Selective Trapping and Fixation of DNAs Using Plasmonic Optical Tweezers

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1. Introduction

Optical manipulation of small biomolecules is an important issue in bioscience. Plasmon-based optical tweezers (POT) has attracted significant interests as a novel efficient trapping method, since it enhances a radiation force and enables us to trap smaller biomolecules. Recently, we have demonstrated POT of DNA. A micro-ring of optically trapped DNAs was formed on a plasmonic substrate upon resonant light irradiation. Also, we found that the micro-ring was permanently fixed on the substrate [1, 2]. Presumably, the micro-ring formation originates from four physical phenomena:

① Radiation force (trapping DNAs as an attractive force)
② Thermophoresis (carrying DNAs from hotter to colder regions)
③ Thermal convection (supplying DNAs from outside of plasmon excitation area to inside)
④ Coulomb's force (fixing DNAs onto a plasmonic substrate)

Since radiation force and thermophoresis strongly depend on the size of DNAs, DNAs with different base pairs (bp) should be optically separated and then fixed as micro-rings with different diameters on a plasmonic substrate. In the present study, we discuss a mechanism of the micro-ring formation and propose a new separation technique of DNAs with different number of bp (plasmonic chromatography, Fig. 1).

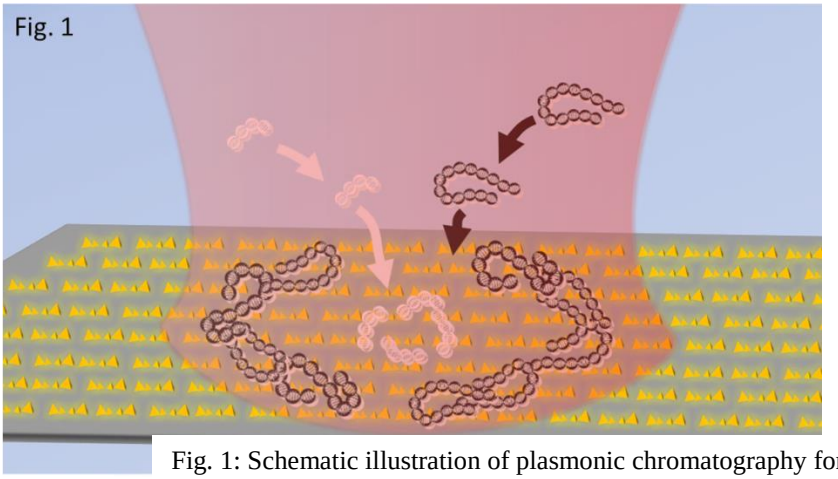

Fig. 1: Schematic illustration of plasmonic chromatography for DNAs. DNAs with different number of base pairs trap at desired positions, leading to multiple-rings formation.

2. Experiments

For a plasmonic substrate, we fabricated gold nanopyramidal dimer arrays on a glass substrate. The plasmonic substrate has a broad absorption band around 800 nm that is ascribed to a gap-mode plasmonic resonance. As trapping targets, λ-DNA (48 kbp) was labelled with

YOYO-1 (λ_{em} = 509 nm) and T4-DNA (166 kbp) was labelled with DAPI (λ_{em} = 461 nm), respectively. These DNAs were mixed in an aqueous buffer solution. We used a cw near-infrared (NIR) laser (λ = 808 nm) for LSP excitation and a cw near-ultraviolet and visible lasers (λ = 375, 473 nm) for fluorescence excitation. Trapping behavior was followed using a fluorescence microscope.

3. Results & discussion

The plasmon excitation resulted in formation of two micro-rings (inner and outer rings) on a plasmonic substrate as shown in Fig. 2(a). These rings were permanently fixed on the substrate. Fluorescence spectra of the inner ring were safely assigned to YOYO-1, indicating that the inner ring consisted of λ–DNA (Fig. 2(b)). On the other hand, fluorescence spectra of the outer ring were surely assigned to DAPI, showing that the outer ring consisted of T4-DNA (Fig. 2(c)).

The position of micro-ring formation depends on the intensity of thermophoresis (repulsive force) and radiation force (attractive force). Thermophoresis repelling from the focal spot exerted DNAs, while radiation force exerted DNAs for trapping. Thermophoresis exerted DNA significantly increase with increasing the number of base pairs. As a result, DNAs with different number of base pairs formed the double micro-rings.

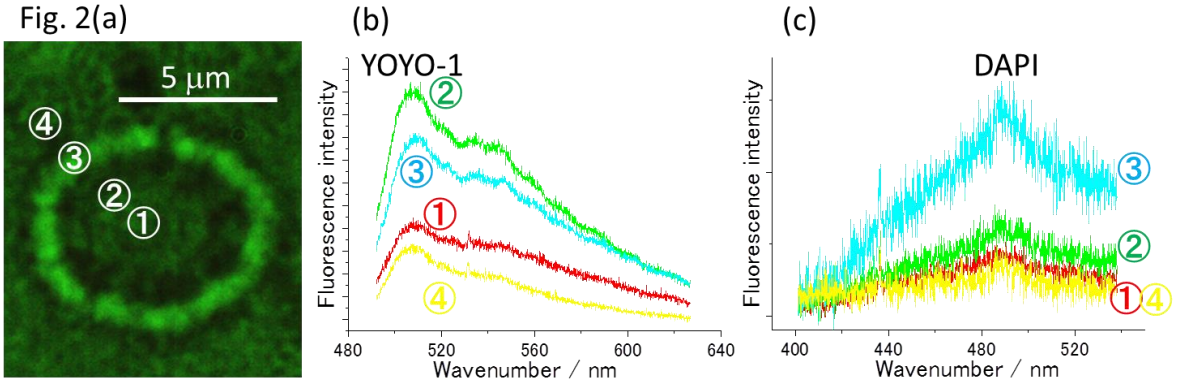

Fig. 2: (a) Optical micrographs of two micro-rings (②: inner ring, ③: outer ring) fixed on a plasmonic substrate by near-infrared laser irradiation. (b), (c) Fluorescence spectra at each positions of a plasmonic substrate. (b): YOYO-1 in λ-DNA (c): DAPI in T4-DNA

4. Conclusion

We successfully separated and fixed DNAs with different number of base pairs on a plasmonic substrate using plasmonic optical tweezers. Taking into account the dependence of thermophoresis on the size of DNA, we suggested the formation mechanism of DNA double micro-rings. Controlling these physical forces, we will provide a novel separating method for DNAs with different number of bp.

References

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