Photonic nanostructures help monitor water quality

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New approaches to quality control of drinking water and monitoring the quality of environmental water resources are currently drawing increased interest. Inspecting optical water clarity is useful in detecting dissolved contaminants. This is usually done in analytical laboratories, which are often located far from the water-sample collection sites. Although ‘dirty’ water samples are well known to absorb light, drinking-water quality assessment is necessary even if the samples look crystal clear. Most of the current analytical techniques developed for laboratory-based water-quality examination require complex and bulky equipment, such as spectrophotometers operated by expert-level personnel. We have developed a new approach to quickly and accurately test water quality using compact portable sensor devices, enabling accurate field testing of water samples through in situ measurements of optical absorption.

Absorption spectroscopy is a well-established technique for detecting the presence of pollutants in gases or liquids. Since most known substances exhibit specific and often easily recognisable features in their absorption spectra, contaminants can be detected through their spectral ‘fingerprints.’ These cause strong absorption of certain colors if a beam of light is propagated along a sufficiently long path through a contaminated sample. This approach also allows measurement of pollutant concentrations. One needs to select light of a wavelength that propagates almost absorption-free through pure water yet would be strongly absorbed by organic or inorganic contaminants. Our novel approach to water-quality monitoring is based on cavity-enhanced absorption spectroscopy. This uses a light beam fed through an optical cavity, resulting in multiple internal reflections. To construct a miniature and ultrasensitive sensor, a photonic-crystal-type optical cavity is used, driven by a blue diode-pumped solid-state laser with a wavelength of 473nm, which is strongly absorbed by most impurities usually dissolved in water.

Our miniature element employs nanostructured optical coatings as Fabry–Perot cavity mirrors. It is suitable to accurately measure small absorption changes within weakly absorbing cavity media at a discrete set of optical wavelengths. The principal sensor diagram for operation in transmission mode is shown in Figure 1. The signal-processing setup and implementation of the devices are illustrated in Figure 2.

The sensitivity of the sensor is also demonstrated in Figure 2, where we show both the spectrum of light fed to the sensor and changes within the transmission peaks caused by variation in water absorption from $A = 0.0005$ to $0.0055 \text{cm}^{-1}$ (for pure and contaminated water, respectively). The effect of small absorption changes (comparable to absorption by pure water) within the cavity is relatively small, although it is easily measurable by the sensitive circuitry. Using Fourier-transform signal processing, absorption changes on a scale smaller than that of water are also measurable.

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Figure 2. Signal-processing setup and predicted sensitivity for nanostructured absorption sensors suitable for water testing. A blue diode-pumped solid-state (DPSS) laser emitting at 473nm is fed through a contaminated water sample to a sensor composed of two identical thin films, each consisting of six repeated sequences of quarter-wave zinc-oxide and silicon-dioxide layers, 2 × Si(2nm)× ZnO(2nm), for which the refractive indices (n) at 473nm are indicated. The spectra of light transmitted within the narrow peaks generated by the water cavity for both pure and contaminated samples are also shown, along with their absorption coefficients (A).

Our team has successfully established the technology to manufacture photonic-crystal-type periodic multilayered nanostructures with precisely controlled layer thicknesses. The water sensors are particularly attractive for environmental monitoring and food processing and can provide real-time quantitative information about chemical-contamination levels in drinking water and, potentially, the types of substances dissolved.

To produce the 1D nanostructures needed for next-generation water sensors, our thin-film sputtering technology seems extremely promising. We have thus far been able to create structures with appropriate layer thicknesses (60–80nm for individual layers) and minimal thickness errors (~2nm per layer) which can be integrated optomechanically into viable test-ready devices. We will next obtain water-absorption measurements for samples of different chemical composition and pursue a cost-effective fabrication process for these new nanophotonic sensors.

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