Electrostatic Self Assembly Of Carbon Nano-Tubes

Robert H. Detig; Electrox Corp.; Fairfield, NJ/US

Abstract

Carbon nano-tubes are self assembled between two electrodes using an electric field for sensor and transistor applications. Transistor behavior, source/drain current versus gate voltage, was demonstrated.

Introduction

Using techniques developed from the electrostatics industry "ropes" of virgin carbon nanotubes are pulverized into individual tubes which are immediately self-assembled between two electrodes on a dielectric surface. A voltage of a few hundred volts exists between these electrodes. Such structures can be used as chemical sensors or field effect transistors. We will describe both the self assembly process and the pulverizing process. One advantage our technique is that no surfactants or wetting agents of any kind are used. The nanotubes have no net electrochemical charge (i.e. no surface functionality is required and no charge director materials are used). The virgin nanotubes (both metallic and semi-conducting are used) have sufficient electrical conducting so they align along electrical field lines, due to dielectro-phoretic forces.

Discussion: Building Sensors or Field Effect Transistors (FET's) Using Virgin CNT's

By virgin nanotubes we mean SWNT's with no surface functionality per se; no wetting agents and surfactants are employed, nor are there any poly-electrolytes (charge directors) added to the diluent. The sensor/transistor assemblies are created between two electrodes on a dielectric surface with gaps between electrodes (called the channel) that ranging from a few microns to as much as 50 microns. Much smaller gaps are also easily produced. The channel widths extend from a few to 10's of microns range. The substrate used here is a silicon wafer, coated with approx 100 nm of SiO_2. On top of the dielectric are patterned two gold electrodes; one, the source, and the other, the drain.

We will discuss the theory behind the operation of this fiber self assembly process and show samples of typical parts, which display transistor behavior. In typical sensor applications, functional surface coatings are added after the fact of assembly; and there may be as many as two dozen of them for a single family of sensors. Beyond the obvious application of building sensors, the process can also assemble the channel of a high performance, field effect transistor; as CNT's have 100 times the mobility of single crystal silicon, the cornerstone of all electronics. Such parts are useful for phased array radars and backplanes for flat panel displays.

Discussion: An Example of the Self Assembly Process

The source/drain metallization patterns, on the surface of a dielectric material have a voltage between them that generates an electric field directly between the electrodes but also fringes above it. These fields will attract particles as shown in Figure 3, and idealized case to be sure. Figure 1 shows the mechanism for electrostatic self assembly of long, thin electrically conducting particles. The fibers will align with the direction of the electric field (E), due to "dielectro-phoretic" forces. Note the particles are assumed to be uncharged (i.e. they have no net charge, neither electrochemical nor electronic charge). Substantial experimental evidence shows this to be the case. Note the two fibers in the center of the sketch and on the right. The electric field at the ends of the "chained" fibers is higher than the average of v/g. The gradient of this E field will draw uncharged particles of high dielectric constant (conductive particles have an effective dielectric constant that is very large) to the top of the 2^{nd} fiber while aligning it also. The general direction of fiber growth is parallel to the adjacent average electric field of v/g. This explains the mechanism of "chaining" of uncharged, electrically conductive particles in an electrical field. Note; carbon nanotubes SWNT are 2/3 semi-conducting and 1/3 metallic. Even the semi-conducting nanotubes, with say a bulk conductivity of 10exp(-10) siemens per cm. have a discharge time constant of 1 millisecond! This means that after one millisecond in an electric field, they behave identical to the metallic fibers. In the regime of this experiment, all CNT's are effectively metallic.

Figure 2a, shows the electrostatic pulverization process, which we call the "tornado" experiment. At a high field (2-3 Kv across 6mm) particles are accelerated between parallel plates until the "ropes" or agglomerates of CNT's, break up. In Figure 2b (not to scale) is a small silicon/silicon dioxide header with two gold electrodes, about 100 nm thick. A small electric field of 150v across 30 microns (max) is established between these two electrodes. Broken up ropes then drift from the edges of the parallel plate "tornado" chamber and then chain up across the 30 micron gap.

Figure 3 shows an actual chain of fibers. Note the actual fibers are CNI (Houston TX) single wall Hipco fibers (dia 1.5nm, length = 500nm). Figure 8 shows the V-I characteristics of our CNT transistors; not useful now, but (someday) when we can pre-sort metallic tubes from the semi conducting types, would be a very useful power transistor working in the terahertz range. Figure 4 shows the actual v-I curves; horizontal is gate voltage, vertical is source/drain current. It shows actual transistor behavior.

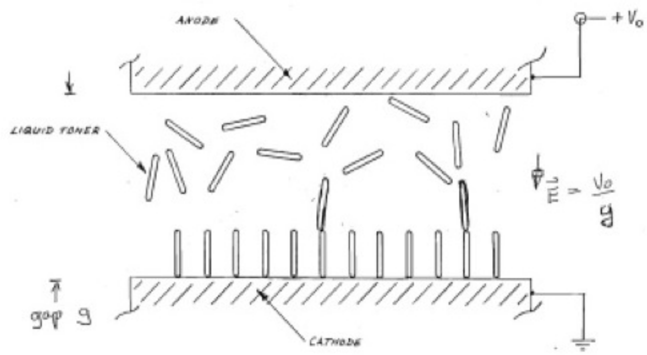

***Figure 1**. Chaining of fibers in a liquid*

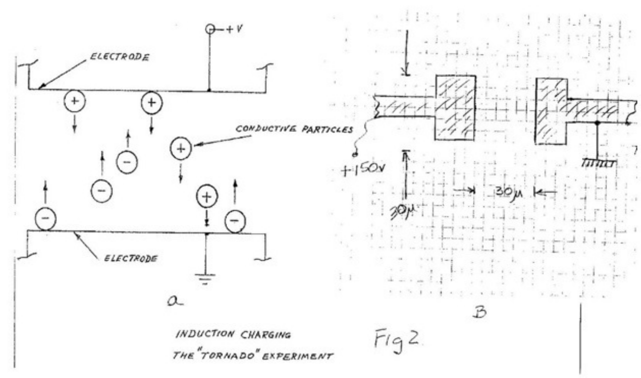

***Figure 2a/b**. Induction charging*

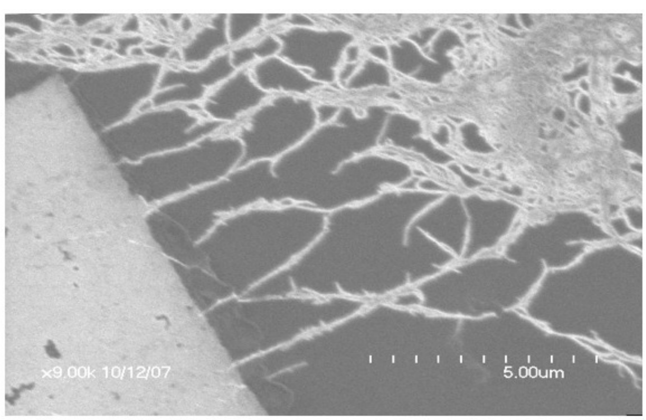

***Figure 3**. Close up of chains, basic fiber L, 500 nm; channel L = 30 μ*

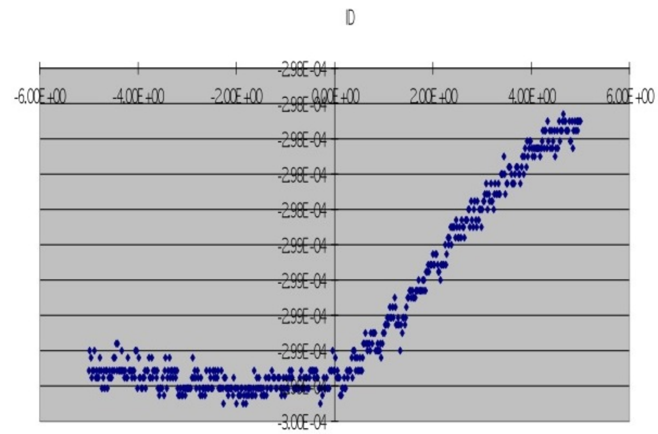

***Figure 4**. Source/drain current (vertical) vs. gate voltage (horizontal)*

Author Biography

Robert H. Detig founded Electrox Corporation in 1992 to adapt electrographic imaging technology as a manufacturing tool for various industries. He holds some of the fundamental patents on the photo-polymer electrostatic printing plates and functional liquid toners.

He was awarded a PhD in Electrical Engineering from Carnegie-Mellon University in Pittsburgh, Penna.