Electrostatic Self Assembly of Virgin Carbon Nanotubes Between Two Electrodes for Sensor and Transistor Applications

Robert H. Detig, Dietmar C. Eberlein

Electrox Corporation, Denville, NJ

ABSTRACT

Using electrostatics and liquid toner techniques from copier/laser printer industry, we are able to "self assemble" virgin carbon nanotubes from dispersions in naphtha like liquids. These assemblies are created between two electrodes on a dielectric surface with gaps between electrodes that range up to 2 mm. The channel widths extend to 6 to 10 mm. The dielectric surfaces include glass/epoxy semi-rigid boards (PWB's), Aramid fiber reinforced Teflon, and soda lime glass. By virgin nanotubes we mean single wall nanotubes ("SWNT") where no surface functionality, per se, has been added. This means that no wetting agents, no surfactants, nor any poly-electrolytes (charge directors) were added to the liquid. The self assembly techniques shown here also work with multi-wall tubes but they are not used for sensors and transistors. The naphtha like liquids are very pure linear, aliphatic hydrocarbons synthesized from gaseous materials. They are a close approximation to the odorless mineral spirits used to thin alkyd paints by the homeowner.

Though SWNT's can be made into traditional liquid toners possessing an electrochemical charge, these formulations require the application of a functional coating on the SWNT. Regrettably, these functional coating degrade the performance of the SWNT material. For this effort we chose and approach that uses the fibers in the virgin state, no coatings of any kind for best sensor performance. After completion these sensor substrates receive a final functional coating, unique to the chemical or bio-agent to be detected,

We will discuss the theory behind our fiber assembly processes and show samples of typical parts we've manufactured multiple times. In addition we hope to have a video presentation of the process. Beyond the obvious application of building sensors, the process can also be applied to assemble the channel of a high performance field effect transistor for use in phased array radars and various types of backplanes for flat panel displays.

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 2nd 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 particles, 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.

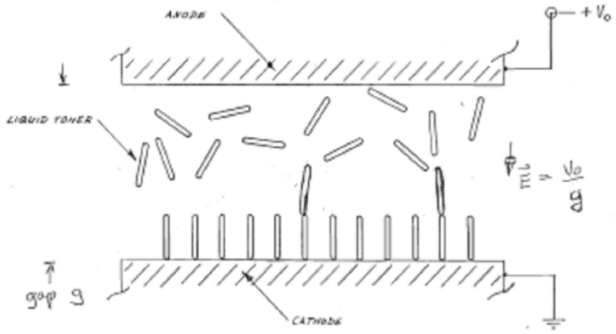

Figure 1: Chaining of Fibers in a Liquid.

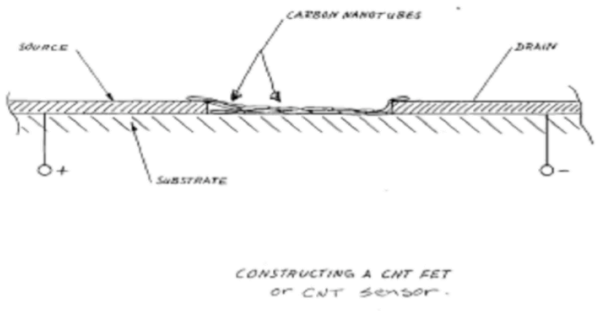

Figure 3: Chaining of Nano-fibers on a Dielectric Surface.

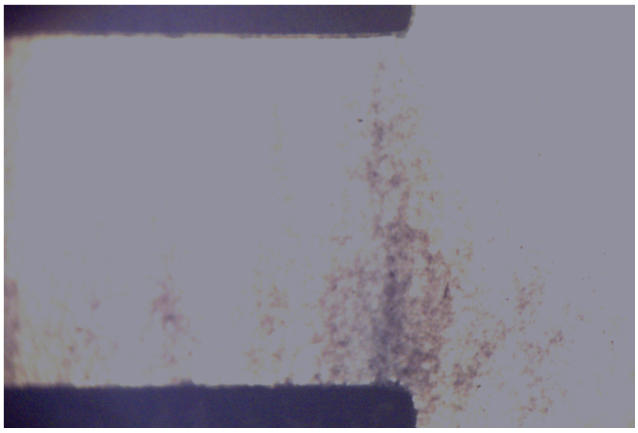

Figure 4: Finished Sensor Viewed with Transmission Illumination.

Figure 3 shows a cartoon depicting the successful growth of fibers from one electrode (called the source) to the other (called the drain of a FET). Or this could represent the substrate for a chemical/biological sensor.

Figure 4 shows the growth of CNT's across a 0.7mm gap between electrodes near the edge of two copper traces on glass. At the edge the CNT's grow in "chains" in a circular pattern as seen on the right. The resistance of the group of chains, range from 1K to 4 meg ohms, for one commercially available sample of single wall nanotubes of dia. 1.0nm and length of 500nm.

CONCLUSION

Virgin nanotubes can be self assembled across gaps between electrodes on dielectric surfaces (glass/epoxy, soda lime glass, and Aramid fiber/Teflon, high frequency PWB); using electric fields. These structures are useful for high performance sensors, and high performance power transistors.