A Micromachined DNA Manipulation Platform for the Stretching and Rotation of a Single DNA Molecule

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MEMS design and Micro-fabrication Lab

Motivation and Objectives

★ **Develop a DNA manipulation platform**

→ Provide a tool to study biophysical properties of a single DNA molecule

★ **Manipulate a single DNA molecule**

→ Stretch and rotate a single DNA molecule

➡ Manipulate a magnetic bead tethering a single DNA molecule

Nanotechnology – Synergy of Top-down Fabrication with Bottom-up Processes

★ Top-down approach

- Micro-photolithography technique

  → Fabricate a micro-scale device

  → Manipulate a single DNA molecule (2-nm diameter)

★ Bottom-up approach

- Chemical self-assembly technique

  → Human-made synthesis

  → Biological objects (DNA and protein)

➡ **DNA manipulation platform**

Advantages of Micromachined Magnetic Manipulator

★ **Noninvasive**

→ No photo-damages compared with optical tweezers

★ **Proper force range between $10^{-14} \sim 10^{-11}$ N**

→ Required DNA stretching forces

★ **Excellent controllability during operation**

→ Stretching and rotation through a simple current control

★ **Compatible with MEMS technologies**

→ Easy assembly

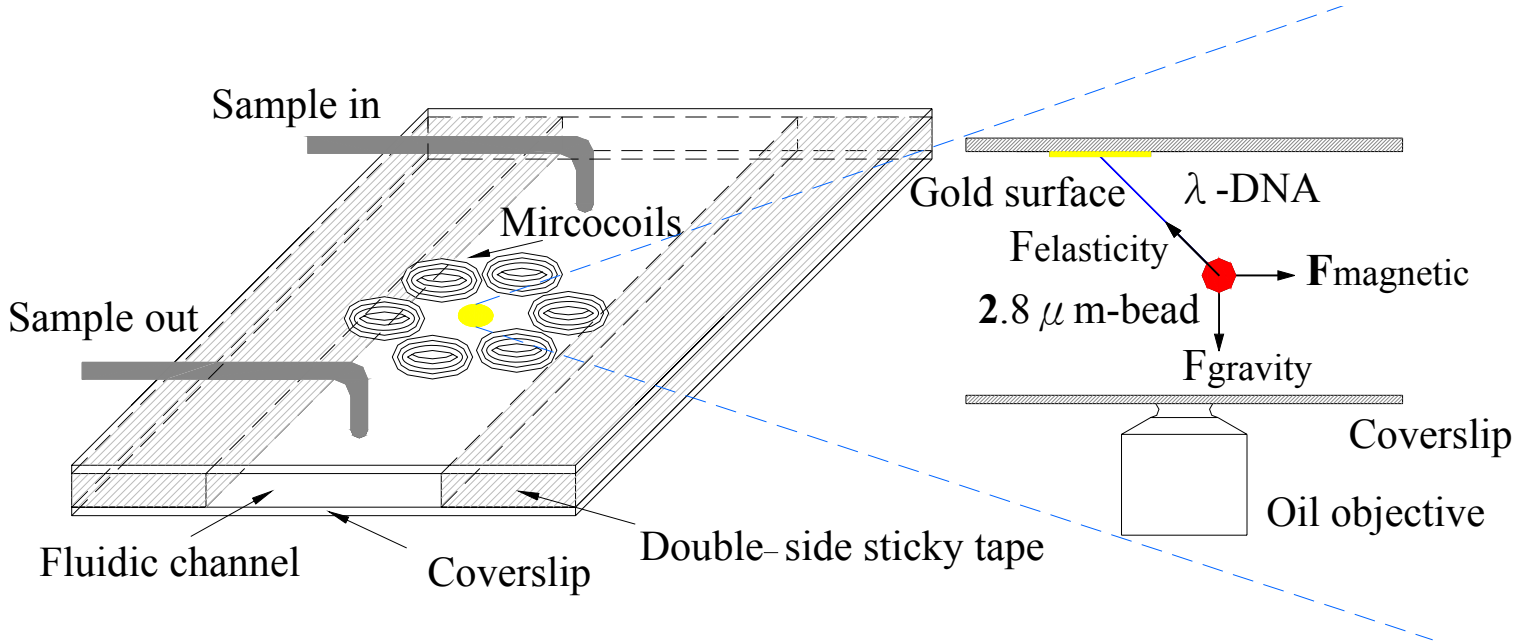
Schematic Illustration of the Magnetic Manipulator

Key components of the magnetic manipulator：

（1）**Six microcoils** → generate required magnetic fields

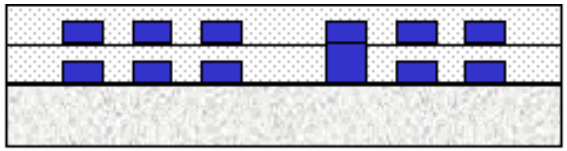
（2）**Gold-patterned surface** → immobilize a single DNA

（3）**Fluidic channel** → observe a dynamic behavior of a single DNA

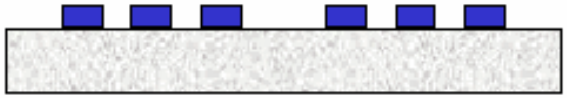


Fabrication Process for the Magnetic Manipulator

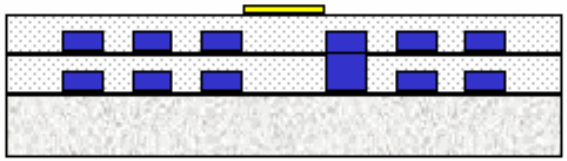
PR molding for conductor pattern



PI coating and bonding pads opening



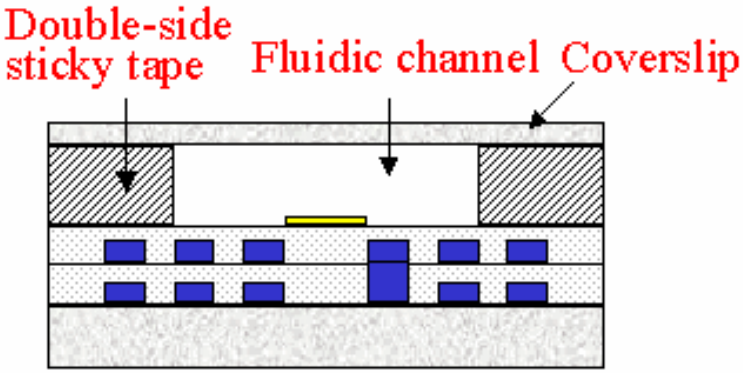
Copper coil electroplating



Localized gold lift-off

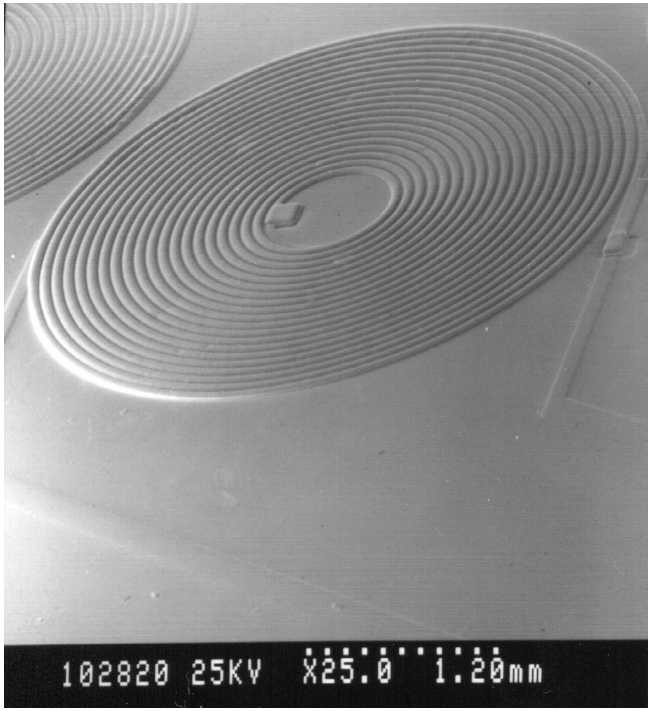
PI patterning and via electroplating

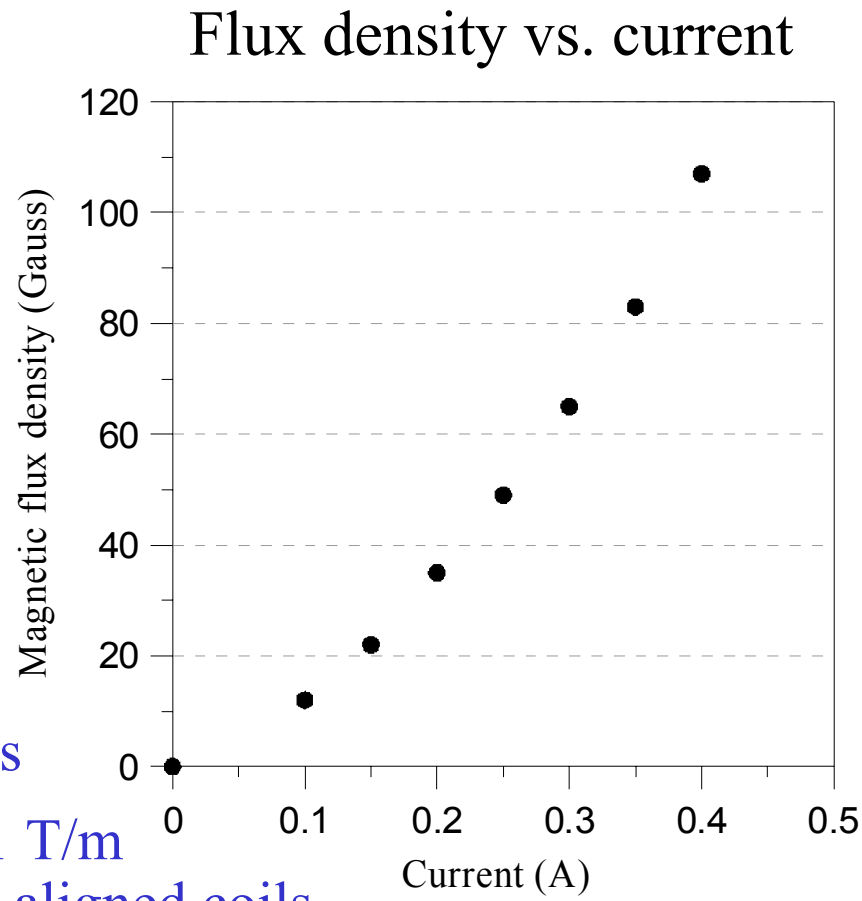
Upper copper coil electroplating



Flow cell assembly

Measurement of Magnetic Fields





Applying 0.25 A ➡ B ≒ 50 Gauss

➡ Magnetic field gradient ≒ 1 T/m
at the center of hexagonally-aligned coils

★ Consistent with numerical data

➡ F_m : ~ **pico-Nt**

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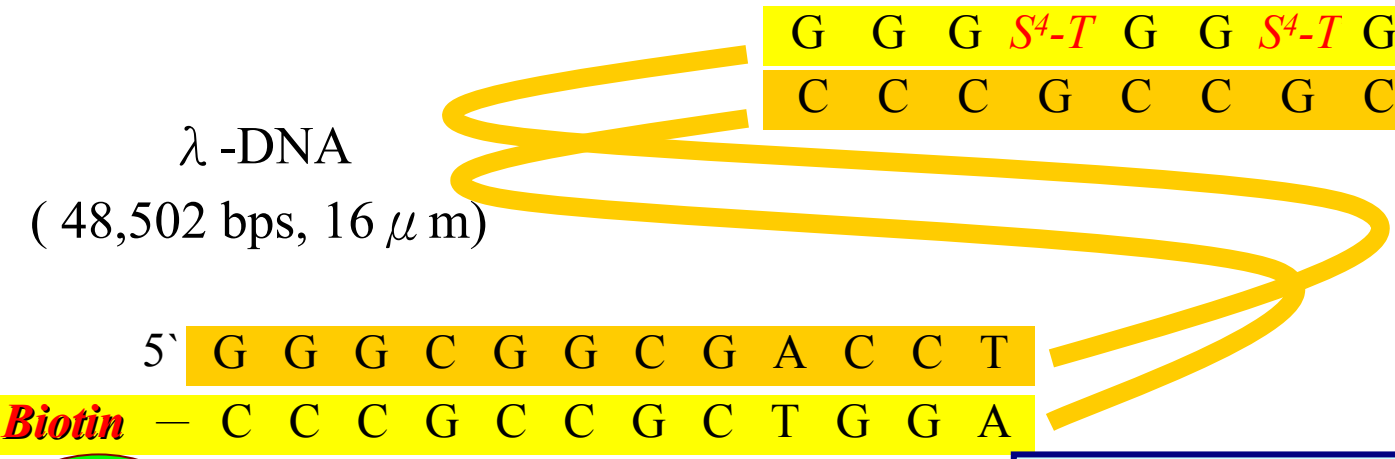
Novel DNA Construction



☆ **High efficiency**
☆ **Strong binding**
☆ **MEMS compatible**

ure：

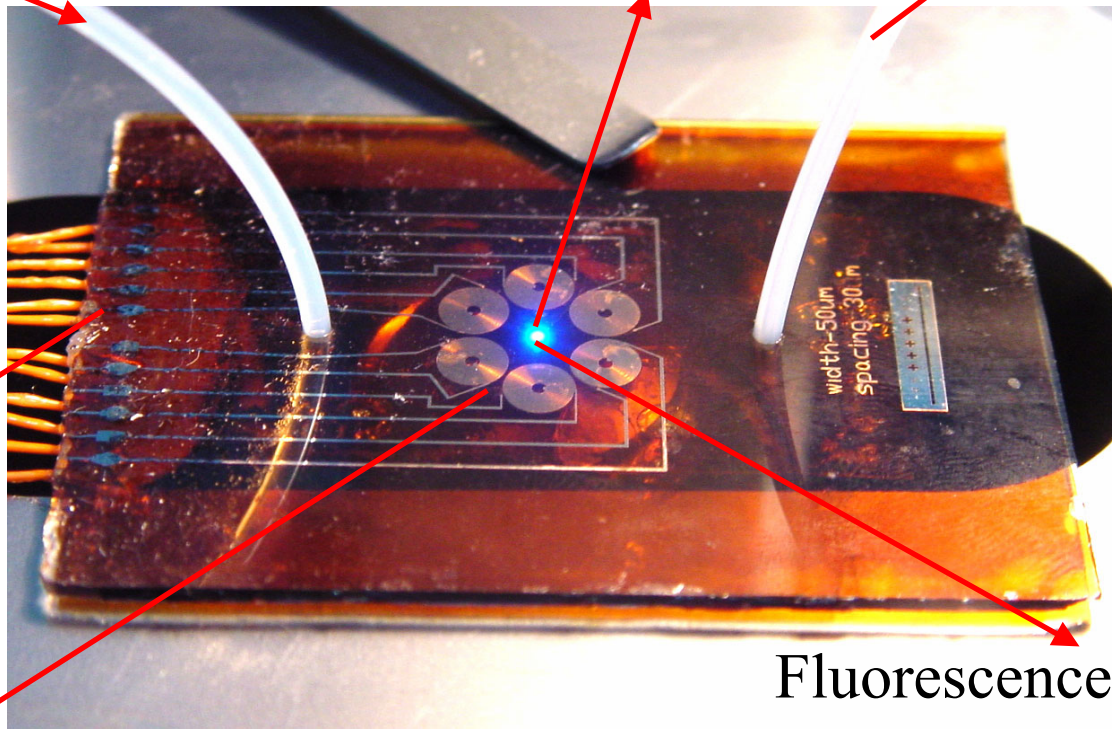
Step1： DNA hybridization and ligation

Step2： Phenol/chloroform extraction and ethanol precipitation

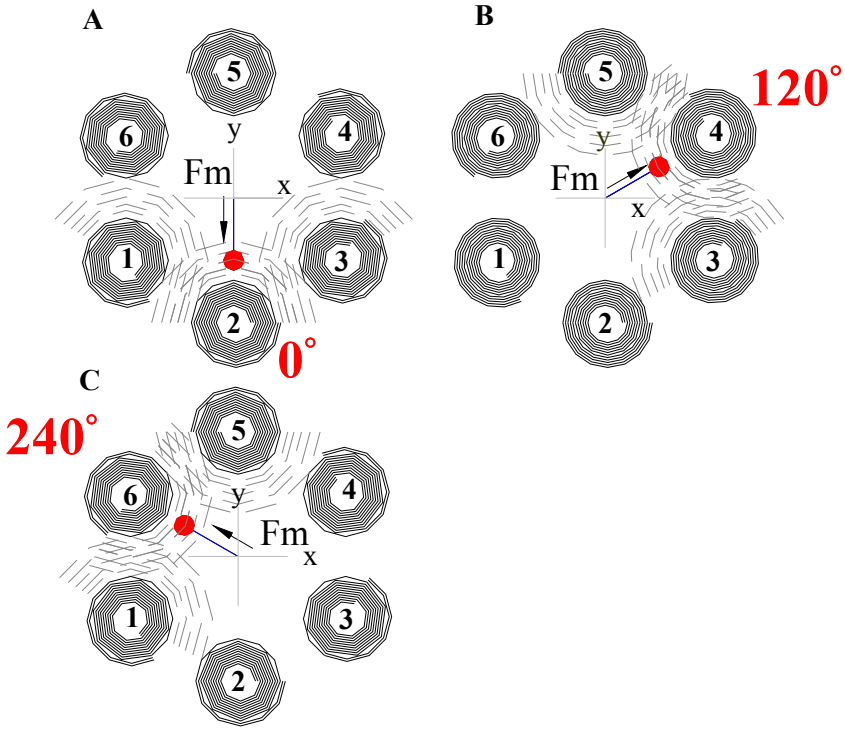
Step3： Klenow fragment (3'→5' exo$^-$)

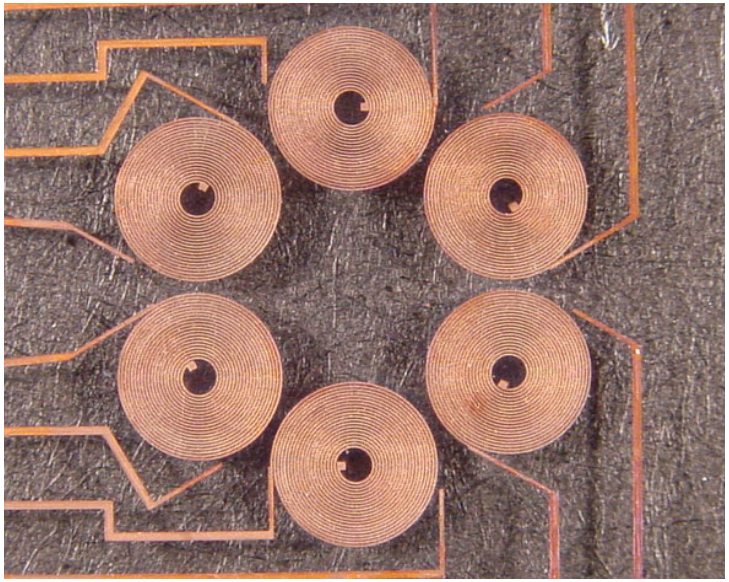
Step4： Phenol/chloroform extraction and ethanol precipitation

Experimental Setup



Principles of DNA Movement





1 cm

Applying currents through coils 1, 2, 3 → move to 0°

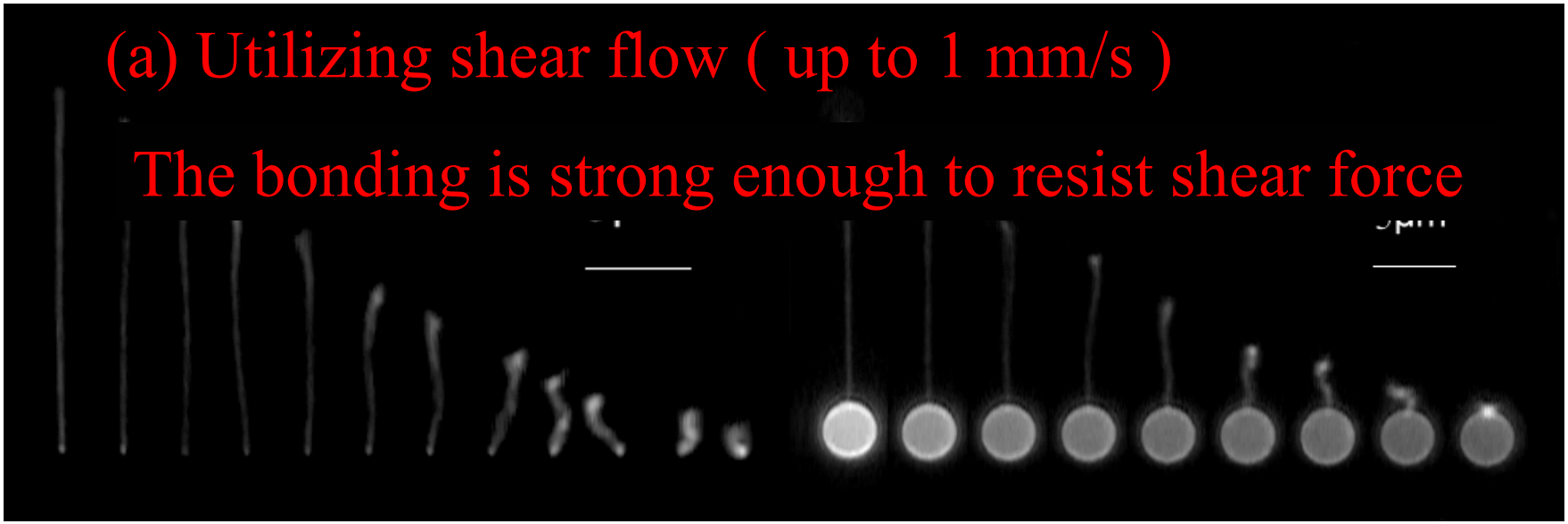
Applying currents through coils 3, 4, 5 → move to 120°

Applying currents through coils 5, 6, 1 → move to 240°

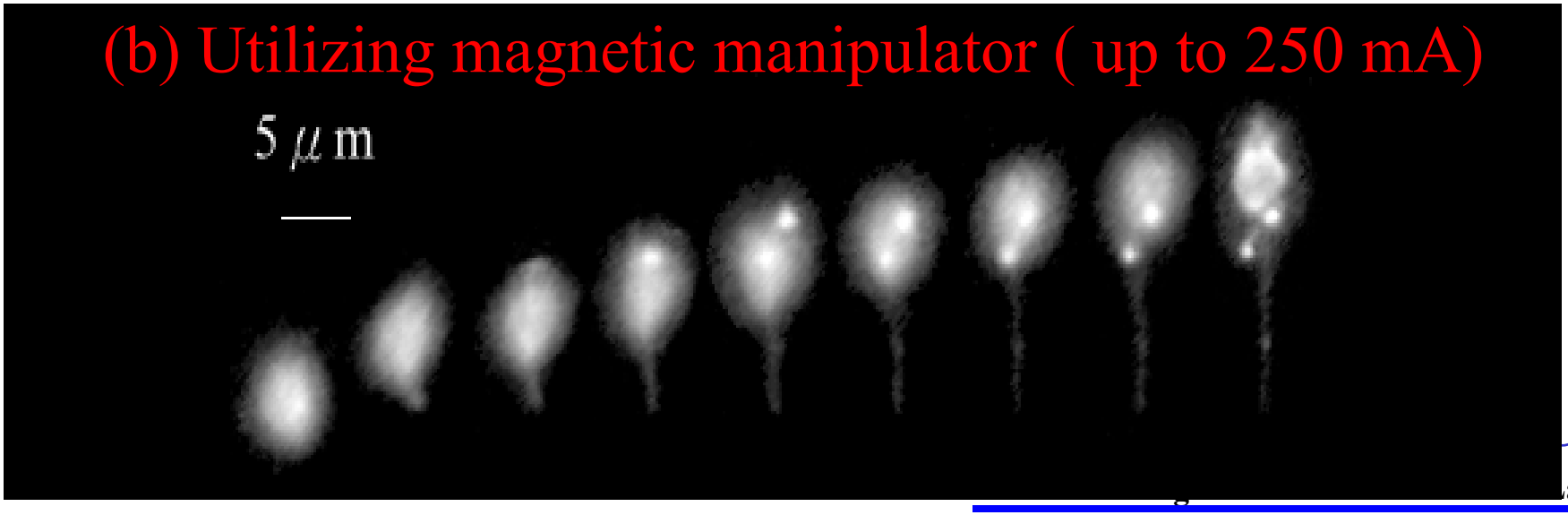
Stretching of a Single DNA Molecule

(a) Utilizing shear flow (up to 1 mm/s)

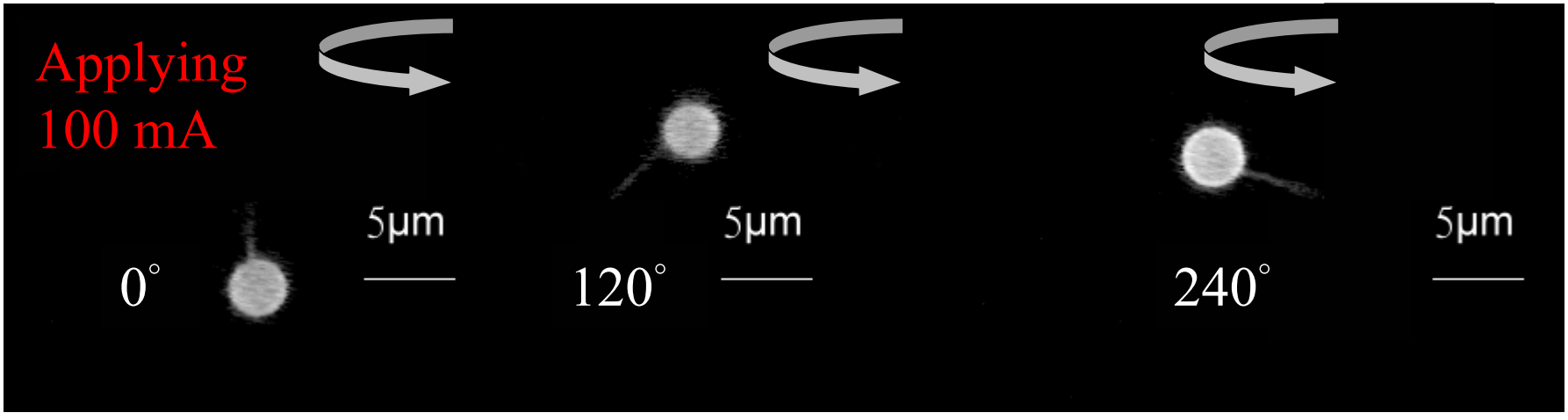
The bonding is strong enough to resist shear force

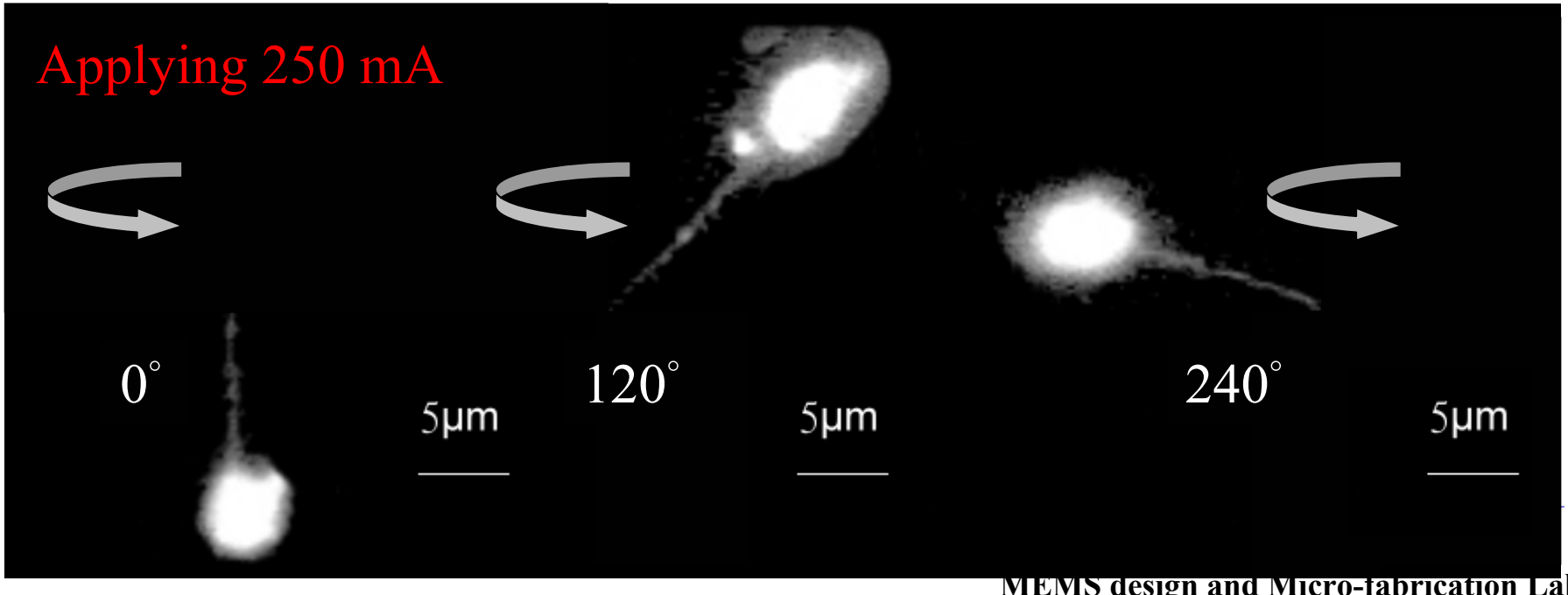


(b) Utilizing magnetic manipulator (up to 250 mA)

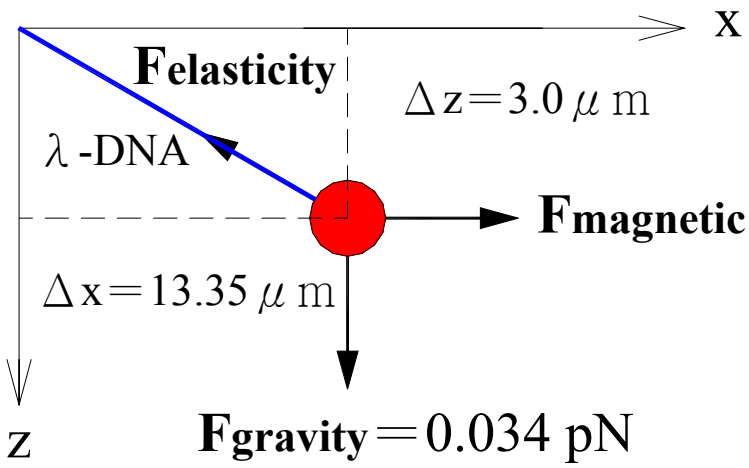


Rotation of a Single DNA Molecule





Free-body Diagram of the Tethered-bead DNA



DNA elastic force

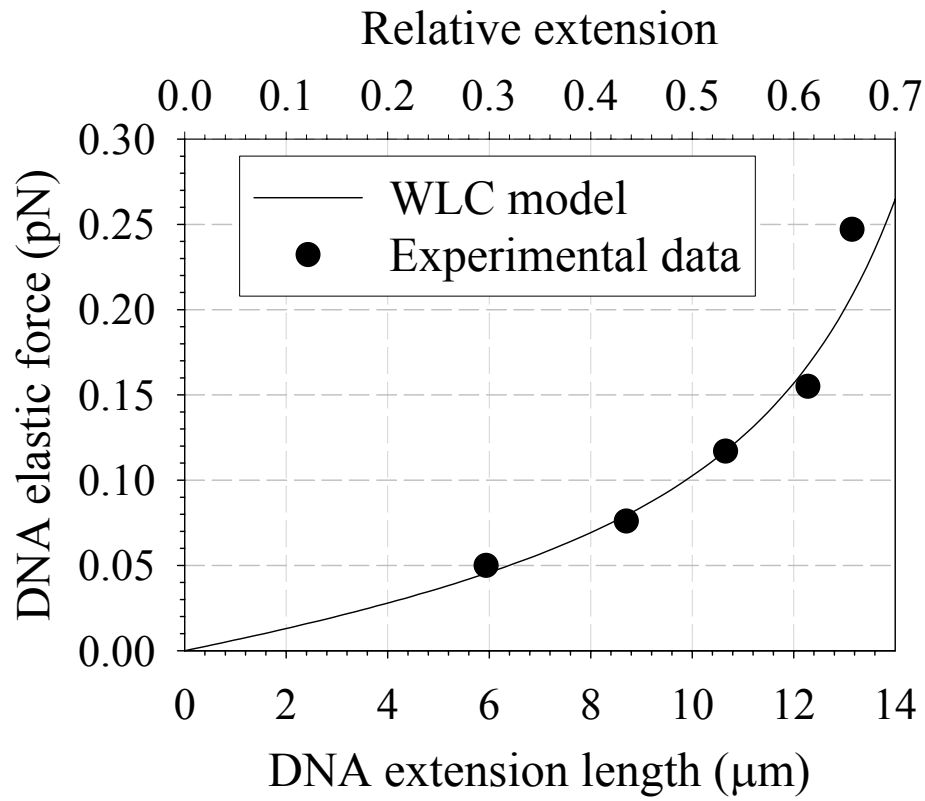
➡ Experimental value = 0.155 pN

Worm-like Chain model：

$$\frac{FP}{K_b T} = \frac{1}{4}\left[1-\frac{R}{L}\right]^{-2} - \frac{1}{4} + \frac{R}{L}$$

➡ Theoretical value = 0.163 pN

Force-extension curve



Spring constant ≒ 10^{-8}～10^{-7} Nt/m

Conclusions

- Development of a magnetic manipulator using MEMS technologies
- Demonstration of a novel DNA construction method
- Successful demonstration of stretching and rotation of a single DNA molecule
- Reasonable agreement between experimental results and theoretical data
- Advantages including

  Noninvasive, proper force range, excellent operation control, low cost, MEMS compatibility

- Providing a powerful tool for nano-biotechnology