

Introduction

Recently, Dr. Sheehan (of USD) has been investigating NEMS and MEMS (nano and microelectromechanical systems), which are on the research forefront in many fields today. His particular interest is nanoscale dc-driven cantilever oscillators. In this research, Sheehan realized the need for contact surfaces that could overcome the problems of adhesion (due to van der Waals/Casimir forces occurring in the nanoscale regime between surfaces) and wear (due to the high frequency of surface collisions – $f \sim 10^7 - 10^8$ Hz).

In the recent months, he has put forward an original idea that addresses these problems. In order to create ideal contact surfaces, multi-walled carbon nanotubes (MWNT) are partially embedded in a parallel fashion on (likely silicon) surfaces (Fig. 1). These surfaces are then arranged in an orthogonal fashion. With this arrangement, the contact between the two surfaces is limited to the points created by the perpendicular nanotubes (Fig. 2). The total area of contact created by the lattice of points is significantly smaller than that of two flat surfaces, and minimal enough to make negligible van der Waals/Casimir force and adhesion. Also, by employing MWNT, their various advantageous properties can be utilized in the embedded surfaces. MWNT have superior electrical, mechanical, and thermal properties. Firstly, they are incredibly strong and rigid, producing unmatched mechanical durability. Further, MWNT are virtually wear-free and frictionless, superb conductors of electricity, and able to handle high temperatures.

Sheehan has said, “MWNT impregnated surfaces can be envisioned for robust linear or cylindrical bearings, high-conductivity electrical contacts, and low-adhesion (non-stick) contacts. They might also scale up to everyday length scales for dry electromechanical applications – e.g., sliding contacts, piston-cylinder, electrical relays.” [1] In theory, these surfaces have vast potential. The many utilizable aspects of MWNT and their arrangement in the surfaces allow for a practical advancement in the battle against frictional wear. This has been, for many generations, an uphill fight. It has been estimated that 20-25% of world energy is used in overcoming losses due to kinetic friction (and the accompanying heat generated). The economic, as well as ecological and scientific value of reducing this percentage is clearly great. These low adhesion, low friction, low wear surfaces address many of the problems in the field of MEMS and NEMS, and further, all nano and microscale industrial processes that involve contact. However, perhaps the most exciting prospects for the MWNT embedded surfaces are those of macroscale. “Conceivably, sliding ONAs [Orthogonally-Oriented Nanotube Arrays] would constitute nearly frictionless, wear-free, and stictionless bearings,” [2] Sheehan has said of his calculations concerning the surfaces. As a tangible example, if a 3-ton truck were supported by a pad of ONAs the size of a silver dollar, a force of only a few ounces would be required for sliding. In contrast, the force necessary to slide this truck on its own tires is roughly 3 tons.

The Research

Sheehan hopes to further research and advance this idea in the following months, and these ideas are still proprietary (a patent is possible). Preliminary work has already begun, and there is much to do and many questions to address.

This summer, with the aid of the SURE grant, I hope to assist Dr. Sheehan with this many stages of this research. Our primary focus will be the actual assembly and development of the surfaces, and if successful, the analysis of their properties. The matter that must be explored in the lab is the actual implantation of the MWNT into the trenched surfaces. Manipulating nanoscale objects and placing them into nanoscale trenches may turn out to be rather challenging. Many promising methods have been proposed, and once an effective method is utilized, it will be possible to study the physical characteristics of the surfaces.

Proposal Specifics

Throughout the entire ten weeks, my schedule will be 40+ hours/week, comprised primarily of lab work. I will be personally responsible for experimentation, including data extraction and analysis. My efforts will concentrate on some of the proposed methods of producing the implanted surfaces. This will surely include wet chemistry, as we will attempt to functionalize the MWNT and their trenches. By saturating a solution with the nanotubes, we will be able to attach certain molecules with polar attraction to the MWNT and their corresponding trenches. In doing so, this polarization may allow us to embed the nanotubes in the surface trenches and bind them there. It may be as simple as allowing the nanotubes to fall into the trenches on their own. We will explore using a vibration technique, allowing the tubes to fall from a higher potential energy state on the surface to a lower state in the trench. The tubes may then adhere themselves via van der Waals force. Many of these methods may be combined, but in principle all of these methods will make use of solvents. Much of the work will be done using larger scale, more simplistic surfaces such as diffraction gratings. These larger surfaces can be purchased with precut trenches that will be easier to use in preliminary examination.

In my work, I will be acquiring lab skills, as this will be my first individual lab experience. In addition, I will learn how to use the Atomic Force Microscope, making frequent use of it to assess the results of our experimentation, as well as investigating the surfaces' basic physical properties. There is a definite publishing possibility, dependent upon the success of the experimentation. Regardless of the outcome, I will produce a write-up. I hope to present my personal findings in conjunction with the overall laboratory progress on the embedded surfaces as many times as possible.

A personal supply budget of \$500 is requested for the purchase of chemical solvents, commercially available nanotubes, and diffraction gratings. I plan to live off campus and commute daily.

References

- [1] Sheehan, D.P., "NEMS DC-Driven Cantilever Oscillator Project Summary," (2005).
- [2] Sheehan, D.P., "Orthogonally-Oriented Nanotube Arrays: Theory," *Incomplete Draft*. (2006)