ELECTROSTATIC AND THERMAL ACTUATED NANO TWEEZERS

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Abstract— The aim of this study is to discuss the new technology in the field of Nano Tweezers. These tweezers integrate the electrostatic and thermal actuation. In this new technology, the Nanotweezers will have the ability work in the field of biotechnology for instance in the manipulation of DNA molecules or force sensing. The project will involve the design and the fabrication part. The new design will feature two tungsten tips that are chemically etched and attached to a carbon fiber-reinforced polymers. It will have electrostatic and thermal actuators. The fabrication part will combine the tungsten etching and the ion deep reactive etching on an insulator made of the silicon wafer to form Nanotips that are sharp and microstructures that are of high aspect ratio respectively.

Keywords— Nanotweezers, Nanotubes, Silicon-on-Insulator, Electrical and Thermal Actuators.

I. INTRODUCTION

In the field of nanotechnology and nanomaterial, reliable and accurate tools for the manipulation of the Nanoscale are sought after to complement new breakthroughs in this fields (1). In order to manipulate a single molecule or some other polymer, many techniques have consequently been developed. The most commonly used tools are the optical tweezers and the Nanotweezers or traps. In this technology, a bio-molecule is anchored between a force transducer and movable surface (2). The magnitude is so little in terms of piconewtons and the sensing is conducted with the help a trapped micron-sized bead or a cantilever whose displacement used as a measure of force. MEMS or microelectromechanical system have a pair of tips that are opposing with the ability to accurately adjust through a high-resolution differential sensor that is capacitive (3). It will have an electrostatic mode to show a resolution of 5nm for a displacement range of 3um. The resonant frequency of 2 kHz and a40-quality factor in the air and in a 550 in a vacuum.

The shape recovery effect of the spring in the electrostatic and thermal actuators is exploited as a mechanism to control the bending and relaxation modes of the Nanotweezers. Driving a potential difference of less than a single volt across the coils does the activation. Assembling involved putting the individual Au Nanowires averaging to 5-10 μm in length and 200nm in diameter on a silicon substrates using the tips of a tungsten. Drawing initials out of the many shapes of the nanowires such as loops, curls, Zigzags, and crosses will make this new nano-tweeZers have applications in the manufacturing of nanostructures that are complex or in modifying minute surface materials in the field of biotechnology among others (4).

II. HISTORY OF THE DESIGN

Nanotechnology involves invention and use of devices and materials at the size scale of molecules and intercellerstructures;it involves constructs and systems on the order of <100nm. In the field of Nanomedicine, construction, repair and improvement of biological systems at the molecular level using engineered nanostructures and devices is very important (1). This design was designed to help in the recent advances in biotechnology and the need for tools that can accurately and non-invasively manipulate Nano-objects. This device enables the trapping of the specimen or DNA molecule and moves it in 3D (2). In practice, the design was built using the top-down technique at the extremity of a fiber polymer. Passing some AC voltage and use of fiber polymers make it totally autonomous and free of bulky elements performed the trapping and the manipulation. This design achieves the trapping and manipulation performance allowing for the DNA molecules to be moved over tens of micrometers in several minutes with very low in-traps intensities (6). This non-invasive design will open up new horizons in nanotechnology by providing an unprecedented level of control of objects that are Nano-sized including heat sensitive bio-molecules.

The design had various advantages compared to other earlier and alternative designs of manipulation (6). One, themotion of the design is much more intricate and versatile than the simple movements that only work by the push of atomic force microscope tip or the trapping action of the optical tweezers that work in an only solution which has limited force in trapping and has no physical interaction with the trapped object (20). Second, the design will offer a sophisticated solution to manipulations in nanotechnology that incorporates automation and measurement capabilities. The nano-tweeZers also differ to the existing tweezers-like gadgets that inherit a lot of problems in fabrication, lack of performance and low yield due to the bad fabrication schemes. Lastly, Nanoscale building blocks can serve as the perfect specimens for the measurement of the properties of transport at the Nanoscale and new devices can be formed from their assembly such as nanowires transistors that can be used to replace their counterparts in the present. Advances in this assembly and measurement tools will result in progress in the design.

III. DESIGN

The Nanotweezers described here was pneumatically actuated and was designed to be operated in a range of environments including liquid and air at a range of scales (10). It comprises of two sharp tungsten tips that are chemically attached and act as electrodes for attracting the molecules. One of the electrodes was fixed while the other was electrostatically and thermally actuated. The gap between the tips (x-direction) was adjusted due to a transverse capacitor that is differential that will measure the relative displacement of the tungsten tips that are moving and measures the relative displacement of the moving tips. It introduced a limit of the voltage of pull-in dependent on the current position so that it allows a residual spacing between the tips of the tweezers. Figure 1 below shows the basic idea of the design.

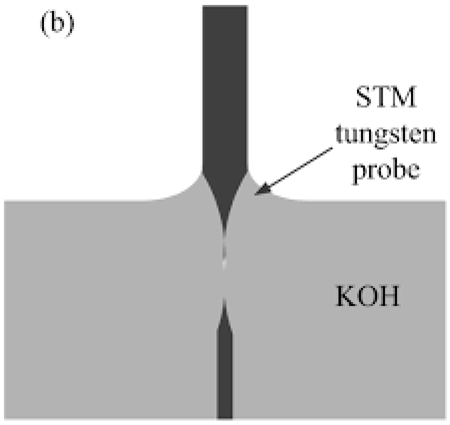

Figure 1: Basic idea of the design

The electrostatic and thermal actuator is an essential flexible membrane that applies force to the tweezers pad when the air inlet is pressured (8). The sensor consisted of the central plates that are relatively more fixed to the external plates thus forming two capacities. The structure used was obtained by the deployment of two polysilicon plates signed to integrate the electrostatic actuator and the tungsten tips of the Nanotweezers. The electrostatic tips use the coulomb forces present between them subject to a difference in potential to maximize the capacity. The thermal tips use a difference in temperature between the two tips and therefore a dissymmetry of dilation between the two tips that have tungsten as its unique material. Part of the material that makes the tips is heated up to obtain a lateral bending. By joules effect, the heating is obtained through the conductive material, which in this case is the shrinking of the local part. This part imposes the electrical resistance thus the dissipated power and a higher temperature. Combining this two actuation to make an electrostatic and thermal Nanotweezers is very effective and efficient (13). They will manipulate molecules in the most efficient way possible.

Parameters such as the length, diameter of the arms, and the initial gap between the tungsten tips affect this model. This model is an Electrostatic and thermal actuated Nanotweezers thus it has a gap of less than 15nm and the van der Waals force become detrimental (17). Considering that these Nanotweezershave two fiber polymers arms, the investigative model for finding out the effects of this parameters takes into account the Van der Waals forces and the electrostatic and thermal actuation. The governing equations are obtained from the model and linearized using the step-by-step linearization method (SSLM). The reduced-order method by Galerkin is used to solve the equations (18). By employing numerical methods the dynamic and static analysis is performed to determine the simulations on the various parameters of the tweezers.

IV. THE MATHEMATICAL MODEL

The figure 2: the schematic view of a tungsten tip Nanotweezers. The fiber polymer arms are made to approach each other when a voltage difference V is applied between them.

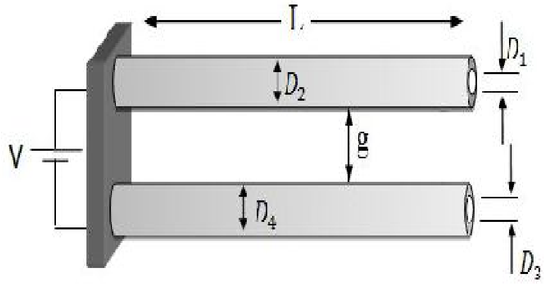

Figure 2. Schematic view of the nano-tweezer.

The present model presents $R1$ and $R3$ as the internal radii and $R2$ and $R4$ as the external of the nano-tweeZers. In real life applications, there is uncertainty in arms of the nano-tweeZers thus they have different specifications such as rigidity in bending, clamped conditions, diameter among many others (18). Thus, in the numerical simulations specifications that are different are assumed for each arm and subscripts a and b are used to denote each one. Therefore, the equations for the above model are as follows.

$$(\mathrm{EI})\ a\ \frac{\partial^4 wa}{\partial x^4} + \rho Aa\frac{\partial^2 wa}{\partial t^2} + Ca\frac{\partial wa}{\partial t} = Fe + Fv$$
(1)
$$(\mathrm{EI})\ b\ \frac{\partial^4 wa}{\partial x^4} + \rho Ab\frac{\partial^2 wa}{\partial t^2} + Cb\frac{\partial wa}{t} = Fe + Fv$$

(EI)*i*are the bending rigidity while *wi* are the arms' lateral deflections. Also ρi and Ai are the mass density and the arms' cross-sections. The system is subjected to damping in real life situations where it is approximated by damping coefficient that is equivalent *ci* per unit length. The electrostatics, thermal and van der Waals forces are represented by *Fe* and *FV* as the forcing terms and have the following form.

$$Fe = \frac{\varepsilon_{0\pi V^2}}{R\sqrt{\frac{S(S+2R)}{R^2}}\ [\ln(1+\frac{S}{R}+\sqrt{\frac{S(S+2R)}{R^2}})]^2}$$

$$Fv = \frac{A_H}{\sqrt[8]{2}}[\frac{1}{(S)^{\frac{5}{2}}}\left(\frac{R_2 R_4}{R_{2+} R_4}\right)\frac{1}{2} - \frac{1}{(S+T)^{\frac{5}{2}}}(\frac{R_2 R_3}{R_{2+} R_3})^{\frac{1}{2}} - \frac{1}{(S+T)^{\frac{5}{2}}}(\frac{R_1 R_4}{R_{1+} R_4})^{\frac{1}{2}} + \frac{1}{(S+2T)^{\frac{5}{2}}}(\frac{R_1 R_3}{R_{1+} R_3})^{\frac{1}{2}}] \quad (2)$$

T is the thickness of the fiber polymers. The external radius of the arms $R2$ or $R4$

Replaces the radius R in the electrostatic force Fe. ε_0And AH are the domain permittivity and Hamaker constants respectively and S is the distance between the two arms, S= g-*wa*-*wb.*

Introducing the parameters

$\hat{x} = \frac{x}{l}, \widehat{w} = \frac{w}{g}, \hat{t} = \frac{t}{t^*}, \hat{c} = \frac{c}{t^{*EI/L^4}}, t^* = \sqrt{\rho A l^4}/EI$ then the governing equations could be written as:

$$\frac{\partial^4 \widehat{W}a}{\partial \hat{x}^4} + \frac{\partial^2 \widehat{W}a}{\partial \hat{t}^2} + \hat{C}\frac{\partial \widehat{W}a}{\partial \hat{t}} = \propto_1 \hat{F}E + \propto_2 \hat{F}$$

$$\frac{\partial^4 \widehat{W}b}{\partial \hat{x}^4} + \frac{\partial^2 \widehat{W}b}{\partial \hat{t}^2} + \hat{C}\frac{\partial \widehat{W}b}{\partial \hat{t}} = \propto_1 \hat{F}E + \propto_2 \hat{F}v \quad (3)$$

Where $\propto_1$and $\propto_2$are the transformed forcing terms defined by:

$$\propto_1 = \frac{\varepsilon_{0\pi V^2}}{(EI)(g^2)};\ \propto_2 = \frac{A_H L^4}{\sqrt[8]{2}(EI)(g^{3.5})} \quad (4)$$

$$\hat{F}_e = \frac{V^2}{R\sqrt{\frac{S\widehat{(\hat{S})+2R}/g}{R^2}\ [\ln\left(1+\frac{g\hat{S}}{R}+\sqrt{g^2 S\left(\frac{\widehat{S+\frac{2R}{g}}}{R^2}\right)}\right]}}$$

$$\hat{F}_V = [\frac{1}{(\hat{S})^{\frac{5}{2}}}\left(\frac{R_2 R_4}{R_{2+} R_4}\right)\frac{1}{2} - \frac{1}{(\hat{S}+T/g)^{\frac{5}{2}}}(\frac{R_2 R_3}{R_{2+} R_3})^{\frac{1}{2}} - \frac{1}{(\hat{S}+T/g)^{\frac{5}{2}}}(\frac{R_1 R_4}{R_{1+} R_4})^{\frac{1}{2}} + \frac{1}{(\hat{S}+2T/g)^{\frac{5}{2}}}(\frac{R_1 R_3}{R_{1+} R_3})^{\frac{1}{2}}] \quad (5)$$

Where $\hat{S}$= 1-$\widehat{w}_a - \widehat{w}_b$the governing equations (4) can then be solved.

Changing the parameters will affect this design in a way that will result in static and dynamic characterization. In dynamic characterization, imposing the exciting voltage suddenly, the fiber polymers are deflected beyond their static equilibrium positions (16). Thus, the dynamic pull-in voltage is smaller than the static pull-in vale as the polymers reach the critical pull-in gap sooner than in the static analysis. On the other hand, static characterization, there is a high non-linear relation between the displacement and the actuation voltage.

V. BASIC PROPERTIES OF THE NANOTWEEZERS

Figure 3 (a)is an image of a typical pair of the designed Nano-tweezers. The length of the two arms is 2.0 μm and the separation between the tips is 700nm. A scanning electron microscope (SEM) was used to check the operations of the Nano-tweezers (14). Applying various voltages between the arms in order to acquire an electrostatic attraction force makes the separation of the tips to gradually decrease when the voltage is increased. When the voltage exceeds a certain value, the applied tips, and the arms suddenly close (14). This is shown in figure 3 (b) as a pull-in. The left arm is put at rest while the right one was positively biased; this resulted in a poor image contrast of the right arm. The motions in this figures could be repeated many times without any plastic deformation. At the closed stage, the two arms have different shapes; the left arm tends to bend more intensively at the base than the other arm suggesting that the arm has a mechanical strength that is lower than that of the other arm. This can be caused by defects in the carbon atoms network in the carbon fiber arms.

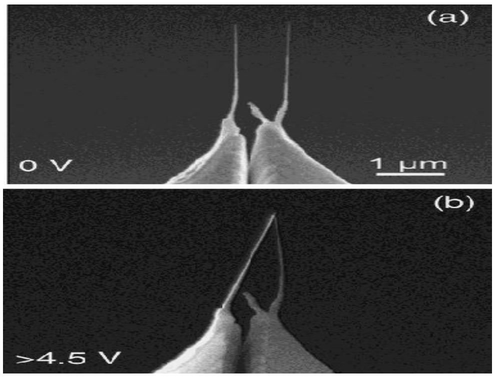

Figure 3: images of motion of the Nanotweezers for AFM: (a) opened and (b) closed.

The major difficulty encountered was a lack of an effective batch-compatible fabrication technique in the integration of the nano-tweeZers with objects such as Nano-wires. To fabricate the Nanoscale objects in the design, two methods can be used either self-assembly technique or top-down methods (20). This design used the top-down technique for micro-Nano integrations, which includes electron beam lithography and the direct growth of Nanoscale features on MEMS electron deposition or using focused-ion-beam chemical vapor deposition. However, this process is costly and time-consuming.

For improvement, the self-assembly method can be used in the case of nanowires being integrated with MEMS and can use one of the following techniques; i) Using an electric field that is external or deposition sites that are selective, where nanowires can be grown with prescribed directions on a microstructure, or ii) where nanowires and microstructures are fabricated separately. Nanowires are then removed and from their fabrication sites and with respect to the microstructure aligned using external fields or secondary forces. Using carbon films that are amorphous is another option to increase the adhesion in between. But, in providing the required level of control on the orientation and number of Nanoscale, self-assembly is far from it (5). Therefore, merging the two to form the self-assembly-based bottom-up approach that is compatible with the philosophy of batch fabrication would form a successful micro-Nano integration technique.

VI. SIMULATION

The simulation analysis of design are provided by the COMSOL software and the during the run time, different values of the forces provided by the electric field are calculated using MATLAB programs. It is more reliablefor calculations. Ahigh-performance computing (HPC) of the design using MATLAB is an efficient tool to work with. After various forces inputs have been provided, the motion is induced to at the tips by providing a required driving force as an input value. Depending on the motion, directions and interactions between the tips and particles the forces between them are Van der Waals Force and electrostatic force. Figure 4 below shows the simulation structure and the electric field of the horizontal component distribution of conventional trapping. The color map corresponds to the magnitude of the electric field horizontal components under the input power P= 32mW. The maximum and minimum magnitude of the electric field horizontal trapping force on a DNA substrate.

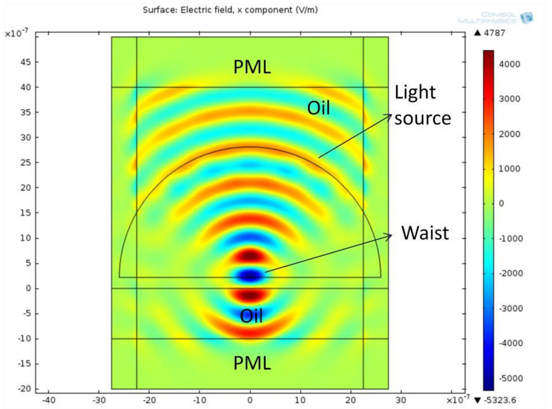

Figure 4: Simulation structure of the electric field of the design.

VII. DNA TRAPPING AND MANIPULATION

Figure 5 shows a DNA trapping and manipulation mechanism, whichmeans handling of DNA molecules using the created Nanotweezers design for the characterization purpose. For this biotechnology experiment, we used the λ-DNA labeled with a fluorescent dye diluted in deionized water. A small droplet of the solution was put on a microscope glass slide. The Nanotweezers were mounted on a fluorescent microscope and approached accurately to the surface of the droplet on a mechanical stage that is 3D. Figure 6 shows the two sharp tungsten tips being used as electrodes to trap the DNA molecules through dielectrophoresis and for conducting measurements on the molecules (19). Through electrostatic actuation, the tip was moved while the other one was fixed. The electrodes gaps were sensed through a differential capacitor that measured the relative displacement of the moving electrode. The mobile parts moved along the electric field when a high voltage was applied between the two electrodes in a few second tending to reduce the gap between the electrodes.

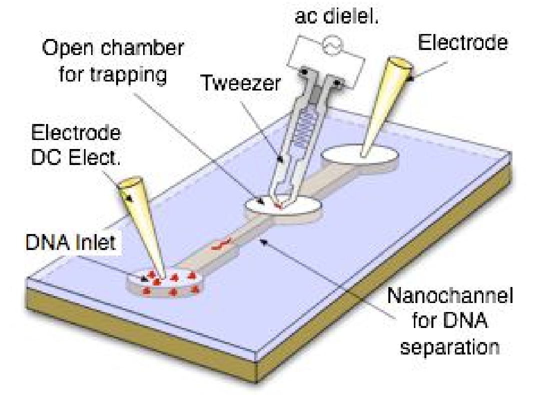

Fig.1 : Principle for DNA molecule isolation and trapping by nano-tweezers

Figure 5: Principle for DNA molecule trapping

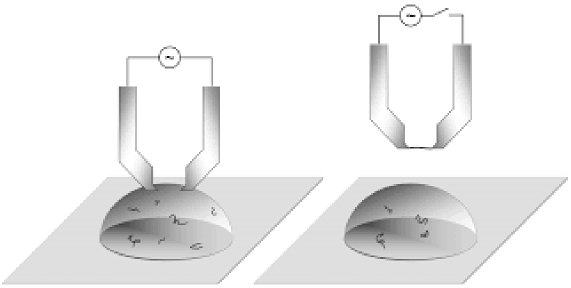

Figure 6: Principle of DNA retrieval by AC di-electrophoresis.

CONCLUSION

This study has demonstrated a recent technology in the field of nano-tweezers. The electrostatic and thermally actuated nano-tweezers have the ability to manipulate very tiny molecules in the field of biotechnology and then provide feedback. The two carbon fiber polymers that form the arms are fabricated using low-cost and the most efficient manufacturing techniques with a range of dimensions. This allowed the design to be scaled to fit the chosen application. This structure will be appropriate and suitable for grasping micro objects of smaller sizes. The Nano-tweezers could also be used as an STM two-tip or conduct an AFM probe (6). The probe can measure the single electron Green's function between the local two tunneling junctions and thus provide detailed information about the electronic and thermal properties of the material (7). Future work will focus on designing a Nanotweezers that manipulate even smaller and tiny cells thus opening up exciting opportunities for modification and manipulation of biological systems such as structures of a cell.

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