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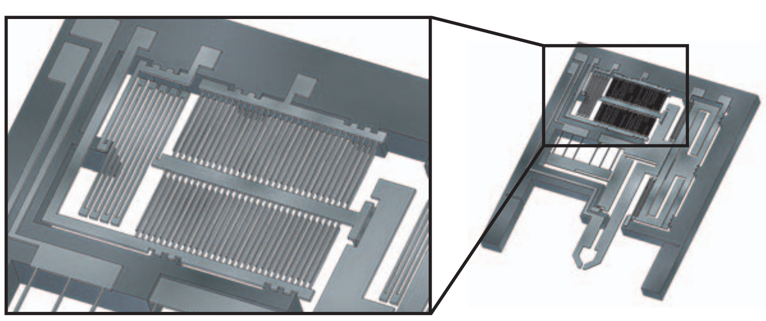
Silicon Nanotweezers with Adjustable & Controllable Gap for the Manipulation & Characterization of DNA Molecules

We describe electrostatically actuated silicon nanotweezers which are intended for the manipulation and characterization of DNA. The microelectromechanical system consists of a pair of opposing tips, the distance of which can be accurately adjusted thanks to a high resolution differential capacitive sensor.

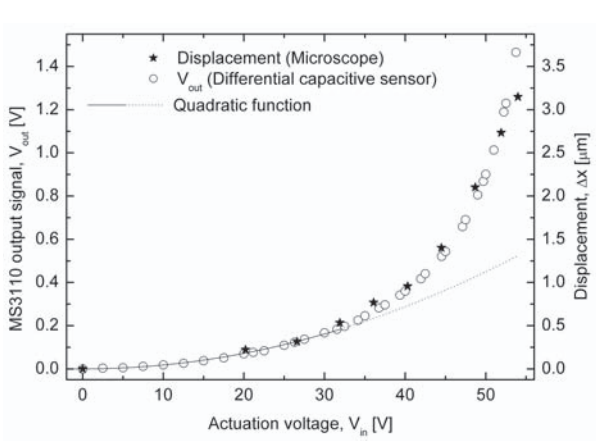
Working principle

The system consists of two sharp tips that act as electrodes for dielectrophoresis. One electrode is fixed, while the other is actuated with a capacitive comb drive actuator. The gap between the electrodes (x-direction) can be adjusted thanks to a differential transverse capacitor that measures the relative displacement of the moving electrode.



Characterization

The following figure reports the variation of the gap as a function of the DC voltage applied to the comb drive actuator, as estimated from SEM microscope observations. It shows a highly non-linear relation between the displacement and the actuation voltage. On the same graph, we have plotted the output signal obtained from the capacitive readout.



Microfabrication

The fabrication process is based on Silicon-On-Insulator (SOI) technology.

(1) A thin Si_3N_4 layer was first deposited by Low Pressure Chemical Vapor Deposition and patterned to form rectangle along <100> direction.

(2) The silicon over layer was then etched by deep Reactive Ion Etching (DRIE).

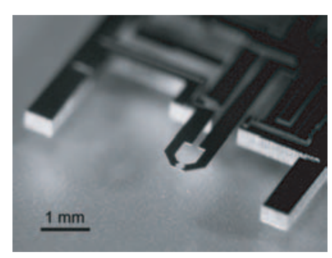
(3) Next, a wet oxidation process was used to cover the structured silicon with SiO_2.

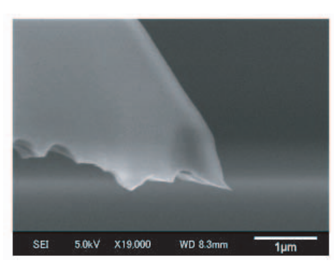
(4) After removing the Si_3N_4,

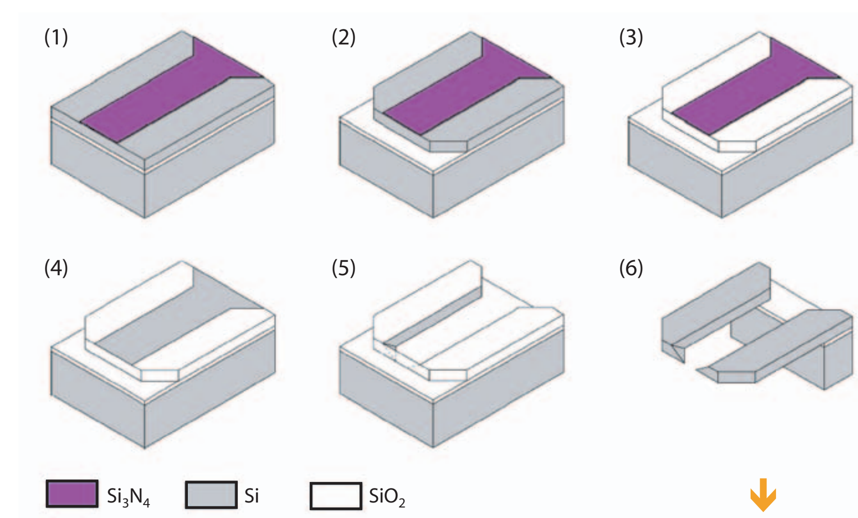
(5) KOH anisotropic etching of Si was performed to obtain {111} facets, and eventually make sharp tips.

(6) The buried oxide was removed by HF, and the handling silicon was structured by DRIE.

In the final step, a thin aluminum film was evaporated on the silicon substrate.

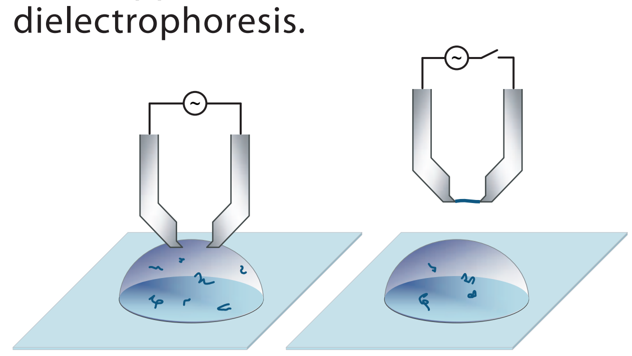




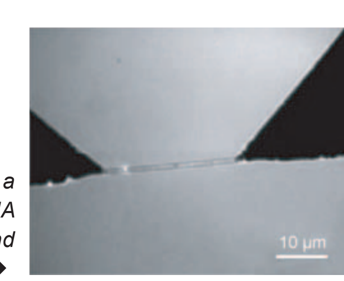


DNA trapping

For the biomechanical experiments, we used λ-DNA labeled with YOYO-1 fluorescent dye diluted in deionized water. The nanotweezers were mounted on a fluorescent microscope and accurately approached to the surface of a droplet of the solution. Then, a high AC electric field (1 MHz) was applied for few seconds in order to capture DNA by dielectrophoresis.



SEM picture of a bundle of DNA permanently bound to silicon tips ▸



MAIN CHARACTERISTICS

Displacement range: 3 μm

Resolution: 5 nm

Resonant frequency: 2 kHz

The device shows a resolution of 5 nm for a displacement range of 3 μm (static mode). It has a resonant frequency at 2 kHz and a quality factor of 40 in air, and 550 in vacuum.

CONCLUSION

We have developed MEMS nanotweezers that have displacement accuracy in the range of few nanometers thanks to the use of an integrated differential capacitive sensor. We expect that such performance should enable the detection of a bundle of DNA, based on a change of mechanical stiffness of the nanotweezers.

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