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Distributed hydrogen determination with fiber-optic sensor

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Abstract

In order to develop a distributed hydrogen sensor, a fiber-optic evanescent-wave sensor was characterized using optical time domain reflectometry (OTDR). A silica core (Ø = 100 μm) fiber was coated with platinum-supported tungsten trioxide (Pt/WO_3) thin film as hydrogen sensitive cladding. The fiber-optic sensors of 15 cm length were spliced into a transmitting fiber cable. Light pulse of 20 ns emitted from laser diode at 1.3 μm wavelength was applied in OTDR measurement. The power loss of about 5 dB in backscattering light at spatial position of the sensor was observed with the exposure to 1 vol.% H_2/99 vol.% N_2. This indicates that the sensor has the potential for distributed measurement to detect the location of hydrogen leakage points along a fiber. The response to hydrogen increased as the fiber sensor length increases (62 dB/m). On the other hand, the OTDR measurement revealed 14 dB/m of propagation loss associated with the sensor device in air. Then, step index (SI) and quasi step index (QSI) multimode optical fiber sensors, which have different refractive index profile were prepared and optical responses were compared. Although the QSI type sensor showed lower sensitivity, light level was higher than that of SI type sensor. Finally, multipoint sensing using three sensors spliced in series was demonstrated.

Keywords: Hydrogen gas sensor; Tungsten trioxide; Optical fiber; Evanescent wave; Optical time domain reflectometry

1. Introduction

For the reduction of environmental impact associated with large utilization of fossil fuels, establishment of renewable and clean energy system [1] is very important. Much attention has been paid for hydrogen as a clean and inexhaustible energy source in recent years. Hydrogen can be easily obtained from water by the help of electrolysis or heat process. It turns into water upon burning and no global warming gas is produced. On the other hand, hydrogen has the wide explosion range (4–75%), small ignition energy (0.02 mJ), and large flame propagation velocity. In addition, it easily leaks out due to the smallest molecule size. The hazard of explosion related to hydrogen leakage is one of the major safety concerns. Therefore, continuous and reliable monitoring of hydrogen leakage would be needed for handling the vast amount of hydrogen gas safely. A great variety of hydrogen sensors using metal semiconductor [2], gas sensitive field effect transistor [3], thermoelectric device [4], optical method [5], etc. had been proposed and practically applied. They exhibited excellent sensitivity and are widely used. Most of them, however, can only sense the leakage at a particular spatial point. The sensor that measures the leakage in a wide area by a single device with low cost would be highly desirable. An optical fiber method utilizing the evanescent-wave absorption has potential to monitor a leakage over a wide area with ease. The sensor of this type has the ability to operate safely in explosive environment and the important characteristics, such as immunity to an electromagnetic noise,

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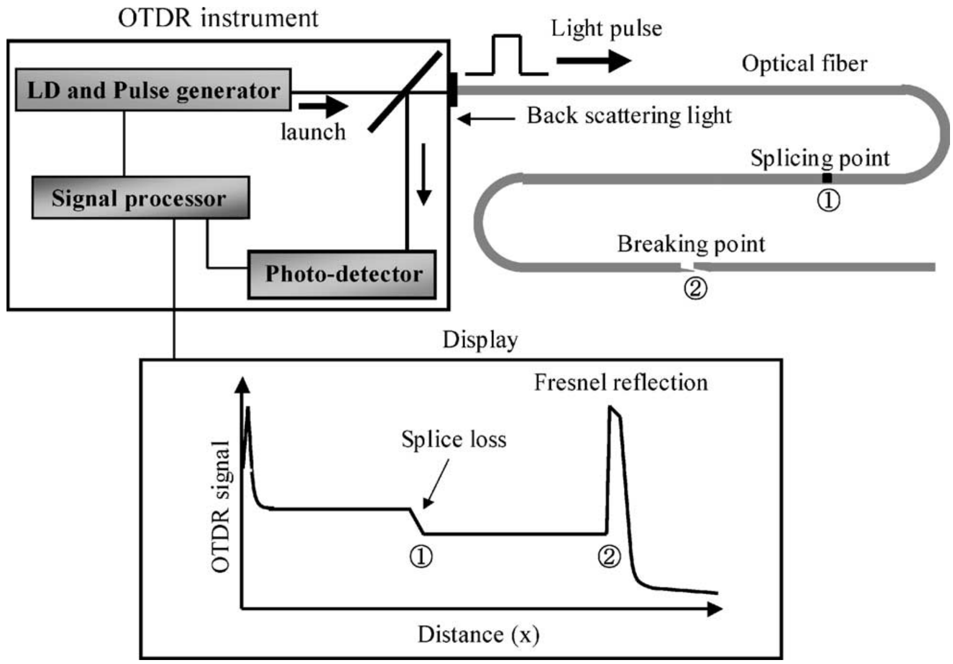

Fig. 1. Principle of OTDR measurement.

simplicity of design, and flexibility of its configuration. Furthermore, the location of the leakage point can be determined by optical time domain reflectometry (OTDR) [6]. This technique is widely exploited for the detection of fault location in fiber-optic telecommunication network. When entire length of fiber cable is sensing region, the distribution of a sensing object along the fiber may be determined by OTDR. This principle has been employed widely in temperature, strain, and chemical sensing [7,8]. The authors previously reported the fiber-optic hydrogen gas sensor using platinum-supported tungsten trioxide (Pt/WO_3) thin film cladding, which was deposited on a silica core by sol–gel method [9,10]. In present paper, this sensor was characterized and evaluated using OTDR technique for development of distributed hydrogen sensor.

2. Principle

2.1. Sensing mechanism

In the presence of hydrogen, WO_3 is reduced to tungsten bronze by the following reaction:

$$\frac{1}{2}xH_2 \rightarrow xH_{ad}$$

$$xH_{ad} + WO_3 \rightarrow H_xWO_3$$

Hydrogen molecules dissociates on platinum into hydrogen ad-atom (H_{ad}) even at room temperature. They react with WO_3 through the spillover process. The reaction accompanies remarkable change in color. In the case of the Pt/WO_3 thin film prepared by sol–gel method, the color changes from grayish semi-transparent to dark blue. It indicates that absorption in longer wavelength increases. In recent years, the application of this phenomenon to gasochromic windows has been studied intensively [11–14]. On the other hand, refractive index of the thin film also changes as a result of above reaction since each dielectric constant of WO_3 and H_xWO_3 has different value. Therefore, optical power propagating through the fiber core, which was coated with the Pt/WO_3 cladding was strongly influenced by the change in evanescent-field absorption coefficient and refractive index of the cladding. Then, hydrogen can be determined with the measurement of transmission loss of the fiber-optic sensor.

2.2. Optical time domain reflectometry (OTDR)

Optical time domain reflectometry (OTDR) is widely used for the detection of fault location in fiber-optic telecommunication network. Typical OTDR system is represented in Fig. 1. A short light pulse emitted from laser diode is launched into an optical fiber cable and propagates through the fiber by total reflection at the interface between core and cladding. However, a very small part of the light is scattered and guided back to the instrument. The back-scattered light is detected with high-speed photodiode in time domain. OTDR trace, as also shown in the display screen of Fig. 1, represents the reflectivity or propagation loss at a specific position along the fiber cable. The distance x from the OTDR instrument, i.e. horizontal axis, is calculated by following equation [15]:

$$x = \frac{c}{2n}\tau$$