Chemical Sensors Based on Optical Ring Resonators

Resonance wavelengths are shifted by absorption of chemicals into polymer cladding layers.

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Chemical sensors based on optical ring resonators are undergoing development. A ring resonator according to this concept is a closed-circuit dielectric optical waveguide. The outermost layer of this waveguide, analogous to the optical cladding layer on an optical fiber, is made of a polymer that (1) has an index of refraction lower than that of the waveguide core and (2) absorbs chemicals from the surrounding air. The index of refraction of the polymer changes with the concentration of absorbed chemical(s). The resonator is designed to operate with relatively strong evanescent-wave coupling between the outer polymer layer and the electromagnetic field propagating along the waveguide core. By virtue of this coupling, the chemically induced change in index of refraction of the polymer causes a measurable shift in the resonance peaks of the ring.

In a prototype that has been used to demonstrate the feasibility of this sensor concept, the ring resonator is a dielectric optical waveguide laid out along a closed path resembling a racetrack (see Figure 1). The prototype was fabricated on a silicon substrate by use of standard techniques of thermal oxidation, chemical vapor deposition, photolithography, etching, and spin coating. The prototype resonator waveguide features an inner cladding of SiO₂, a core of Si₃N₄, and a chemical-sensing outer cladding of ethyl cellulose. In addition to the ring resonator, there are input and output waveguides separated from the straight segments of the ring resonator by an evanescent-wave-coupling gap of 2 μm.

Figure 2 presents results of a test of the prototype in an open room. During the test, the temperature of the sensor was stabilized to ±0.1 K. The sensor was left undisturbed by chemicals, except during a short interval when a cotton swab wetted with acetone was placed 4 in. (≈10 cm) away from the sensor and another short interval when a cotton swab wetted with isopropyl alcohol was similarly placed near the sensor. The chemical exposures resulted in easily detectable signals that exceeded background variations by at least an order of magnitude. The jagged nature of the portions of the plot corresponding to the chemical exposures has been attributed to “mode hops,” in which the specific ring-resonator mode that was being followed moved out of the tuning range of a laser used as the input light source, causing the laser to lock onto a new mode.

The results have been interpreted as demonstrating the feasibility of optical polymer-based sensors. Inasmuch as the index of refraction of ethyl cellulose is known to respond to wide variety of volatiles, sensors like this one could be useful as non-specific indicators of spills of volatile compounds.

This work was done by Margie Homer, Allison Manfreda, Kamjou Mansour, Ying Lin, and Alexander Ksendzov of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a technical solution report (TSP) (see page 1).

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