

OBSERVING AND TAMING BROWNIAN MOTION OF SILICON NANONEEDLE IN MICROMACHINED PDMS CHAMBER

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ABSTRACT

This paper presents an effective way to obtain rotational motion of an encapsulated silicon nanoneedle in an appropriate cylindrical PDMS chamber containing liquid and to provide control over its Brownian motion by an external non-uniform AC electric field.

Keywords: Brownian motion, Brownian ratchet, nanosphere lithography, non-uniform AC field, PDMS

1. INTRODUCTION

Producing a net-unidirectional rotation from Brownian motion of a nanoneedle by 3-phase electrostatic rectification is under investigation (Fig. 1). Unlike in an electrostatic motor, Brownian motion provides the motive force; however, a periodically rotating electrostatic field rectifies this motion to produce a net rotation. This work aims at an engineering solution to novel, efficient nano-scale actuators exploiting Brownian motion inspired by biomolecular motors.

Brownian motion is the random motion of suspended micro/nano particles due to thermal fluctuations. Slender particles for the observation of rotation and the control of their motion—e.g. a nanoscopic needle—are preferable to widely used spherical beads whose rotation is indistinguishable. We have achieved taming, i.e. limiting the degree of freedom of Brownian motion of the nanoneedle by encapsulating it in a PDMS chamber and observed the alignment of the nanoneedle along the external electric field.

2. FABRICATION

We adopted nanobead masking; i.e. nanosphere lithography, in DRIE of silicon (Si) to prepare nanoneedles of

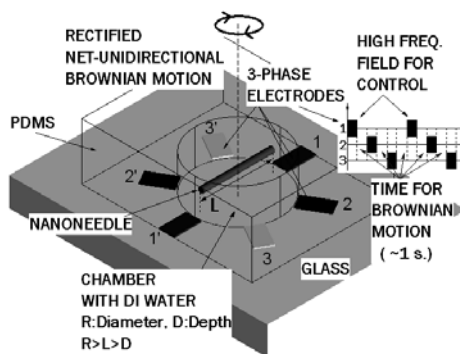


Figure 1. Conceptual design for micromachined Brownian motor.

3.5 μm in length [1]. Si substrate is exposed to O_2 plasma, 3 minute-100 sccm at 50 watt in a RIE system, and diluted solution of beads (Bang Laboratories Inc., polystyrene beads, diameter=230 nm, 200(DIW):1(Original concentration)) is spin-coated to form an etch mask for anisotropic DRIE etching of Si. Subsequently, isotropic etching is applied to facilitate breaking of the nanoneedles at a specific length. Then, the sample is ultrasonicated and centrifuged (Fig. 2). It is refreshed by DI water to prepare the nanoneedle solution. Si nanoneedles with aspect ratios close to 20 are fabricated. For encapsulation, cylindrical PDMS chambers are prepared with an SOI mold [2]. Their diameters are 2, 4, 6 and 8 μm with a depth of 2.2 μm . Triangular shaped Ni electrodes are fabricated onto coverglass by photolithography.

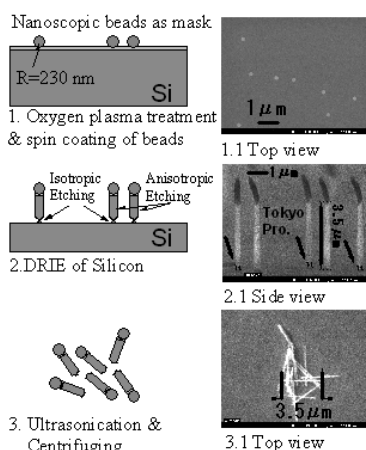


Figure 2. Fabrication of Si nanoneedles (1)Oxygen plasma treatment for enhancing hydrophilicity of the surface and spin-coating of beads. (2) DRIE of Si (3) Ultrasonication and centrifuging.

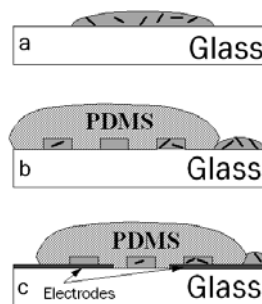


Figure 3. Experimental procedure (a) Introduction of nanoneedle solution onto the coverglass (b) Sealing PDMS chamber array and encapsulation of Si nanoneedles (c) Encapsulation and control of Brownian motion by electrodes microfabricated onto the coverglass.

3. RESULTS AND DISCUSSIONS

Rotational Brownian motion of an encapsulated 3.5 μm long- \varnothing 200 nm Si nanoneedle was observed (Fig. 3ab, Fig. 4). The height of the chamber is less than the length of the nanoneedle and smaller than the chamber diameter; therefore the degrees of freedom are limited in vertical and translational direction. This can be understood from color change of the needle caused by defocusing during motions perpendicular

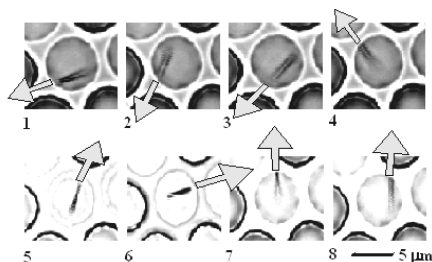


Figure 4. Rotational Brownian motion of a 3.5 μm long Si nanoneedle in a 6 μm -2.2 μm PDMS chamber. Arrow is the reference for the direction. Captures are at different instants of time.

to the observation plane. After this verification, an electric field ($10V_{pp}$, 10 kHz) was applied to the encapsulated nanoneedle (Fig. 3c) between triangular shaped Ni electrodes. Although it could escape from the PDMS chamber during the observation, alignment of the nanoneedle with the field was observed with suppressed vertical motion (Fig. 5).

Following this, we made a flow cell between copper tapes ($\sim 80\mu\text{m}$ in thickness) separated by $190\pm 30\mu\text{m}$ on a coverglass. After a water droplet containing nanoneedles was introduced on the gap, coverglass was put over it and 1MHz square wave was applied between copper tapes. The Brownian motion of the needle was completely restricted with an electric field of $37\text{ mV}/\mu\text{m}$, while no control was possible around $2\text{ mV}/\mu\text{m}$. Partial alignments were observed around $5\text{ mV}/\mu\text{m}$ (Fig. 6). Those data can lead to a proper region of operation for the Brownian motor to distinguish it from an electrostatic motor.

4. CONCLUSIONS

Rotational Brownian motion of an encapsulated Si nanoneedle in an appropriate disk-shaped PDMS chamber is observed. The alignment of the nanoneedle is achieved at 10 kHz-83 $\text{mV}/\mu\text{m}$ (avg.) external non-uniform AC electric field. 3-Phase rotational system is in progress.

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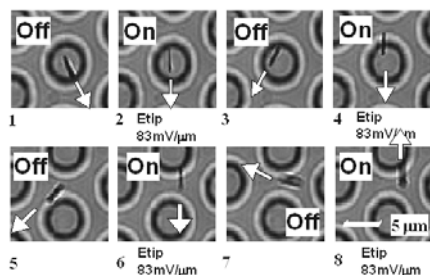


Figure 5. On/Off control of Brownian motion of a $3.5\mu\text{m}$ long Si nanoneedle and alignment with non-uniform electric field (10 kHz, 50% duty cycle, square wave AC). Vertical motion is limited. Regardless of sealing, attraction to the electrode can be seen. Arrow is the reference for the direction.

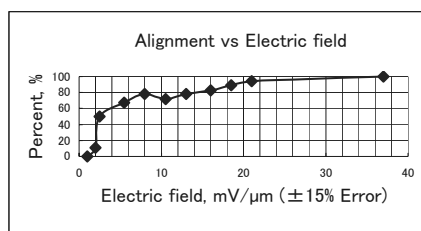


Figure 6. Alignment of nanoneedle in electric field. (1MHz, 50% duty cycle, square wave)