Manufacturing

Growing Aligned Carbon Nanotubes for Interconnections in ICs

Carbon nanotubes are embedded in silica with their tips exposed as contacts.

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A process for growing multiwalled carbon nanotubes anchored at specified locations and aligned along specified directions has been invented. Typically, one would grow a number of the nanotubes oriented perpendicularly to a silicon integrated-circuit (IC) substrate, starting from (and anchored on) patterned catalytic spots on the substrate. Such arrays of perpendicular carbon nanotubes could be used as electrical interconnections between levels of multilevel ICs.

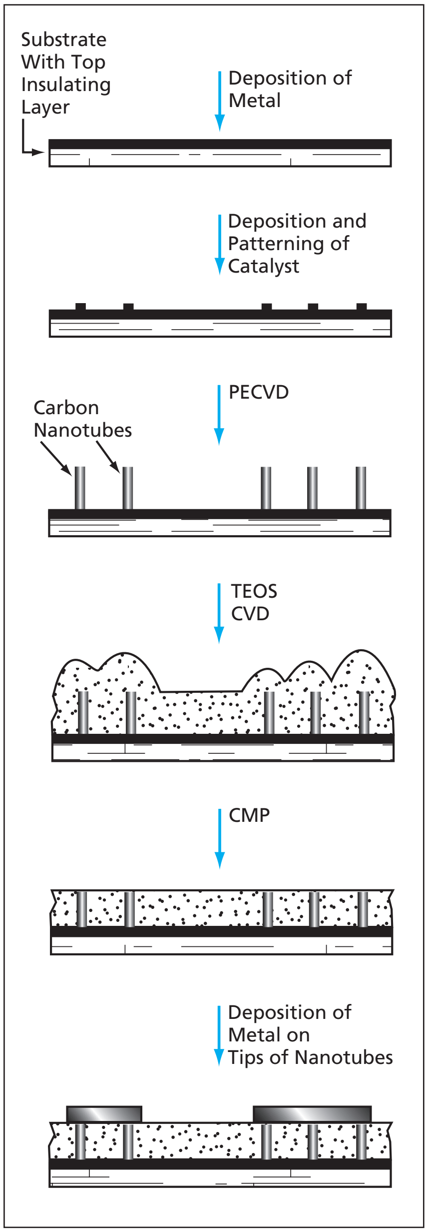

Figure 1. A **Bottom-Up Approach** is followed in growing carbon nanotubes, embedding them in a silica matrix, exposing their tips, and using the exposed tips as electrical contacts.

The process (see Figure 1) begins with the formation of a layer, a few hundred nanometers thick, of a compatible electrically insulating material (e.g., SiO_x or Si_yN_z) on the silicon substrate. A patterned film of a suitable electrical conductor (Al, Mo, Cr, Ti, Ta, Pt, Ir, or doped Si), having a thickness between 1 nm and 2 µm, is deposited on the insulating layer to form the IC conductor pattern. Next, a catalytic material (usually, Ni, Fe, or Co) is deposited to a thickness between 1 and 30 nm on the spots from which it is desired to grow carbon nanotubes.

The carbon nanotubes are grown by plasma-enhanced chemical vapor deposition (PECVD). Unlike the matted and tangled carbon nanotubes grown by thermal CVD, the carbon nanotubes grown by PECVD are perpendicular and freestanding because an electric field perpendicular to the substrate is used in PECVD. Next, the free space between the carbon nanotubes is filled with SiO_2 by means of CVD from tetraethylorthosilicate (TEOS), thereby forming an array of carbon nanotubes embedded in SiO_2. Chemical mechanical polishing (CMP) is then performed to remove excess SiO_2 and form a flat-top surface in which the outer ends of the carbon nanotubes are exposed. Optionally, depending on the application, metal lines to connect selected ends of carbon nanotubes may be deposited on the top surface.

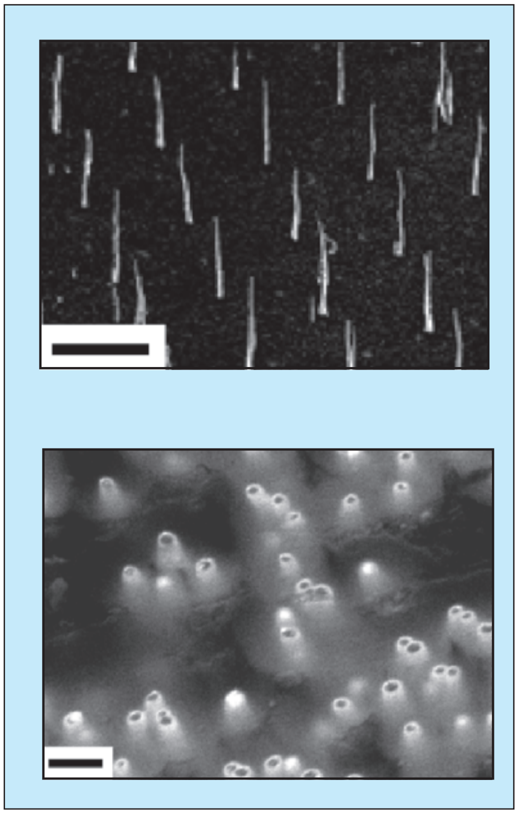

Figure 2. These **Electron Micrographs**, both taken at an angle of 45°, show specimens of arrays of carbon nanotubes at two different stages of processing. (The scale bar on the top is 5 µm, the one on the bottom is 0.2 µm.)

The top part of Figure 2 is a scanning electron micrograph (SEM) of carbon nanotubes grown, as described above, on catalytic spots of about 100 nm diameter patterned by electron-beam lithography. These and other nanotubes were found to have lengths ranging from 2 to 10 µm and diameters ranging from 30 to 200 nm, the exact values of length depending on growth times and conditions and the exact values of diameter depending on the diameters and thicknesses of the catalyst spots. The botton part of Figure 2 is an SEM of an embedded array of carbon nanotubes after CMP.

This work was done by Jun Li, Qi Ye, Alan Cassell, Hou Tee Ng, Ramsey Stevens, Jie Han, and M. Meyyappan of **Ames 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 the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-15042-1.