# An optical liquid level sensor based on core-offset fusion splicing method using polarization-maintaining fiber

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**Abstract.** A simple liquid level sensor using a small piece of hydrofluoric acid (HF) etched polarization maintaining fiber (PMF), with SMF-PMF-SMF fiber structure based on Mach-Zehnder interference (MZI) mechanism is proposed. The core-offset fusion splicing method induced cladding modes interfere with the core mode. Moreover, the changing liquid level would influence the optical path difference of the MZI since the effective refractive indices of the air and the liquid is different. Both the variations of the wavelength shifts and power intensity attenuation corresponding to the liquid level can be obtained with a sensitivity of -0.4956nm/mm and 0.2204dB/mm, respectively.

## 1. Introduction

In recent year, more and more liquid level sensors based on fiber sensing principles occur with the developments of optical fiber sensing technologies. Compared to the traditional electric-based liquid level sensors, the optical fiber liquid level sensors benefit from immune to electromagnetic interference, easy to fabricate， resistance to erosion, high sensitivity and capability of remote sensing, adapt to work in harsh environments, and thus there are lots of considerable meanings to research the fiber-optic liquid level sensors[1,2]. For example, Sarfraz Khaliq proposed a fiber-optic liquid level sensor based on a long period grating (LPG) in 2001[3]. Tuan Guo reported a fiber Bragg grating (FBG) liquid level sensor based on a bending cantilever beam in 2005[4].These sensors possess advantages such as absolute response parameter and high sensitivities. However, they are limited to large temperature cross sensitivities and complex fabrication processes which require the expensive ultraviolet light laser, phase masks, etc. In the present study, we propose a brief approach, employing a small piece of hydrofluoric acid (HF) etched polarization maintaining fiber (PMF), with SMF-PMF-SMF fiber structure based on MZI for the sensor application of liquid level. The MZI is formed by inserting a PMF with a length of 25 mm between two single mode fibers (SMF-28). The sandwich structure is fabricated by arc discharge fusion splicing with a small core-offset of 4.5, so it is compact and robust. Since the core of the fusion splicing cross section is offset, the core mode and cladding modes of the PMF could be excited at the same time in the first fused splicing cross section and interference would occur in the second fusion splicing cross section. By detecting the intensity variations and wavelength shifts of the selected resonance peaks, the liquid level variations information can be obtained. It is also notable that the fabrication of the sensor is simple and cost effective, including only the fusion splicing and a brief HF acid etching processing. Experimental results indicate that the sensitivity of the sensor reaches up to -0.4956nm/mm and 0.2204dB/mm, respectively.

## 2. Experiments

The schematic diagram of the proposed liquid level sensor is shown in Fig.1. A gain-flattened Erbium-doped fiber amplified spontaneous emission (ASE) source with wavelength range of 1450 to 1650nm is used as the light source. And the polarization state of the output light from the ASE source is a non-polarized light. Thus a polarization controller (PC) is used to adjust the polarization states of the input light in order to obtain a high fringe visibility. The transmission spectrum is detected with an optical spectrum analyser (OSA, AQ6370, Japan). The maximum resolution of the OSA is 20 pm. A length of 25 mm PMF(PANDA, 1017-C, YOFC the birefringence index of the PMF is 7.7024 × 10-4.) is spliced between two conventional SMFs with mismatched core-offset fusion splicing to construct an all-fiber modal interferometer which we call in-fiber MZI. Both ends of the PMF are mismatch fusion spliced (using a commercial fusion splicer (Fujikura FSM-40S)) with the lead-in SMF1 and lead-out SMF2, respectively. The core offset size is about 4.5. The core and cladding diameters of the used SMF are 9 and 125, respectively. The PMF inserted between the two SMFs has the same core and cladding diameters as the SMF. Although the processing of the sensor head is only using the splicing method, it still needs carefully cleaving and fusion splicing procedures. The splicing loss could reduce the fringe visibility and transmission loss of the interference spectrum. After finished the fabrication of sensor head, we slowly etched the cladding of the PMF in 4% HF acid for~2h.

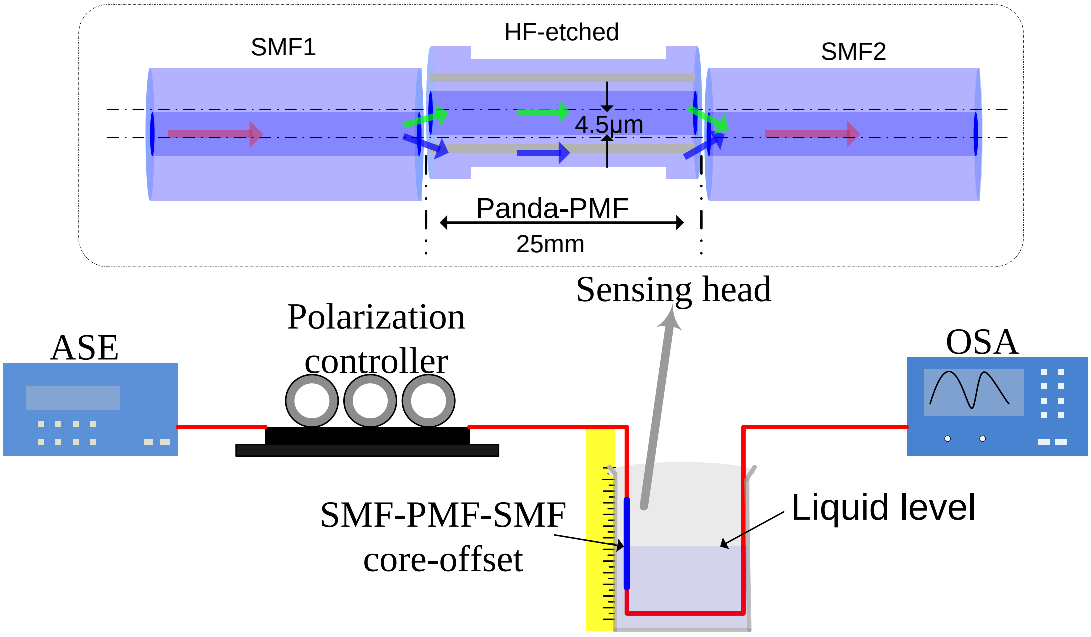


**Fig 1.** The schematic diagram of the proposed sensor.

## 3. Results and Discussion

It's well known that only one exited cladding mode is dominant in the interference between the core mode and the cladding modes by using the fast Fourier transform method [5-10]. The power intensity is mainly distributed in the core mode and a strong cladding mode. Other excited higher order cladding modes are weak. The main interference pattern is mainly formed by the interference of the dominant strong cladding mode with the core mode.

Fig.2 expresses the interference patterns of the proposed in-fiber MZI sensor corresponding to the liquid level variations with a liquid refractive index of 1.333. The dip wavelength has a blue shift of about 10nm as the liquid level increasing from 0 mm to 20 mm and the fringe visibility of the interference patterns is decreased gradually. The wavelength shifts and intensity attenuation of the resonant dip around 1536nm are researched with the liquid level increasing shown as the inset picture in Fig.2. The different colour spectrums represent the different liquid levels. The interference spectrum variations show a considerable dependence on the changing liquid level. Wavelength blue shift and intensity attenuation occurs with the increasing of the liquid level. Finally, the sensitivity of the fiber-optic liquid level sensor is calculated as -0.4956nm/mm and 0.2204dB/mm with a linear fitting method shown in Fig.3. The high sensitivity and correlation coefficient contribute to the great potential as a liquid level sensor in many applications.

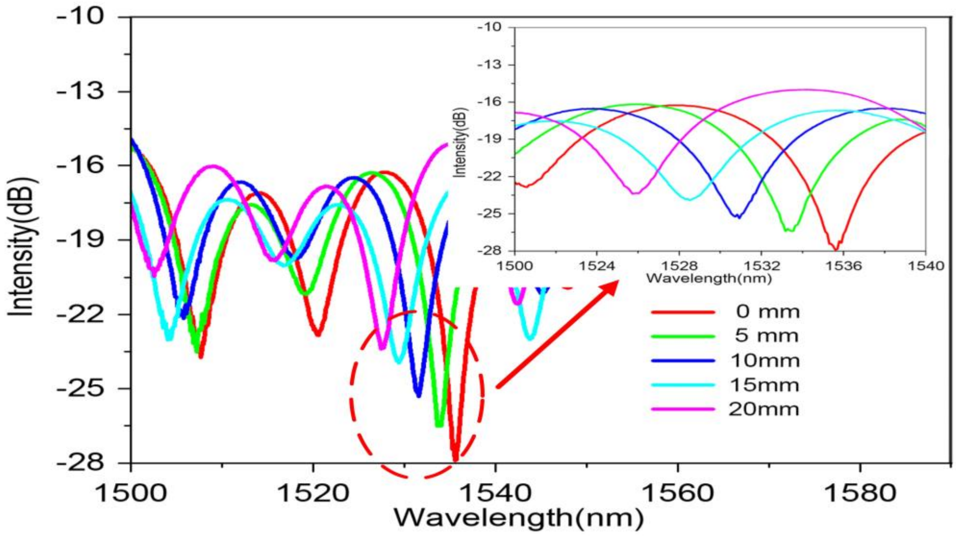


**Fig 2.** Transmission spectrums of the proposed liquid level sensor

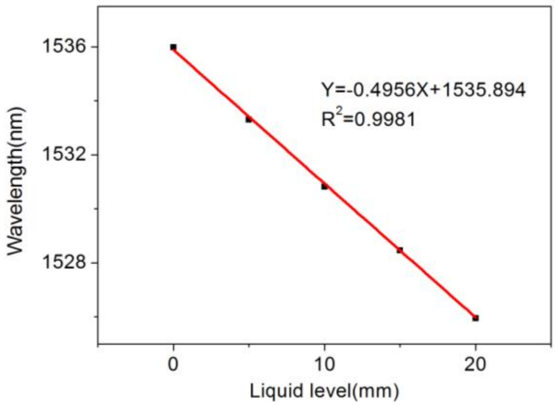


**Fig 3.** (a) Wavelength shifts

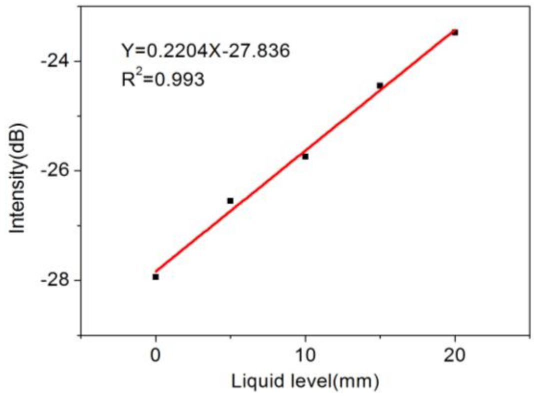


**Fig 3.** (b) Power intensity attenuation

## 4. Conclusion

In conclusion, a compact polarization-dependent in-fiber MZI based on core-offset fusion splicing is proposed and demonstrated experimentally and theoretically for the application of liquid level measuring. The MZI is fabricated by core-offset fusion splicing one section of PMF between two SMFs. The core mode and the dominant cladding modes resulted in interference in the transmission spectrum. Therefore, the liquid level variations on the MZI part can be measured by detecting the wavelength shifts and power intensity attenuation which depend on the ratio of the length of PMF immersed in the liquid and air. Experiment results show that high sensitivity of -0.4956nm/mm and 0.2204dB/mm are obtained within the measurement range of 0 to 20mm. Compared with other liquid level sensors, the alternative simple fabrication process and high sensitivity shows the proposed sensor has a promising for industrial liquid level measurement applications.

## 5. References

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