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A new type of three-finger micro-tweezers

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Abstract
A new type of three-finger micro-tweezers driven by electrostatic force is presented in this paper. The whole system consists of three-finger micro-tweezers and a specially designed high-frequency ac power supply. The three fingers are alternately driven by the power supply with a high-frequency voltage. The direction of the electrostatic forces on the fingers produced by the high-frequency voltage is gyrating between the three fingers quickly, which is equivalent to the invariable forces pointing to the geometrical centre of the micro-tweezers. The tweezers can grasp and manipulate micro objects of size in the range from 30 μm to 100 μm stably.

Keywords: three-finger micro-tweezers, particulate, micro-manipulate, micro-assembly

(Some figures in this article are in colour only in the electronic version)

1. Introduction

With the development of modern science and technology, many research realms need manipulation and assembly of micro objects, such as microelectromechanical systems (MEMS). New tools for these purposes have been developed rapidly. The first micro-tweezers were made by Chen *et al* [1]. And the first nanotweezers were made by Kim and Lieber with nanotubes [2]. Nowadays, the popular methods to produce micro-manipulators are the piezoelectric material-driven manipulators [3–5] and the electrostatic force-driven manipulators [6]. There are also some other micro-manipulators, for example, the thermal actuated micro-tweezers [7–9], laser tweezers [10, 11], etc. Most of these researches are two-finger micro-tweezers. The application of two-finger micro-tweezers in manipulating and assembling spherical, columnar or complicated micro objects is not stable. In order to overcome this drawback, we use carbon fibres to create three-finger micro-tweezers, which are alternately driven by a power supply with a high-frequency voltage. In this paper, the manufacture process of the three-finger micro-tweezers and the design considerations of the power supply will be introduced. Experiments on closure, opening, grasping and manipulating of micro objects of size 50 μm are presented.

2. Three-finger micro-tweezers

2.1. Fabrication of three-finger micro-tweezers

The most important challenges in the manufacture of three-finger micro-tweezers are how to divide the three fingers symmetrically in space and how to apply the electrostatic forces to obtain symmetrical movements of the fingers. Here, carbon fibres and optical fibres are used to make the three-finger micro-tweezers. With remarkable properties in mechanics and electrical conduction carbon fibre is suitable for electromechanical devices in micro scale. Young's modulus of carbon fibre is 225 GPa. Three carbon fibres, with a diameter of 5 μm, were attached individually in the joint gap between each pair of three tightly tied optical fibres, whose diameter is 125 μm, and this process could ensure the three fingers are parallel and symmetrical in space. Figure 1 is the schematic illustration of the tweezers' cross section.

The free ends of the carbon fibres act as the fingers and the other ends are fixed on the electrodes. The electrodes are formed by three Au films deposited on a slide. Figure 2 is a schematic illustration of the three-finger micro-tweezers. Figure 3 shows an optical micrograph of the actual three-finger micro-tweezers. The length of the fingers was about 2 mm; the distance between each pair of fingers is 108 μm.

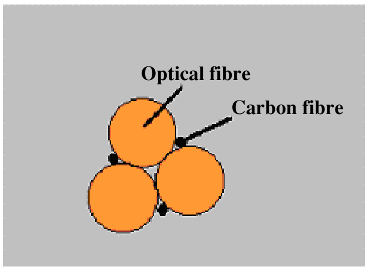

Figure 1. Schematic illustration of the tweezers' cross section.

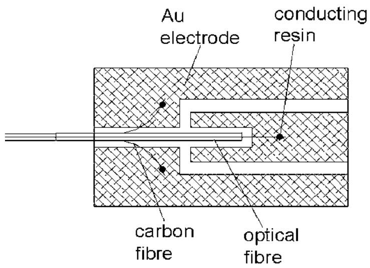

Figure 2. Schematic illustration of the three-finger micro-tweezers.

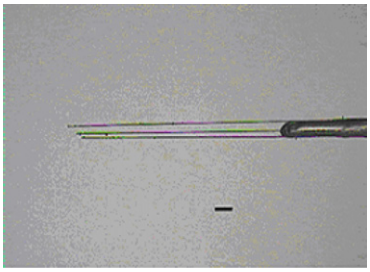

Figure 3. Optical micrograph of the three-finger micro-tweezers. Scale bar, 10 μm.

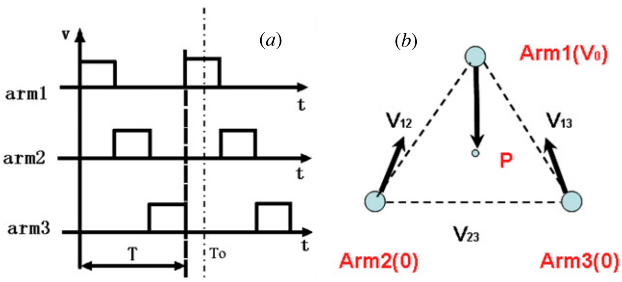

Figure 4. (*a*) The waveform of the voltage used to drive the three-finger micro-tweezers. (*b*) Illustration of the voltage on each finger at time t_0.

In order to close and open the three fingers together, a power supply with an alternating high frequency is designed and the waveform is shown in figure 4(*a*). From figure 4(*b*), at each time position (t_0), only one of the fingers is equally biased between the two sides (arm1 in this illustration), i.e. $V_{12} = V_{13} \neq V_{23}$. At such electrical voltage, non-symmetrical movements of the three fingers are expected if dc voltage is adopted.

However, by using ac voltage, the bias voltage between every two fingers is rotating. If the frequency is high enough, the tweezers can achieve symmetrical movements of the fingers towards the geometrical centre. 20 kHz is selected as the frequency of the ac voltage, which is far from the resonance frequency ($\omega_1 = 1.5$ kHz, $\omega_2 = 9.8$ kHz, $\omega_3 = 27.572$ kHz) of the fingers.

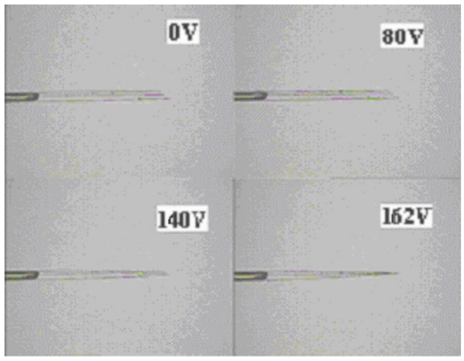

Figure 5. Optical micrographs of the three-finger micro-tweezers at 0, 80, 140, 162 V.

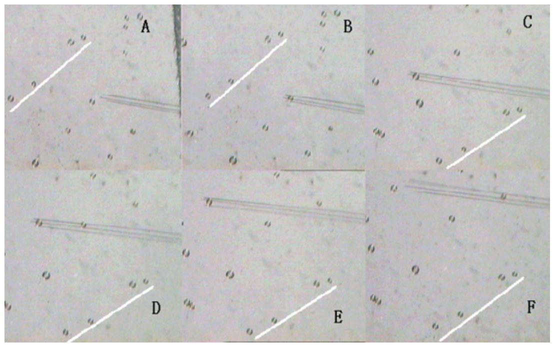

Figure 6. Micrograph of the process of manipulating the polymer ball.

2.2. Experiment

The experiments on the micro-tweezers' closing, grasping and manipulating of micro objects have been carried out under an optical microscope.

In the experiment, the electromechanical response of the micro-tweezers was investigated by applying voltages to the electrodes. With the increase of the peak voltage value, every two fingers of the three got closer to each other simultaneously and could return to their original positions when the voltage was removed. Every finger of the micro-tweezers has an elastic response before closure. As the voltage increased to 162 V, the fingers of the tweezers closed suddenly. Figure 5 shows the closure process of the micro-tweezers. During the voltage increase no vibration has been observed.

The three-finger micro-tweezers can grasp particles of size in the range from 30 μm to 100 μm. Figure 6 shows the process of manipulating a non-conductive object, such as a polymer ball whose diameter is about 50 μm. Figure 6(A) shows the tweezers approaching the ball; figure 6(B) shows the ball about to be grasped; figures 6(C) and (D) show the ball being moved to another place by the micro-tweezers; figure 6(F) shows that the ball has been put down, and the micro-tweezers are leaving the ball. The manipulation is stable and repeatable. If a fine insulating material can be deposited on the fingers, the micro-tweezers can also grasp conductive objects.

3. Conclusions

We have proposed an appropriate structure for three-finger micro-tweezers. The tweezers are suitable for grasping and manipulating micro objects of size in the range 30–100 μm. Although there are some deficiencies in manufacturing processes, the prospect of three-finger micro-tweezers is very promising.

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