Sensors and Actuators A 232 (2015) 13–19

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

An ultrasonic manipulator with noncontact and contact-type nanowire trapping functions

Xu Wang, Junhui Hu*

State Key Lab of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing, PR China

ARTICLE INFO

Article history:
Received 28 December 2014
Received in revised form 12 April 2015
Accepted 13 April 2015
Available online 11 May 2015

Keywords:
Ultrasonic trapping
Nanowires
Noncontact and contact
Acoustic streaming

ABSTRACT

The ultrasonic manipulation technology had a breakthrough recently, which makes ultrasonic trapping, orientation, transportation, rotation and concentration of nanowires possible. However, the existing manipulation technology based on ultrasound cannot integrate the noncontact and contact nanowire trapping functions in one device. It would widen the application range if a manipulator has both the noncontact and contact trapping functions. In this work, we proposed and developed a dual function device capable of trapping individual nanowires in the noncontact and contact ways. The device is simply made up of a piezoelectric component, a vibration transmission needle, and a micro manipulating probe. The vibration transmission needle, made of steel, is bonded along the narrower side of the piezoelectric component to transmit vibration energy from the piezoelectric component to the manipulating probe. The micro manipulating probe, made of fiberglass, is bonded to the tip of the vibration transmission needle, to generate an acoustic streaming field to trap an individual nanowire in water film on a substrate. In the experiments, individual silver nanowires with a 300 nm-diameter and length up to 30 μm can be trapped and transferred in the contact and noncontact ways. The analyses show that making the micro manipulation probe oscillate linearly and elliptically at proper working frequencies is a way to integrate the noncontact and contact trapping functions in one device.

1. Introduction

The nanomanipulation technology has potential applications in many fields, such as fabrication of high-performance electronic and photonic devices [1], micro machining [2], property testing of nanomaterials [3], assembly of nanostructures [4,5], etc. To implement the manipulation functions, researchers in various areas have proposed and investigated different strategies. These strategies can be classified as physical, chemical and biological methods according to the working principle [6]. The physical method mainly includes optical [7], dielectrophoresis [8], mechanical [9–13], microfluidic [14], magnetic [15] and acoustic methods [16–18]. The optical method can trap and rotate individual nanowires, in which the trapping force has a magnitude of piconewtons. However, the optical method could be harmful to biological samples owing to the heat generation in a laser beam [19]. The dielectrophoresis effect is quite competitive in the manipulations of biological samples such as cell sorting [11]. However, it is weak in the precise positioning of samples and in the manipulation of single samples. The mechanical method is usually based on a micro gripper or AFM probe. Micro grippers, which are usually fabricated by MEMS process, can pick and place nanoscale objects by electrostatic, piezoelectric, thermal and pneumatic actuations [9–11]. The method is reliable and stable in the pick-and-place manipulation. Its demerits include the difficulty in the control of clamping force and in the release of clamped samples. A microscopic system assisted with two AFM probes can pick and place nanoscale components to build 2D or 3D nanoscale structures [12,13]. However, the systems are usually ineffective because they have to use bulky driving systems with sophisticated control units and a series of imaging processing units. In the microfluidic method, micro entities can be trapped and transferred in the suspension flowing through microfluidic channels [14]. Merits of this method include small sample consumption, portability, disposable use, no harmful effect on biological samples, etc. However, it is very difficult to use this method to implement some manipulations such as assembling of nanoscale structures, and implementation of the manipulations on arbitrary substrates provided by customers. In the magnetic method, nanowires are driven by controlled magnetic field, and the nanowires' motion may be used to drive a nearby object in a noncontact or contact way [15].

The ultrasonic nanomanipulation technology utilizes the physical effects of sound to manipulate nanoscale objects [16–18]. Its main features are [6]: (1) no selectivity to the material properties

* Corresponding author. Tel.: +86 25 8489 1681.
E-mail address: ejhhu@nuaa.edu.cn (J. Hu).

http://dx.doi.org/10.1016/j.sna.2015.04.013
0924-4247/

of manipulated samples; (2) little heat damage to manipulated samples; (3) simple and flexible device structures; (4) diversified manipulation functions; (5) capability to implement the manipulations on devices or substrates supplied by users. (6) Capability to manipulate single and multiple nanosamples. The ultrasonic nanomanipulation technology has been applied in the electrical measurement system for single nanowires such as ZnO NWs in China, and more R&D work for its application is under the way.

In ultrasonic nanotrapping, there are two working modes, i.e., the noncontact and contact modes. In the noncontact mode, the trapped nano-object is not in contact with the micro manipulating probe. While in the contact mode, the trapped nano-object is in contact with the micro manipulating probe. The noncontact mode has the merit that a trapped nano-object does not stick to the micro manipulating probe, and releasing the trapped object is not a problem. However, in the noncontact mode, the trapped nano-object can only be moved on the substrate surface. Other nano-objects on its motion path will obstacle its transfer. The contact mode can overcome this problem. But sticky samples may adhere to the manipulating probe, and do not fall even if the ultrasonic vibration is switched off. The existing ultrasonic technology cannot integrate the noncontact and contact nanotrapping functions into one device [6,16,17]. It brings more convenience to the assembling of nano-objects if an ultrasonic manipulator has both the noncontact and contact trapping functions.

In this work, we explored the possibility to integrate the noncontact and contact nanowire trapping functions into one ultrasonic device. The device is simply made up of a piezoelectric plate, a vibration transmission needle (VTN), and a micro manipulating probe (MMP). The VTN is bonded along the narrow side of the piezoelectric plate. The MMP is bonded to the tip of the VTN, parallel to the piezoelectric plate. Vibration is generated by the piezoelectric plate, and transferred to the MMP through the VTN. The physical mechanism of the function integration is analyzed, and its trapping characteristics are experimentally investigated. It is found that the noncontact and contact nanotrapping functions can be realized in the same device by tuning the driving frequency or phase difference between the normal vibration components at the MMP's root.

2. Device structure and functions

Fig. 1 shows the experimental setup for the noncontact and contact trapping of individual nanowires. The device is simply made up of the piezoelectric plate, vibration transmission needle (VTN) made of steel, and micro manipulating probe (MMP) made of fiberglass. The VTN is bonded along the narrow side of the piezoelectric plate. The MMP is bonded to the VTN's tip, and parallel to the piezoelectric plate. The width, length and thickness of the piezoelectric plate are 5 mm, 10 mm, and 1 mm, respectively. The angle θ between the MMP and VTN is 95°. The electromechanical quality factor Q_m, piezoelectric coefficient d_{33}, and relative dielectric constant $\varepsilon_{33}{}^T/\varepsilon_0$ of the piezoelectric plate are 2000, 325×10^{-12} m/V and 1450, respectively. The VTN is 0.8 mm thick, and 28 mm long out of the plate. The MMP is 10 μm thick and 2 mm long. The resonance frequency of the device is about 136 kHz, at which the VTN vibrates flexurally. The VTN, which is above the suspension film, is parallel to the substrate. The water film thickness is about 0.3 mm. The suspension is formed by deionized water and dispersed nanowires. The distance between the MMP and substrate is 5 μm. Silver nanowires are used in the experimental aqueous suspension. The diameter of AgNW is about 300 nm, and the average length of AgNW is 10–30 μm.

Experiments show that the device can trap a silver nanowire in the water film on the substrate surface in two working frequency ranges, as shown in Fig. 2, in which the vertical axis represents the measured average value of the z-directional vibration velocity magnitude of the VTN. In the frequency range from 131.2 to 132.2 kHz, the trapped nanowire is not in contact with the MMP; in the frequency range from 133.9 to 134 kHz, the trapped nanowire is in contact with the MMP. Fig. 3 contains a series of images to show the noncontact trapping and transfer of a silver nanowire. In the noncontact mode, the trapped nanowire is on the substrate and can only be transferred on the substrate surface. Fig. 4 contains a series of images to show the contact-type trapping and transfer of a silver nanowire. In the contact mode, the trapped wire is in contact with the MMP. In both modes, the AgNW rotates while being sucked to the MMP. From image (b) to (d) in Fig. 3, the trapped nanowire is moved on the substrate surface by moving the manipulating device. From image (d) to (g) in Fig. 4, the trapped wire is moved above the substrate surface, and in image (h) in Fig. 4, the trapped nanowire is released.

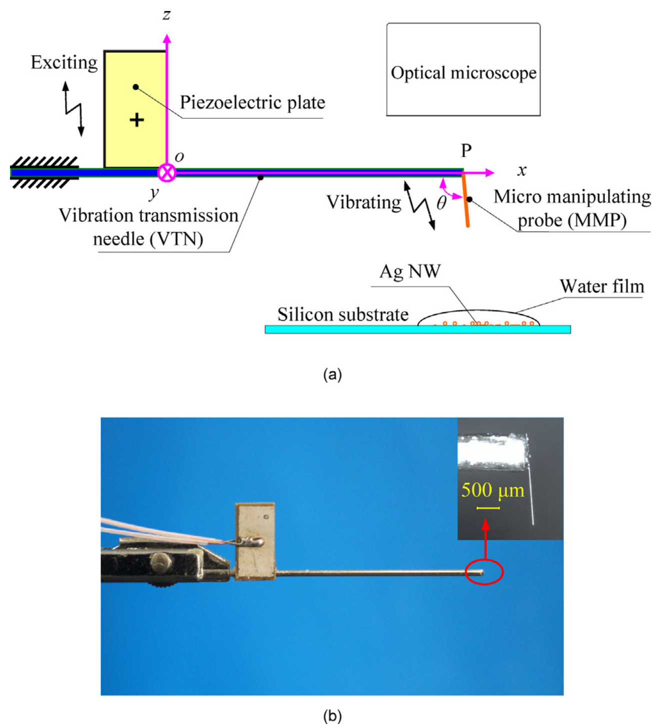

Fig. 1. Experimental setup for the noncontact and contact-type trapping of a single silver nanowire in water film on a substrate. (a) Schematic diagram. (b) Construction of the ultrasonic transducer.

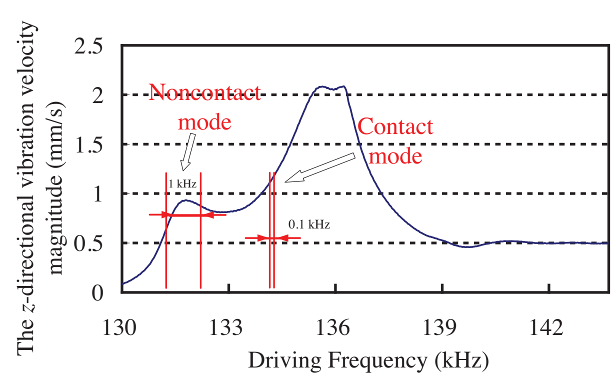

Fig. 2. Measured z-directional vibration velocity magnitude of the vibration transmission needle (VTN) versus driving frequency.