



Novel Materials Containing Single-Wall Carbon Nanotubes Wrapped in Polymer Molecules

Coating carbon nanotubes in polymer molecules creates a new class of materials with enhanced mechanical properties for printed circuit boards, antenna arrays, and optoelectronics.

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In this design, single-wall carbon nanotubes (SWNTs) have been coated in polymer molecules to create a new type of material that has low electrical conductivity, but still contains individual nanotubes, and small ropes of individual nanotubes, which are themselves good electrical conductors and serve as small conducting rods immersed in an electrically insulating matrix. The polymer is attached through weak chemical forces that are primarily non-covalent in nature, caused primarily through polarization rather than the sharing of valence electrons. Therefore, the electronic structure of the SWNT involved is substantially the same as that of free, individual (and small ropes of) SWNT. Their high conductivity makes the individual nanotubes extremely electrically polarizable, and materials containing these individual, highly polarizable molecules exhibit novel electrical properties including a high dielectric constant.

The polymer coating, however, greatly inhibits the Van der Waals attraction normally observed between separate, or small ropes of, SWNT. The polymer coating also interacts with solvents. The combination of the Van der Waals inhibition and the polymer-solvent interaction causes the wrapped nanotubes to be more readily sus-

ended in solvents at high concentrations, which in turn substantially enables the manipulation of SWNT into many kinds of bulk materials including films, fibers, solids, and other types of composites. Also, the polymer-coated SWNT can be treated for the removal of the polymer molecules, restoring the SWNT to a pristine state.

Aggregations of the polymer-coated SWNT are substantially aligned and provide a new form of electrically-conducting rod composite, where the conducting rods have cross sectional dimensions on the nanometer scale and lengths of hundreds of nanometers or more. The electrical properties of the composite are highly anisotropic.

This innovation can be made compatible with matrices of other materials to facilitate fabrication of composites. Composite materials with polymer-coated SWNTs suspended in a polymer matrix have a novel structure of a suspended nanotube being smaller in its cross-sectional dimensions than the typical scale length of the individual polymer molecules in the matrix. This microscopic, dimensional compatibility minimizes the propensity of the composite to fail mechanically at the interface between the matrix and the SWNT, producing a composite material

with enhanced properties such as strain-to-failure, toughness, and resistance to mechanical fatigue. These materials also serve as the active element for a range of transducers because they can change their physical dimensions in response to applied electric and magnetic fields. If treated with certain chemicals, the material can also change dimensionally and electronically in response to adsorption of chemicals on the nanotube surface, and can serve as chemical sensors and transducers.

This work was done by Richard E. Smalley and Michael J. O'Connell of Rice University and Kenneth Smith and Daniel T. Colbert of Carbon Nanotechnologies, Inc. for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to MSC-24070-1, volume and number of this NASA Tech Briefs issue, and the page number.

Light-Curing Adhesive Repair Tapes

Adhesive resins in tapes are rigidized in place by exposure to light.

Marshall Space Flight Center, Alabama

Adhesive tapes, the adhesive resins of which can be cured (and thereby rigidized) by exposure to ultraviolet and/or visible light, are being developed as repair patch materials. The tapes, including their resin components, consist entirely of solid, low-outgassing, nonhazardous or minimally

hazardous materials. They can be used in air or in vacuum and can be cured rapidly, even at temperatures as low as -20°C . Although these tapes were originally intended for use in repairing structures in outer space, they can also be used on Earth for quickly repairing a wide variety of structures. They can

be expected to be especially useful in situations in which it is necessary to rigidize tapes after wrapping them around or pressing them onto the parts to be repaired.

As now envisioned, when fully developed, the tapes would be tailored to specific applications and would be pack-

aged in light- and radiation-resistant, easy-to-use dispensers. The resins in the tapes would be formulated to be curable by low-power light at specific wavelengths that could be generated by light-emitting diodes (LEDs). Each such tape dispenser would be marketed as part of a repair kit that would also include a companion battery-powered LED source operating at the required wavelength.

Each tape consists of a fine-weave fabric impregnated by a resin. On one side of the tape there is a cover ply that prevents the tape from sticking to itself when it is rolled up as in a dispenser. Depending on the specific intended application, the cover ply and resin can be selected such that the cover ply can be either released from the tape or cured in place as an integral part of a repair patch.

The feasibility of the light-curing tapes was demonstrated in experiments in which tapes were made from fiber-glass fabric impregnated, variously, with (1) cationic epoxy resins plus a sensitizer that preferentially absorbs light at a wavelength of 380 nm, (2) free-radical curing acrylate resins, or (3) blends of resins of both types. Methods of incorporating adducts into the epoxies to tailor their viscosities were developed. The tapes were applied to aluminum and carbon/epoxy composite substrates that had been prepared by sanding and wiping with alcohol. The resins were cured by 380-nm light from LEDs. The blends of resins of both types were found to be advantageous in that during exposure to the light, their acrylate components contributed rapid buildup of strength, while their epoxy components contributed adhesion and longer-term strength.

Poly(ethylene terephthalate) backing films were shown to pass the needed 380-nm light and, when prepared with corona treatment, to adhere well as parts of cured tapes. Peel tests confirmed generally high degrees of adhesion to aluminum substrates. Demonstrations of repairs were made, including bonding pipes of various materials together, patching burst pipes, and patching punctures. A 1-in. (2.54-cm) patch over a 1/2-in. (1.27-cm)-diameter hole was pressurized to 120 psi (≈ 0.83 MPa) without failure or delamination.

This work was done by Ronald Allred and Andrea Hoyt Haight of Adherent Technologies, Inc. for Marshall Space Flight Center. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32532-1.

Thin-Film Solid Oxide Fuel Cells

Mass, volume, and the cost of materials can be reduced for a given power level.

Marshall Space Flight Center, Alabama

The development of thin-film solid oxide fuel cells (TF-SOFCs) and a method of fabricating them have progressed to the prototype stage. A TF-SOFC consists of the following:

- A fuel electrode (anode) of nickel or other suitable metal, about 10 micrometers thick, made porous in a required pattern as described below;
- A solid electrolyte deposited on the anode of 0.5- to 2-micrometer thickness;
- An oxidizer electrode (cathode) in the form of a layer of a mixed ionic-electronic conductive oxide deposited to a typical thickness between 1 and 10 micrometers on the solid-electrolyte face opposite that of the anode; and
- An electrically insulating structure that encloses the aforementioned components and includes manifolds for the delivery of fuel to the anode, delivery of air or other oxidizing gas mixture to the cathode, and removal of combustion products.

The porosity of the anode in a TF-SOFC is necessary to enable delivery of the fuel to the anode side of the solid electrolyte. The cathode is required to be porous or at least permeable to the oxidizer to enable delivery of oxygen to the cathode side of the solid electrolyte. The solid electrolyte layer is re-

quired to be dense and free of defects so that neither the fuel nor the oxidizer leaks through it. The relatively small thickness of the electrolyte also makes it possible to operate the TF-SOFC at temperature lower than is necessary for a thicker-electrolyte fuel cell of older design. In turn, operation at lower temperature increases the reliability and enables a wider choice of materials for constructing the TF-SOFC.

In the fabrication of a TF-SOFC, nickel foil to be used as the anode material can be rolled or otherwise processed to produce an ordered crystal structure so that subsequent epitaxial deposition of the solid electrolyte material on the anode will cause the solid electrolyte to be also crystallographically ordered and, therefore, to be dense and relatively free of defects, as required. The epitaxial deposition of the solid electrolyte and the deposition of the electronically and ionically conductive cathode layer on the electrolyte can be effected by any of several established processes for deposition of thin oxide films. After deposition of the solid electrolyte, the required porosity is introduced into the nickel by photolithographic patterning and etching.

The cathode layer can be deposited either before or after patterning of the anode. Optionally, to enhance the activity of the porous anode structure, a mixed-ionic-and-electronic-conductor film can be deposited on the anode patterning and etching.

Typically, the total thickness of the anode/solid electrolyte/cathode sandwich of a TF-SOFC is only about 15–25 micrometers. Operating at a temperature between 450 and 500 °C, a TF-SOFC can utilize hydrogen or methane as a fuel. The power density of a TF-SOFC can exceed 10 W/cm³ (10 kW/liter), while the power per unit mass is ≈ 3 W/g (or ≈ 3 kW/kg). Relative to older thicker-electrolyte fuel-cell designs, TF-SOFC designs can reduce costs of materials and reduce the volumes and masses of fuel cells capable of generating a given amount of electric power.

This work was done by Xin Chen, Nai-Juan Wu, and Alex Ignatiev of the University of Houston for Marshall Space Flight Center.

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