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Topic of research - Study and Modelling of Optical Fiber Sensor Probes for Gas Detection

Findings

Energy crises are a major issue due to the limited availability of fossil fuels. The byproducts produced in the combustion of these fossil fuels are catastrophic for the environment. The highly efficient and abundant available hydrogen gas, along with the use of green technology to produce, store, and transport hydrogen, plays an important role in solving the aforesaid requirement up to a large extent. Hydrogen gas is prone to an explosion due to its wider flammability limit (4.0-74.5% volumetric concentration in air), lower ignition energy (0.018 mJ), and higher deflagration index (550 Bar m/s). Hence control and monitoring of hydrogen gas in the environment is necessary during production, transportation, storage, and applications. To monitor hydrogen, highly selective and sensitive sensors are required. Various types of sensors are already merchandized and demonstrated. Electrical-based sensors may produce sparks in hazardous environments therefore in hazardous environments optical fiber sensors are most effective because only an optical signal is used for sensing while its electrical components such as source and detector are located remotely. Fiber optic sensors also have other advantages such as immunity to electromagnetic interference hence better signal-to-noise ratio and distributed remote sensing capability. Different types of fiber optic probes have been proposed to detect hydrogen such as cladding removed, taper, interferometric, Bragg grating, side polished, etc. In side polished optical fiber probes the cladding is partially or fully removed to expose the evanescent tail of the guided modes. This exposed evanescent tail penetrates the palladium layer deposited on the polished surface of the fiber. Palladium is highly reactive with hydrogen and also its selectivity is very high to detect hydrogen. After absorption of hydrogen in palladium, palladium becomes palladium hydride, and hence the optical properties of the palladium layer changes, which affect the characteristics of the guided modes propagating through the core of the polished fiber. This change in optical beam characteristics is interpreted to determine the hydrogen concentration in the environment.

This research is mainly focused on the design of side polished optical fiber probes for hydrogen gas detection. We investigated and proposed different designs of the side polished single mode fiber hydrogen sensors with improved/high sensitivity. We have used an equivalent planar waveguide model of side polished single mode fiber probe to design these sensors.

We have carried out the numerical investigations on side polished single mode fiber hydrogen gas sensor (with buffer layer and palladium layer). The loss of the plasmon modes depends on the presence of hydrogen atoms in Pd layer. The remaining thickness of the cladding layer between the core and palladium acts as a buffer layer which controls the coupling between guided and plasmon modes. We studied this coupling effect and optimized the thickness of the buffer layer to maximize the guided mode to the plasmon mode coupling. We achieved an improvement of 82% in the sensitivity to the reported experimental results for 4% hydrogen concentration. An empirical relation to determining the optimized buffer (silica) thickness for a given palladium thickness has also been obtained. After investigating the effect of the different buffer materials on the sensitivity, it was found that the Teflon buffer based design achieved maximum sensitivity of 34 dB.

We also investigated single mode fiber hydrogen sensors in which the sensing layer is a combination of zinc oxide and palladium. With the optimized design we could achieve the sensitivity of 1200 dB for the third LMR while for the first and second LMR conditions, the sensitivity is obtained as 290 dB and -229 dB respectively. The presence of a buffer layer of Ag, Al, or Si between the fiber core and the sensing layer enhances the sensitivities to 795 dB, 1022 dB, and 2200 dB for the first, second, and third LMR conditions respectively, with reduced sensing layer thickness. The use of 300 nm buffer thickness and 2.0 buffer index provides maximum sensitivity which is nearly about 3000 dB. To achieve maximum sensitivity, for a lower buffer index a large buffer thickness is required and vice-versa.

We have also carried out numerical investigations on SPR based dual mode side polished fiber hydrogen sensors. The proposed design of the fiber sensor has shown huge sensitivity with the design parameters the core thickness of 4.43 µm, sensing layer thickness of 30 nm, buffer thickness of 10 nm and buffer index of 1.35 for the concentration of 0-1% hydrogen. The use of a buffer improves the fabrication tolerance of sensing layer thickness for which sensitivity is maximum. The proposed design of the side polished single mode fiber with Pd transducer layer and deeply polished fiber core exhibits a huge sensitivity of 2645 dB.