Gas Sensors Based on Vertically Aligned Nanowire Arrays

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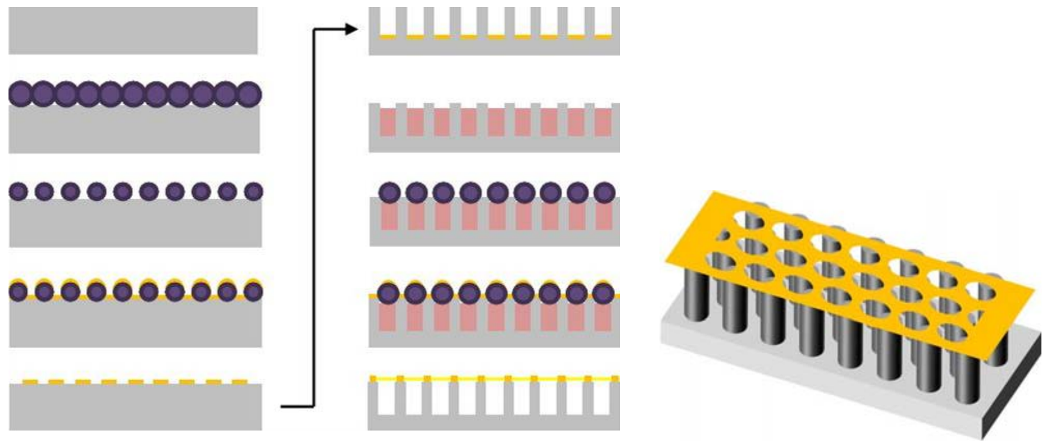
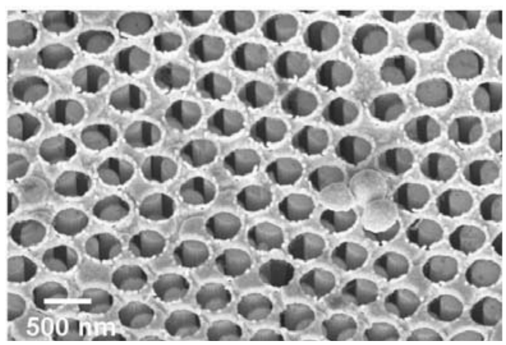
Nanowires, nanotubes, and other types of nanostructures can be highly effective in gas sensing applications due to their favorable mechanical, electrical, chemical, and optical properties, among others. In particular, silicon nanowires (SiNWs) show great promise due to their compatibility with existing processes, ease of fabrication, and wide range of available surface coating and modification techniques. Ultrasensitive gas detection can be achieved by incorporating a very large array of such nanowires in a single device; arranging each nanowire in a vertical orientation further enhances detection capabilities by maximizing both nanowire density and surface exposure. Here, we present a new nanosphere-based fabrication method for creating large arrays of vertical SiNWs with a periodically perforated top electrode layer. This process is ideal for gas sensing devices but can easily be extended to a wide array of future applications.

In a typical vertical nanowire sensor configuration, bottom and top electrodes are required to electrically connect each nanowire. While the substrate itself typically serves as the bottom electrode, the challenge lies in making a porous top electrode layer that electrically connects the tips of the nanowires while still allowing gases to pass through to the sensing areas beneath. In our approach, outlined in Figure 1(a), large arrays of vertically aligned SiNWs were first created through metal-assisted chemical etching of silicon. The gold etch template, which determines the resulting nanowire diameter and period, was made using nanosphere lithography; the diameter of the deposited polystyrene nanospheres defined the SiNW array's period while the combination of this initial diameter and subsequent etching of the nanospheres in oxygen plasma defined the resulting nanowire diameter. The entire array was then covered with a thick photoresist that was subsequently etched back in oxygen plasma to just reveal the SiNW tips. At this point, a second layer of nanospheres, identical to the ones used earlier in making the etch template, was deposited. The new nanospheres perfectly occupy the empty spaces between the nanowire tips and form a close-packed array on top of the SiNWs. After slightly etching down the second nanosphere array in oxygen plasma (to define the pore diameter), evaporating a metal electrode layer, and finally removing the photoresist and nanospheres with acetone, a large SiNW array topped with a periodically perforated electrode layer is formed as shown in Figure 1(b). SEM images of the completed device are shown in Figure 2. This method has been used to create sensors with SiNW arrays up to 15 mm x 15 mm in area with nanowire diameters and lengths of 100~200 nm and up to 15 µm, respectively. Initial testing with NH_3 and NO_2 gases shows that sensors with the pores exhibit significant gains in sensitivity and response rate over those without the pores.

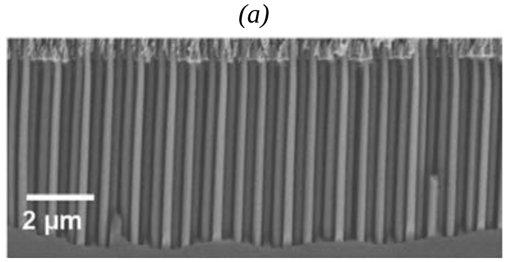


(a) *(b)*

Figure 1: (a) Process flow for fabrication of vertical nanowire arrays with a periodically-perforated top electrode; (b) Schematic of the completed device.



(a)



(b)

Figure 2: (a) SEM image showing the perforated electrode layer above the SiNW array; (b) Side view of the same structure.