Optik - International Journal for Light and Electron Optics 171 (2018) 781–785

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Highly sensitive liquid level sensor based on an optical fiber Michelson interferometer with core-offset structure

Pengfei Li[a], Haitao Yan[a,b,*], Haojie Zhang[b]

[a] College of Physics and Engineering, Henan University of Science & Technology, Key Laboratory of Photoelectric Functional Materials, Luoyang, 471003, China
[b] Puyang Institute of Opto-Electronic Industrial Technology, Puyang, Henan 457000, China

ARTICLE INFO

Keywords:
Optical fibers
Core-offset structure
Michelson interference
Liquid level measurement

ABSTRACT

A highly sensitive liquid level sensor based on an optical fiber Michelson interferometer with core-offset structure has been proposed and demonstrated. The sensor was fabricated by offset splicing a section of single-mode fiber (SMF) between another two SMFs and coated the reflection film at the end-face of the pigtail. This sensor was then used to measure liquid level and the dip of the measured reflection spectra caused by Michelson interference shifted obvious when the sensor is immersed in pure water. A good linear relationship between the liquid level and spectrum dip wavelength shift was detected ($R^2 = 0.9971$), while the dip intensity of the interference fringes fluctuates very little. The measured sensitivity up to 77 pm/mm was shown when the water level changed from 0 to 40 mm. In summary, this optical fiber sensing system would be appreciated in applications to liquid level measurement due to its good linearity, sensitivity, simple structure, and low cost.

1. Introduction

Liquid level sensors have been widely applied in the fields of fuel storage system, metallurgy [1], biochemistry [2], ground water and so on. Different types of sensors are available with different measuring principle for liquid level, including capacitive system liquid level sensor [3], magneto-strictive liquid level sensor [4], et al. However, the traditional liquid level sensors are very susceptible to the magnetic field, liquid properties, and explosive environment, et al. Optical fibers have been identified as promising liquid level sensors, as optical fibers are more reliable, safe, cost effective, miniature in size, large bandwidth, immunity to electromagnetic fields (IMFs), and potentials of working in harsh environments such as corrosive environments, high temperature than electric materials [5]. Moreover, optical fiber sensors can be fabricated by various methods, such as, fiber grating Bragg (FBG) [6], photonic crystal fiber (PCF) [7], taper fiber [8], thin core fiber [9], et al. Chang proposed a novel liquid level indicator using an etched chirped fiber Bragg grating and established the relationship between the liquid level (air-water interface position) and the grating period according to the overlapping spectrum peak wavelength [10]. Liu demonstrated an optical fiber liquid level sensor based on the silica tube structure, and found that the intensity increased linearly against immersing depth [11]. Dong designed a D-shaped fiber structure for liquid level sensing with a sensitivity of 191.89 pm/mm for the water level measurement [12]. These optical fiber sensors usually use HF, silica tube, PCF and D-shaped fiber, which leads to not only a great expense but also more difficult and dangerous.

---

[*] Corresponding author at: College of Physics and Engineering, Henan University of Science & Technology, Key Laboratory of Photoelectric Functional Materials, Luoyang, 471003, China.
E-mail address: yanhaitaoyht@163.com (H. Yan).

https://doi.org/10.1016/j.ijleo.2018.06.126
Received 27 April 2018; Received in revised form 21 June 2018; Accepted 27 June 2018

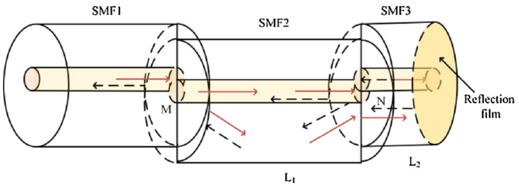

Fig. 1. Schematic diagram of the liquid level sensor structure.

In this paper, we proposed a new type of optical fiber Michelson interferometer liquid level sensor with core-offset structure, which was fabricated much more easily and cheaply. The cladding mode in the core-offset of Michelson interferometer was modulated by liquid at different level, and the high reflection film was used to reduce the effect of intensity loss of the light transmission. In addition, we also investigated comprehensively the mechanism and liquid level characteristics of the sensor.

2. Principles of the sensor

The liquid level sensor with the core-offset structure is fabricated by offset splicing a section of single-mode fiber (SMF) between another two SMFs and coated the reflection film at the end-face of the pigtail, as illustrated in Fig. 1. As there would be mode mismatch at the offset points (M), the light propagating through the SMF1 should be divided into two parts in the core mode and the cladding mode. At the offset point *N*, a part of light in the core mode and cladding mode from SMF2 will be coupled into SMF3, whilst a part of light in the cladding mode will be transferred from SMF2 to SMF3. On the other hand, the reflected light propagates twice through the offset points *M and N* in the presence of high reflection film, which can effectively increase light in the cladding mode in SMF2 and improve the interference fringe. The interference intensity and free spectral range (FSR) [13] can be expressedas:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \tag{1}$$

$$FSR = \frac{\lambda^2}{2(L_1 + L_2)\Delta n_{eff}} \tag{2}$$

where I_1 and I_2 are the intensity of light in the core mode and cladding mode, respectively. L_1 and L_2 are the lengths of the SMF2 and SMF3, respectively. Δn_{eff} is the difference of the effective refraction index between the core mode and the cladding mode in SMF2. $\Delta\varphi$ is the phase difference of the core and cladding modes after transmission along SMF2 and can be calculated as:

$$\Delta\varphi = \frac{4\pi(L_1 + L_2)\Delta n_{eff}}{\lambda} \tag{3}$$

λ is the wavelength of the propagating light. As the effective refraction index of the cladding will change with the increase in liquid level, the Eq. (3) can be modified to the following:

$$\Delta\varphi = \frac{4\pi(L_1 - L_{liquid} + L_2)(n_{eff}^{core} - n_{eff}^{clading1})}{\lambda} + \frac{4\pi(L_{liquid} + L_2)(n_{eff}^{core} - n_{eff}^{clading2})}{\lambda} \tag{4}$$

n_{eff}^{core} is the core effective refraction index; $n_{eff}^{clading1}$ and $n_{eff}^{clading2}$ are cladding effective refraction index in the air and liquid surrounding environment, respectively. L_{liquid} is the length of SMF2 immersed into the liquid. When the phase difference $\Delta\varphi$ equals to $(2m + 1)\pi$ $(m = 0, 1, 2....)$, the interference becomes minimized, and the wavelength λ can be calculated as

$$\lambda = \frac{4(L_1 - L_{liquid} + L_2)(n_{eff}^{core} - n_{eff}^{clading1})}{2m + 1} + \frac{4(L_{liquid} + L_2)(n_{eff}^{core} - n_{eff}^{clading2})}{2m + 1} \tag{5}$$

From Eq. (5), we can be known that the liquid level applied to the core-offset structure induces a proportional wavelength shift. Therefore, the wavelength shifts of a core-offset structure based on an optical fiber Michelson interferometer are proportional to the liquid level.

3. Sensing experiment and discussion

3.1. Sensor fabricated

Three sing-mode fibers (G652, 9/125 μm) and a polarization splicer (Fujikura FSM-100 P) are used to make the sensor. Firstly, two sing-mode fibers (SMF1 &SMF2) were stripped out the cladding, and adjusted the offset of two fibers manually after cleaning by the alcohol. The same splice operation was done for SMF2 and SMF3. Fig. 2 gives the orientation and displacement along the axis, as well as the microscope image of the offset points. Finally, the high reflection film was coated at the end-face of the SMF3. The length of SMF2 is ca. 40 mm, and that of SMF3 is ca. 2 mm. In this paper, three sensors with different offsets (8 μm, 9 μm and 10 μm) were prepared. The reflection spectra for these three samples in natural environment were obtained by using the Amplified Spontaneous Emission (ASE) and Optical Source Analysis (OSA).