Manufacturing & Prototyping

Composite Layer Manufacturing With Fewer Interruptions

Lyndon B. Johnson Space Center, Houston, Texas

An improved version of composite layer manufacturing (CLM) has been invented. CLM is a type of solid freeform fabrication (SFF) — an automated process in which a three-dimensional object is built up, point-by-point, through extrusion of a matrix / fiber composite-material precursor. The elements of SFF include (1) preparing a matrix resin in a form in which it will solidify subsequently, (2) mixing fibers and matrix material to form a continuous pre-impregnated tow (also called "towpreg"), and (3) dispensing the towpreg from a nozzle onto a base while moving the nozzle to form the dispensed material into a series of patterned layers of controlled thickness.

In CLM, the translation and the extrusion operation are such that the final size and shape of the fabricated object are as specified by a computer-aided design (CAD). Sometimes, in order to achieve the desired final shape, it is necessary to interrupt the deposition and cut the towpreg so that no material is deposited while the nozzle is translated to a position where deposition is to resume. The present improved version of CLM includes the use of an algorithm that generates a nozzle path with a minimum number of interruptions.

This work was done by Bor Z. Jang, Junhai Liu, and Shizu Chen of Auburn University 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-23452-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Improved Photoresist Coating for Making CNT Field Emitters

This technique could contribute to development of cold cathodes for diverse applications.

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An improved photoresist-coating technique has been developed for use in the fabrication of carbon-nanotube- (CNT)-based field emitters of the type described in "Fabrication of Improved Carbon-Nanotube Field Emitters" (NPO-44996), *NASA Tech Briefs*, Vol. 32, No. 4 (April 2008), page 50. The improved photoresist-coating technique overcomes what, heretofore, has been a major difficulty in the fabrication process. This technique is expected to contribute to the realization of high-efficiency field emitters (cold cathodes) for diverse systems and devices that could include gas-ionization systems, klystrons, flat-panel display devices, cathode-ray tubes, scanning electron microscopes, and x-ray tubes.

To recapitulate from the cited prior article: One major element of the device design is to use a planar array of bundles of carbon nanotubes as the field-emission tips and to optimize the critical dimensions of the array (principally,

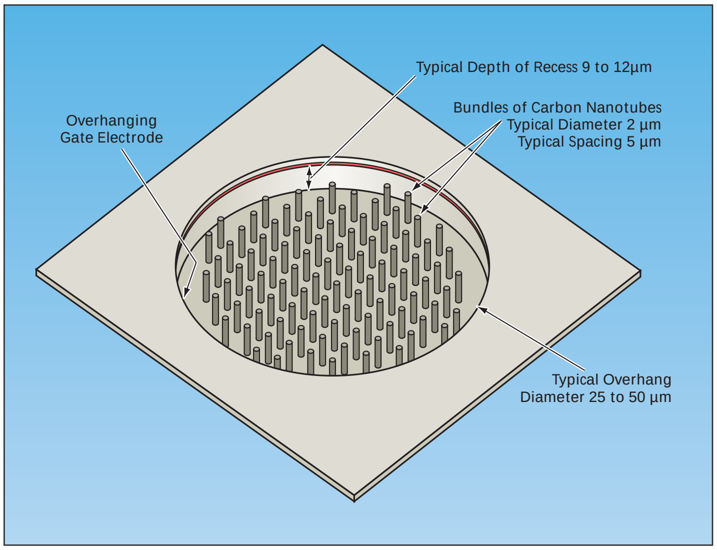

Figure 1. A **CNT-Based Field Emitter** of the type to which the present innovation applies includes a gate electrode that overhangs a recess containing an array of bundles of carbon nanotubes. For the sake of clarity, this drawing is simplified and not to scale.

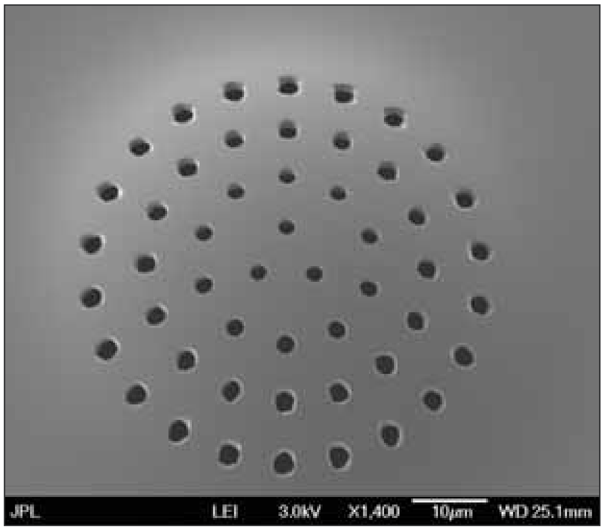

Figure 2. **Holes To Define Catalyst Dots** were formed in a photoresist membrane bridging a recess like that of Figure 1. This scanning electron micrograph was recorded at tilt angle of 20° to make the slight bulge of the membrane more visible.

heights of bundles and distances between them) to obtain high area-averaged current density and high reliability over a long operational lifetime. Another major element of the design is to configure the gate electrode (an anode used to generate the electron-emitting and -accelerating electric field) as a ring that overhangs a recess wherein the bundles of nanotubes are located (see Figure 1), such that by virtue of the proximity between the ring and the bundles, a relatively low applied potential suffices to generate the large electric field needed for emission of electrons.

The major difficulty in the fabrication process as practiced before the development of the improved photoresist-coating technique arises in the step immediately after the formation of the overhang and the recess. In this step, it is necessary to spin-coat the flat bottom surface of the recess with a uniform layer of a photoresist that is to be patterned with holes in a subsequent photolithographic step. The patterned photoresist is then to be used in subsequent deposition and liftoff steps to form dots of a catalytic material, about 2 μm in diameter and spaced about 5 μm apart, upon which the bundles of CNTs are to be grown. The difficulty is caused by a combination of the dimensions of the recess and overhang, the surface tension and viscosity of the photoresist solution, and the centrifugal force associated with spin coating. The net effect is that it becomes difficult or impossible to make the photoresist solution flow into or out of the recess and, hence, difficult or impossible to coat the bottom of the recess to the required uniform thickness. Often, the photoresist solution bridges over the recess.

The concept underlying the improved photoresist-coating technique is to turn the source of difficulty to advantage. In this technique, one does not attempt to make the photoresist solution flow into the recess: Instead, the photoresist solution and spin-coating conditions are chosen to maximize the tendency of the photoresist solution to become formed into a uniform-thickness membrane bridge over the recess. After spin coating, the workpiece is subjected to a soft bake in which the air trapped in the recess expands, causing the photoresist membrane to acquire an outward bulge between 5 and 10 μm. The bake solidifies the membrane, which thereafter retains the bulge. Then the pattern of holes is formed on the photoresist membrane bridge (see Figure 2). Experiments have confirmed that the patterned membrane bridge can be used to form the corresponding pattern of dots of catalytic material on the flat bottom surface of the recess and that the bundles of carbon nanotubes can be grown on these dots.

This work was done by Risaku Toda and Harish Manohara of Caltech for NASA's Jet Propulsion Laboratory.

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