Scientists report significant advances in flexible electronics research

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In work that represents a key step toward bringing bendable, flexible electronic devices into our homes and businesses, Stanford University researchers have created very thin, high-performance transistors using networks of carbon nanotubes deposited onto flexible surfaces.

The work is reported in a recent online edition of *Nano Letters*.

Single-walled carbon nanotubes (SWNTs), each resembling a tiny seamless cylinder of chicken wire, have many properties that make them attractive for electronics research. They conduct electricity well, are mechanically strong, and chemically stable, and research groups across the world are investigating how to use them to create new electronics, particularly bendable electronics applications such as flexible roll-up display screens and electronic "skin."

These applications require thin semiconducting films - thin transistors, essentially - uniformly deposited onto large, flexible substrates, such as polymers, using methods that are compatible with large-scale manufacturing. But such methods have so far eluded scientists, partially because large amounts of SWNTs tend to be too disorganized to be suitable for incorporation into devices. They are randomly aligned, have different chiralities (that is, have molecular structures that are not symmetric), and can bundle together.

Stanford chemical engineer Zhenan Bao said to PhysOrg.com, "My group's work demonstrates a simple method to produce low-power, highmobility flexible transistors with good electrical characteristics."

In past research, Bao and her colleagues developed a one-step process in which the chirality and alignment of SWNTs can be homogenized at room temperature by controlling the surface chemistry of the substrate onto which the nanotubes are deposited. The result is a well aligned layer of SWNTs, but the group used silicon dioxide as the gate dielectric (a component of a transistor), which is a very rigid material.

"We've now built upon that research using a polymer dielectric, which, aside from being mechanically robust and physically flexible, has chemical functionality to tune the surface chemisty and can smooth a rough substrate," said Stanford researcher Mark Roberts, the first author of the paper. "Furthermore, they can be extremely thin with high capacitances, which is desirable of a gate dielectric, and their resistance to water could also be very useful in certain applications."

Additionally, the transistors work at low power, needing only an operating voltage below one volt.

The group chemically modified a polymer surface with a very thin layer terminated with an amine, a compound belonging to class of organic compounds derived from ammonia. The amine "functionalizes" the polymer surface, helping the semiconducting nanotubes adhere. The researchers then deposited the nanotubes via spin-coating, in which the polymer substrate is rapidly rotated - between 3600 and 4000 revolutions per minute - and a solution containing SWNTs is applied to it.

Using various analysis methods, Bao and her group discovered that their method yielded a layer of SWNTs that did not bundle and were well aligned. Further, the chemical properties of the amine layer allowed the nanotubes to self-sort their chiralities, which Bao and her group describe as "a major step toward the realization of inexpensive SWNT electronic devices on transparent, flexible substrates."

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