

# JMEMS Letters

## A Compact Manually Actuated Micromanipulator

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**Abstract**—This letter reports a compact, versatile, and user-friendly micromanipulator that uses an elastically deformable silicon microtweezer to grab microentities, and a micrometer head for rotational manual actuation. The micro-/macroconnection is achieved via a graphite interface that results in a compact and portable design and placement on most translation stages. The system which can operate in both air and liquid, and transport objects between the two media, has a wide range of applications. We demonstrate but a few of them, including *in situ* construction of microstructures in 3-D, isolation and placement of individual microparticles on designated spots on sensors, *on-demand* microcontact printing of microparticles, and manipulation of live stem cell spheres. [2011-0237]

**Index Terms**—Microgripper, micromanipulator, microstamping, microtweezer.

### I. INTRODUCTION

Microtweezers or microgrippers are developed and used in various fields to manipulate microparticles. They can also be implemented in automatic/robotic devices and be used to study the mechanical properties of various objects [1] and cells [2]. Several different actuation methods have been used in microtweezers, such as thermal flexure [3], shape memory alloys [4], scratch drive [5], pneumatic [6], piezoelectric [7], and optical trapping [8]. These sophisticated methods require extensive fabrication steps, electrical connections, power sources, as well as other additional components (e.g., heating and magnifying elements) for actuation, which directly affect their versatility and design parameters. In order to address several complexities in the fabrication and operation of the aforementioned methods, researchers have proposed mechanical actuation as an alternative [9].

We fabricated a compact and easy-to-use micromanipulator by combining an elastically deformable and replaceable micromachined tweezer structure with manual mechanical actuation. The device can grab, move, and place microparticles in both air and liquid and between the two media.

### II. DESIGN AND FABRICATION

The device is composed of a micromachined silicon structure that serves as the tweezer, a micrometer head, and a graphite interface con-

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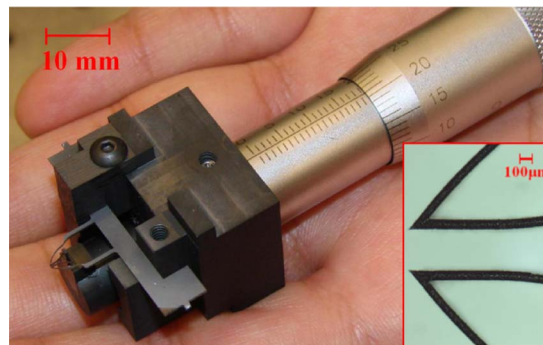


Fig. 1. Compact micromanipulator. The device is composed of a micromachined silicon tweezer, a micrometer head, and a graphite interface connecting the two. The inset shows a micrograph of the tweezer tips.

necting the two. The microtweezer is fabricated from a 500- $\mu\text{m}$ -thick Si/SiO<sub>2</sub> wafer. A single-mask photolithography process is employed to define the tweezer structure, followed by deep reactive-ion etching of the wafer. After removing an individual tweezer from the wafer by cutting the breakout tabs, it is placed on a graphite interface, which allows connection to the spindle of a micrometer head for manual actuation by rotating the thimble (Fig. 1). The microtweezer is secured on the graphite interface by a screw on each side of the die. The clamp/screw on one side is intentionally not in place for improved visual clarity (Fig. 1).

The inset of Fig. 1 shows a micrograph of the tips of the microtweezer. The tips close by elastic deformation of the silicon tweezer structure. The structure was designed using a finite-element software package to achieve closure of the tips by a manual input transferred to the structure by means of a micrometer head, without exceeding critical stress values that could cause fracture. The micrometer head that we used has a nonrotating spindle with a resolution of 1  $\mu\text{m}$  and a dynamic range of 25 mm (Global Towns NRM-100). The sharp tips of the microtweezer allow manipulating relatively small particles (down to 10  $\mu\text{m}$ ), while their parallel orientation (inset of Fig. 1) facilitates grabbing larger particles.

The microtweezers/micrometer assembly can be attached on a variety of translation stages to allow translation and rotation in six dimensions.

Fig. 2(a) shows the design and operation concept of the system. The “cone” in Fig. 2(a) (machined out of graphite) is connected directly to the micrometer’s spindle and can be moved back and forth by rotating the micrometer’s thimble manually. The tip of the cone rests against the bridge (or “saddle”) that connects the two prongs of the microtweezer. Moving the cone backward exerts a force on the saddle, which deforms the tweezer elastically and closes the tips. Similarly, moving the cone tip forward opens the tweezer.

The entire silicon structure is operated elastically; hence, no noticeable hysteresis or permanent deformation is caused.

The stress distribution in the microtweezers was analyzed using the ABAQUS finite-element package. Fig. 2(b) shows the result of a simulation whereby the cone tip moves backward by 110  $\mu\text{m}$ , bringing the tips into contact, closing the tweezer completely. The maximum Von Mises stress (red color) of about 103 MPa occurs where the saddle contacts the cone tip, and is well below the tensile strength of silicon ( $\sim 7$  GPa).

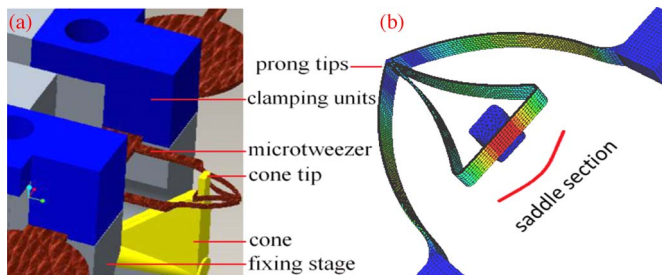


Fig. 2. (a) Design schematic of the graphite interface (clamping units, fixing stage, and cone tip), securing and actuating the silicon microtweezers. (b) ABAQUS stress analysis of the microtweezer. Maximum stress occurs at the section marked in red, while the blue color represents areas of least stress.

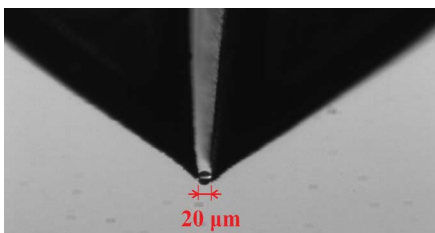


Fig. 3. Micrograph of a 20- $\mu\text{m}$  bead held by the microtweezer.

Fig. 3 shows a 20- $\mu\text{m}$  polystyrene microsphere (Spherotech) grabbed by the tweezer. The elastic deformation of the silicon structure constitutes a restoring force that tends to open the tweezer. However, since the effective stiffness of the manually actuated micrometer head is far greater than that of the silicon structure, a given amount of manual actuation effectively “locks” the distance between the two tips. Hence, a given distance between the tweezer tips can be maintained virtually indefinitely without providing continuous user input or any other kind of electrical or magnetic actuation. This provides a significant advantage in holding particles in place (or under a given amount of compression) for long amounts of time.

We characterized the mechanical behavior of the device by observing the distance between the tips versus the horizontal displacement of the saddle/cone tip. Fig. 4 shows both the experimental observations and the results of a finite-element simulation. Displacements were measured by means of calibrated bright field microscopy. Fig. 4 shows a linear input–output relationship and a good agreement with simulation results. Measurements were made during both closing and opening of the tips with no noticeable difference between the tip separations, indicating that the device exhibits no significant hysteresis. According to the slope of the line in Fig. 4, and the micrometer’s output (spindle) resolution, the resolution of the prong tip motion is approximately 3  $\mu\text{m}$ .

The primary failure mode of the device is the fracture of the silicon tweezer upon crashing into a much less compliant surface. We were able to use a tweezer for up to 6 months (about 100 uses) before it was accidentally crashed into a hard surface. Another possible mode of tweezer failure is overtightening of the thimble. However, since the tweezer motion is observed during operation, the occurrence of this is unlikely. Since multiple tweezers are fabricated on a silicon wafer, a broken tweezer can be replaced without difficulty.

### III. APPLICATIONS

#### A. Particle-by-Particle Microconstruction and Placement

Due to the device’s compact size and lack of need for any electrical instrumentation or wiring, the dynamic range and resolution of motion

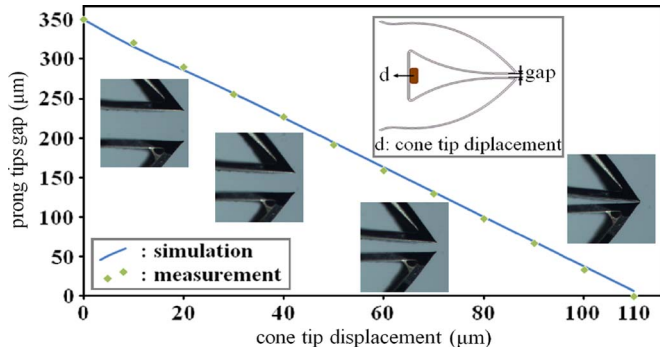


Fig. 4. Variation of tip separation with horizontal displacement of (d) saddle (positive input is away from the tweezer tips).

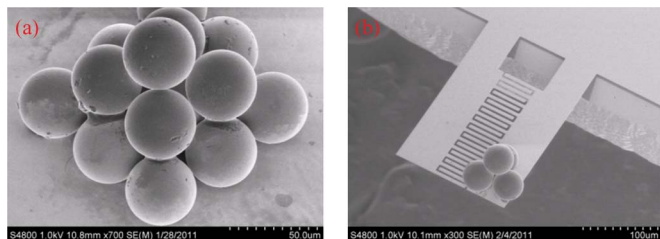


Fig. 5. (a) SEM image of the three-layer pyramid constructed with 40- $\mu\text{m}$ -diameter beads. (b) Two-layer pyramid of 40- $\mu\text{m}$  polystyrene beads on a cantilever tip.

depend on those of the motion stage where the device is attached to. The Thorlabs PT1 used here has a 25-mm dynamic range and a resolution of 20  $\mu\text{m}$ /thimble graduation, although much smaller movements ( $\sim 2$   $\mu\text{m}$ ) can be achieved by monitoring the movement under a microscope. Since the device can easily be attached to/disconnected from most translation stages, it is possible to grab a particle and move it to a far location (e.g., to another laboratory) while the target entity is held by the tweezer. Using translation stages enables multiple features such as stacking particles into 3-D geometries or placing them at distinct positions on other devices/sensors.

Fig. 5(a) shows a three-layer pyramid structure constructed using 40- $\mu\text{m}$  beads. A conductive tape was used to provide adhesion for the first layer of beads, as well as to assist in scanning electron microscopy (SEM). The  $3 \times 3$  bottom layer was constructed by placing beads directly on the conductive tape. To improve the structural integrity of the pyramid, the bottoms of the beads of the second and third layers were first dipped partially into grease.

Being able to place individual microparticles on specific areas of microstructures is important. For example, it is known that a cantilever mass sensor requires particles at its tip for maximum sensitivity [10]. Similarly, magnetic beads need to be at the cantilever tip for maximum magnetic actuation [11]. The current system can place individual particles on the tip of a micromachined cantilever. Fig. 5(b) shows a two-layer pyramid built by placing individual beads on the tip of a cantilever, avoiding adjacent structures. Such a capability could enable “on-demand” weighing of microparticles or organisms individually isolated from a large group of samples.

#### B. “On-Demand” Microcontact Printing of Discrete Particles

Functionalization of microareas individually and discretely without contaminating neighboring areas is an important advantage that can eliminate wasting chemicals and allow separate functionalization of areas within a device or multiple areas that are in close proximity. With the current system, a microstamp can be used for precise



Fig. 6. (Left) Bright field and (right) fluorescence micrographs of microstamped 40- $\mu\text{m}$  beads. The arrows indicate beads stamped by FITC-BSA.

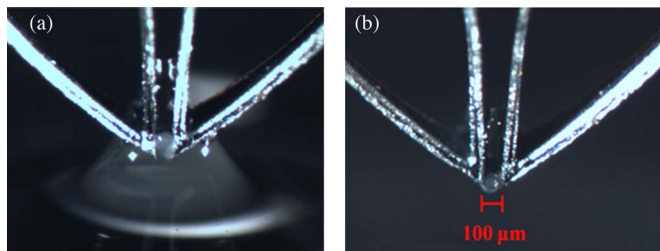


Fig. 7. Micrographs of (a) a cell sphere being pulled out of viscous Matrigel and (b) cell sphere held by a microtweezer in air.

functionalization of discrete spots. We used polydimethylsiloxane (PDMS) as the stamp material to transfer “ink” to a target surface [12] and fluorescein-isothiocyanate-labeled bovine serum albumin (FITC-BSA, Sigma) as the ink. Fig. 6 shows nine 40- $\mu\text{m}$  beads arranged in a line formation using the device. The stamp was grabbed and inked using the tweezer and brought to contact with specific beads (indicated by arrows in Fig. 6). Fig. 6 shows fluorescence only from the targeted beads. This result demonstrates that the manipulator can apply sufficient pressure on individual beads to transfer the ink without causing the stamp to slip off the tweezer or moving a bead out of position.

### C. Manipulation of Individual Live Cell Spheres

The ability to discriminate and move individual groups of live cells within or out of aqueous media is an important advantage since it can lead to arrangement of cells in specific patterns or placement on surfaces of sensors, or isolation of individual cell spheres from a culture, as we demonstrate next.

Stem cells grow as multiple spheres in soft agar. Before the cells are interrogated, multiple aspiration and incubation steps are used to separate all of the spheres from the viscous media [13]. This standard procedure not only requires time and reagents but also cannot isolate a single sphere. As a result, many spheres are wasted that could otherwise remain in the media until needed. We were able to isolate a single mouse prostate stem cell sphere directly from the viscous media (Matrigel) that it was suspended in. The tips of the microtweezer were able to reach in the gel and remove a single 100- $\mu\text{m}$  cell sphere (Fig. 7). The force provided by the microtweezer was sufficient to compete with the surface tension of the viscous gel [Fig. 7(a)] but not large enough to damage the cell sphere. Fig. 7(b) shows that the cell sphere remained intact after being pulled out of the Matrigel.

## IV. CONCLUSION

We have developed and demonstrated a compact, portable, and multipurpose micromanipulator actuated manually by rotating the thimble of a micrometer head connected to a microtweezer structure

via a graphite interface. The tweezer operation is based on the elastic deformation of silicon, which significantly reduces hysteresis effects and greatly simplifies the overall device design. The device can operate in both air and liquid and transport entities between the two media. Due to its compact and highly portable nature, the device is also capable of transporting entities from one setting to another. Three applications have been demonstrated in this letter: With its relatively sharp tips and large dynamic range, the device was able to arrange microspheres in 3-D (including designated spots of sensor surfaces) and perform on-demand microcontact printing. The device was also able to isolate and remove a single stem cell sphere from viscous media without harming either the sphere or the tweezer. Due to its compact and versatile nature, we expect this device to be highly useful in a wide range of studies in biology and engineering.

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