

are now possible, provided that the process can be refined so that the magnetite globules are mostly elongated along their (111) crystallographic axes. At the time of reporting the information for this article, scanning-electron-microscopy and electron-diffraction experiments to determine length-to-width

ratios and crystallographic orientations were under way.

*This work was done by D. C. Golden of Hernandez Engineering; Douglas W. Ming, Richard V. Morris, Gary E. Lofgren, and Gordon A. McKay of Johnson Space Center; and Craig S. Schwandt, Howard V. Lauer, Jr., and Richard A. Socki of Lockheed Martin.*

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## A New Process for Fabricating Random Silicon Nanotips

**This process is relatively simple and inexpensive.**

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An improved process for the fabrication of random arrays of silicon nanotips has been demonstrated to be feasible. Relative to other such processes, this process offers advantages of low cost and simplicity. Moreover, this process can readily be combined with other processes used to fabricate integrated circuits and other monolithic silicon structures.

Arrays of silicon nanotips are subjects of research and development efforts directed toward utilizing them as field emitters in flat-panel displays, vacuum microelectronics, and microwave devices. Other silicon-nanotip-fabrication processes developed thus far predominantly include lithography, etching, and/or elaborate deposition steps followed by oxide sharpening steps and are both process intensive as well as expensive. In addition to being cheaper and simpler, the present process can efficiently produce silicon nanotips that range in height from a few microns to several tens of microns and are distributed over large areas.

The process mentioned here can be summarized as consisting of (1) the growth of micro-etch masks on a silicon substrate, followed by (2) etching away of the masks, along with some of the substrate, to make an array of sharp tips. In the first step of the process, a cleaned silicon substrate is subjected to reactive ion etching (RIE) in a certain mixture of oxygen and carbon tetrafluoride under radio-frequency excitation. This process step results in the growth of fluorine based compounds in the form of stumps randomly distributed

on the substrate. These stumps are known in the art as "polymer RIE grass." The dimensions of these stumps are of the order of hundreds of nanometers, the exact values depending on process time and gas composition. The areal density of the stumps decreases with increasing process time as they grow and merge with neighboring stumps. These stumps constitute the micro-etch masks for the next step of the process.

In the second step of the process, the substrate covered with the micro-etch masks is subjected to deep reactive ion etching (DRIE) process, which consists of cycles of reactive ion etching alternating with passivation (the Bosch process). The gas used in the etching substeps is sulfur hexafluoride ( $\text{SF}_6$ ); the gas used in the passivation substeps is octafluorocyclobutane ( $\text{C}_4\text{F}_8$ ). The portions of the substrate directly under the RIE grass stumps are etched more slowly than are the portions between the stumps. Hence, what remains at the end of the process, after the stumps and parts of the substrate have been etched away,

are silicon spikes where the stubs were (see figure).

In a variation of the process, one starts with a silicon or silicon-on-insulator substrate with the intent to etch through the full thickness of the substrate. That is to say, one chooses the thickness so that the DRIE step releases individual nanotips. Such individual silicon nanotips may have utility as microscopic probes in biomedical applications.

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

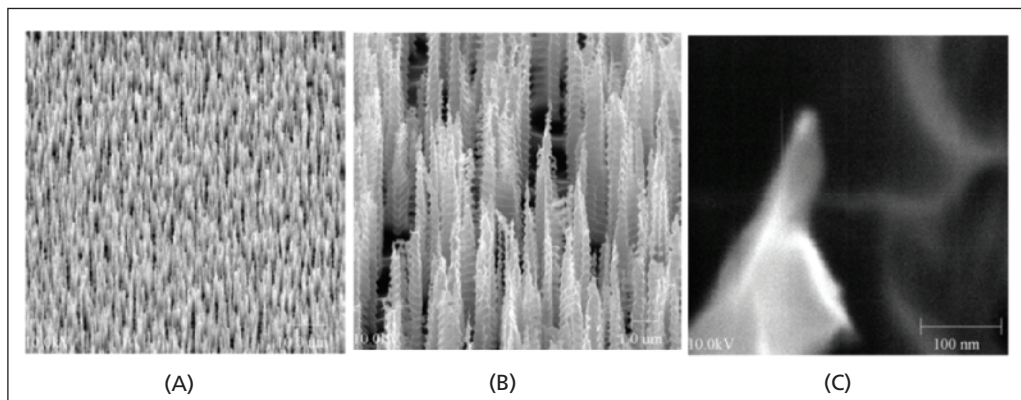
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**An Array of Silicon Nanotips**, shown here at three different magnifications, was fabricated as described in the text. The heights of these nanotips range from about 5 to about 6  $\mu\text{m}$ . The average diameter of the sharp tip portions is about 20 nm. The scalloping of the sides is an artifact of the DRIE process.