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Procedia Engineering 87 (2014) 1390 – 1393

Procedia Engineering

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EUROSENSORS 2014, the XXVIII edition of the conference series

Development of a Pneumatically Actuated Cantilever Based Micro-Tweezer

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Abstract

This paper presents a novel micro-gripper design with the dual functions of manipulation and force sensing. The device consists of two parallel plates, each mounted on torsion bars, which can be made to rotate towards or away from each other by use of a pneumatically- or hydraulically- actuated balloon. The plates can be conveniently fabricated using photo-etching and the design allows for a range of ratios between actuation pressure and tip opening displacement and/or force. The elastic gripping tips can be designed to provide sufficient compliance that their strain can be used to monitor and/or control the gripping force.

Keywords: pneumatically actuated, cantilever, micro-tweezer

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1. Introduction

The rapid evolution in the biological sciences has led to an increased requirement for manipulating entities at the micro and nano- scale. In general, manipulating such objects as single cells can be classified into contact and non-contact techniques. The non-contact techniques are mainly optically-based [1-4], where a highly focused laser beam is used to trap and move a microbiological object. Although the performance of such techniques is satisfactory, complex and expensive optical setups are required [5] and the exposure may have long term negative effects on the manipulated micro-objects [6]. Micro-pipettes and grippers are the most commonly used contact techniques for manipulating biological micro-objects. Pipettes use a negative pressure applied through a nozzle but, despite its capability to manipulate single cells, this technique requires a highly skilled user to achieve the manipulation without damage to the cells. Furthermore, pipettes have limited versatility and, if cells are smaller than the opening

doi:10.1016/j.proeng.2014.11.702

of the pipette nozzle, several can be drawn into the pipette rather than isolating just one [7]. Also, it is not possible to control very accurately the forces acting on the objects being manipulated. Micro-grippers show much greater versatility to manipulate a range of object sizes and also the possibility of controlling and measuring the forces acting on the gripped objects. Micro-grippers are complex micro-electro-mechanical-systems (MEMS) [8] and can be categorized according to their actuation mechanism: electrostatic, shape memory alloy (SMA), magnetic or piezoelectric, each of which has its advantages and disadvantages. Fluidic microactuators, with their high force and power densities, have been widely advocated for manipulating precise amounts of liquid within microfluidic and micro total analysis systems (µTAS) [9]. The actuation can be either pneumatic [10] or hydraulic, and can therefore operate in liquid environments for biological manipulation. In this paper, we present the development of a new type of pneumatically actuated cantilever based micro-tweezer for operation in liquid environment.

2. Methodology

The micro-gripper described here is pneumatically actuated and is designed to be operated in a range of environments, including air and liquid, at a range of scales. It comprises two main parts; the actuation mechanism and the flexible gripper arms (Figure 1). The actuator is essentially a flexible membrane that applies force to the gripper pad when the air inlet is pressurised. The gripper plate was cut from stainless steel sheet using a photo-etching technology to give an outer envelope, which was sandwiched between two PMMA layers. When pressure is applied to the pad, the arms pivot around a torsional spring consisting of a bar-shaped ligament of the gripper plate. The arms themselves are designed to be flexible so that the gripping force can, in principle, be monitored by measuring the strain at the pivot end of the arm or the slope at its free end. The design can be operated with two arms closing together when actuated (as shown in Figure 1) or can be operated so that the jaws are opened by actuators on the opposite sides of the gripper plates using the spring force and compliance of the arms to offer the gripping force, limited, if necessary, by the air pressure. The whole design is scalable by controlling the dimensions of the components of the gripper, in particular the arms and torsion bars.

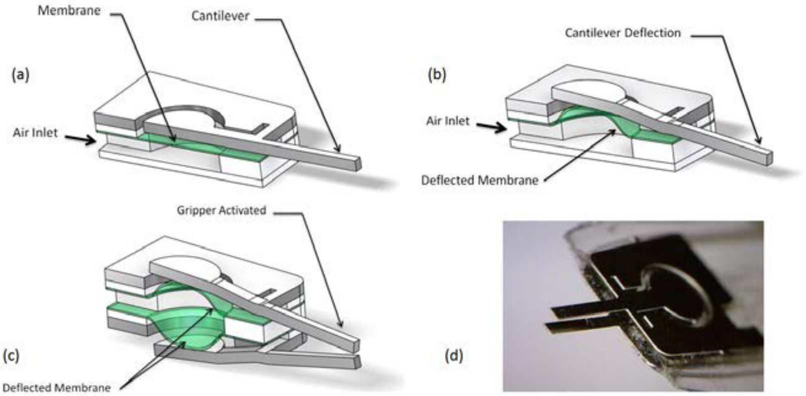

Fig. 1: Schematic drawings of working principle of the gripper device (a-c), and picture of assembled microgripper (d).

3. Testing & Results

To validate the above-mentioned design principles, a prototype device was realised in 50 µm thick stainless steel sheet with a pad diameter of 2 mm, arms of length 3 mm and breadth 0.45 mm, and torsion bars of breadth 0.3 mm and length 0.625 mm. The performance of the device was evaluated using two tests; a dynamic test where the feed air pressure was pulsed at a range of frequencies and pressures and the tip displacement with no loading was measured, and a static test where the input load and output load were measured.

For the dynamic test, an optical sensor was used to obtain the deflection at the cantilever tip using a similar approach to an AFM where a laser beam at a fixed angle is reflected from the end of the cantilever and the position of the spot on a photodetector recorded, Figure 2. Deflection data were acquired using a LabView control interface at a rate of 300 samples per second for a record length of around 20 cycles (e.g. Figure 3) whilst the pressure was pulsed from zero to 1, 2, 3, 4, and 5 bar at frequencies of 1, 2, 4, 8, 20, 50, 100, and 300 Hz.

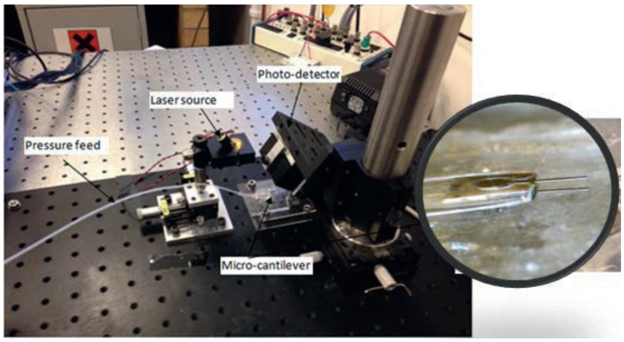

Fig. 2: Dynamic test set-up with optical sensor

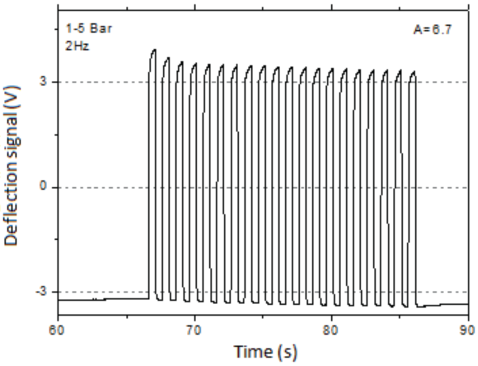

Fig. 3: Typical dynamic test output from optical sensor

For the static tests, a digital balance with read-out up to four decimal places (in grammes) was used to measure the force generated at the tip of the cantilever. The tip was brought into contact with a 1.5 mm diameter metallic ball mounted on a lightweight conical holder as shown schematically in Figure 4.

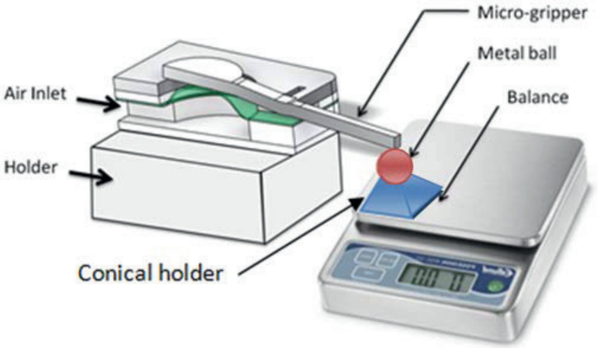

Fig. 4: Schematic test set-up for static loading of cantilever.

The pressure in the feed line was then increased incrementally to 5 bar, recording the output force at approximately 0.2, 0.3, 0.4, 0.5 and 1 bar, and thereafter at 1 bar intervals. The results are shown in Figure 5 for forward and reverse increments of pressure up to 5 bar using two dwell times (10s and 30s) before the force was recorded. The same procedure was used to determine the input force for a given pressure by applying the membrane directly to the metal ball and recording the force at the same increments of pressure. Figure 6 shows the relationship between the input force and the output force for each of the pressure increments.

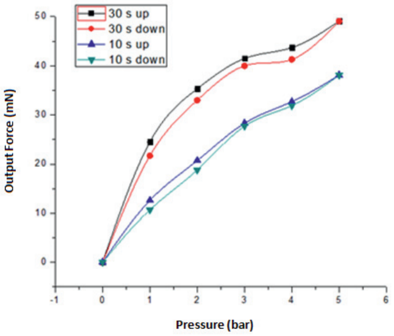

Figure 5: Measured cantilever tip (output) force vs input pressure

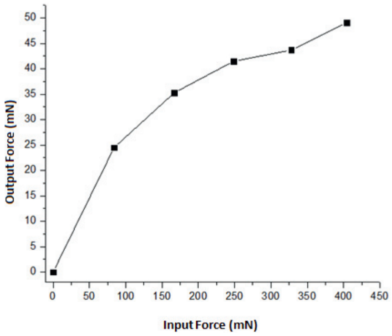

Figure 6: Measured input and output forces at

pressures used in Figure 5

A fully-assembled version of the device was used to demonstrate that actuator in pick-and-place mode and also in sensor-gripper mode. The pick-and-place function was demonstrated in air and underwater and consisted of manipulating acid washed zirconium microbeads of 200 µm diameter (OPS Diagnostics, Lebanon NJ, USA). The device was mounted on a computer controlled CNC machine to precisely control the motion of the micro-tweezer. Figure 8 shows the precision of placement that could be achieved using the proposed manipulation technique**.**

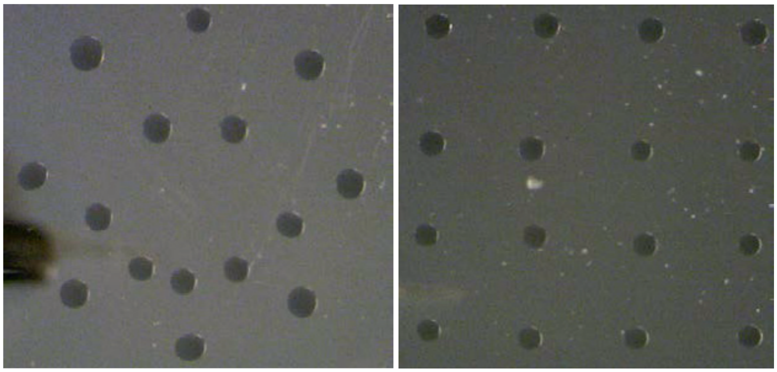

Fig. 8: Various pick-and-place arrangements of 200µm zirconium microbeads

4. Conclusion

A pneumatically actuated cantilever based micro-tweezer was designed, fabricated and tested. The stain steel cantilevers can microfabricated using photoetching technology and are readily assembled in layers with elastic membranes to form 3D micro-tweezers, which tackles the main challenge on the assembly of miniaturized devices. The micro-tweezer can be actuated dynamically for a frequency up to 300Hz. The deflection and the output force of the microtweezer can be controlled by a pneumatic pressure. The manipulation of microbeads as small as 200 µm is demonstrated in liquid environment. The pick-and-place operation of the microtweezer can be precisely controlled and automated using a CNC machine. The fabrication and assembly technology of the cantilever based micro-tweezer are scalable, paving the way to enable further miniaturized devices for single cell manipulation in physiological conditions.

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