baseplate.

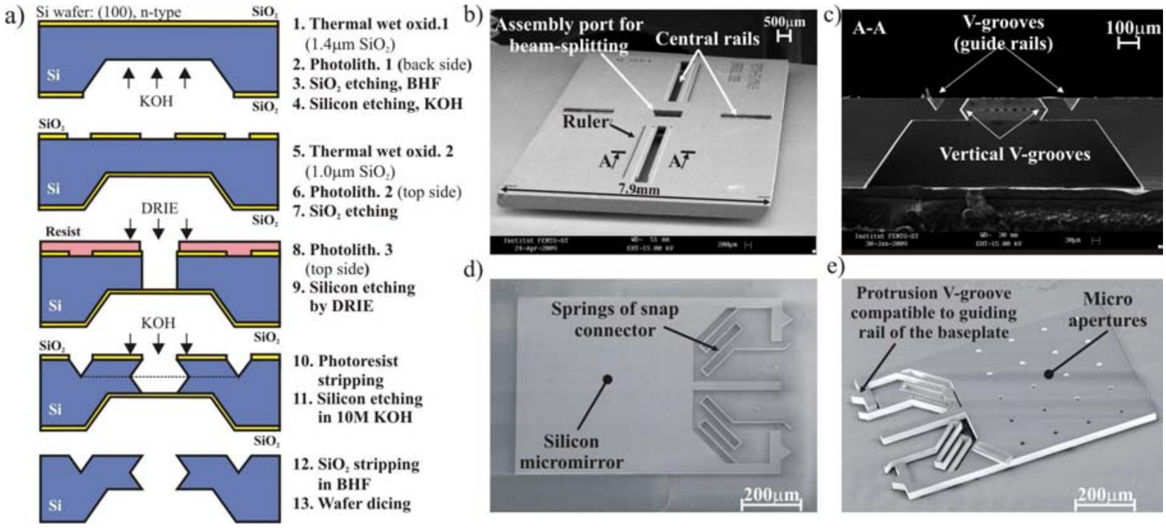

Fig. 2. Fabrication of silicon components of RFS-MOT: a) flow-chart of baseplate fabrication process, b) two-directional baseplate with four rails, c) cross-sectional view of the rail, d) holder with silicon micromirror, e) holder with matrix of microapertures.

3. Fabrication of silicon components of RFS-MOT

The baseplate was fabricated on n-type, (100)-oriented wafer. The crucial parts- the rails, were formed in 300-µm-thick membrane, back-side wet etched in 10M KOH solution (80^{o}C) using thermal SiO_2 mask (Fig. 2a). The membrane was bilaterally covered with thermal 1.0-µm-thick SiO_2, which was patterned on the top side and used as a mask to etch 300-µm-wide trench through the membrane by DRIE in A601E system (Alcatel, France). The original shape of central rail with two vertical V-grooves was achieved by subsequent wet KOH etching (10M, 60^{o}C) of vertical sidewalls of the trench, keeping the same SiO_2 mask layer. Each vertical sidewall was converted into two (111)-oriented sidewalls, inclined to each other at the angle of ~110^o. After stripping of the SiO_2 layer, the wafer was divided into chips by diamond saw dicing. Figure 2b-c shows an example of fabricated structure.

The holders were fabricated in a 50-µm-thick device layer of n-type, (100)-oriented SOI wafer with 1.0-µm-thick buried oxide layer (BOX) and 400-µm-thick substrate layer. The structures were etched into the device layer by DRIE, using thermal SiO_2 mask. In order to release the structures, small cavities were back-side etched though the substrate layer in 10M KOH. A chuck (AMMT, Germany) was employed to protect already formed silicon structures on the top side. Finally, the exposed area of BOX as well as SiO_2 mask were etched in BHF solution, releasing the holders. Different types of holders, equipped with micro-optical components (e.g. micromirrors) or prepared to be hybrid integrated with it (e.g. ball microlens), have been fabricated (Fig. 2d-e).

4. Micro-assembly experiments

The assembly of RFS-MOT requires an accurate positioning of every manipulated component in the rails. This is challenging since many factors may influence the final result, e.g. the quality of the motion generated by micropositioning stages, the microgripper control, microfabrication tolerances, surface forces, stability of the grasp, stiffness of the spring, etc. Up to now, few micro-assembly stations have been available and very few studies have been carried out to characterize the achieved positioning accuracy [4].

The micro-assembly experiments were carried out using 9 degrees of freedom (DOF) micro-assembly station, comprising microgripper (4 DOF), 3 video microscopes, all interfaced with one control computer (Fig 3b). The total motion of 20 mm was achieved (resolution of few nanometers) thanks to the combination of coarse and fine motions of Nanocube stages (PI). To characterize the positioning accuracy of assembled holders, the repeatability of the micro-assembly workstation must firstly be addressed. We propose a new optical method to characterize the positioning accuracy. It employs a triangulation laser displacement sensor LC2420 Keyence (200 µm measuring range, 10 nm resolution), that is moved by the Nanocube to scan the component, as shown in Fig. 3c. Dedicated software calculates the pitch and yaw angles and position of the assembled holder in a reference frame which are the main influence parameters for optical products. To validate this method, the scanning of the baseplate surface has been performed (Fig 3d) while a controlled rotation was applied by very accurate rotation stage (SR-3610, Smaract, 3 µ° in resolution). Five scanning cycles were made for every rotation step of 0.5°. Finally, a comparison between the applied rotation and the measured orientation of the substrate was obtained (Fig. 3e,f). The experimental results show that the orientation can be measured with an accuracy better than +/- 0.08° and +/-0.04° for the yaw and pitch angles respectively, with a standard deviation always smaller than 0.01°. This validates the usefulness of this method for further investigation of assembly process.

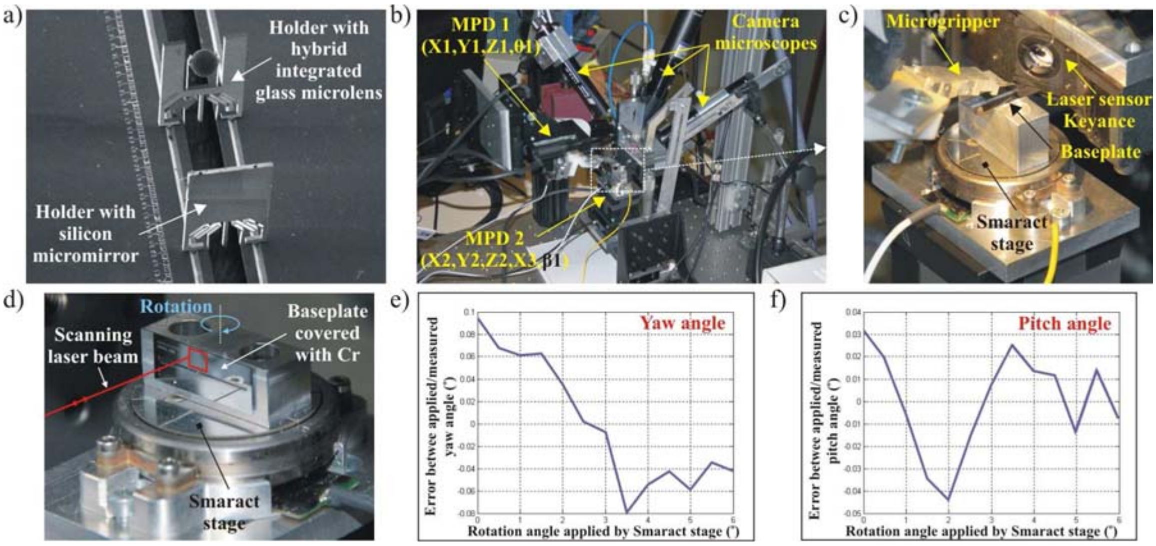

Fig. 3 Characterisation of assembly process: a) different holders assembled on the baseplate, b) experimental set-up for measuring of positioning accuracy - microgripper mounted on 4 DOF micropositioning device (MPD1), the baseplate mounted on 5 DOF device (MPD2), c) zoom on the worktable, d) angle measurements by laser sensor, e) error values between set and measured orientation of the substrate for yaw and pitch angles.

5. Conclusions and perspectives

The reconfigurable silicon free-space micro-optical table, presented in this paper, generates multiple possibilities of its application towards a new generation of complex MOEMS. It can be used as a tool to build proof-of-concept demonstrators or to characterize new micro-optical components. Nevertheless, the accuracy and repeatability of the assembly process have to be investigated. Preliminary results, based on the developed measurement method with laser displacement sensor, indicate that the orientation of assembled holder can be determined with sufficient accuracy better then +/- 0.08° and +/-0.04° for the yaw and pitch angles respectively.

Acknowledgments

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References

[1] Das AN, Popa DO, Sin J, and Stephanou HE, Precision Alingnment and Assembly for a Fourier Transform Microspectrometer, *Journal of Micro-Nano Mechatronics*, Nov. 2009, vol. 5, no1-2, pp. 15-28.
[2] Descour M R, Kärkkäinen A H O, Rogers J D, and Liang C 2002 Toward the development of miniaturized imaging systems for detection of pre-cancer *IEEE Journal of Quantum Electronics* **38** No.2 122-130
[3] Bargiel S, Rabenorosoa K, Clévy C, Gorecki C, and Lutz P, Towards Micro-Assembly of Hybrid MOEMS Components on Reconfigurable Silicon Free-Space Micro-Optical Bench, *Journal of Micromechanics and Microengineering* 2010, Vol. 20, No.4, 5012.

[4] Tamadazte B, Marchand E, Dembele S and Lefort-Piat N, CAD model based tracking and 3D visual-based control for MEMS microassembly *The International Journal of Robotics Research*, To appear, 2010