Georgia Institute of Technology
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Contact: John Toon (404-894-6986)
E-mail: (john.toon@edi.gatech.edu)
or Jane Sanders (404-894-2214)

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GALLIUM-BASED SYNTHESIS FACILITATES VOLUME PRODUCTION OF ALIGNED SILICON-BASED NANOWIRES WITH OPTICAL PROPERTIES

Using molten gallium as a catalyst, researchers at the Georgia Institute of Technology have simultaneously grown hundreds of thousands of silica nanowires from each micron-scale catalyst droplet. Bundles of the highly aligned and closely packed nanowires form unusual structures resembling cones, cherries, carrots and comets.

Use of gallium catalysts could facilitate high-volume production of silica ($SiO2$) nanowires, improving the vapor-liquid-solid (VLS) process now used to make the structures. The gallium catalysts also produce nanowires that spontaneously divide into branching structures that could have potential applications as optical splitters in nanometer-scale photonic systems.

The National Science Foundation-sponsored work was reported in the February 2002 issue of the *Journal of the American Chemical Society*.

"These nanowires demonstrate many amazing growth phenomena unlike any previously observed through a conventional VLS growth process," explained Zhong Lin Wang, director of the Georgia Tech Center for Nanoscience and Nanotechnology, and a professor of materials science and engineering.

Carrot-shaped structures were produced from bundles of aligned nanowires grown on a silicon substrate. Each carrot contains hundreds of thousands of nanowires.

"These silica nanowires could have applications ranging from optics to surface coatings. It's my hope that they can be useful as small-scale optical fibers useful for splitting a signal."

The ability to grow large bundles of aligned nanowires from a single catalyst could

Georgia Tech Research News & Publications Office
430 Tenth Street, N.W., Suite N-116
Atlanta, Georgia 30318 USA
Tel: (404) 894-6986 Fax: (404) 894-4545
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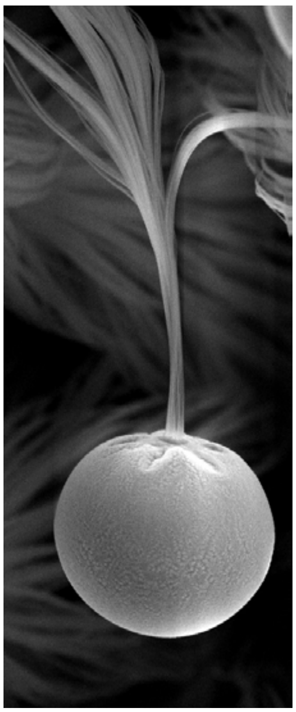
help lower production costs, potentially opening up new applications for the structures.

In standard VLS synthesis techniques used for producing silica nanowires, each wire grows from a single particle of gold, cobalt, nickel or other high melting point metal. Vapor-phase silicon evaporated from a wafer inside a high-temperature furnace condenses on the surface of the molten catalyst, where it combines with oxygen and crystallizes to form silica nanowires.

In the standard process, the size of the catalytic particle controls the diameter of the nanowire grown from it. Because the wires grow individually from the catalyst particles, they produce tangled masses of varying lengths.



Cherry-like structure composed of nanowires.

But by using droplets of gallium 5 to 50 microns in diameter -- thousands of times larger than standard catalytic particles -- Wang and collaborators Zheng Wei Pan, Zu Rong Dai and Chris Ma grow hundreds of thousands of nanowires from a single catalyst. The nanowires attached to each droplet grow to approximately the same length, and remain well ordered, aligned to form hollow macro-scale structures that resemble snowy-white cones, carrots, cherries or comets.

"The importance of this process is that it will allow us to grow many aligned wires rather than tangles of wires," said Wang. "The uniformity of the wires produced in this way could be very useful."

Some of the nanowires spontaneously split into branches, often more than once, with the diameters of the branches equal. "This is very different from any existing types of nanowires," said Wang. "This branching ability makes it possible to produce junctions that may have applications to light propagation."

Though Wang has not yet investigated the optical properties of the nanowires, he believes they could ultimately be useful as switches and for making small-scale photonic connectors. "We want to see how light is transmitted through the branches and whether we can get light from both ends," he explained. "This could be a very important optical structure."

Formation of the nanowires takes place in a high-temperature tube furnace. Gallium nitride powder is placed in a crucible located in the center of an alumina tube with a long silicon wafer stripe nearby atop an alumina plate.

As argon gas is flowed through the furnace, the gallium nitride is heated to approximately 1,150 Celsius, which causes the powder to decompose into molten clusters of metal and nitrogen gas. The liquid gallium clusters agglomerate, forming droplets large enough to be visible inside the furnace. Carried by the argon flowing through the furnace, the droplets condense on the silicon wafer. The hot gallium stimulates the vaporization of silicon from the wafer, then serves as a catalyst for a reaction between the silicon vapor and oxygen to form silica.

Over a period of five hours, bundles of silica nanowires form between the gallium droplets and the surface of the wafer, pushing the gallium upward. Silica nanowires with somewhat different properties also form between gallium droplets and alumina surfaces inside the furnace.

On the silicon substrate, the wires have diameters of 15-30 nanometers and lengths of 10-40 microns. On the alumina substrate, the silica nanowires are larger, with diameters of 50-100 nanometers and lengths of 10-50 microns.

Silica nanowires produced by the standard VLS process are composed of a single crystal. Nanowires produced by the gallium catalyst are composed of amorphous silica.

Beyond investigating the optical properties of the silica nanowires, Wang hopes next to investigate whether the gallium catalyst system can be used to produce other nanostructures.

Technical Contact: Z.L. Wang (404-894-8008); E-mail: (zhong.wang@mse.gatech.edu).