PHOTONIC SENSORS / Vol. 4, No. 2, 2014: 128–131

Spectral Absorption Gas Sensor Based on Anti-Resonant Reflecting Optical Waveguide

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Abstract: An air-silica microstructure optical fiber based on the anti-resonant reflecting optical waveguide (ARROW) principle was used to develop a spectral absorption gas sensor. The ARROW fiber has an air core and an air cladding layer. An ARROW fiber with a length of 725 mm was used to construct a sensing system to detect acetylene gas. The gas was injected into the fiber from one end of the fiber. The transmission spectra were collected using an optical spectrum analyzer. The results indicate that the system can detect the gas of different concentrations and has the good system linearity. The response time of the system is about 200 s.

Keywords: Microstructure optical fiber, ARROW fiber, gas sensor, spectrum absorption, acetylene gas

Citation: Haihu YU, Yu ZHENG, Huiyong GUO, Beibei CAO, and Huifeng WEI, “Spectral Absorption Gas Sensor Based on Anti-Resonant Reflecting Optical Waveguide,” *Photonic Sensors*, 2014, 4(2): 128–131.

1. Introduction

Some microstructure optical fibers, such as hollow-core fibers, hollow-core photonic crystal fibers, have been used to develop new gas sensors of the spectral absorption type, in which the microstructure optical fibers are used as a new kind of gas chambers [1–3]. Compared to the conventional spectral absorption gas chambers, such microstructure optical fiber-based gas chambers remove the optical collimators, the high reflection mirrors, the focusing lens, etc., which is helpful to miniaturize the sensing system and to reduce the sensing noises. The optical fiber based on the anti-resonant reflecting optical waveguide (ARROW) principle is a kind of microstructure optical fibers, in which a Fabry-Perot cavity-like cladding layer is used to limit the light transmitting along the axial direction [4]. In this paper, an ARROW fiber was used to construct a sensing system to detect acetylene gas (C_2H_2). In this system, the C_2H_2 gas was injected into the fiber from one end of the fiber, and the transmission spectra were collected using an optical spectrum analyzer. The linearity of the system was calculated, and the response time was measured.

2. Experiment

The air-silica ARROW fiber was made by Yangtze Optical Fiber and Cable Company Ltd.,

Received: 5 January 2014 / Revised version: 20 February 2014

DOI: 10.1007/s13320-014-0178-z
Article type: Regular

China. The structure of the ARROW fiber is shown in Fig. 1. The fiber had an air fiber core and an air cladding layer. The diameter of the air core was 18μm, and that of the air cladding was 43 μm. The experimental setup is shown in Fig. 2. The length of the ARROW fiber was 725 mm. The ARROW fiber was coupled with multimode optical fibers using specially made flange plates. The end face intervals between the ARROW fiber and the multimode fibers were 100 μm. The gas to be detected would flow into the fiber from one end of the ARROW fiber. On each of the flange plates, there was a blowhole of 1 mm. The coupling flange plates were placed inside two miniature air chambers. The transmission spectra were collected using an optical spectrum analyzer (Yokogawa AQ6370B) with a stable wide bandwidth light source with the wavelength ranging from 1480 nm to 1580 nm. The stable bandwidth of the light source could cover the absorption area of C_2H_2 in the near infrared region. The resolution of the optical analyzer was set to the highest precision, i.e. 0.02 nm, and the sensitivity was set to High 2. High purity C_2H_2 was injected into the gas chamber by using a syringe of 5 ml to create different C_2H_2 concentrations. 5 ml C_2H_2 was injected into the air chamber each time. After the 7th injection, totally 35 ml C_2H_2 was injected. The data were recorded 10 min later after each injection.

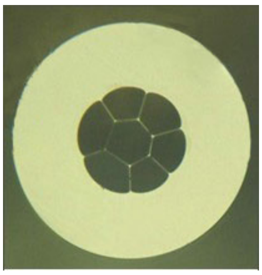

Fig. 1 SEM (scanning electron microscope) image of the ARROW fiber.

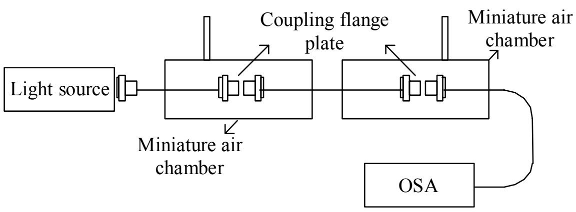

Fig. 2 Schematic diagram of the experimental setup.

3. Results

All the measured absorption spectra are shown in Fig. 3. There are two absorption areas from 1510 nm to 1540 nm, which is in accordance with the standard absorption spectrum of C_2H_2 in the HITRAN database. On the measured absorption spectra, the absorption peaks can be clearly revealed. The absorption peaks near 1520 nm are shown in Fig. 4. The baseline of the absorption was obtained by least-square smoothing curve processing, and the absorption curve was processed by Gaussian linear fitting [5].

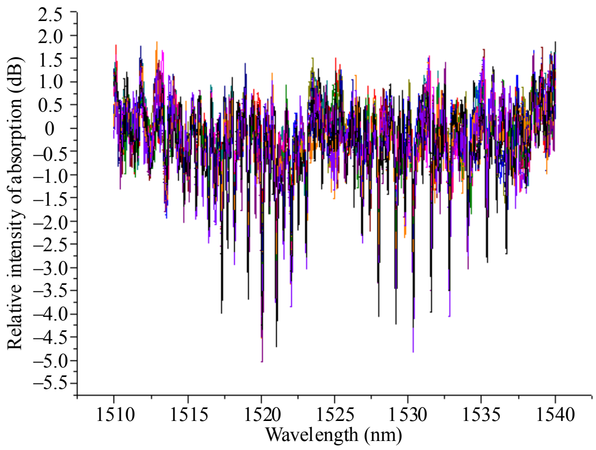

Fig. 3 Absorption spectra of C_2H_2.

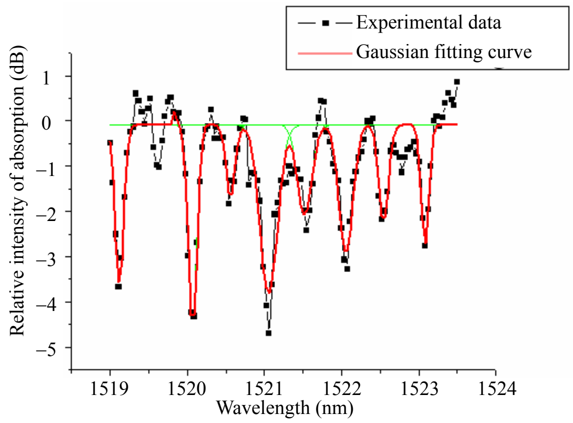

Fig. 4 Data demodulation and fitting.

Through the baseline calculating and Gaussian linear fitting, the C_2H_2 absorption spectra of different concentrations in Fig. 5(a) were changed to the curves in Fig. 5(b). After the linear fitting, some weak absorption peaks were ignored. As shown in Fig. 5(c), the strongest absorption peak is near

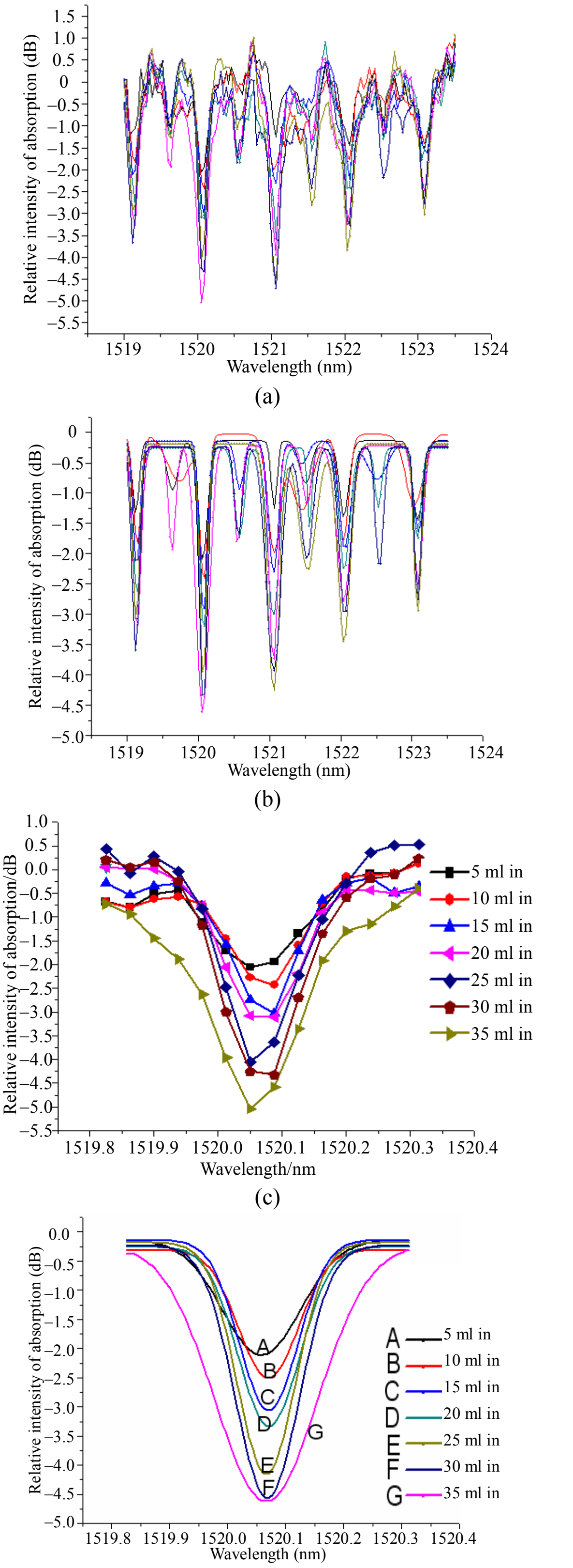

Fig. 5 Absorption curves and Gaussian linear fitting: (a) multimodal data, (b) multi-peak Gaussian fitting, (c) unimodal data, and (d) single-peak Gaussian fitting.

1520 nm and had an absorption intensity of 4.5 dB after the 7th injection. The absorption intensity change is shown in Fig. 6, corresponding to the data at 1520.05 nm shown in Fig. 5(c), which shows the good system linearity. From the Beer-Lambert's absorption law, the gas concentration is proportional to the absorbance ratio. This result indicates that this ARROW fiber-based sensing system can detect C_2H_2 of different concentrations.

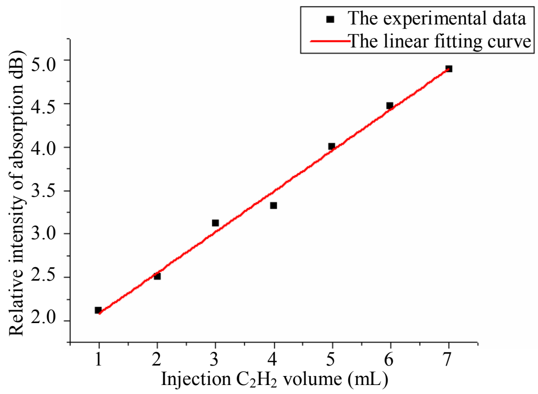

Fig. 6 Absorption intensity change.

High purity N_2 was aerated into the system for an hour to clean the system, and then 20 ml of high purity C_2H_2 was injected into the gas chamber. The data of the peak at 1520 nm were recorded. As shown in Fig. 7, the response time of the system was about 200 s. Considering that the length of the ARROW fiber was 725 mm, this response speed was rather high.

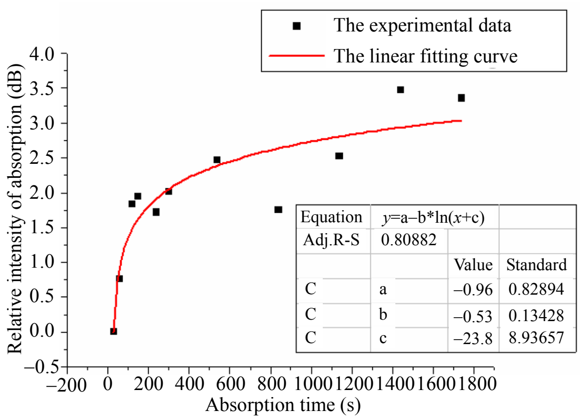

Fig. 7 Absorption time curve.

4. Conclusions

The ARROW fiber, with an air fiber core and an air cladding layer, has a large gas flow area, which makes it suitable to be used in the optical fiber gas sensor. The experimental results indicate that the system can detect acetylene gas of different concentrations and has the good system linearity. Considering that the length of the ARROW fiber is 725 mm, the response time, about 200 s, is relatively short. This experiment illustrates that the ARROW fiber is a promising microstructure optical fiber for the novel sensor development.

Acknowledgment

This work was supported by the Major Program of the National Natural Science Foundation of China (Grant No. 61290311).

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