Tracking the Movement of Carbon Nanotubes during Dielectrophoretic Deposition

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Dielectrophoresis (DEP) is a powerful method for the fabrication of a wide variety of carbon nanotube (CNT) devices: from single CNT transistors to CNT matts. The experiment starts by immersing the substrate pre-patterned with electrodes into a solution containing suspended nanotubes. Applying an alternating voltage between the opposing electrodes results in an inhomogeneous electric field, which leads to a DEP force on the CNTs and making them move toward or away from the electrodes.

The DEP force is not the only source of movement acting on the CNTs. Other forces such as the electrothermal force on the solution were proven as effective or, in some cases, more influential in the final deposition pattern compared to the DEP force[1]. The relative effectiveness of each force can be drastically different in CNT solutions with different properties, such as different levels of conductivity.

Here, using particle-tracing simulations, we study the movement of semiconducting and metallic CNTs in aqueous solutions with low conductivity (not containing surfactants) for various situations during DEP. The movement patterns are investigated for three cases: no CNT deposited, one CNTalready connected to one of the electrodes, or a CNT bridging the two electrodes. The nanotubes' paths are traced by calculating their incremental movements in short steps in time. The force fields used in the calculations are derived from finite element simulations of the electric field and also fluid motion in the solution. At each step, the DEP force, the electrothermal motion of the solution, and also the Brownian movement of the CNTs are taken into account.

The results show that while the electrothermal force is usually suppressed because of the low conductivity of the solution- in contrast with when surfactants are present in the solution - the Brownian motion can significantly affect the deposition pattern of semiconducting CNTs. In the case of a nanotube connected to just one of the electrodes, the change in the field results in a considerable enhancement in the DEP force toward the nanotube tip, and other nanotubes deposit nearby, aligned with the already deposited tube. When a CNT is bridging the electrodes, on the other hand, the heat produced because of the current passing through the CNT changes the temperature profile on and around it, which leads to a considerable alteration in the electrothermal force.

These simulations can act as a guide for engineering the deposition of different nanotube types using DEP, and enable more control and selectivity in the process for both nanotubes and other nanomaterials.

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[1] A. KashefianNaieni, A Nojeh, Nanotechnology, 23, 495606 (2012).