Low-cost H_2S gas sensor based on plastic optical fiber

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A new simple and low-cost fiber optic sensor for cumulative detection of H_2S and other sulphide compounds is described. The transducer is based on a plastic optical fiber and exploits a non-reversible chemical reaction, whose products interact with the evanescent field tails thus increasing the propagation losses with the exposure time. The sensor has a sensitivity of the order of few ppb.

1 Introduction

Measuring the total exposure to toxic gases is a common request in the fields of safety and environmental monitoring, but can also find relevant applications in cultural heritage preservation, such as in the conservation of ancient artifacts. Usually electrochemical sensors are used, but these types of sensors are sensitive to the instantaneous gas concentration and thus require integrating the sensor readings to compute the cumulative exposure; a method that may lead to important errors, as it has already been highlighted in [1]. In this paper we present an alternative solution that is able to evaluate directly the cumulative exposure. The sensor is based on optical fibers and it has several advantages, mainly the intrinsic fire safety and reduced invasive impact that makes it an ideal sensor for the detection of pollutants especially in museum showcases containing precious ancient artifacts [2].

In this paper we describe the realization and characterization of a fiber sensor for the detection of H_2S and other sulphide vapors, although the same working principle can be applied also to the detection of other toxic substances. The transducer operating principle is based on the variation of the propagation losses experienced by the guided light in a plastic optical fiber coated by a thin metallic film when exposed to the substance under investigation. In the considered case in this work, a silver film has been deposited onto the fiber surface after etching of the cladding to take advantage of the silver irreversible chemical reaction with the sulphides.

The substitution of plastic for glass optical fibers accounts for the possibility of having all the advantages of a fiber-based device without the typical costs of fiber sensors and furthermore, of improving the sensitivity for evanescent field sensing [3]. The usage of POF allows a substantial reduction of the final device cost since it is possible to use incoherent light sources and low precision connections given the higher numerical aperture and the larger diameter in comparison with glass fibers. In addition, they structure allows easily removing the cladding to improve the interaction between the deposited film and the propagating fields and thus enhance the sensitivity.

2 POF and sensors development

The plastic optical fibers (POF) used in this work have a 0.98 mm diameter core made of PMMA (polymethylmethacrylate) surrounded by a fluoropolymeric cladding for a total diameter of about 1 mm.

Some prototypes of plastic fiber sensors have been realized by means of a two step process, which consists in the etching of the cladding in organic solvent (ethylacetate for about 40 s), followed by the deposition of a thin silver layer in a plasma glow discharge. A nanostructured silver layer with a thickness of about 40 nm has been deposited onto a fiber length of about 10 cm. The developed sensors have been tested in a controlled environment rich in sulphide vapors.

3 The measurement set-up

The measurement set-up (Fig. 1) has been arranged in a very simple, though reproducible way. The POF sensor has been placed inside a reaction chamber made with a glass bowl and fed using a red LED source through a coupler that allows monitoring the injected light intensity. The sensor output is measured using a home-made optical power meter. Two solid state temperature sensors have been placed inside and outside the reaction chamber to monitor the operating conditions and the room temperature; a commercial electrochemical gas sensor has been used to measure the sulphide concentration of the gases injected into the bowl. The acquired data are shown in real-time and saved for subsequent analyses.

4 POF sensor response

Preliminary tests have been performed in the presence of a sulphide-rich atmosphere containing more than 100 ppm in order to verify the maximum transmission reduction.

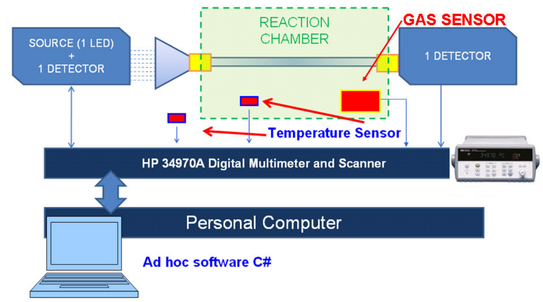

Fig. 1 *The realized set-up.*

The result obtained during this test is shown in Fig. 2: the transmission ratio reduces by more than 95% as the Ag reacts with the sulphide vapors, showing that a high sensitivity can be expected using such this approach. An optical spectral analysis carried out by feeding a POF sensor with white light and analyzing the output by means of an *Avantes* spectrometer during the exposure to sulphide vapors confirmed the absence of wavelength dependent absorptions.

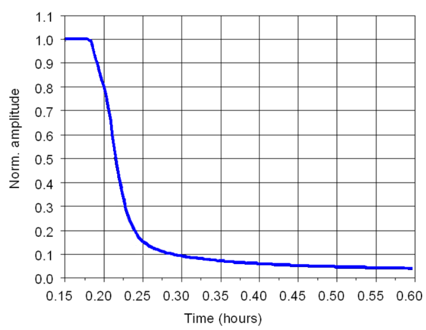

Fig. 2 *Normalized transmission ratio*

Fig. 3 reports two Scanning Electron Microscope images of the fiber surface before and after the sulphuration reaction showing that after the test silver is almost completely substituted by silver sulphides (the clusters in the rightmost part of the photo), which is responsible for the increase in the attenuation.

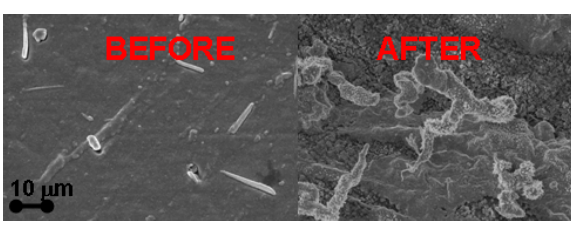

Fig. 3 *SEM images of the fiber surface after and before the sulphuration reaction*

A second test has been performed in the presence of low concentrations of sulphide. Fig. 4 shows the excellent fiber sensor sensitivity that can easily detect sulphide concentration in the order of 0.08 ppm, a very low concentration of pollutant, well within the typical specifications required by most of cultural heritage preservation applications. The second plot in Fig. 4 shows for comparison the reading from the commercial sensor and the last plot is the computed exposition after adjusting (ex-post!) the sensor offset.

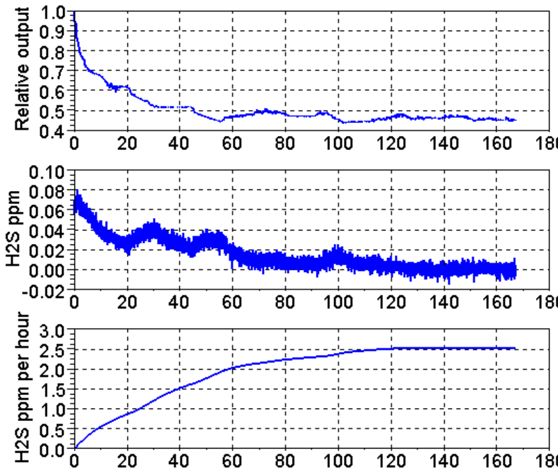

Fig. 4 *Normalized transmission ratio in presence of low sulphide vapors concentration*

5 Conclusions and future prospects

In this paper an innovative sensor based on a low cost plastic optical fiber and suitable for H_2S vapor monitoring has been described. Preliminary characterizations have demonstrated a good repeatability and a fast response. Therefore the developed sensor can be successfully proposed to monitor the total exposure over time to sulphide compounds and to detect hazardous situations. In the next future, thanks to the high versatility of the low pressure plasma processes, the possibility to functionalize POF with inorganic and organic molecules will be investigated with the final goal of developing sensing elements for the selective detection of gases like NO_x, CO_x, and of chemicals correlated to human body and human diseases.

References

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