Silicon Nanotweezers: A Biophysical Tool for Molecular Manipulation

ナノピンセットによる DNA の捕獲と DNA の特性評価

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We report the first characterization of DNA bundles combining at the same time electrical and mechanical measurements performed thanks to a MEMS tool having integrated actuator and differential capacitive position sensor. Our experiments show that a rope of DNA has a quasi-ohmic conductivity and behaves like a viscoelastic material.

Keywords: Lambda-DNA, DNA tweezers, Dielectrophoresis, Molecular conduction, Differential Capacitive sensor.

1. INTRODUCTION

In the last two decades, the development of instruments for the mechanical and electrical characterizations of DNA have triggered particular interest to biophysicists since it is believed that such tools could find applications, for example, in the observation of DNA-protein interaction or in molecular electronics. The manipulation of a single DNA strand is most often achieved with optical or magnetic tweezers [1], while the measurement of electrical conductivity of DNA is usually achieved with nanometer gap electrodes [2].

To our knowledge, none of the results presented so far has demonstrated combined electrical and mechanical measurements on DNA. We report hereafter such experiments conducted on DNA bundles with various diameters.

2. WORKING PRINCIPLE

We have recently demonstrated the retrieval of λ-DNA molecules from a water droplet by dielectrophoresis, using silicon tweezers coated with aluminum [3]. By including electrostatic actuation and differential capacitive sensing of displacement, we succeeded to make tweezers having an adjustable gap with few nanometers accuracy [4]. Such capability, which corresponds to few nN force sensitivity, thus enables the mechanical stretching of DNA bundles and the straightforward observation of its effect in terms of strain-stress characteristics.

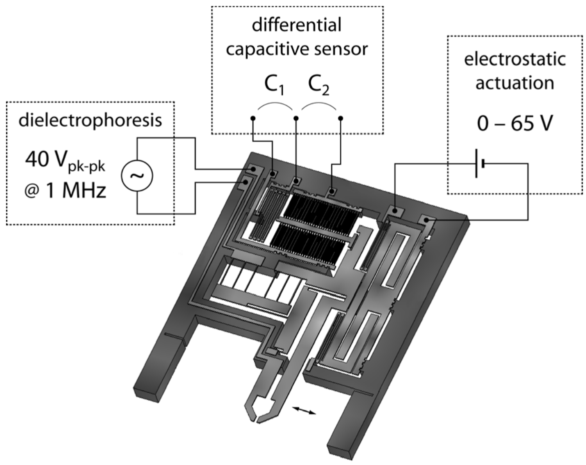

Figure 1 *Three-dimensional schematic of the MEMS nanotweezers fabricated with SOI technology.*

The design of the MEMS tweezers used in our experiments is illustrated in Figure 1. The system consists of two electrodes for the DC electrostatic actuation of the tweezers, three probes connected to a commercial IC capacitive readout for the differential capacitive sensing, and two electrodes for either dielectrophoresis or current measurements through the silicon tips. Note that the initial resistivity measured between the electrodes was always bigger than TΩ. All our measurements were achieved in a Faraday cage.

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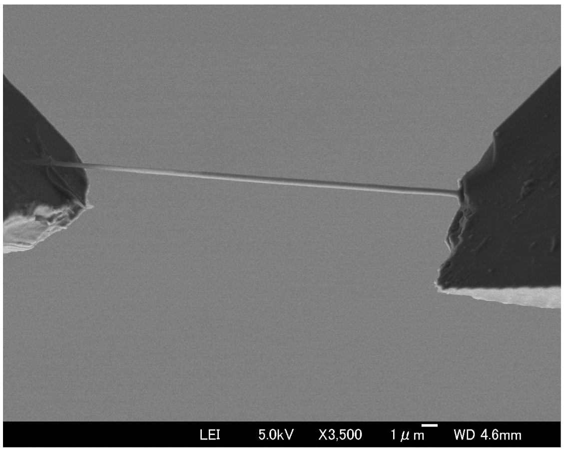

Figure 2 *Three-dimensional schematic of the MEMS nanotweezers fabricated with SOI technology.*

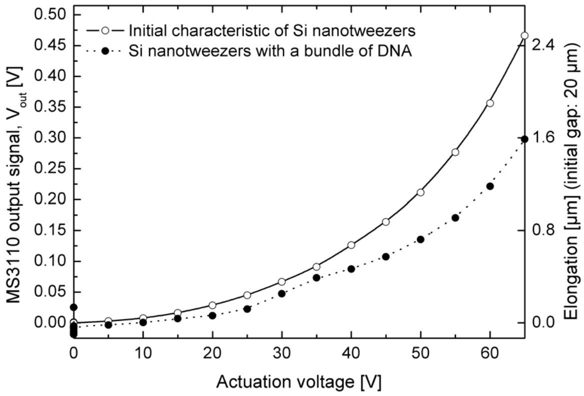

Figure 3 *Mechanical stretching of a bundle of DNA. A clear increase of the stiffness could be observed after the retrieval of a bundle of DNA.*

3. RESULTS

For each series of measurements, we always checked the retrieval of a DNA bundle either with an optical microscope or under SEM observation (Figure 2). Figure 3 shows the effect of mechanical stretching of a DNA bundle, as compared to the same measurements conducted on empty tweezers (before catching DNA). In Figure 4, we measured the current flowing through DNA bundles having different diameters, just after retrieval from the droplet (25°C, 50-60% humidity). Empty tweezers showed a resistivity higher than 5 TΩ, while the resistivity of DNA bundles was in the range of few tens of GΩ. We could also observe that the conductivity increased linearly with the cross sectional area of the DNA bundle (data not shown in this abstract). Figure 5 is a sequence showing the dynamic stretching of a DNA bundle. The movie shows that it simply behaves like a viscoelastic material.

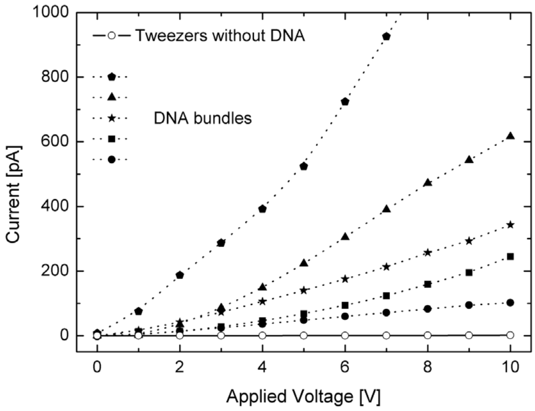

Figure 4 *Electrical characterization of DNA bundles with different diameters. Measurements done at room temperature (25°C), with ~50-60% humidity. The bundle diameters range from 100 nm to few µm.*

4. CONCLUSION

We have conducted a series of electrical and mechanical measurements on DNA bundles using MEMS nanotweezers fabricated by Silicon-On-Insulator technology. Our results demonstrate the quasi-ohmic characteristic of "wet" DNA bundles that can be modulated by mechanical stretching. We have also observed a viscoelastic behavior of DNA bundles under dynamic solicitation.

References

[1] C. Gosse and V. Croquette, *Biophys. J.* **82**, pp. 3314-3329, 2002.

[2] R.G. Endres, D.L. Cox and R.R.P. Singh, *Rev. Mod. Phys.* **76**, pp. 195-214, 2004.

[3] G. Hashiguchi *et al.*, *Anal. Chem.* **75**, pp. 4347-4350, 2003.

[4] C. Yamahata *et al.*, *Proc. MMB 2006*, Okinawa, Japan, May 9-12, 2006.

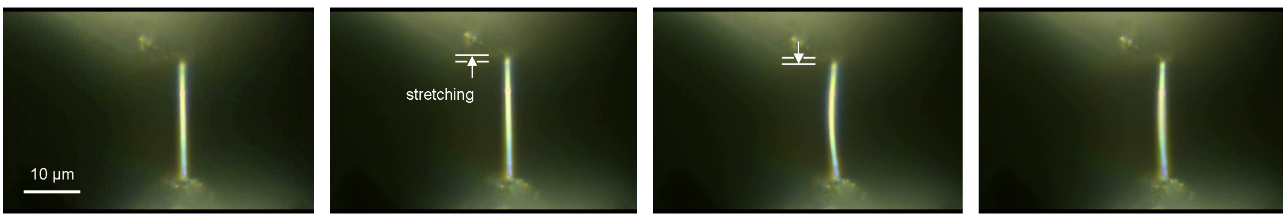

Figure 5 *Sequence showing the elongation of a DNA bundle by oscillating silicon nanotweezers.*
Movie taken at room condition under a Keyence VHX-500 Digital Microscope (× 5000 magnification).