REPEATABLE AND RECONFIGURABLE CONTROL OF DNA ORIGAMI ORIENTATION USING DIELECTROPHORESIS

Dongwon Lee[1], Qinyi Lu[2], Doohwan Jung[1], Yonggang Ke[2] and Hua Wang[1]
[1]Georgia Institute of Technology, Atlanta, Georgia, US
[2]Emory University, Atlanta, Georgia, US

ABSTRACT

DNA origami has drawn growing attention due to its self-assembly, mass production, and nanoscale design capabilities. Thus, the potential of DNA origami to nanoelectronics and nanophotonic devices has been shown in many studies. Especially, the performance of nano-optical devices depends on the precise position and orientation of optical components. Although sticky layers, such as a trimethylsilyl layer, were utilized for precise placement of DNA origami, this method limits the orientation control after the deposition of DNA origami. To resolve these challenges, we introduce the method to control DNA origami orientation through Dielectrophoresis (DEP) after the placement of DNA origami.

KEYWORDS: DNA origami, Dielectrophoresis (DEP), Microelectrode arrays (MEA), Nanofabrication

INTRODUCTION

DNA origami, a technique that designs and folds single-strand DNA into a complex 3-dimensional nanostructure, holds tremendous potential in future drug delivery, biosensors, and nanofabrication, thanks to its self-assembly, mass production, and elaborate design capabilities [1]. Manipulating DNA origami at molecular level is a key to enable these applications. For example, DNA origami-based structures have shown exceptional promise for nano-optical devices [2]. The efficiency of nano-optical devices however relies on the precise placement and orientation control of the optical components. Therefore, trimethylsilyl monolayer with EBL has been used for precise placement of DNA origami, yet with very limited orientation controls. To resolve this issue, in this paper, we will demonstrate a fine and reconfigurable control of DNA origami orientation using MEA array and DEP forces (Figure 1a, b).

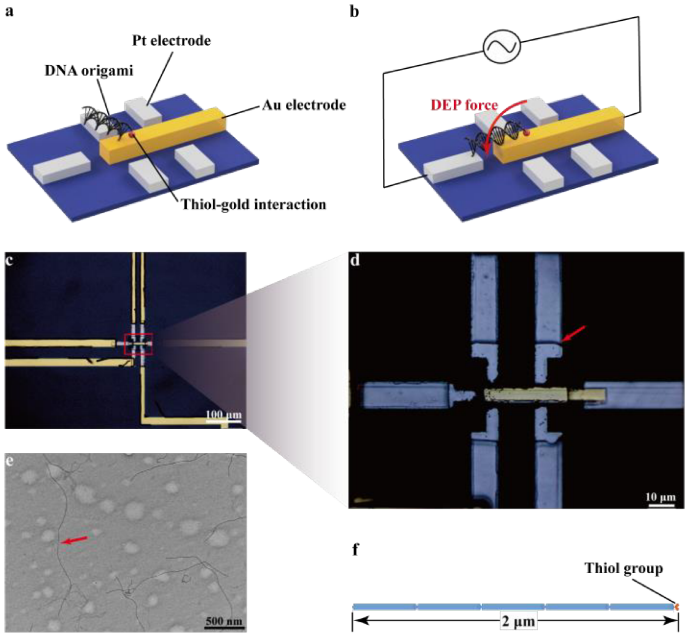

Figure 1: (a) Sketch of the fabricated Au/Pt MEA with DNA-origami (b) the DEP-based DNA origami orientation control. (c) Microscopic image of the fabricated MEA. (d) Enlarged micro-scopic image of MEA. The red arrow points to the boundary of the etched region. (e) TEM image and (f) schematic of DNA origami. The red arrow points to the 2μm-long 6HB DNA origami.

EXPERIMENTAL

We fabricated platinum (Pt) and gold (Au) MEA using electron beam lithography. Then, routing for the microelectrodes was fabricated and a Parylene C layer was deposited for insulation. The Parylene C layer at the center of the electrode array was etched through oxygen plasma (Figure 1c, d). Finally, DNA origami molecules, 2μm 6-helix bundles (6HB), were attached to the Au microelectrode via thiol-Au bonds. The TEM image and schematic of 2μm 6HB DNA origami are shown in Figure 1e and 1f.

To verify the controllable and reconfigurable orientation of DNA origami by different DEP forces, i.e., different AC voltage amplitudes across the Au and the selected Pt electrodes, electrochemical impedance spectroscopy (EIS) was conducted. First, the impedance of the buffer solution was compared with the solution with DNA origami. Also, the finite element method (FEM) was conducted to determine how strong electric field (E-field) is needed to enable control of DNA origami orientation. Then, we repeatedly changed the amplitude of AC voltage to show the

activation voltage of DEP-based DNA origami orientation control and its repeatability. Finally, to verify the orientation reconfigurability, we oriented it to other Pt electrodes in the MEA and measured EIS change vs. different DEP AC voltage amplitude.

RESULTS AND DISCUSSION

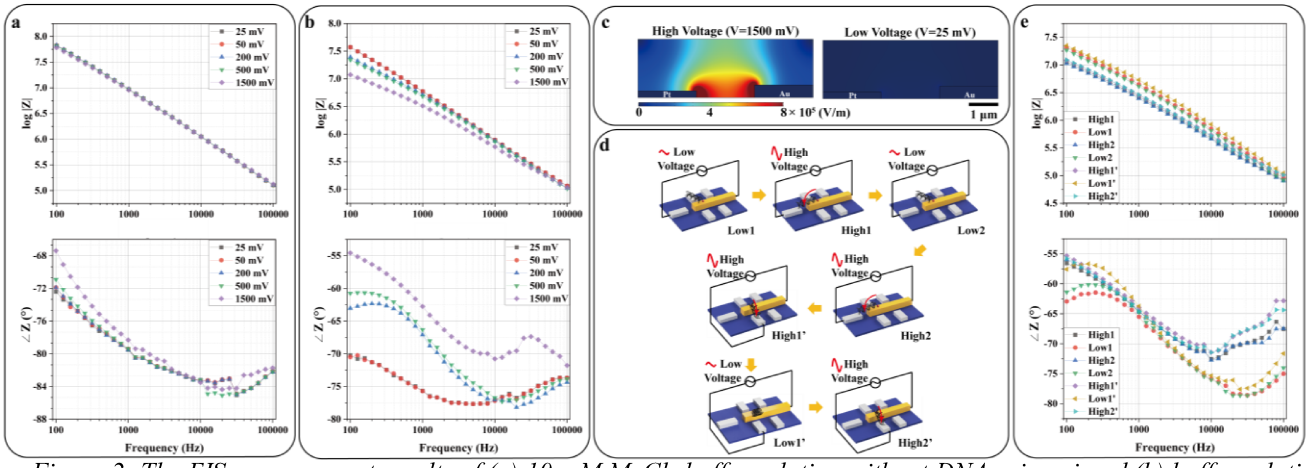

Figure 2: The EIS measurement results of (a) 10 mM $MgCl_2$ buffer solution without DNA origami and (b) buffer solution with DNA origami for different DEP AC voltage amplitudes. (c) E-field distribution between Au and Pt electrodes with high and low applied voltages. (d) Sketch and (e) EIS results of the repeatability and reconfigurability measurements. The impedance was measured with the repeatedly High/Low DEP AC voltages. High and Low means that the amplitude of the applied AC voltage is 1500 mV and 25 mV, respectively. A quotation mark means the change of Pt microelectrode connections.

The EIS measurement of the buffer solution without and buffer solution with DNA origami are shown in Figure 2a and 2b. The magnitude and phase of buffer solution impedance were not significantly changed by the change in amplitude of AC voltage. However, in the case of DNA origami, as the higher AC voltage was applied, the magnitude of impedance became lower. Also, the phase of impedance became larger as higher AC voltage was applied. This impedance change by voltage amplitudes indicates that more DNA origami connects Au and Pt electrodes when higher voltage, i.e., stronger DEP force, is applied. The E-field intensity is calculated using FEM. When 1.5 V is applied, the E-field intensity between Pt and Au electrodes is over 5×10^5 V/m (Figure 2c). This means that at least 5×10^5 V/m E-field is needed to control DNA origami. Figure 4d shows the scenario of repeatability and reconfigurability test of DEP-based DNA origami orientation control. First, the AC voltage amplitude was repeatedly changed to show the orientation control is repeatable. Then, the electrode connection is changed to show the reconfigurability. Figure 2e shows the EIS measurement results according to Figure 4d scenario. Regardless of repeated voltage amplitude changes and changed electrode connection, amplitude and phase of impedance depend on voltage amplitude. This means that DEP-based DNA origami orientation control is repeatable and reconfigurable.

CONCLUSION

In this paper, DEP-based DNA origami orientation control has been presented. EIS was conducted to verify the change of DNA origami orientation by DEP. We showed how intense E-field needed to control DNA origami orientation. Lastly, the repeatability and reconfigurability of DEP-based DNA origami control are demonstrated. The proposed method can ensure not only the placement of DNA origami but also the orientation control after placement. This work will open up new applications of DNA-origami to nanophotonic devices and nanoelectronics.

REFERENCES

[1] P. Wang, T. A. Meyer, V. Pan, P. K. Dutta, and Y. Ke, "The beauty and utility of DNA origami," *Chem*, 2, 359-382, 2017.

[2] A. Gopinath, E. Miyazono, A. Faraon, and P. W. K. Rothemund, "Engineering and mapping nanocavity emission via precision placement of DNA origami," *Nature*, 535, 401-405, 2016.

CONTACT

* D. Lee; phone: +1-404-409-0332; dongwon.lee@gatech.edu