

The Effect of Field Frequency and Solution Conductivity on Dielectrophoretic Deposition of Carbon Nanotubes

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Dielectrophoresis (DEP) is a popular method for the deposition of one or multiple carbon nanotubes (CNTs) or CNT mats between two electrodes. The CNTs are initially suspended in a solution. By applying an alternating voltage between the electrodes, a DEP force is exerted on the CNTs. The low-temperature nature of this method, overall control over the deposition location and direction, and the ability to prepare solutions containing different types of nanotubes, have led to the widespread use of DEP. Current methods for the preparation of CNT suspensions can result in solutions with a wide range of conductivities depending on the amount of surfactant dissolved. Despite interesting recent works, the effect of the conductivity of the solution on the DEP results is not yet fully understood and, in fact, has often been neglected.

We report on DEP experiments in a range of applied voltage frequencies using solutions with similar CNT concentrations and different conductivities. The solutions were made by starting with a commercially available, surfactant-free CNT product and adding various amounts of surfactants to it. DEP experiments using electrodes with multiple designs were performed at different frequencies and the results show that the conductivity of the solution is an extremely influential factor in determining the morphology and pattern of the CNTs deposited between the electrodes at each frequency. Figure 1 shows an example of the change in the deposition pattern for two of the solutions with identical DEP settings except for frequency. Note that a 0.5 weight % surfactant leads to a drastic difference in the results, as well as in the frequency dependence of the deposition behavior; whereas increasing the frequency tends to attract more nanotubes in a solution with no surfactant, in the presence of surfactants it seems to have the reverse effect.

Our finite-element simulations show that this effect can be attributed to the change in the physical properties of the solution in the proximity of the electrodes as a result of the temperature gradients caused by Joule heating (which is a function of solution conductivity) in the solution itself, and also in the electrodes. The electrothermal force leads to strong movements, which drag the CNTs toward or away from the gap between the electrodes, depending on the frequency and actual conditions of the experiment.

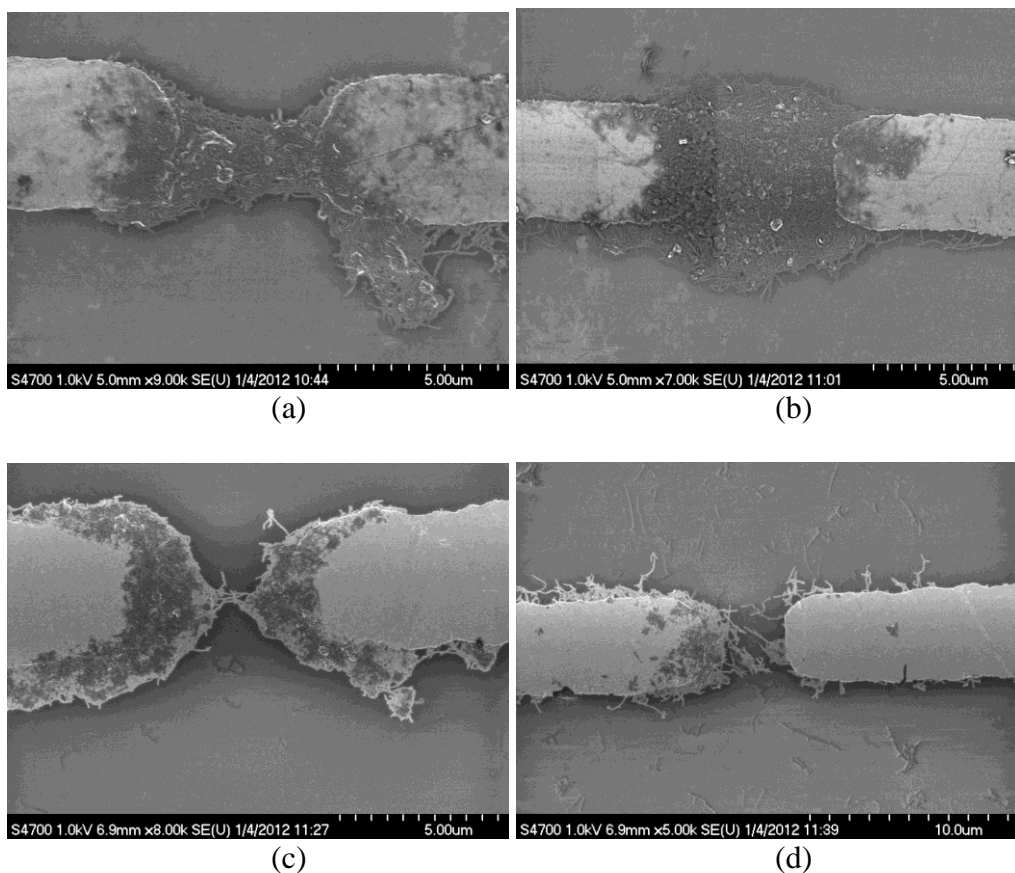


Figure 1: Scanning electron micrographs of CNT deposition results from solutions with 0 ((a) and (b)) and 0.5 ((c) and (d)) weight % surfactant at $f = 200$ kHz ((a) and (c)) and 1 MHz ((b) and (d)), $v = 5$ V, and $t = 1$ min. Note the drastic differences in the different cases. In (a) and (b) the movement of the solution is slowest and CNTs easily fill the gap between the electrodes, whereas in (c) and (d) the electrothermal force pushes the solution above the gap and to the sides and, thus, the CNTs can hardly find a chance to deposit anywhere but adjacent to the electrodes. The frequency has different effects for the two solutions. With no surfactant the CNTs cover a larger area whereas for the 0.5 weight % solution the CNTs are more sparse at 1 MHz.