Researchers Discover How to Make the Smallest, Most Perfect, Densest Nanowire Lattices -- And It's a SNAP

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Santa Barbara, Calif. --Researchers participating in the California NanoSystems Institute (CNSI) at the University of California at Santa Barbara (UCSB) and at Los Angeles (UCLA) have invented a new technique for producing "Ultra High Density Nanowire Lattices and Circuits" -- the title of their paper being published expeditiously at 2:00 p.m. March 13 on the "Science Express" website, Science Magazine's rapid portal for publication of significant research findings to appear subsequently in print in Science.

The method, for which a patent is pending, is akin to intaglio printmaking processes in which printing is done from ink below the surface of the plate. Intaglio processes emboss paper into the plate's incised lines.

The CNSI nanowires are like the embossed ink on a paper substrate, except that the nanowires are much, much smaller than ink lines. Take, for instance, a grid of crossed nanowires. Each cross represents the element of a simple circuit! The nanowire junction density reported in the "Science Express" article is in excess of 1011 per square centimeter.

The process is, moreover, so straightforward that the authors nicknamed it "SNAP," for Superlattice NAnowire Pattern transfer.

Two and a half years ago, principal investigators into nanoscale phenomena at UCSB and UCLA joined together to form the California NanoSystems Institute. The genesis of the research being reported via the "Science Express" website dates to a meeting between the two university groups in the early days of the Institute when the researchers first got together to describe to each other problems they faced.

At that meeting James Heath, then a chemistry professor at UCLA and now at the California Institute of Technology, explained one big stumbling block to the making of molecular computers. He said that contacts to single molecules had to be established through a massive crosswire array.

To put the problem in its simplest form, attaching a nanowire to each end of a single molecule offers the possibility of creating a molecular switch. Heath and his colleagues have shown that passing a current through this simple circuit changes the molecule configuration and creates a molecular switch with a transistor-like action. What Heath wanted was a crosswire array for establishing electrical contacts to a large ensemble of single molecules.

UCSB Materials Professor Pierre Petroff immediately responded to Heath's challenge by sketching out on the blackboard the rudiments of the idea for constructing the high density nanowire lattice that is reported in the "Science Express" paper, authored by Heath and Petroff and their postdoc and students.

The first step is construction of the stamp or (to recur to the intaglio analogy) the incised plate. The second step is use of the stamp to make the wires.

Key to the process is the MBE (Molecular Beam Epitaxy) approach to making compound semiconductors by laying down one layer of one type of material and then another of another type of related material--alternating materials layer by layer as if stacking alternating pieces of cardboard and paper. The materials used are standard compound semiconductors gallium arsenide and aluminum gallium arsenide.

Then one takes a piece of the compound semiconductor (say, a two-inch square) and turns it on its side where the pattern of alternation in the materials appears. Next one selectively etches out to a certain depth one of the two materials so that the surface resembles a saw-tooth. That saw-tooth or corrugated surface is the stamp on which the nanowires are formed by plasma deposition of a material -- almost any material, metal or semiconductor.

Petroff recalls that he was initially attracted to the idea because the process would be cheap, "a millimeter size stamp without any lithography," as he puts it. "The process allows us to make metal lines," he said, "which are highly perfect. The SNAP process has demonstrated the smallest metal lines with the closest spacing that have ever been made. That is an achievement in itself!

"Through deposition, the channels turn into wires that can be made out of almost any material. After deposition of a metal layer, it can be transferred onto a substrate via epoxy bonding, wafer fusion or other process."

The researchers have measured conductivity over the wires up to 10s of microns in length. (Though the wires extend without touching and without interruption for 100s of microns, they have only tested conductivity over 10s of microns). The researchers have also measured resistance between wires and shown that the wires do not short out.

Repeating the process at right angle to the original impress produces a grid work of crossed wires--and therefore circuits. Petroff figured out how to remove the stamp from the metal wires by etching out an oxide, thereby enabling reuse of the stamp.

"Now," said Petroff, "the question is how do we affix a contact to one wire without touching another. That's the real challenge. There are ways of doing that." He describes one approach using a focused ion beam to deactivate selected wires, which is a little like cutting one strand of hair in a bundle.

In addition to molecular switches, other obvious applications for the nanowire lattice include nano-sensors and bio-sensors. Petroff's research group is also employing the technique to order nano-particles in an effort to make very high-density magnetic storage devices.

Finally, Petroff points out, the nanowire construction technique will enable investigations into the basic physical properties of matter whose surface energy exceeds interior bulk energy. The construction technique, he emphasizes, is superb for such studies because the nanowires can be made out of such a wide variety of materials.

The paper's first author is Heath's postdoc Nicholas Melosh (who received his Ph.D. in materials from UCSB).

Melosh said, "The significance of the SNAP technique is that the wires created are near the same length-scales as the fundamental building blocks of matter -- molecules and atoms. Potentially, these wires could interface with a single molecule."

Heath's graduate student Akram Boukai is also an author. The other authors are Petroff's graduate students: Frederic Diana, Brian Geradot, and Antonio Badolato. A note at the end of the paper thanks Caltech Physics Professor Michael Roukes for teaching the CNSI researchers "how to perform high frequency nanomechanical resonator measurements."

Note: Professor Petroff can be reached at 805-893-8256 or by e-mail petroff@engineering.ucsb.edu; Professor Heath, by phone at 626-395-6079 or e-mail heath@caltech.edu.

Images

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