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Hybrid U-Shaped-Microbend SMF Evanescent Wave Sensor for River Water Quality Assessment: A Preliminary Study

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ABSTRACT

A hybrid U-shaped-microbend fiber optic evanescent wave sensor was developed by combining two types of bending structures on the optical communication single mode optical fiber (SMF28). To study the effect optical microbending on the output power, corrugated plates consisted of cylindrical structured surface with various distance between the glass rods of 6 cm, 12 cm and 18 cm were constructed. The macrobending effect was introduced by bending the SMF into two shapes, namely U-shaped and S-shaped. The bare SMF with various bending designs were immersed into numerous water sources from Sg. Simin, Sg. Batang Benar and Sg. Klang. The output demonstrated that Sg. Simin was the most polluted river, followed by Sg. Klang and Sg. Batang Benar using U-shaped microbend SMF with distance between glass rod of 6cm and 1310 nm laser source. This result showed an excellent agreement with water quality index (WQI) data released by the Department of Environment (DOE), Malaysia. Maximum optical output power was obtained by using Sg. Simin's water sample due to better light absorption from the evanescent waves by the pollutant particles, that avoided light leakage in comparison with less polluted water sources. The optimum sensing performance was successfully resulted by using U-shaped SMF due to its durability and uniform evanescent waves radiated from the cladding. In conclusion, the hybrid U-shaped-microbend SMF sensor based on evanescent waves propagation portrays an excellent potential to detect water pollution by monitoring the presence of pollutants around the fiber.

Keywords: *U-shaped; Macrobend; Microbend; Fiber optic sensor; Bending loss; Water quality; Pollutants*

INTRODUCTION

Water quality monitoring is a crucial fundamental for water environmental protection. It has an adverse impact on the sustainability of water resources [1]. River streams are important source to supply water in industrial, domestic uses and recreational activities. Urban rivers are mostly polluted due to the presence

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of many pollutants from various sources such as from markets, factories and hydrocarbon residuals from motor vehicles [2]. Types of pollutants can be categorized into four categories, such as dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids [3]. High BOD can be attributed to adequate partially treated sewage and effluent from agro-based and manufacturing industries. Due to awareness on this issue, the Department of Environment (DOE) of Malaysia plays an important role to determine the status of river water quality and to detect changes in river water quality [4]. The Water Quality Index (WQI) has been used to indicate the level of pollution and the corresponding suitability in terms of water uses according to the National Water Quality Standards for Malaysia (ANNEX) [5].

Recently, there are various types of sensors that have been developed for water quality monitoring such as electrochemical sensors, electronics sensors and biosensors [6-11]. Electronic nose (eNose) systems are appreciated for their portability, usability, and near real-time response [12]. Cinti *et. al* [13] had introduced a novel reagentless paper-based electrochemical phosphate sensor, manufactured with a simple and inexpensive approach. The development of a bacteria-based inhibition biosensor array for detection of different types of pollutions in water such as heavy metal ions (Zn^{2+}), pesticides (DDVP) and petro-chemicals (pentane), in water by one study [6] proves the important of sensor for the community's health [14].

Today, rapid development of optical sensors exhibits a bright potential in various sensing applications. One of the outstanding properties of optical sensors is due to its resistance to the electromagnetic interference [15]. In water quality monitoring, the optical sensors reacted with the pH level of the surrounding medium [16]. Note that the level of polluted water is determined based on its acidic level. The pH value is directly related with refractive index. The main principle of optical sensors was based on the changes of the refractive index of the sensing medium [17].

To enhance its sensing ability, many works have been performed such as by manipulating the fiber optics structure, coating with various types of materials such as metals, metal oxide, graphene oxide etc and doping with active materials namely Erbium and neodynium [17-23]. The usage of materials usually involved complicated technique and expensive equipments. Microbend and macrobend sensors had been proved able to enhance the sensing properties due to the presence of evanescent field in various region of the sensors [24-26]. Recently, macrobend sensors have been utilized for many applications such as accoustic vibration sensors, humidity sensors and displacement sensor [27-29]. Applications of microbend fiber optics commonly used in medical fields namely for perioperative pediatric vital signs monitoring, human identification and Apnea detection [30-32].

The main objective of this study is to investigate the river water quality around Nilai, Negeri Sembilan and Selangor based on an interaction between evanescent waves and pollutants by using standard telecommunications optical fiber (SMF28). Two types of macrobend design were employed, namely S-shaped and U-shaped in order to create the evanescent field. For the sensitivity amplification purpose, the macrobend SMF was combined with microbend structure by sandwiching the macrobend fiber with the corrugated plates. The effect of glass rods distances and types of light excitation wavelength had been studied. We strongly believed that this research output will contribute to the water security area in which the polluted level of river water able to be detected by using simple and less complicated optical sensor.

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EXPERIMENTAL

Figure 1 displays the design of hybrid macro-microbend SMF which was sandwiched with the cylindrical corrugated plate. Two shapes with diameter about 10cm were proposed, namely U-shaped SMF (Figure 1(a)) and S-shaped SMF (Figure 1(b)) to create the evanescent field. Figure 2 shows the photograph of the corrugated plates fabricated in our project. The corrugated surface with depth about 5 cm was created by glued the cylindrical rods on the plates. The properties of the corrugated plates were varied by varying the distance between cylindrical rods, *d* at 6 cm, 12 cm and 18 cm. The plates were made by acrylic material which is a type of transparent plastic made of polymethyl methacrylateacrylic.

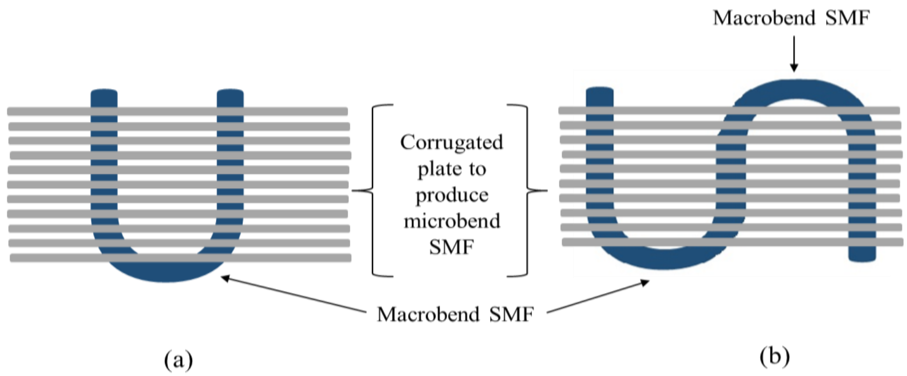

Figure 1: Design of hybrid macro-microbend SMF which was sandwiched with the cylindrical corrugated plate (a) U-shaped (b) S-shaped

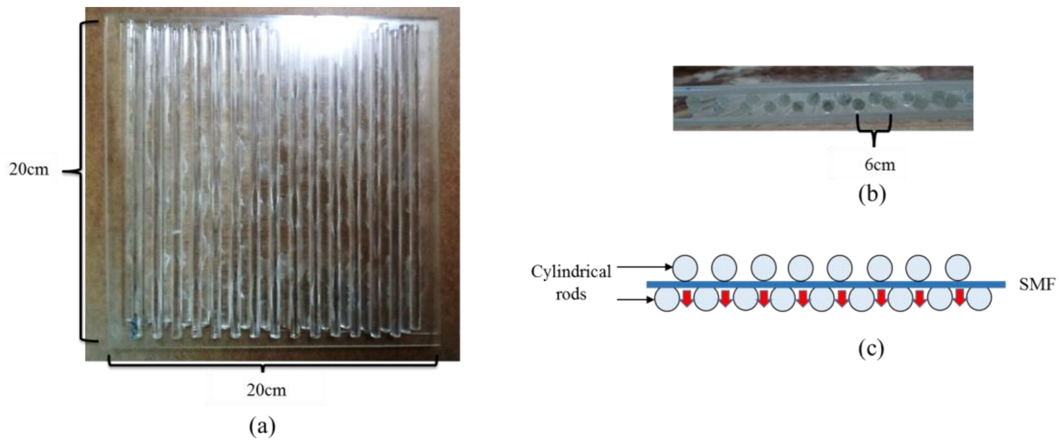

Figure 2: Corrugated plates made by acrylic material (a) Upper view (b) Side view (c). Illustration SMF which was sandwiched by the cylindrical rod producing the microbend fiber

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Table 1: Water quality index (WQI) data by Department of Environment based to the National Water Quality Standards for Malaysia (ANNEX) [5]

River	Water Quality Index	Category	Class
Sg. Klang, Selangor	63	Slightly polluted	3
Sg. Simin, Rantau, N. Sembilan	80	Slightly polluted	2
Sg. Batang Benar, Nilai, N. Sembilan	89	Clean	2

For the verification purpose, the sensing properties of our proposed sensor was compared with the water quality index (WQI) data recorded by the Department of Environment in 2016 as listed in Table 1. According to the WQI data; among the three rivers, Sg. Simin was the most polluted river. Meanwhile, Sg. Klang was slightly polluted in term of its quality [5]. Sg. Batang Benar is the cleanest river among these rivers. Next, the river water sample was placed into the water tank with dimension of 21.7 cm width, 2.2 cm height and 31.5 cm length. To assess the polluted levels of the river water quality, our proposed sensor was immersed into the water tank with various sample of water as illustrated in Figure 3. Two different laser excitations with wavelength of λ=1310 nm and λ=1550 nm were transmitted along the U-shaped and S-shaped-microbend SMF. The optical power output was recorded by using an optical power meter. The effect of microbend was investigated by varying the distance between cylindrical rods of the corrugated plates. The smaller the microbending radius, the greater amount of light was radiated away from the bend fiber resulted stronger evanescent waves. Note that, stronger evanescent wave will produce better sensitivity of the sensor. Table 2 lists the important parameters which had been studied in this research.

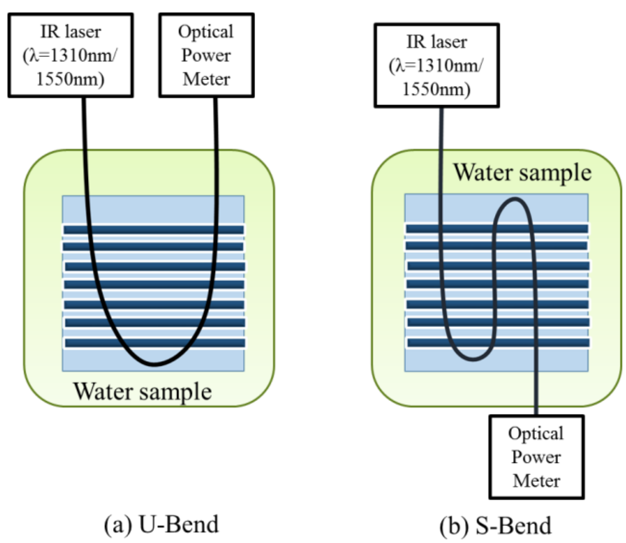

Figure 3: Experimental setup of hybrid macro-microbend SMF evanescent wave sensor for the river water quality assessment

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Table 1: Parameters of hybrid macro-microbend sensor

Parameter	Value
Laser excitation wavelength	1310 nm, 1550 nm
Distance between glass rods (microbend)	6 cm, 12 cm, 18 cm
Size of SMF	9/125 µm
Design of macrobend SMF	U-bend, S-bend
River water sample	Sg. Simin, Sg. Batang Besar, Sg. Klang

RESULTS AND DISCUSSION

Figure 4 displays the optical output power when hybrid U-shaped microbend SMF had been immersed into various types of the river samples. We found that Sg. Simin displays maximum output power when distances between glass rods were varied at d=6 cm, 12 cm and 18 cm in comparison with Sg. Batang Benar and Sg. Klang. Using this water sample, the power values were decreased about 14.80 % and 4.80 % as value d was increased from 6 cm to 12 cm and from 12 cm to 18 cm respectively. For Sg. Klang water sample, the decrement percentages were about 8.50 % and 1.20 %. Only small differences were resulted as the sample was changed to Sg. Batang Benar in which the percentage of power drop were obtained about 0.87 % and 0.55 %. Note that the U-bend SMF using 1310 nm of laser excitation wavelength exhibits an excellent agreement with the WQI data released by DOE.

Greater output power by Sg. Simin explains the presence of more pollutants because only small portion of light was radiated away from the SMF due to light leakage. This condition caused large part of light was absorbed by the pollutants resulted higher output power. Apparent changes of output can be clearly observed when d=6 cm. At this respective value of d, the output power dropped about 11.06 % as the sample was changed from Sg. Simin to Sg. Klang. About 19.62 % power was decreased when the sample was replaced from Sg. Simin to Sg. Batang Benar. The same pattern can be observed as d were increased to 12 cm and 18 cm. Obviously, the usage of smaller value of d resulted smaller bending radius. Consequently, greater amount of evanescent waves able to be propagated in comparison with larger radius bending radius of the fiber. At d=6 cm, the sensor shows excellence performance in which it portrays better sensitivity and outstanding selectivity.

It is noteworthy to mention that the sensitivity of sensor was determined based on the changes amount of optical output power as different level of polluted water was used. The greater the changes, the better the sensitivity of our proposed sensor. As the excitation wavelength was replaced with λ=1550 nm, the results did not synchronize with data from DOE which indicated the instability of the sensor. Note that the sensitivity of the optical sensor is highly influenced by the value of excitation wavelength, which is directly affected the amount of penetration depth. The greater the penetration depth, the better the sensitivity and selectivity of the sensor [33, 34].

SCIENCE LETTERS

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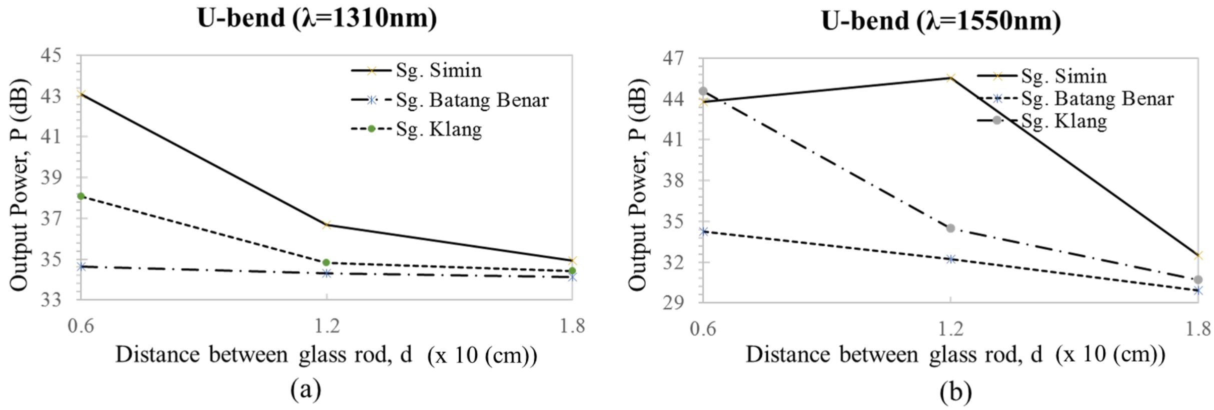

Figure 4: Optical power output using U-shaped-microbend SMF as laser excitation wavelengths were varied (a) λ=1310 nm (b) λ=1550 nm

Figure 5 shows the optical power output when the S-bend SMF was used as medium of light transmission. Apparently, the results did not show consistence output. This indicates that the U-bend SMF was more stable and better sensitive than the S-bend. The presence of pollutant particles around the U-shaped-microbend SMF were an important indicator to assess river water quality. It is noteworthy to mention that the main principle of optical sensor is based on the detection refractive index of the surrounding medium. The presence of large amount of pollutant particles will cause only small portion of light to be radiated away from the fiber, in which results higher optical power output as illustrated in Fig. 6(a). As the river sample was replaced with Sg. Klang, the optical power output was slightly decreased due to part of light was radiated away from the SMF because the amount of pollutants was decreased (Fig. 6(b)). Fig. 6(c) explains the phenomenon occurred as the SMF was immersed into Sg. Batang Benar. As stated by DOE, among these three rivers, Sg. Batang Benar was the cleanest river which was indicated by the less presence of pollutants in the water. This conditions can be explained by considering that large amount of light was radiated away from the U-shaped-microbend SMF resulting low optical power output.

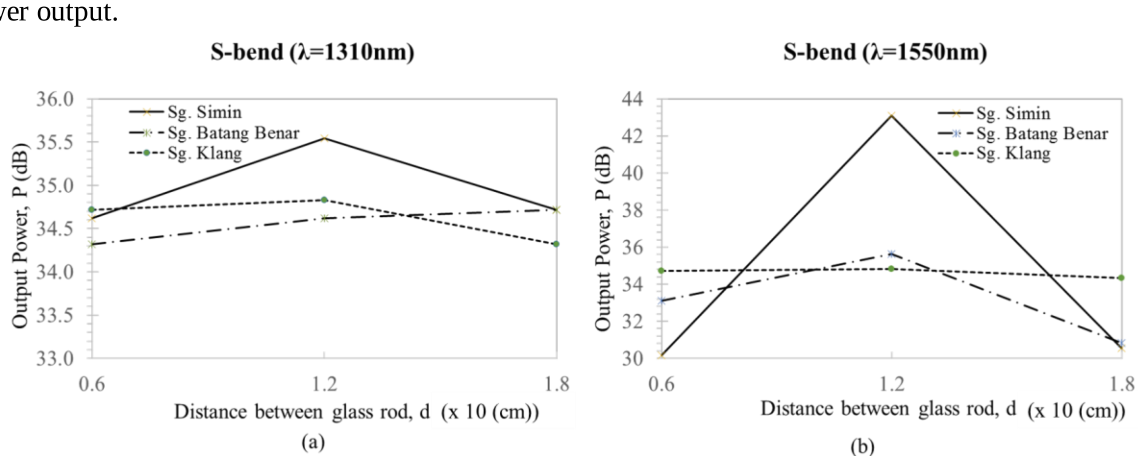

Figure 5: Optical power output using S-shaped-microbend SMF as laser excitation wavelengths were varied (a) λ=1310nm (b) λ=1550nm

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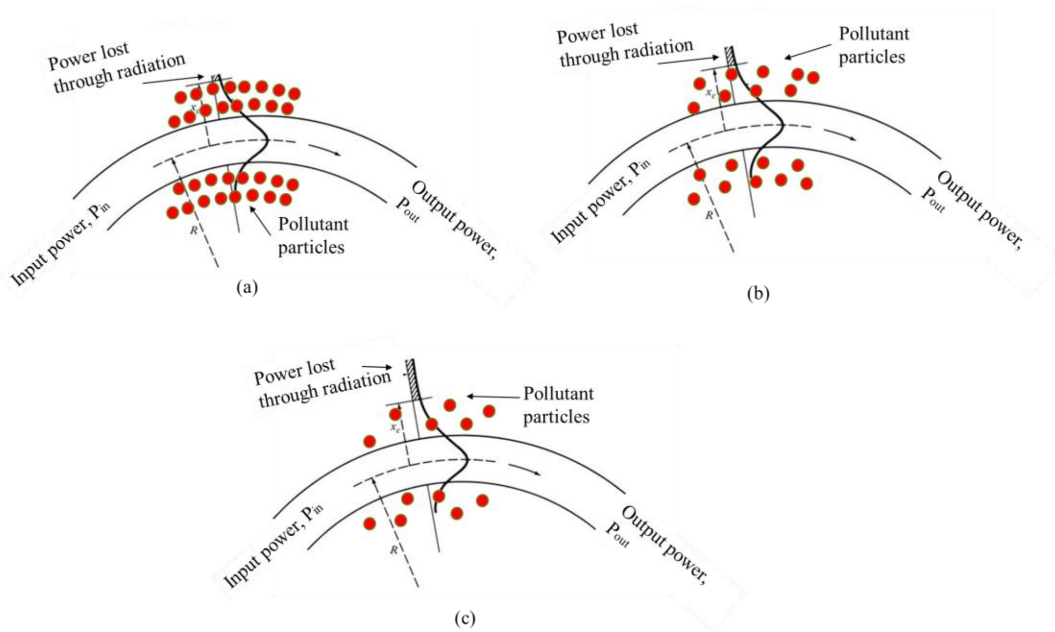

Figure 6: The effect of pollutant particles on the values of optical power output for various river water samples (a) S. Simin (b) Sg. Klang (c) Sg. Batang Benar

CONCLUSIONS

In conclusions, the U-shaped microbend SMF exhibits better potential for water quality assessment than the S-shaped SMF. By considering the amount of output power changes, small microbend radius by employing cylindrical rod corrugated plates with the distance of rod was maintained at 6 cm resulted excellence sensitivity and selectivity characteristics of the sensor. For future work, our proposed U-shaped microbend SMF will be coated with nanomaterials such as metal nanoparticles and metal oxides to enhance the evanescent field strength based on surface plasmon resonance effect.

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