Wavelength multiplexed hydrogen sensor based on palladium-coated fibre-taper and Bragg grating

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A novel configuration of a wavelength multiplexed hydrogen sensor based on a palladium-coated tapered fibre and a fibre Bragg grating is presented. This scheme allows cascading several sensors along a single fibre, which increases the capability of implementing multipoint sensor networks for volumetric detection. Moreover, in this configuration the light interacts twice with the palladium layer, thus enhancing the sensitivity of the sensor.

Introduction: Many different types of fibre-optic hydrogen sensors have been reported to date in the literature [1–4]. Most use palladium as transducer since it enables the selective detection of hydrogen. Absorption of hydrogen by a Pd film alters the complex dielectric constant of this material, which modifies the optical properties of Pd, allowing the detection and measurement of hydrogen by optical techniques. Most of the reported fibre-optic hydrogen sensors have very little multiplexing capability, requiring optical switches for addressing the sensors. Some applications of hydrogen sensors involve volumetric detection, for which a large number of sensors (hundreds) are needed. Recently, a wavelength multiplexed hydrogen sensor was reported, based on a Pd-coated fibre Bragg grating (FBG) [5]. However, this device shows little sensitivity and requires thick layers of Pd, which makes the device's time response too long for many applications.

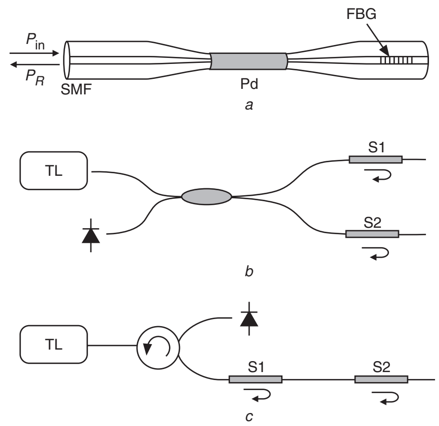

Fig. 1 *Diagram of sensor, and multiplexing schemes*

a Diagram of sensor
SMF: singlemode fibre; Pd: palladium film; FBG: fibre Bragg grating
b and *c* Multiplexing schemes
TL: tunable laser

In previous papers, we reported a hydrogen sensor based on a Pd-coated singlemode tapered fibre [6, 7]. In this device, the light absorption changes when the palladium coating absorbs hydrogen resulting in light transmission changes. The device showed high sensitivity to low concentrations of hydrogen, with fast time response. Other advantages of this sensor are the possibility of tailoring the sensor's response by controlling its geometry or the light wavelength, and the simplicity of the sensor's interrogation system.

Device: In this Letter we report a slightly different device. It comprises a Pd-coated tapered fibre and an FBG (Fig. 1*a*). The operation of the device is again based on the interaction along the taper waist between the evanescent fields of the fundamental fibre-mode and the Pd coating, although in this case the hydrogen concentration is detected through the intensity changes of light reflected by the FBG. Adding an FBG we found two important advantages. First, the sensitivity of the sensor is enhanced since the reflected light passes twice through the Pd-coated fibre section. Secondly, using FBGs with different wavelengths several sensors can be multiplexed. Moreover, the FBG can be used to simultaneously measure temperature, which may be of interest since the chemical reaction between Pd and H_2 depends strongly on temperature.

Experimental results and discussion: All measurements were carried out at room temperature and 1 atm pressure. Fig. 2 shows the response of two sensors, S1 and S2, when they were exposed to certain hydrogen concentrations. Both devices were made with tapers having 25 µm diameter and 8 mm length, onto which a Pd layer having a nominal thickness of 8 nm was evaporated. To form the final sensors S1 and S2, the Pd-coated tapered fibres were then spliced to Bragg gratings having ~30 dB peak reflectivity and ~0.25 nm width, centred at 1539.2 and 1544.8 nm, respectively. Figs. 2*a* and *b* give the measured reflection spectra when the sensors were exposed to 0, 5 and 9% hydrogen concentration. It is shown that the intensity of the reflected signal at the Bragg wavelength increases as the hydrogen concentration was increased. For 9% hydrogen concentration the response of S1 nearly doubles the curve obtained for 0% concentration.

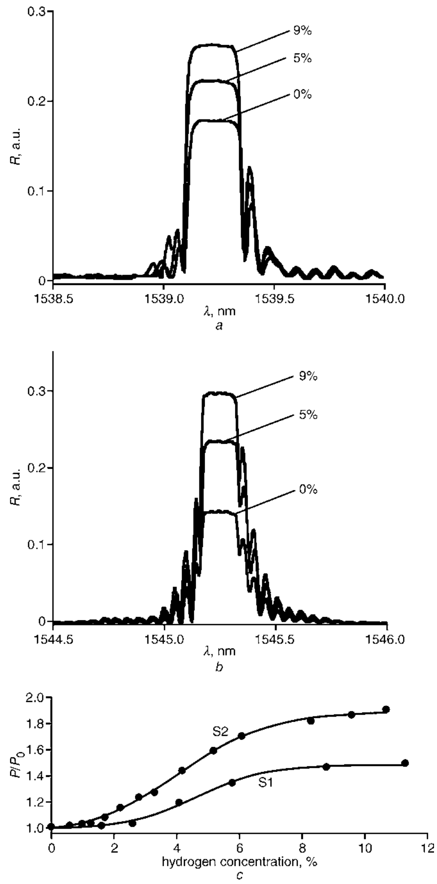

Fig. 2 *Reflection spectra of S1 and S2 for different hydrogen concentrations, and normalised response of S1 and S2 against hydrogen concentration*

a and *b* Reflection spectra of S1 and S2, respectively
c Normalised response of S1 and S2 against hydrogen concentration

Fig. 2*c* gives the calibration curves of both sensors. P is the intensity of the reflected signal at the Bragg wavelength for a given concentration, and P_0 is the intensity for 0% hydrogen. In both cases P/P_0 increases quickly for low concentrations and it tends to saturate for values above ~6%. Such behaviour makes the device readily suitable for detecting and measuring hydrogen in atmospheres containing concentrations well below the explosive limit (4%). We believe that the responses of S1 and S2 are different because of inaccuracies during the fabrication process.

Time response of both sensors was similar to that reported in [6, 7]. As an example, sensor S1 when it was exposed to 4% hydrogen concentration took ~50 s to reach 90% of the overall transmission change, and approximately 40 s to recover after the hydrogen flow was stopped. The sensor's response is fully reversible. Actually, both devices were exposed to a large number of cycles during at least six months and no relevant changes have been observed in their responses.

A straightforward way to set up a wavelength multiplexed multipoint sensor network for volumetric detection consists in connecting in parallel a set of sensors having different Bragg wavelengths by using fibre couplers (Fig. 1*b*). In this way, a single light source is required to interrogate all sensors. Responses such as those shown in Fig. 2 would be obtained from each sensor. Additionally, the number of sensors may be increased if several sensors can be multiplexed in a single fibre. To demonstrate the feasibility of our sensor to be arranged in-line along a single fibre, we spliced sensors S1 and S2 to form a two-sensor chain, as depicted in Fig. 1*c*.

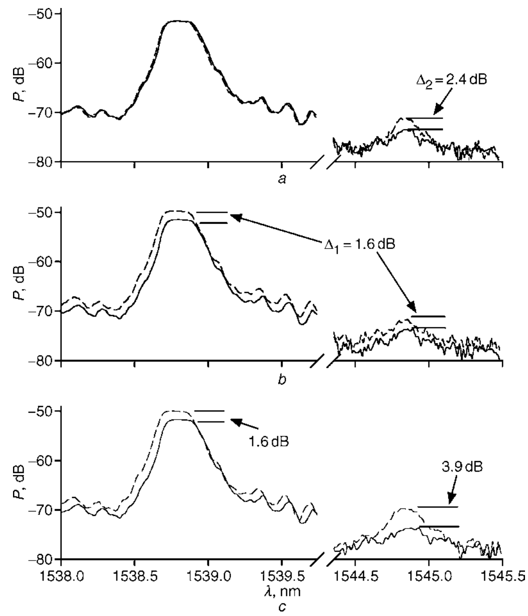

Fig. 3 *Reflection spectra of S1 and S2 in series, when exposed individually to 9% hydrogen*

a Only S2 *b* Only S1 *c* Both S1 and S2 exposed to hydrogen

Fig. 3 gives the reflection spectra obtained when sensors S1 and S2 were exposed separately to 9% hydrogen concentration. The reflected light intensity from sensor S2 is approximately 20 dB weaker than light coming from sensor S1, since light coming from S2 is attenuated by the Pd-coated tapers of both sensors. The attenuation of both devices measured in air was ~10 dB. Fig. 3*a* corresponds to the case that only S2 was exposed to hydrogen. It is shown that the intensity coming from S1 does not change, while the intensity coming from S2 shows an increase, $\Delta_1 \sim 2.4$ dB, in accordance with Fig. 2*c*. Fig. 3*b* corresponds to the case that only S1 is exposed to hydrogen. Here both peaks increase by the same amount, $\Delta_2 \sim 1.6$ dB. The reflection from sensor S1 increases due to the absorption of hydrogen on its Pd-coated taper, which causes a light attenuation decrease. Such light attenuation decrease in S1 also causes more light to enter S2 and thus the reflection from S2 also increases. Finally, Fig. 3*c* shows the response when both sensors, S1 and S2, were exposed simultaneously to hydrogen. The light intensity coming from S1 increases ~1.6 dB, as in Fig. 3*b*, while light intensity coming from S2 increases ~3.9 dB, which corresponds to $\Delta_1 + \Delta_2$.

The number of sensors per fibre that can be multiplexed is basically limited by the attenuation of each sensor, which can be tailored controlling the geometry of the fibre taper [7]. Devices with shorter and/or thicker tapers will show lower attenuation. Thus, a proper design of the sensors will allow arranging more than two of them along a fibre.

Conclusions: We have demonstrated a novel configuration of a hydrogen sensor based on a palladium-coated tapered fibre and a fibre Bragg grating. This type of sensor shows high sensitivity and short time response, and it allows wavelength multiplexing. Multiplexing two sensors in a fibre has been demonstrated. The device presented in this Letter is suitable for building multipoint hydrogen sensor networks.

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