



Materials & Coatings

Carbon Nanofibers Synthesized on Selective Substrates for Nonvolatile Memory and 3D Electronics

This method can impact the application of carbon nanofiber tubes in 3D electronics applications.

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A plasma-enhanced chemical vapor deposition (PECVD) growth technique has been developed where the choice of starting substrate was found to influence the electrical characteristics of the resulting carbon nanofiber (CNF) tubes. It has been determined that, if the tubes are grown on refractory metallic nitride substrates, then the resulting tubes formed with dc PECVD are also electrically conducting.

Individual CNFs were formed by first patterning Ni catalyst islands using e-beam evaporation and liftoff. The CNFs were then synthesized using dc PECVD with $C_2H_2:NH_3 = [1:4]$ at 5 Torr and 700 °C, and ≈ 200 -W plasma power. Tubes were grown directly on degenerately doped silicon $\langle 100 \rangle$ substrates with resistivity $\rho \approx 1\text{--}5$ m Ω -cm, as well as NbTiN. The ≈ 200 -nm thick refractory NbTiN deposited using magnetron sputtering had $\rho \approx 113$ $\mu\Omega$ -cm and was also chemically compatible with CNF synthesis. The sample was then mounted on a 45° beveled Al holder, and placed inside a SEM (scanning electron microscope). A nanomanipulator probe stage was placed inside the SEM equipped with an electrical feed-through, where tungsten probes were used to make two-terminal electrical measurements with an HP 4156C parameter analyzer.

The positive terminal nanoprobe was mechanically manipulated to physically contact an individual CNF grown directly on NbTiN as shown by the SEM image in the inset of figure (a), while the negative terminal was grounded to the substrate. This revealed the tube was electrically conductive, although measurable currents could not be detected until ≈ 6 V, after which point current increased sharply until compliance (≈ 50 nA) was reached at ≈ 9.5 V. A native oxide on the tungsten probe tips may contribute to a tunnel barrier, which could be the reason for the suppressed transport at low biases. Currents up to ≈ 100 nA could be cycled, which are likely to propagate via the

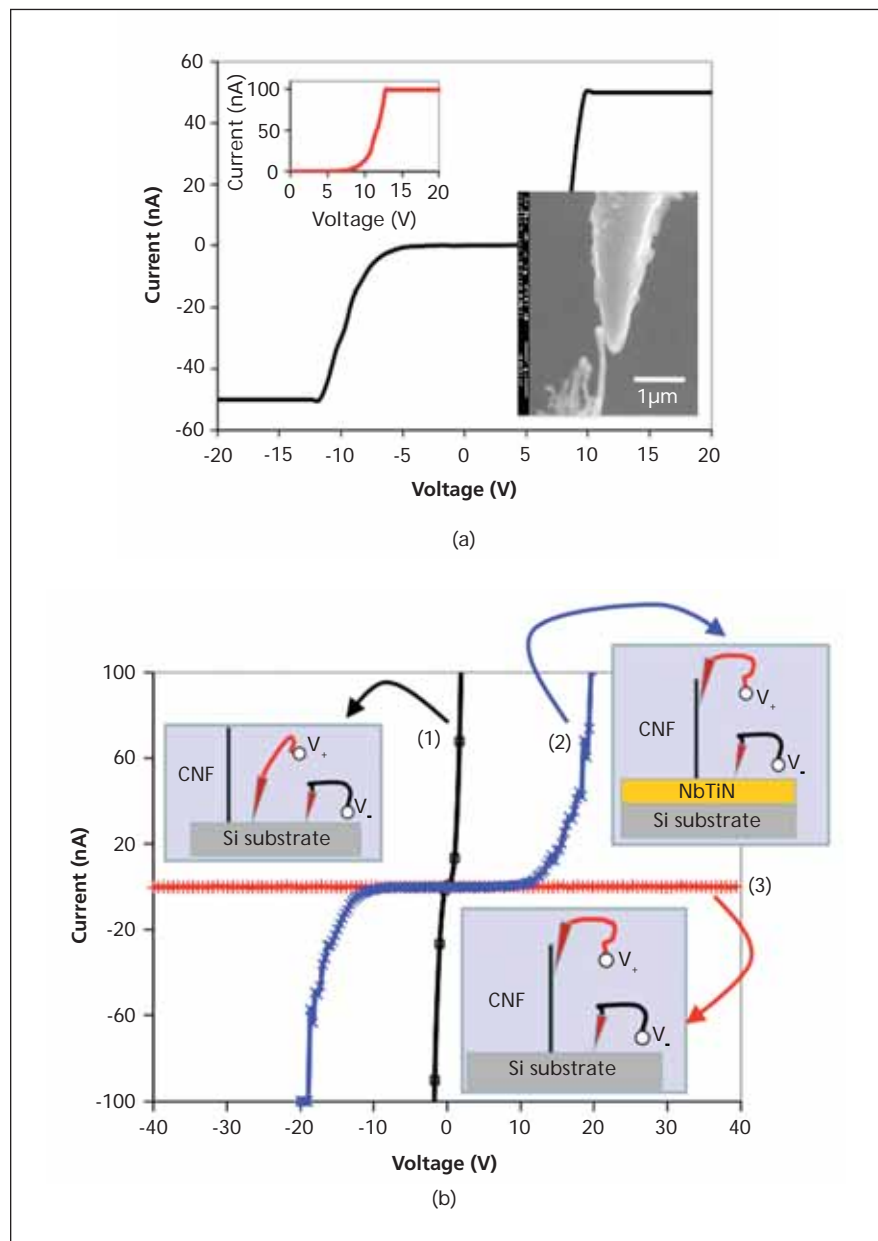


Figure (a) Electrical Transport Measurements for a single CNF grown on an NbTiN buffer layer on Si. A nanoprobe was in contact with a CNF, as the SEM image in the inset indicates. The top inset shows the I-V characteristic when compliance was increased to 100 nA. (b) Curve (1) corresponds to the case where both probes were shorted to the substrate and indicates high conductivity; curve (2) shows the CNF grown on NbTiN was electrically conductive; curve (3) corresponds to the case where no electrical conduction was detected for a CNF grown directly on Si, and suggests such CNFs are unsuitable for dc NEMS applications.

tube surface, or sidewalls, rather than the body, which is shown by the I-V in figure (a).

Electrical conduction via the sidewalls is a necessity for dc NEMS (nanoelectromechanical system) applications, more so than for the field emission applications of such tubes. During the tests, high conductivity was expected, because both probes were shorted to the substrate, as shown by curve 1 in the I-V characteristic in figure (b). When a tube grown on NbTiN was probed, the response was similar to the ≈ 100 nA and is represented by

curve 2 in figure (b), which could be cycled and propagated via the tube surface or the sidewalls. However, no measurable currents for the tube grown directly on Si were observed as shown by curve 3 in figure (b), even after testing over a range of samples. This could arise from a dielectric coating on the sidewalls for tubes on Si. As a result of the directional nature of ion bombardment during dc PECVD, Si from the substrate is likely re-sputtered and possibly coats the sidewalls.

This work was done by Anupama B. Kaul and Abdur R. Khan of Caltech for NASA's Jet

Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

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Nanoparticle/Polymer Nanocomposite Bond Coat or Coating

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This innovation addresses the problem of coatings (meant to reduce gas permeation) applied to polymer matrix composites spalling off in service due to incompatibility with the polymer matrix. A bond coat/coating has been created that uses chemically functionalized nanoparticles (either clay or graphene) to create a barrier film that bonds well to the matrix resin, and provides an outstanding barrier to gas permeation.

There is interest in applying clay nanoparticles as a coating/bond coat to a polymer matrix composite. Often, nanoclays are chemically functionalized with

an organic compound intended to facilitate dispersion of the clay in a matrix. That organic modifier generally degrades at the processing temperature of many high-temperature polymers, rendering the clay useless as a nano-additive to high-temperature polymers. However, this innovation includes the use of organic compounds compatible with high-temperature polymer matrix, and is suitable for nanoclay functionalization, the preparation of that clay into a coating/bondcoat for high-temperature polymers, the use of the clay as a coating for composites that do not have a high-

temperature requirement, and a comparable approach to the preparation of graphene coatings/bond coats for polymer matrix composites.

This work was done by Sandi G. Miller of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18607-1.