

percapacitor to act also in countdown circuit mode, where the discharge time constant of the circuit is used as the time to keep the FPGA power off in order to save power. Once the supercapacitor-based circuit reaches a given level, this voltage is sensed and the wake-up sequence to the FPGA begins.

The supercapacitors also provide the ability to store and harvest recharge energy for the battery. RF energy can be beamed into the system and then fed back into the battery/supercapacitor

network. Alternatively, mechanical energy from a MEMS device can be used to re-charge the supercapacitor. The capacitors can be quickly charged up and then act as a power reservoir for the battery. The completely described system above is currently in development.

*This work was done by Douglas J. Sheldon of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*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:*

*Innovative Technology Assets Management  
JPL*

*Mail Stop 202-233*

*4800 Oak Grove Drive*

*Pasadena, CA 91109-8099*

*E-mail: iaoffice@jpl.nasa.gov*

*Refer to NPO-47718, volume and number of this NASA Tech Briefs issue, and the page number.*

---

## **Bump Bonding Using Metal-Coated Carbon Nanotubes**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Bump bonding hybridization techniques use arrays of indium bumps to electrically and mechanically join two chips together. Surface-tension issues limit bump sizes to roughly as wide as they are high. Pitches are limited to 50 microns with bumps only 8–14 microns high on each wafer. A new process uses oriented carbon nanotubes (CNTs) with a metal (indium) in a wicking process using capillary actions to increase the aspect ratio and pitch density of the connections for bump bonding hybridizations. It merges the properties of the CNTs and the metal bumps, providing enhanced material performance parameters.

By merging the bumps with narrow and long CNTs oriented in the vertical direction, higher aspect ratios can be obtained if the metal can be made to wick. Possible aspect ratios increase from 1:1 to 20:1 for most applications, and to 100:1 for some applications. Possible pitch density increases of a factor of 10 are possible.

Standard capillary theory would not normally allow indium or most other metals to be drawn into the oriented CNTs, because they are non-wetting. However, capillary action can be induced through the ability to fabricate oriented CNT bundles to desired spacings, and the use of deposition tech-

niques and temperature to control the size and mobility of the liquid metal streams and associated reservoirs.

This hybridization of two technologies (indium bumps and CNTs) may also provide for some additional benefits such as improved thermal management and possible current density increases.

*This work was done by James L. Lamb, Matthew R. Dickie, Robert S. Kowalczyk, and Anna Liao of Caltech; and Michael J. Bronikowski of Atomate Corporation for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46592*