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Technical note

Silicon end-effectors for microgripping tasks

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ABSTRACT

Micromanipulation is a key task to perform serial assembly of MEMS. The two-fingered microgrippers are usable but require specific studies to be able to work in the microworld. In this paper, we propose a new microgripping system where actuators and the end-effectors of the gripper are fabricated separately. End-effectors can thus be adapted to the manipulated micro-objects without new design and/or fabrication of the actuator. The assembly of the end-effectors on our piezoelectric actuators guarantee a great modularity for the system. This paper focuses on the original design, development and experimentation of new silicon end-effectors, compatible with our piezoelectric actuator. These innovative end-effectors are realized with the well known DRIE process and are able to perform micromanipulation tasks of objects whose typical size is between 5 μm and 1 mm.

1. Introduction

There are several ways to assemble micro-objects (microassembly). First, batch assembly with flip-chip processes is commonly used in MEMS production. It allows to build planar MEMS by the assembly of several planar components. It is especially used when microfabrication processes of two different microparts cannot be realized on the same substrate. Secondly some research teams improve methods to assemble microproducts by self-assembly methods. In this case, micro-objects are driven by non-contact forces or capillary forces in the required position. This parallel assembly principle allows to position a large number of objects simultaneously but the efficiency is mainly low and several objects do not reach their final position at all [1]. Serial assembly is a third approach which is used for more complex out-of-plane structures or prototyping. In this case, innovative robots have to be able to manipulate micro-objects with a high accuracy. The study of new micromanipulation methods continues to be a big issue for the development of serial assembly nowadays.

The major difference between micromanipulation and manipulation at macroscopic scale concerns the nature of predominant forces applied to the objects. The volume forces (weight, inertia) are indeed negligible in respect to the surface forces (pull-off force, electrostatic forces, etc.) for microscopic objects. These forces, whose effects are negligible on a macroscopic scale, drastically modify contact behavior [2–6].

These surface forces may affect micromanipulation tasks, especially grasping and releasing. The success of this kind of task depends on several parameters like the materials, the size of both the microgripper and the object, the nature of surrounding medium (vacuum, air, liquid). Some handling micromanipulation strategies are currently being studied to propose an innovative principle adapted to the microworld (capillary grippers, ice grippers, adhesion grippers, etc.). The two-fingered microgrippers are usually used, but require a specific design to be able to manipulate micro-objects despite adhesion.

This article deals with a new type of two-fingered microgripper which is able to handle micro-objects whose size is lower than 100 μm. Section 2 is focused on the modular approach of the gripper. Section 3 deals with the architecture of the end-effectors and Section 4 describes their mechanical design. Finally Section 5 presents the fabrication and experimentations to conclude in Section 6.

2. Modular architecture of the gripper

Microtweezers which are capable of manipulating objects up to 100 μm are usually realized in monobloc structures using standard microfabrication techniques. In this case, end-effectors (in contact with the manipulated object) and actuators (able to induce the movement of the end-effectors) are built in the same fabrication process. This monobloc approach has two major drawbacks:

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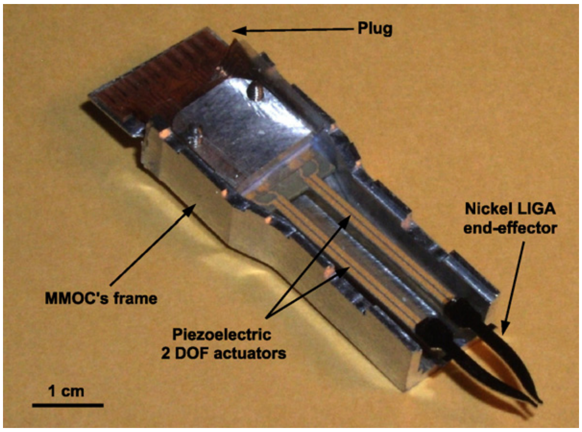

Fig. 1. MMOC microgripper with previous end-effectors in nickel.

- As the adhesion between the end-effector and the object could perturb the release of the object, the design (size, roughness) of the end-effectors must be carefully studied for every type of object. Consequently, a monobloc gripper including actuators and end-effectors must be redesigned and fabricated for every type of application.
- The reliability of MEMS microfabrication process is lower and lower when the complexity increases. The structures of the actuators are usually more complex (e.g. electrostatic actuator including electrodes, mechanical spring, etc.), than the design of the end-effector (e.g. a simple beam). Consequently, in a fabrication batch of monobloc grippers, a lot of actuators are not efficient despite the fact that end-effectors could be used.

To overcome both drawbacks, we propose to manufacture actuators and end-effectors separately and to assemble them together to build the whole gripper.

To perform gripping actuation, we currently use a duo-bimorph piezoelectric actuator [7]. Developed in our institute and called MMOC (*Microprehensile Microrobot On Chip*) [8], this actuation principle allows open-and-close motion as well as up-and-down motion. The structure of the actuators has been designed to use different end-effectors, called *finger tips*. They are temporary fixed onto special pads at the end of piezoelectric actuators by a removable thermal glue [9]. Initially, nickel end-effectors of a thickness of 180 μm (Fig. 1) were designed and produced with LIGA[2] process. They enabled the manipulation of objects whose typical size is above 100 μm. This article focuses on the design of new end-effectors which are able to manipulate objects below 100 μm.

As the behavior of the micro-objects under 100 μm is dominated by surface and contact forces, performing manipulation under this limit is a great challenge [10]. Surface forces must be reduced to ensure that micro-objects can be released after the handling. Four aspects can be taken into account: reducing gripper surface, texturing gripper surface, controlling the environment, and/or using a physical principle to overcome adhesion.

In this article, we propose new end-effectors which have adapted shape and textured surface to reduce adhesion. To increase the number of application fields, the end-effectors are able to operate in different environments like air, vacuum or liquids. There are great interests in bioengineering for handling micro-objects in biological liquids [11]. Moreover, an original solution to reduce perturbations in micro-assembly tasks is based on performing tasks in a liquid medium which is able to decrease both surface and contact forces [12–14].

The innovative end-effectors compatible with the MMOC microactuators and immersible in various liquid media, are described subsequently.

3. Architecture of the end-effectors

The proposed end-effectors have to be able to manipulate objects whose typical sizes are between 100 μm and a few micrometers. The design requires the definition of material constraints associated with the fabrication processes and the required mechanical behavior for micromanipulation tasks.

3.1. Materials and microfabrication capabilities

As regards the material of new end-effectors, two parameters must be taken into account: the mechanical properties (material, geometry) and the micromachining capabilities. First, a piezoelectric actuator cannot be immersed, thus end-effectors must be sufficiently long to have their extremity fully immersed and their base safely in the air. Therefore the capillary distance and the depth of the liquid medium must be taken into account to define the length of the end-effectors. Secondly, to manipulate micro-objects, the width and the height of end-effectors must be up to 100 μm, so microfabrication is the only way to produce this kind of mechanical object. Thus, the material has to be compatible with microfabrication processes.

Consequently, there are few materials which can be used, and crystalline silicon is one of the best choices. In fact, silicon has great mechanical features in the microworld: its Young modulus is 20% lower than structural steel and its yield stress 1.2 GPa [15] is two to four times greater than structural steel. Concerning liquid compatibility, only a few liquids like TMAH, KOH or EDP[3] are incompatible with silicon [16].

3.2. Architecture of the end-effectors

The shape of the end-effectors must be defined according to their main functions. The gripping surface has to be adapted to the size of the micro-objects. If the end-effectors are as twice as thick or more than the grasped micro-object, it is practically impossible to see the latter. The end-effectors could in fact hide the grasped object because of the light diffraction and the very small depth of focus (about a few micrometers in microscopical vision). According to the main objective of this work, minimum size of the object is 10 μm. So the thickness of the end-effectors has to be close to this value.

When micromanipulation is performed in liquid medium, end-effectors must generate minimum disturbance. Large geometry at liquid interface generates large liquid medium flow and capillary effects. Then the grasping part of the end-effector is long and thin to go through the liquid medium (about 1 mm). Furthermore, end-effectors have to be mounted manually on the microgripper with a removable thermal glue. The Surface of the glued part is consequently close to 1 mm^2 with a length of a few millimeters for manual handling.

Considering these constraints, the design of the end-effector is composed of two thicknesses of silicon (close to 10 μm and 1 mm) and both parts, thin and thick, are a few millimeters long. Several mechanical studies were made to estimate the deformation of the

[2] RontgenLIthographie, Galvanoformung, Abformung—Lithography, Electroforming and molding.

[3] TMAH: tetramethylammonium hydroxide, KOH: potassium hydroxide and EDP: ethylene diamine and pyrocatechol.