

Manipulating Nanoparticles in Solution with Electrically Contacted Nanotubes Using Dielectrophoresis

The physical principles of self-assembly that give rise to complicated three-dimensional structures on the nanometer scale in both biological and synthetic systems

have been studied extensively. The forces at work include non covalent inter and intramolecular interactions, i.e hydrogen bonding, van der Waals, metal-ligand interactions, π - π stacking, and hydrophobic vs hydrophilic interactions. These bottom-up principles of self-assembly, while efficient and economical, generally are passive; i.e., they are controlled only by macroscopic quantities such as temperature, pH, and solvent concentration. It would be a distinct advantage if this assembly process could be actively, electronically controlled, especially with nanometer spatial resolution. In this regard, top-down approaches to the manipulation of matter have been successful at the nanometer scale only with atomic force microscopy (AFM)/scanned probed technologies, which are difficult to scale to a massively parallel environment, such as that envisioned in the nascent field of molecular electronics.

In a separate, related research theme, the use of electric fields generated by an external voltage source to actively manipulate the locations of nanometer scale objects and large molecules such as DNA and proteins is well-known from conventional, established techniques such as gel electrophoresis. Here, the electrodes used are typically macroscopic in size, i.e., many centimeters. A recent variant on this research theme is the integration of microelectronic fabrication techniques such as photolithography to fabricate electrodes with dimensions on the order of millimeters or hundreds of micrometers. In these electrophoresis techniques, charged species respond via the Coulomb force to dc electric fields. As a result, a limitation of the technique is that neutral species are unaffected and hence cannot be manipulated.

One available technique to electronically manipulate the position of both neutral and charged species in solution is to use ac electric fields, a technique called dielectrophoresis.¹ The physical principles of dielectrophoresis are well-established. If a polarizable object is placed in an electric field, there will be

an induced positive charge on one side of the object and an induced negative charge (of the same magnitude as the induced positive charge) on the other side of the object. The positive charge will experience a pulling force; the negative charge will experience a pushing force. However, in a non uniform field, the electric field will be stronger on one side of the object and weaker on the other side of the object. Hence, the pulling and pushing forces will not cancel, and there will be a net force on the object. This is the dielectrophoresis (DEP) force.

The key physical insight in this paper is that we use carbon nanotubes as the electrode to generate the electric field gradient; the nanotubes are electrically contacted by lithographically defined metal electrodes, which are far away from the region of interest, so that the fields from the metal electrodes are numerically insignificant compared to the fields generated by the nanotube itself. Since the electric field gradient in the vicinity of a nanotube is large, nanoparticles as small as 2 nm in diameter can be manipulated despite the large tendency for random, thermal Brownian motion important for such small particles. This is an order of magnitude smaller than previous nanoparticles that were manipulated with lithographically defined electrodes, and represents the first use of nanotube electrodes in dielectrophoresis.

Because this allows an electronic link to the nanometer world, this technology may find applications as a component of massively parallel, actively controlled nanomanufacturing platforms and, generally speaking, may provide a bridge between top-down and bottom-up approaches to nanotechnology.

Conclusions

The use of nanotube electrodes to manipulate nanoparticles in solution using dielectrophoresis. The technique should find broad applicability. In contrast to AFM-based nanofabrication techniques, this is purely electronic and hence requires no mechanical motion at either the nanoscale or macroscale. Thus, the technique is inherently scalable for massively parallel nanomanipulation. In addition, it should be possible to manipulate biological nanostructures such as DNA, viruses, and proteins using nanotube electrodes.