CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

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Project Number

S0605

Project Title

A Porous Silicon Optical Nanosensor for the Detection of Volatile Organic Compounds

Abstract

Objectives

Recent news of the use of nerve agents in global terrorist attacks poses an immediate concern to international security. In addition, Volatile Organic Compounds (VOCs) diminish indoor air quality and can contribute to the formation of smog. Thus, developing cost-effective chemical detection methods is a priority, with applications in border protection and environmental monitoring. This research aims to utilize the optical properties of a porous silicon (pSi) rugate filter to develop a low-cost, real-time sensor for a broad range of VOCs.

Methods

Sixteen samples of pSi were electrochemically fabricated from p++-type silicon wafers. These samples were hydroxylated through ozone oxidation and a ring-opening living polymerization reaction with a heterocyclic silane was carried out to stabilize the pSi from oxidation in air, water, and basic media. After confirming pSi stability, a broad range of VOCs (e.g., benzene, chloroform, dichloromethane, ethanol, perchloroethylene, toluene, etc.) were chosen to test the optical rugate filter. Both pure and complex mixtures of vapors were cycled through a flow chamber and a CCD spectrometer continuously monitored for changes in the reflected stopband of the sensor to identify the VOC.

Results

ATR-FTIR spectra confirmed the ring-opening reaction with grafting via Si-O-Si bonds to the pSi surface. Hydrophobicity was demonstrated by water contact angles of 120-130 degrees. A stable stopband was maintained after varying thermal and alkaline conditions. The VOC sensing for both pure and complex mixtures produced consistent, predictable stopband shifts with a mean precision of 0.03 nm for pure VOCs and 0.79 nm for complex mixtures and a threshold detection concentration of 1 microgram per cubic meter.

Conclusions

The VOCs under analysis underwent microcapillary condensation in the cavities of the pSi, changing the composite refractive index of the sensor and causing a predictable optical stopband shift which can be used to identify VOCs of interest. With a precision which parallels state-of-the-art chemical detection, as well as high stability and portability, this sensor is viable in chemical detection systems for real-time air quality monitoring and forensic analysis. Future work includes introducing multiparametric dimensions, such as electrical signals, to distinguish similar species, as well as integrating the sensors with a smartphone camera.

Summary Statement

I developed stable, real-time porous silicon optical rugate filters to sense target volatile organic compounds by their unique refractive indices.

Help Received

Dr. Michael J. Sailor and other members of the Sailor Laboratory at the University of California San Diego (UCSD) provided the porous silicon material, laboratory equipment, and guidance. Sensing experiments were conducted independently.