Towards *In-Vivo* Radio Transmitting Nanorobots

(Brief Summary)

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ABSTRACT

An implementable design of a Nano Electro Mechanical (NEM) Carbon Nanotube (CNT) cantilever for communication in nanorobots is sketched in this brief summary. Nano communication devices can provide future nanorobots with the ability to communicate its status to an outside entity as well as synchronize in a medium, to form an intelligent swarm. We develop a model which can help to tune the cantilever, based on its geometry and other properties, for the intended oscillation frequency. Electrostatic actuation over CNT cantilever is used to omit radio signal transmission. The electricity can be harvested from the blood sugar. The design is envisioned to be a part of an autonomous inorganic nanorobot for medical purposes.

Keywords: nano-electro-mechanical systems (nems), actuator, cancer, energy harvesting, carbon-nanotube (cnt) detector, tumor detection

1 INTRODUCTION

Nano Electro Mechanical Systems (NEMS) [1] have been studied extensively in recent times due to their increasing use in applications like sensors, actuators and low power switches. NEM devices are characterized by small dimensions in the ranges up to a few hundred nanometers. The small dimensions and geometry of the NEM devices imply the operating parameters and the application of these devices in real life. For example, NEM based transistor switches exhibit zero leakage current so that they switch (in principle) at lower voltages than the conventional silicon based electronic switches [2, 3, 4]. Due to the recent advances in the fabrication technology and testing practices in the sub-micron level, NEM devices are being explored to a higher extent. Moreover, the requirement and, the futuristic drive for state-of-the-art devices with higher component ratio and capacity has fueled the exploration for newer NEM devices.

CNTs find their applications in many scopes including biological sensing and detection, electron transport in semiconductors for their properties of unique mechanical and electrical properties and ballistic electron transport capability. Due to these advantages of CNTs, they are used in cantilever based NEM devices for sensing and radio tranceiving applications [5, 6].

2 NANORADIO AND PULSE GENERATION

There has been a growing interest in the miniaturization of devices, specifically for active and passive electronic systems, including devices used for radio communication. Conventional nano particles in medicine are basically used for targeted treatment, imaging, florescence agents, magnetic and thermal induced actuation [7]. Recent advances in material research and fabrication techniques has paved the way for testing newer combinations and material geometry to improve the effect of nanoparticle-based treatment techniques. Recently, researchers fabricated tiny autonomous DNA nanorobots to be used in sensing and targeted delivery of drugs [8, 9, 10]. The point of providing autonomity to these nanorobots can be extended to the idea of including a communication module to the nanorobots. A concept exists in theoretical computer science called, *programmable matters*, defined as a particle system comprising of individual smart particles which can perform logical operations and communicate with other particles in the system, resulting in synchronization in movement, foraging or actuation. The ability of programmable matters to exhibit phenomenal changes to its properties upon action of chemical or bio-sensing [2, 11], or a combination of both [12], influences in realizing inorganic nanorobots for varied *in-vivo* sensing and actuation purposes.

Synchronization of programmable matters is feasible provided that every matter communicates its *status* to its respective neighbors through molecular interactions or radio frequency communication. Theoretical results exist for extending the harmony in synchronous beeping of fireflies to programmable matters. But the implementation feasibility of the programmable matters can be considered only when appropriate hardware is operational. Molecular communication can be effective in cases where the interaction results in subsequent actuation like payload exposure or florescent marking. Though the concept of radio frequency communication for medical nanorobots is in its early stages of research, there are considerable advances to conceptualize a model for such radio usage [13, 14, 15]. We have provided the first implementable design of a down-scaled cantilever geometry which can be fabricated as a part of different nanodevices, and at the same time, using a challenging very low electrostatic power supplied by electrons harvested in blood [16]. Oscillation in the frequency range that fits the *in-vivo* radio requirement is achieved. The nanoscale and the frequency requirements enforced us to attach a (gold) mass at the end of the cantilever.

2.1 Nano-Radio Design

The design and simulation of a field-emitting CNT cantilever oscillator is outlined in this brief summary (due to space limitations, the exposure of the design and simulation results are deferred to the full paper version). The nanoradio is designed for use in *in-vivo* medical devices. The Federal Communications Commission (FCC) purposes the Medical Device Radio communications Service (MedRadio) spectrum for use in diagnostic and therapeutic purposes in implanted medical devices. The frequency ranges allowed by the authorized standard ranges from 401 – 457 MHz [17]. Figure 1 depicts the conceptual design for a CNT cantilever beam which is based on a micrometer scale design [14]. A constant Direct Current (DC) voltage source is applied to the cantilever and the counter electrode, which are etched parallel to each other. Due to the increase in electron density in the cantilever, it eventually bends towards the counter electrode due to the capacitive action between the parallel plates. The electrostatic force forces the nanotube to (almost) contact the counter electrode. The nanotube eventually loses electrons as field emission and is forced by the property of elasticity, to retreat. Eventually, there is a constant switching between the electrostatic and elastic force on the cantilever beam.

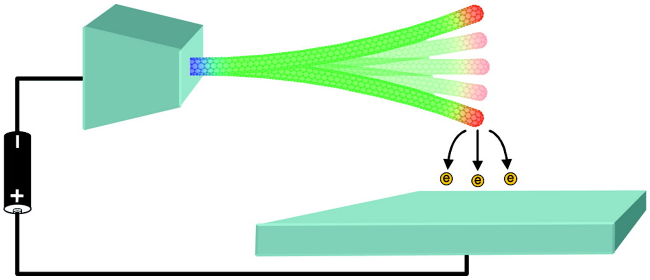

Figure 1: Schematic of a Uniform CNT cantilever oscillator. Reprinted (adapted) with permission from Nano Lett. 2010, 10, 5, 1728-1733 [14], Copyright 2010 American Chemical Society

2.2 Pulsed Clock Source

In another perspective, the time cycle of one cantilever oscillation is indirectly the discharge time of the capacitor which depends on: the field emission current I_{fe} (calculated as the surface charge emitted per unit time), the design parameters of the nanotube, including the length and radius of the nanotube, initial distance between the nanotube tip and the counter electrode and the angle between the attached end of the nanotube and the base electrode. Let t_{osc} be the time taken for one oscillation cycle of the nanotube, i.e., t_{osc} includes a high-to-low (discharge) and a low-to-high (charge) cycles. Thus, I_{fe} is given by $\frac{dQ}{d(t_{osc})}$. The parameter d_0 can be made smaller (within a threshold so the system does not become unstable), so that I_{fe} is increased. This means that T_{osc} is reduced, thus the system oscillates with higher frequency.

A separate design of a pulse generating circuit from the mechanical oscillator can be implemented to provide stable clock source to an implementable NEM logic circuit, possibly a single bit storage element (flipflop). Theoretically, mechanical switches are shown to exhibit zero leakage current so that they switch (in principle) at lower voltages than the conventional silicon based electronic switches. Fig. 2 shows a schematic of a NEM relay switch. The electron mobility in the counter electrode (in Fig. 1) varies with respect to the mechanical oscillations of the CNT cantilever. This, in turn, can be used to influence (as a gate source) the upper actuation electrode in Fig. 2, thus providing an electrical equivalent pulse of the cantilever oscillations. This design can thus be a part of logical flipflops and single bit computation elements. In our scenario, the actuation electrode is a part of the electrode structure of an energy harvester and a capacitor, as proposed in [16]. The charge-discharge cycle of the capacitor and the gate contact of the high frequency CNT oscillator can result in a ‘charged source – gate contact’ scenario. Thus, the

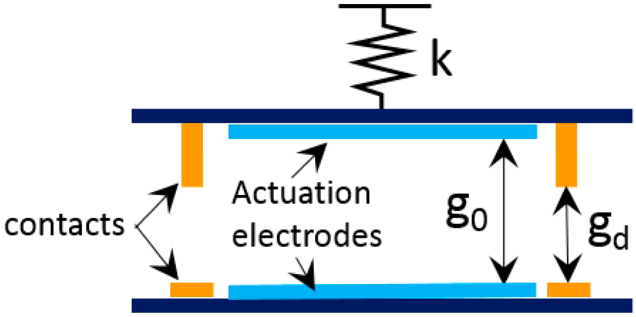

Figure 2: Model of a NEM relay. Reprinted (adapted) with permission from [18]

field emission current from the CNT oscillator can be used to generate a sequential pulsed output for possible use as a clock source to a logic circuit.

3 CONCLUDING REMARKS

A CNT based NEM cantilever is designed. In our previous work, we have provided a proof-of-concept design of an energy harvesting autonomous inorganic nanorobot having the capability of bio detection and actuation. This work provides a theoretical explanation on inclusion of a communication module in the nanorobot. We envision a future with millions of programmable matters that can (speaking on a broader sense) provide personalized treatment and cope with cancer. The oscillator can also be used as a clock source for realizing nanocircuits. We believe that this model can motivate researchers to explore the potential in using inorganic nanorobots for fighting cancer.

ACKNOWLEDGEMENTS

We thank the Lynne and William Frankel Center for Computer Science, the Rita Altura Trust Chair in Computer Science, the Kreitman School of Advanced Graduate Studies, Ben-Gurion University of the Negev for their support. This research was also supported by a grant from the Ministry of Science & Technology, Israel and German Research Funding Organization (DFG, Grant#8767581199). The simulations were performed with COMSOL Multiphysics (License #17075968). We also thank Prof. Zeev Zalevsky from Bar-Ilan University, Israel, Prof. Yonathan Sivan from Ben-Gurion University of the Negev and Prof. Tsu-Jae King Liu, University of California, Berkeley, for their useful comments and assistance.

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