Materials

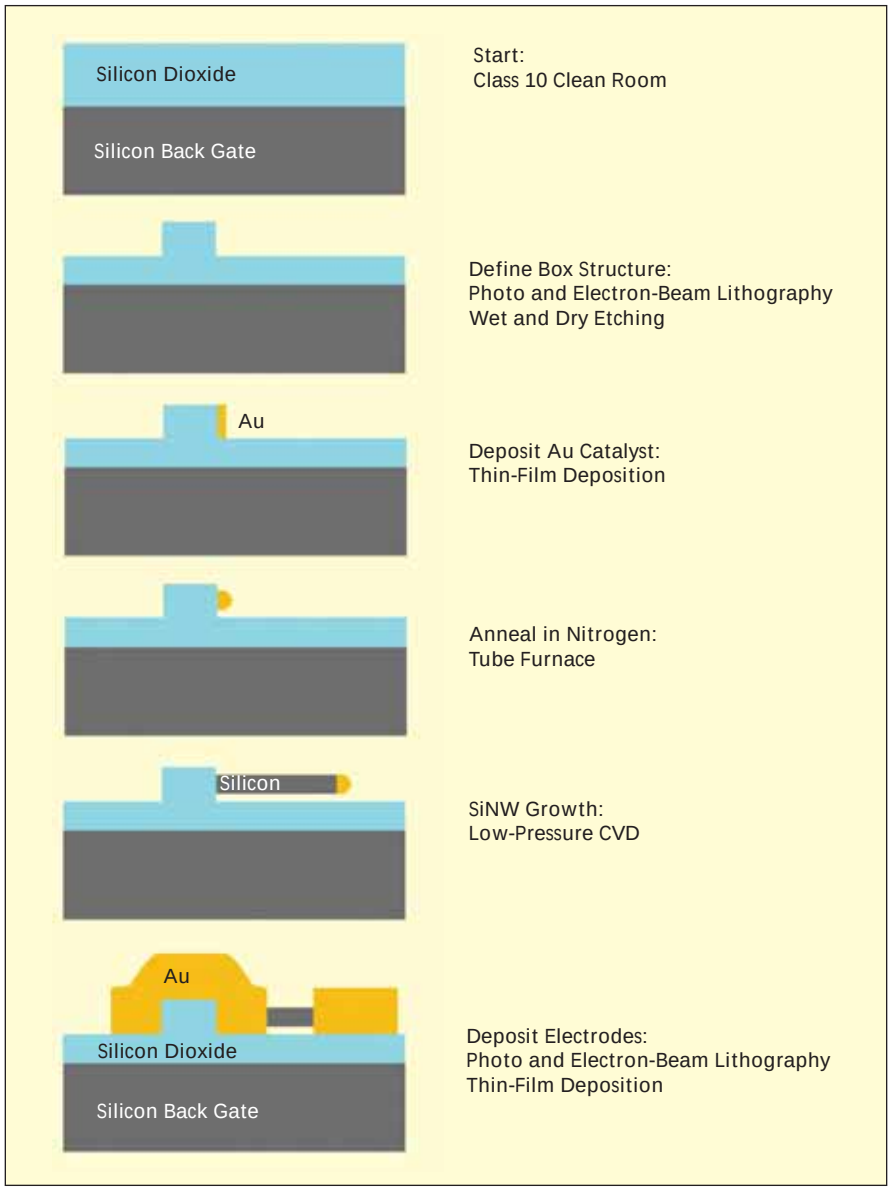
Silicon Nanowire Growth at Chosen Positions and Orientations

There are numerous potential applications in highly miniaturized sensors and electronic devices.

Goddard Space Flight Center, Greenbelt, Maryland

It is now possible to grow silicon nanowires at chosen positions and orientations by a method that involves a combination of standard microfabrication processes. Because their positions and orientations can be chosen with unprecedented precision, the nanowires can be utilized as integral parts of individually electronically addressable devices in dense arrays.

Nanowires made from silicon and perhaps other semiconductors hold substantial promise for integration into highly miniaturized sensors, field-effect transistors, optoelectronic devices, and other electronic devices. Like bulk semiconductors, inorganic semiconducting nanowires are characterized by electronic energy bandgaps that render them suitable as means of modulating or controlling electronic signals through electrostatic gating, in response to incident light, or in response to molecules of interest close to their surfaces. There is now potential for fabricating arrays of uniform, individually electronically addressable nanowires tailored to specific applications.



Gold Particles on substrate surfaces catalyze the growth of silicon nanowires by chemical vapor deposition. The nanowires grow outward, carrying the gold particles at their tips. The nanowires can be grown across gaps to form nanobridges.

The method involves formation of metal catalytic particles at the desired positions on a substrate, followed by heating the substrate in the presence of silane gas. The figure illustrates an example in which a substrate includes a silicon dioxide surface layer that has been etched into an array of pillars and the catalytic (in this case, gold) particles have been placed on the right-facing sides of the pillars. The catalytic thermal decomposition of the silane to silicon and hydrogen causes silicon columns (the desired nanowires) to grow outward from the originally catalyzed spots on the substrate, carrying the catalytic particles at their tips. Thus, the position and orientation of each silicon nanowire is determined by the position of its originally catalyzed spot on the substrate surface, and the orientation of the nanowire is perpendicular to the substrate surface at the originally catalyzed spot.

The diameter of the nanowire is determined by the diameter of its catalytic particle. In principle, using this technique, the diameter of the silicon nanowire can be controlled precisely by the dimensions of the surface pillar. In the example of the figure, the positions and diameter of the catalytic particles are determined as follows: The right-facing pillar surfaces are coated with gold in a directional evaporative deposition process. The deposition thickness is chosen in conjunction with the area of the pillar faces so that the amount of gold on each face is such that if the gold were aggregated into a hemisphere at the center of each face, the diameter of the hemisphere would equal the desired di-

ameter of the nanowires to be grown from the pillar faces. The aggregation is effected by heating the workpiece in an inert atmosphere.

The pillar array can then be used as a reference mark for straightforward device fabrication in a process called alignment. Knowing the position of the silicon nanowires avoids the present difficulties of working with random or semi-random distributions of silicon nanowires. In an important class of potential applications, nanobridges would be coated with biomolecules (e.g., antigens) that bind to other biomolecules of interest (e.g., the antibodies corresponding to the antigens) to enable highly sensitive detection of the molecules of interest. Sensors comprising arrays of multiplexed nanobridges functionalized for detection of proteins symptomatic of cancer have already been demonstrated to be feasible.

This work was done by Stephanie A Getty of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15368-1

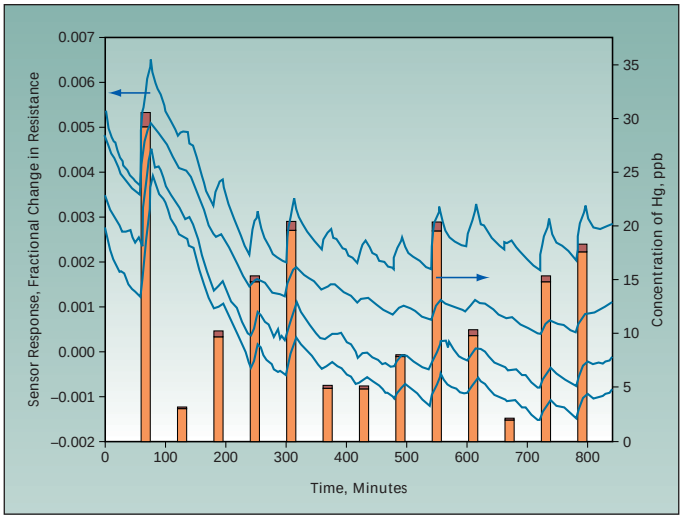
Detecting Airborne Mercury by Use of Gold Nanowires

Mercury has been detected at concentrations as low as 2 ppb.

NASA's Jet Propulsion Laboratory, Pasadena, California

Like the palladium chloride ($PdCl_2$) films described in the immediately preceding article, gold nanowire sensors have been found to be useful for detecting airborne elemental mercury at concentrations on the order of parts per billion (ppb). Also like the $PdCl_2$ films, gold nanowire sensors can be regenerated under conditions much milder than those necessary for regeneration of gold films that have been used as airborne-Hg sensors. The interest in nanowire sensors in general is prompted by the expectation that nanowires of a given material covering a given surface may exhibit greater sensitivity than does a film of the same material because nanowires have a greater surface area.

In preparation for experiments to demonstrate this sensor concept, sensors were fabricated by depositing gold nanowires, variously, on microhotplate or microarray sensor substrates. In the experiments, the electrical resistances were measured while the sensors were exposed to air at a temperature of 25 °C and relative humidity of about 30 percent containing mercury at various concentrations from 2 to 70 ppb (see figure). The results of this and other experiments have been interpreted as signifying that sensors of this type can detect mercury at ppb concentrations in room-temperature air and can be regenerated by exposure to clean flowing air at temperatures <40 °C.



Four Gold-Nanowire-Mat Sensors were exposed to various concentrations of Hg in air at a temperature of 25 °C and a relative humidity of about 30 percent.

The responses of the experimental sensors were found to be repeatable over a period of about 4 months, to vary approximately linearly with concentration from 2 to 20 ppb, and to vary somewhat nonlinearly with concentration above 20 ppb. Although mercury concentrations were found to be measurable down to 2 ppb, the limit of sensitivity may be lower than 2 ppb: Experiments at lower concentrations had not yet been performed at the time of reporting the information for this article.

This work was done by Margaret Ryan, Abhijit Shevade, Adam Kisor, and Margie Homer of Caltech; Jessica Soler of Glendale City College; and Nosang Myung and Megan Nix of the University of California, Riverside, for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-44787

Detecting Airborne Mercury by Use of Palladium Chloride

These sensors can be regenerated under relatively mild conditions.

NASA's Jet Propulsion Laboratory, Pasadena, California

Palladium chloride films have been found to be useful as alternatives to the gold films heretofore used to detect airborne elemental mercury at concentrations of the order of parts per billion (ppb). Somewhat more specifically, when suitably prepared palladium chloride films are exposed to parts-per-billion or larger concentrations of airborne mercury, their electrical resistances change by amounts large enough to be easily measurable. Because airborne mercury adversely affects health, it is desirable to be able to detect it with high sensitivity, especially in enclosed environments in which there is a risk of leakage of mercury from lamps or other equipment.

The detection of mercury by use of gold films involves the formation of gold/mercury amalgam. Gold films