New approach allows integration of biosensors into electronics

Joe Shapter and Jamie Quinton

Direct attachment of carbon nanotubes makes silicon substrates conduct even in the presence of a normally insulating oxide layer.

Biosensors are powerful analytical instruments due to their selectivity, sensitivity, and range of possible applications. But integration of the sensing element into the electronic circuitry used to read the sensor output would be a huge step forward. The power of this type of integration has been obvious in the development of micro electro-mechanical systems (MEMS), as both the moving and electronic parts of a device could be packaged on one chip.

Of course, this type of integration will require the construction of biosensors on silicon substrates. Often the oxide layer on silicon makes this difficult as it is fairly unreactive as well as insulating. Our recent work has overcome these obstacles by attaching single-walled (carbon) nanotubes (SWNT) directly to silicon substrates. These nanotubes provide a conduit to access the electronic states of the semiconducting substrate, making electron transport into the silicon possible. These currents could be read directly in an integrated package with both a sensing element and electronic circuitry.

Figure 1 presents a schematic of the approach used to attach the nanotubes. In short, the native oxide of p-type silicon (100) wafers is hydroxylated. The OH groups produced react with functionalized single-walled carbon nanotubes via a condensation reaction using a standard coupling agent. We have confirmed the attachment of the SWNTs to silicon using a variety of surface and spectroscopic techniques.

This chemical approach has two distinct advantages over the various growth processes often used. First, the nanotubes are chemically bound to the surface, whereas grown tubes can have adhesion issues. Second, the tops of our nanotubes have chemical functionalities that can react further to attach species appropriate to applications such as biosensing. Grown tubes often have end caps, and further modification is difficult without destroying the prepared substrate. In addition, the attachment procedure is quite simple compared to some other approaches, and, perhaps most importantly, yields only vertically aligned nanotubes. As such, these structures are available for further functionalization leading to a variety of possible applications.

For example, the nanotubes could be used to construct sensors that require the measurement of current. We have probed the ability of the nanotube substrates to conduct electrons. Figure 2 shows cyclic voltammograms (CVs) obtained with SWNTs directly attached to the silicon electrode as well as some control experiments. The nanotube surface produces distinct redox waves with anodic and cathodic peak positions at 474mV and 596mV, respectively (see Figure 2a). These are very similar to those observed on a gold substrate, as shown in the inset. No signal is observed with only the oxide layer present. This proves that the nanotubes have in essence ‘electronically’ punched through the insulating oxide layer such that the electronic states of the

Continued on next page
Figure 2. Cyclic voltammograms (CVs) using (a) single-walled (carbon) nanotubes (SWNTs) directly attached to a silicon working electrode in 0.1 mmol L\(^{-1}\) ferrocene dissolved in 0.1 mol L\(^{-1}\) tetrabutylammonium perchlorate (TBAP)/CH\(_3\)CN solution. (b) SWNTs directly attached to a silicon working electrode in 0.1 mol L\(^{-1}\) TBAP/CH\(_3\)CN blank solution; and (c) a hydroxyl terminated silicon working electrode in 0.1 mmol L\(^{-1}\) ferrocene dissolved in 0.1 mol L\(^{-1}\) TBAP/CH\(_3\)CN solution. The scan rate is 100 mV s\(^{-1}\). The inset shows the CV on a gold electrode with the same ferrocene solution under the same conditions.

Our work successfully demonstrates a new, direct-chemical anchoring approach to the fabrication of vertically-aligned shortened carbon nanotube architectures on a silicon (100) substrate. The new interface demonstrates excellent conductivity to the substrate, and as such this approach has numerous potential applications. The attachment of SWNTs directly to a silicon surface provides a simple new avenue for the fabrication and development of silicon-based electrochemical and bio-electrochemical sensors, solar cells, and nanoelectronic devices using further surface modification.

Author Information

Joe Shapter and Jamie Quinton
School of Chemistry, Physics and Earth Science
Flinders University
Bedford Park, Australia

References