Nanocomposite optical sensors detect trace chemicals

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Novel coatings composed of carbon nanotubes embedded in cadmium arachidate matrices improve the robustness and performance of fiber-optic chemical sensors.

Single-walled carbon nanotubes (SWCNTs) have been widely exploited in recent years as highly adsorbent nanocoatings on optoelectronic sensors for chemical detection in air and water. Excellent sensing performance has been obtained so far, such as detection limits of less than one part per million (ppm), high repeatability, and response times of few minutes. Nevertheless, the adhesion of carbon nanotubes to the fiber end-face still represents a challenge that must be addressed for practical applications and before the sensors can be commercialized. We propose the use of sensitive coatings composed of a nanocomposite material of SWCNTs embedded in cadmium arachidate (CdA) matrices to improve the robustness and sensitivity of the optoelectronic chemical sensors. The experimental results demonstrate that such a composite integrated with optical fiber technology offers great potential for room-temperature detection of trace chemicals in water and could lead to significant improvements of optical fiber sensors based on standard SWCNT layers. To the best of our knowledge, no experimental data has been reported before on the capability of such nanoscale coatings to detect chemicals in liquid environments.

The sensor configuration is based on a low-finesse Fabry–Pérot interferometer created by the deposition of thin sensitive nanocoatings on the terminal face of standard single-mode fibers (see Figure 1). The presence of the analyte molecule changes the nanocoating’s refractive index and thickness. When light is transmitted through the fiber to this sensing layer, these changes modulate the intensity of light reflected back into the fiber. The optical nanosensors, interrogated by an appropriate optoelectronic setup, enable one to determine the chemical concentration within the sample by monitoring the fiber-film reflectance.

The deposition of the CdA/SWCNT nanocomposites on the distal end of properly prepared fibers has been accomplished by the Langmuir–Blodgett (LB) technique. We chose CdA as the host-matrix material because its peculiar amphiphilic molecular structure is particularly suitable for the LB deposition process. Figure 2 shows typical scanning electron microscope (SEM) images of a CdA/SWCNT nanocomposite thin film. They reveal both the tendency of carbon nanotubes to aggregate, forming bundles, as well as their good CdA-assisted adhesion to the surface.

We experimentally investigated the capabilities of the CdA-SWCNT-based optical-fiber sensor by detecting toluene and xyylene in water at room temperature. Figure 3 reports typical responses of the sensor when toluene is injected into the sample at different concentrations (20–100 ppm). The analyte adsorption within the nanocomposite promotes significant changes in its optical properties. These changes lead to a strong decrease of the fiber-film reflectance. The experimental results reveal the capability of the optoelectronic transducer to detect the tested pollutants at parts-per-million levels, with good repeatability, and the ability to recover the initial baseline signal upon the complete analyte molecule desorption. Similar results have been obtained.
in the case of xylene adsorption measurements conducted with the same concentration range.

We found linear behavior of the characteristic curves of the sensor (see Figure 4) for both the analytes in the investigated range (0–100ppm) as well as the typical higher sensitivity of SWCNT-based material toward xylene ($1.0 \times 10^{-3}$ppm$^{-1}$) than toluene ($4 \times 10^{-4}$ppm$^{-1}$). In Figure 4, we compare the sensing performance obtained with the nanocomposite to that obtained with pure SWCNTs. The results clearly reveal that a significant enhancement in sensitivity can be obtained by using a CdA/SWCNT overlay ($4 \times 10^{-4}$ppm$^{-1}$) with respect to standard carbon nanotubes sensors ($1.2 \times 10^{-4}$ppm$^{-1}$).

In conclusion, these CdA/SWCNT-based nanocomposite sensors have strong potential for enhanced chemical trace detection in water. Their integration with optical fiber technology could open the way to their exploitation for practical water-quality-monitoring applications and their transfer to the market.
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