NANOWIRE FORMATION USING METALLIZATION OF EXTENDED AND IMMOBILIZED DNA

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ABSTRACT
This paper presents a novel fabrication process of silver nanowires using metallization of DNA molecules. First, we stretched and immobilized λDNA molecules by applying an AC voltage between two electrodes that were placed 15 μm apart in a microchannel. Next, naphthalene diimide molecules labeled with reducing groups were intercalated into the λDNA so that the reducing groups were arrayed along the λDNA strand. Finally, the λDNA was metallized with silver using treatment with Tollens’ reagent and reduction of silver ions along the λDNA, which resulted in formation of silver nanowires. The experiments demonstrated that the fabricated nanowires have nonlinear current-voltage characteristics.

KEYWORDS: Nanowire, DNA, Electrostatic orientation, Metallization, Reducing group, Intercalator

INTRODUCTION
Nanoscale structures can be fabricated using synthesis, assembly, and manipulation of DNA molecules, and a DNA nanowire is one of the strong candidates for nanoelectronic components. However, a DNA nanowire has high electrical resistance, and its value differs depending on DNA base sequence and fluctuates under the influence of conditions of ambient temperature and humidity. One of the solutions to this problem is to metallize DNA molecules by deposition of metal molecules on a DNA strand. Many research groups have already reported about metallized DNA nanowires [1, 2]. However, their fabrication processes required complicated pretreatment such as modification of DNA molecules before their immobilization and metallization. Moreover, their processes were poorly-reproducible and low-yield due to unreliable immobilization techniques. In order to solve these problem, we present a novel fabrication process of metallized DNA nanowires. In our proposed process, unmodified DNA molecules are metallized using intercalator molecules that are introduced into DNA molecules after their straight stretch and firm immobilization between microelectrodes by electrostatic orientation. This permits simple, highly-reproducible, high-yield formation of nanowires, which will be important for accurate analysis of their electrical properties.

EXPERIMENTAL METHODOLOGY
Figure 1 shows procedure of nanowire formation. First, a solution including DNA molecules is introduced between two electrodes through a microchannel. Long DNA molecules have random coil conformation in a solution due to thermal motion of solvent molecules (Fig. 1(a)). Next, when an alternating electric field of about 1 MV/m and 1 MHz is applied between two electrodes, DNA molecules polarize and are electrostatically stretched parallel to the electrical field. Then, DNA termini are aligned and immobilized on the electrode edges [3] (Fig. 1(b)).

![Figure 1: Procedure of formation of metallized DNA nanowires.](image-url)
Next, a solution of naphthalene diimide molecules labeled with reducing groups, galactoses, as shown in Fig. 2 is introduced between the two electrodes. Then, the naphthalene diimide molecules are intercalated into a double strand of DNA so that the galactoses are arrayed along the structure of DNA. Finally, when Tollens' reagent including silver ions is injected, the DNA is metallized with silver because aldehyde groups of the galactoses reduce silver ions along the DNA (Fig. 1(c)).

EXPERIMENTAL RESULTS

A microfluidic device for nanowire formation consists of two gold electrodes and a microchannel (Fig. 3). The electrodes were placed 15 μm apart on a glass plate. The microchannel measuring 50 μm in depth was made of PDMS (polydimethylsiloxane). Figure 4 shows a photograph of the fabricated device.

A solution including λDNA molecules of 16 μm in length was injected into the microchannel, and they were stretched and immobilized between the electrodes by applying an AC voltage of 1 MHz and 20 V_{pp}. The λDNA molecules were preliminarily labeled with the fluorescent dyes (Hoechst 33258) which don’t interrupt intercalation of naphthalene diimide molecules. The fluorescence image of the stretched and immobilized λDNA is shown in Fig. 5. Also, the SEM images of the silver nanowires formed by λDNA metallization are shown in Fig. 6. The fabricated nanowire had a linear chain conformation of silver clusters, and its average width was about 50 nm.

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Figure 7 shows the combined electrical property of all nanowires formed between a pair of electrodes in the microchannel measuring 1 mm in width. The electrical conductivity of λDNA was drastically increased by metallization, and it was found that the fabricated nanowire has nonlinear current-voltage characteristics. The number of nanowires formed between the electrodes is approximately proportional to the channel width. As shown in Fig. 8, the total electrical resistance of all nanowires formed between a pair of electrodes decreased with the increasing channel width because the number of the nanowires increased with the channel width.

**CONCLUSIONS**

We fabricated silver nanowires using metallization of λDNA molecules after their straight stretch and immobilization between the two microelectrodes which were placed 15 μm apart in a microchannel. The fabricated nanowires had a linear chain conformation of silver clusters, and their average width was about 50 nm. Also, their total resistance decreased with an increase in applied voltage and the number of them. Naphthalene diimide molecules labeled with reducing groups that were used for DNA metallization in this study can be intercalated into double-stranded DNA, but cannot be into single-stranded DNA. In the near future, in order to give molecular recognition property to metallized DNA nanowires, we will make non-metallized portion on the nanowires using partial metallization of DNA complexes consisting of single strands and double strands.

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**REFERENCES**


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