Electrostatic Printing of Carbon Nano-tube Toners; The Self Assembly Of Virgin Carbon Nanotubes from Non-Aqueous Dispersions

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Abstract

Carbon nano-tubes are self assembled between two electrodes using an electric field for sensor and transistor applications. Also CNT toners re produced for imaging and coating purposes.

Introduction

Using electrostatics and liquid toner techniques from copier/laser printer industry, we are able to "self assemble" virgin carbon nanotubes from dispersions in Isopar diluents. 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 technique shown here also work with multi-wall tubes. The naphtha like liquids are very pure linear, aliphatic hydrocarbons synthesized from gaseous hydrocarbons. They are a close approximation to the odorless mineral spirits used to thin alkyd paints, sold in hardware stores.

SWNT's were also made into traditional liquid toners possessing an electrochemical charge, these formulations require the application of a functional coating on the SWNT. In some applications, these functional coating degrade the performance of the SWNT material for sensors and transistors. After completion, sensor substrates would 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.

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 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 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 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.

CNT Toners

CNT's configured as liquid toners, on the other hand, need an acidic (or basic) surface functionality imparted by appropriate surface coatings; which interact with a polyelectrolyte called a charge director; to yield a net pos. (or neg.) charge. These toners can then be imaged, patterned and coated, etc. by traditional electrostatic printing techniques.

The functionality imparted to the CNT can be accomplished by a thin resin coating, or a self assembled mono-layer of material. Dispersing the modified CNT's in a diluent, with a polyelectrolyte; produces an ionization reaction which produces an electrochemical charge, either negative or positive, on the nanotube which allows one to move the particles under the action of an electric field; then image it or uniformly coat it on a surface. Many nanotubes have functionality as produced by the manufacturer so the making of a toner is greatly simplified.

We will show samples of CNT's imaged on a printing plate capable of features in the 100 micron region, with even very small features possible in the future. Alternately the toners can be uniformly coated on electrically conductive surfaces. Basically all of the technology of digital printing is available to patterning these CNT toners.

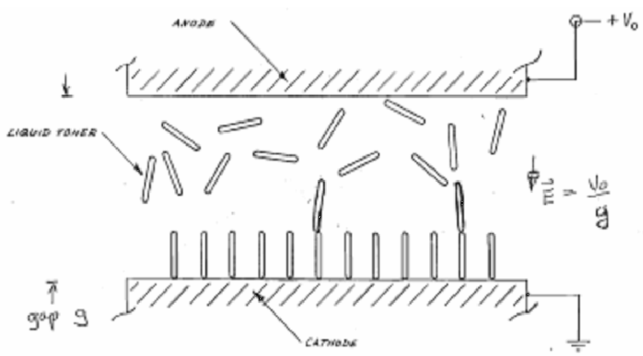

Figure 1. *Chaining of fibers in a liquid*

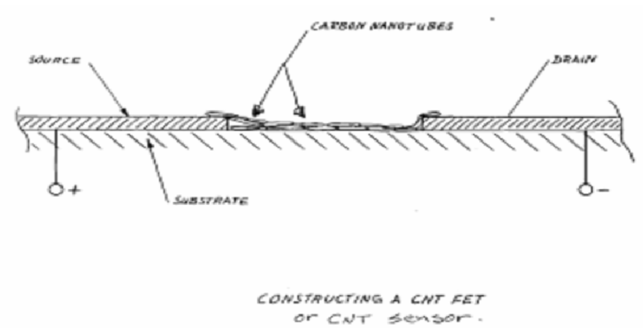

Figure 3. *Chaining of nano-fibers on a dielectric surface*

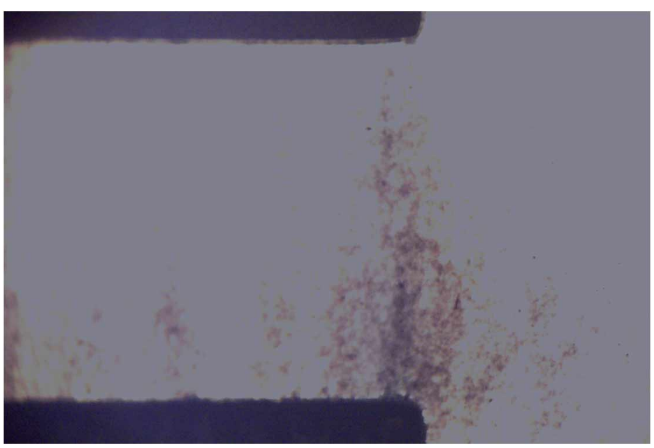

Figure 4. *Finished sensor viewed with transmission illumination*

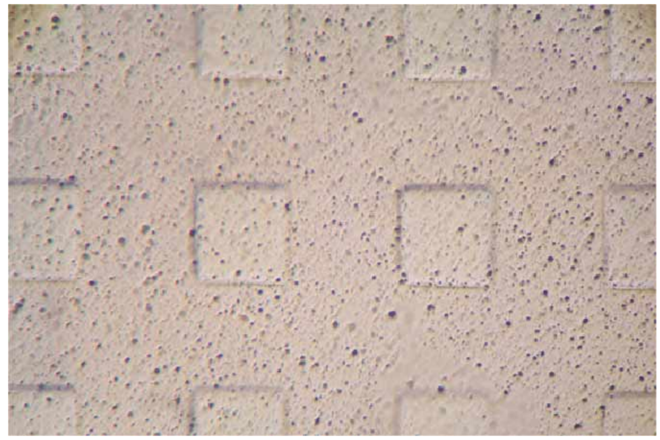

Figure 5. *Electrostatic Printing Plate, before development with CNT toner*

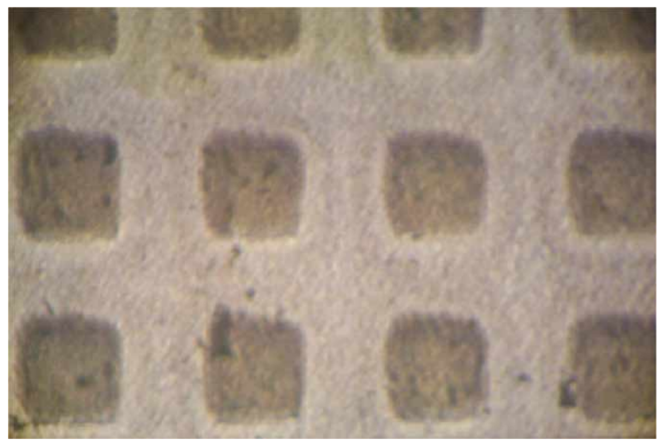

Figure 6. *Electrostatic Printing Plate imaged with CNT toner*

Conclusions: Virgin carbon nanotubes are self assembled between two electrodes from Isopar dispersions by electric fields, Also, nanotubes are made into traditional liquid toners by imparting suitable surface functionality. They can then be imaged or coated by traditional means.

Author Biography

Robert H. Detig founded the Electrox Corporation in 1992, to apply 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 by Carnegie-Mellon University in Pittsburgh, Pennsylvania

Dietmar C. Eberlein is Chief Engineer and a principal of the Electrox Corp. He has broad experience in all aspects of electro-photography, with extensive practical experience with liquid toners at Savin/Ricoh. He also worked at Olivetti USA, and the Minox Corp. in Germany. He holds a BS in Mechanical Engineering.