SINGLE DNA MANIPULATION IN SUBLITHOGRAPHIC NANOWIRE ARRAY CHIPS

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ABSTRACT

We show the feasibility of self-assembled nanowire post-array embedded in microchannels to manipulate the dynamics of single long T4-DNA molecule. DNA molecules in the spot-array of nanowires are fully elongated, and interestingly they exhibit not only the dynamics inside nanopillar array but also that inside gel matrix.

KEYWORDS

Single DNA manipulation, Nanowire array chips.

INTRODUCTION

Nanobiodevices based on advanced nanotechnology open up a novel research field for biomolecule analysis with the ultrahigh resolution, including a single biomolecule analysis. An electrophoretic operation of biomolecules by utilizing artificial nanostructures in microchannels has emerged as a promising technique since it was first proposed. A number of unique artificial nanostructures, such as nanopillar arrays [1], nanowall arrays [2], nanofilter arrays [3], nanofence arrays [4], nanochannels [5], and nanoparticles [6] have been examined to control the dynamics of biomolecules. These highly ordered nanostructures have provided less time-intensive and required fewer manual operations when compared with other conventional methods. Comprehensive overviews of recent technological and practical developments of nanobiodevices have been given elsewhere.

Although recent progresses in micro- and nano-fabrication technologies have allowed us to fabricate smaller and more precise artificial nanostructures for manipulating biomolecules, there is still an inherent size limitation of lithographic technology. In this paper, we demonstrate the feasibility of bottom-up nanowire array embedded in microchannels to control the dynamics of long T4-DNA molecules.

EXPERIMENTAL

To fabricate nanowires embedded in microchannels, we have utilized a conventional photolithography, electron beam lithography, and vapor liquid solid growth technique for nanowires (Figure 1). In this method, the spatial controllability of nanowires can be accomplished by defining the spatial position of metal catalysts only inside microchannels via a lift-off process with different thicknesses of Cr layers (Figures 1d). The Cr layer thickness inside the microchannel is intentionally controlled to be much thinner than that outside the microchannel, which allows us to remain the metal catalysts only inside the microchannel during the lift-off process of Cr layer.

The nanowire array chips were fabricated on fused silica substrates. First, a 250 nm thick Cr layer was deposited on the substrate by sputtering in Figure 1a, which was a mask for the dry etching process to fabricate a microchannel. Positive photoresist was coated by spin-coating, and then the microchannel pattern with a width of 25 μm was formed by photolithography (Figure 1b). After development of the resist, the patterned area of Cr was etched by immersing in Cr etchant for 5 minutes. The microchannel was formed by reactive ion etching under CF_4 gas (Figure 1c). The depth of the microchannel was controlled to 2 μm, which is larger than the gyration size of T4-DNA. The inlet and outlet via holes of 1.5 mm diameter for the microchannel were formed with an ultrasonic driller. We also patterned the metal catalysts to define the spatial position of nanowires inside the microchannel. A 10 nm thick Cr layer was deposited inside the microchannel (Figure 1d). Positive resist was coated on the microchannel by spin-coating (Figure 1e), and then the hexagonal array pattern was drawn by electron beam lithography in Figure 1f. After developing the resist, the Cr layer of the array pattern was removed by Cr etchant. A 3 nm thick Au metal catalyst for nanowire growth was deposited inside the microchannel by sputtering, and then the resist was lifted off using dimethylformamide followed by acetone. Next, the Cr layer was lifted off by Cr etchant. Note that the presence of thicker Cr layer on the outside of microchannel allows us to remain Au metal catalyst pattern only inside the microchannel (Figure 1g). Using the well-patterned catalyst array, we fabricated spatially patterned SnO_2 nanowires by pulse laser deposition (Figure 1h). Details of the nanowire fabrication conditions are given elsewhere [7]. A SiO_2 layer, which acted as an adhesion layer when performing sealing process with fused silica cover plate, was covered as a shell layer on the nanowire surface by sputtering. The cover shell layer also creates a negatively charged surface on the nanowires, which is essential to avoid the detrimental

978-0-9798064-5-2/μTAS 2012/$20©12CBMS-0001

adhesion of negatively charged DNA. Although the appropriate shell material depends on the pH condition of the solvents employed, use of the shell layer allows us to control the surface charge of the nanostructures by considering the isoelectric point of the materials used. Finally the microchannel was sealed using a 130 µm thick fused silica cover plate according to the literature method [1].

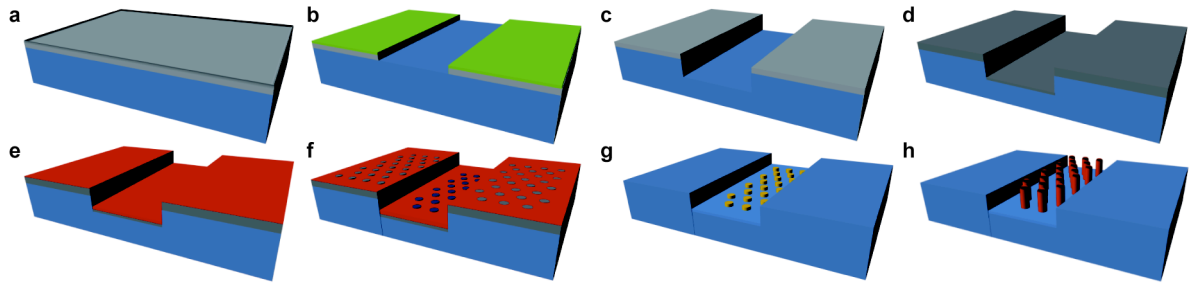

Figure 1. Schematic of fabrication procedure for self-assembled nanowires embedded in a microchannel. The microchannel and spatially-controlled nanowires are formed on fused silica substrate by utilizing sublithographic techniques. (a) 250 nm Cr layer deposition. (b) Photolithography. (c) Microchannel fabrication by etching. (d) 10 nm Cr layer deposition. (e) Electron beam resist coating. (f) Nanowire position patterning by lithography. (g) Lift off of Cr layer. (h) Vapor-Liquid-Solid (VLS) nanowire growth.

RESULTS AND DISCUSSION

Figure 2 shows the FESEM images of random nanowire array inside a microchannel, and the TEM image of nanowires. The nanowire array structure is 300 nm in the spot diameter and 500 nm in the spacing between spots (Figures 2a), and the fabricated nanowire consists of Au catalyst (10 nm in diameter), the SnO_2 single crystalline nanowire (10 nm in diameter), and an amorphous SiO_2 layer (10 nm in thickness), as shown in Figure 2b. The nanowire position is well controlled and the fabricated nanowires are only grown inside the microchannel. The SnO_2 single crystalline nanowire is uniformly covered by the amorphous SiO_2 layer.

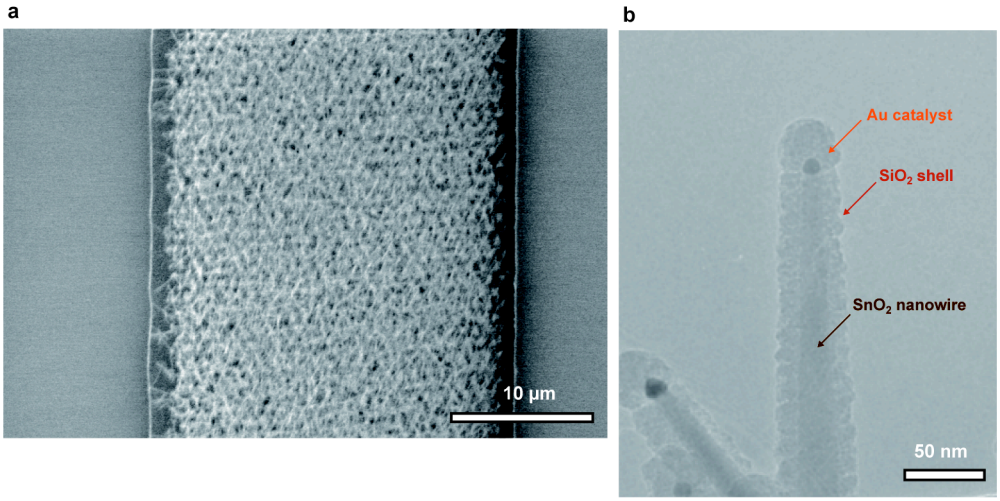

Figure 2. (a) FESEM image of fabricated nanowire array; scale bar, 10 µm. (b) TEM image of fabricated nanowires; scale bar, 50 nm.

To elucidate the potential of the nanowire array structure to control DNA molecules, we performed single molecule observation of T4 DNA molecules in the nanowire array structures. Figure 3 shows the observed dynamics of T4-DNA when colliding with the nanowire spot-array. T4-DNA could be fully elongated by the collision with the nanowire array structure. This highlights that the nanowire array would have the potential to control and separate long DNA molecules. The T4-DNA molecule inside the nanowire array structure shows the migration behaviors, including a collision, elongation, contraction, and so on. And furthermore, from 0 to 2.0 s, the fragmented stained-DNA molecule by photocleavage migrated faster than the center of mass in elongated DNA molecule, resulting in the separation of DNA molecules.

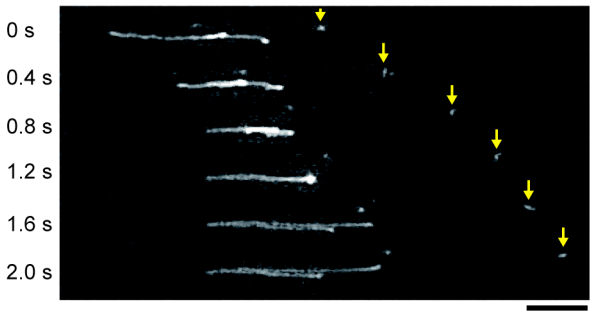

Figure 3. Time-course observation of a T4 DNA molecule in the nanowire array structure under 10 V/cm; scale bar, 10 µm. Yellow arrows indicated the fragmented stained-DNA molecule by photocleavage.

CONCLUSIONS

In summary, we have demonstrated the precisely positioned sub-lithographic scale nanowire array structure embedded in microchannels on fused silica substrate to manipulate the dynamics of a single long DNA molecule. Our experimental results highlight that the nanowire array structure have a great potential for serving as new members of nanostructures from the viewpoint of elongation of biomolecules, and also superior to the conventional gel matrix in terms of the spatial controllability inside microchannels, which is essential to further integrate with other functionalities. The spatial controllability of sub-lithographic scale nanowires inside microchannels offers a flexible platform to manipulate DNA molecules, and moves researchers towards the goal of further integration with other nanostructures.

ACKNOWLEDGEMENTS

This research was supported by the Japan Society for the Promotion of Science (JSPS) through its “Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)."

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