Formaldehyde sensing using micro-loop resonator

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Preface: The 2nd International Conference on Physical Instrumentation and Advanced Materials 2nd ICPIAM 2019

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Preface: The 2nd International Conference on Physical Instrumentation and Advanced Materials

2nd ICPIAM 2019

This 2nd International Conference on Physical Instrumentation and Advanced Materials – The 2nd ICPIAM was held on Tuesday 22nd October 2010 in the City of Heroes, Surabaya, Indonesia, where one top University in Indonesia, Universitas Airlangga is located. The first ICPIAM was held at the same city in 2016. The ICPIAM conferences are aiming to confer and share all the innovation on recent developments and trends in engineering and scientist for research communities. This conference series provided an international forum to present, discuss, and exchange innovative ideas and recent developments in the field of instrumentation, computation, and advanced materials in medical application. The 2nd ICPIAM hosted contributions on image processing, some photonics and optical techniques, nano-materials and nanostructure, smart materials and structures, as well as advanced manufacturing techniques. On this occasion, 2 plenary speakers and 2 keynote speakers as well as 5 invited speakers had delivered their outstanding research works in various fields of instrumentation, computation, and material science. There were 105 oral presentations in total by participants which brought great opportunity to share research works knowledge among others graciously. Efforts taken by peer reviewers contributed to improve the quality of papers provided constructive critical comments; improvements and corrections to the authors are gratefully appreciated. We are very grateful to all advisory committee, session chairs, student volunteers and administrative assistants from the university management who selflessly contributed to the success of this conference. Also, we are thankful to all the authors who submitted papers, because of which the conference became a story of success. It was the quality of their presentations and their passion to communicate with the other participants that really made this conference series a grant success. Also, we want to say our thank full for Universitas Jember who will be able to hold the 3rd ICPIAM Conference in 2021 as our co-partner in the conference series in Jember.

Last but not the least, we thank full for enormous support of AIP Conference for supporting us in every step of our journey toward success. Their support was not only the rigorous guidance but also an inspiration for organizers.

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Formaldehyde Sensing Using Micro-Loop Resonator

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Abstract. Formaldehyde (CH2O) liquid sensor has been successfully fabricated using micro-loop resonator (MLR) based on whispering gallery mode (WGM) concept. An excellent sensing response towards formaldehyde liquid concentrations level ranging from 0% to 5% was observed. It is because of the changeable effective index and surface absorption phenomenon which lead to different light characteristic inside the MLR. The output power reduced linearly from -18.9 dBm to -36.2.dBm as the concentration increases. The sensitivity obtained was 3.6561 dBm/% with linearity of 99.1% and resolution of 0.0207%. The proposed sensor has simplicity, easy fabrication, better resolution and low cost. This application is essential in monitoring toxic gases and human health.

INTRODUCTION

Formaldehyde (CH2O) is a carcinogenic volatile organic compound (VOC) which is used as a regent for adhesives such as phenol-formaldehyde (PF) resins and urea-formaldehyde (UF) [1]. Besides, it also exhibit as a colourless and pungent-smelling gas. Formaldehyde as a multifunctional chemical has been widely used in various product manufacturing process such as plastics and resins. Unfortunately, it has also been illegitimately used as a preservative in vegetables, meat, fish and fruits to adjourn the spoilage process for their fresh appearance [2]. It lead to irritating health effect such as coughing, abdominal pain, vomiting, coma, renal injury, nausea, breathing difficulties and sneezing [3][4]. Concentrations level as low as 1 to 3 ppm levels would cause bad effect to the throat, eyes and nose and could cause fatality if concentrations levels more than 15 ppm. Thus, scientific research on formaldehyde detection has significant importance as environmental awareness increased [5].

Micro-loop resonator (MLR) comprises of a single mode fiber and directional coupler has been introduced in 1982. The overlapping portion is maintained by electrostatic and the Van der Waals force. The efficiency of the MLR could be achieved by ensuring slow variation during the tapering procedure [6]. MLR has superiority in terms of anti-interference, high resolution, quick response, stable measurement, stable chemical properties, large fractions of evanescent waves, low transmission loss, small size and easy preparation [7]. These prominent factors increase the sensing performances due to excellent interaction between the waveguides and surrounding analyte. Furthermore, whispering gallery mode (WGM) on the resonator cavity could improve the resonation quality based on Q-factor of the resonated wavelength.

Recently, numerous formaldehyde sensing technique has been introduced by researcher such as cataluminense [8], spectroscopy [9], bio-sniffer [10] and chemiresistor [11]. These techniques required complicated manufacturing process, high cost, huge equipment, high-temperature operation and while for fiber coated nanomaterials required highly thorough handling attention during the synthesis process [12][13]. Therefore, a low cost, workable and

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simple formaldehyde liquid sensing has been proposed in this work. It has been realized by manually twist the tapered fiber into a self-touching loop under an optical microscope and exposed it to the formaldehyde liquid.

EXPERIMENTAL DETAILS AND SENSING MECHANISM

The waist diameter of single-mode fiber (SMF-28, Corning) was reduced into 7 µm by using a flame brushing technique. It has an approximately around 8 mm of tapering length [14]. The MLR was formed by manually circled the microfiber into a 300 µm self-touching loop. The coupling would occur when the electrostatic and Van Der Waals force causing surface attraction. It prevent the microfiber from straighten out due to the elastic forces [15]. The loop and waist diameter were identified using the microscope with magnification of 20X. Figure 1 depicted the sample of MLR utilized throughout the sensing experiment.

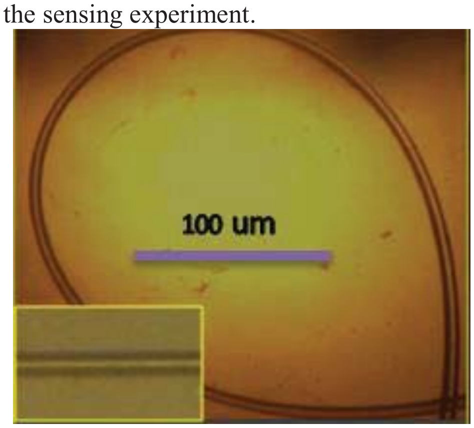

FIGURE 1. Image of the MLR captured using microscope

The MLR was positioned inside the controlled chamber (with dimension of 22 x 12 x 12 cm) as illustrated in Fig. 2. An Amplified Spontaneous Emission (ASE) operating within a range of 1530nm – 1560nm was launched to the input port of the MLR while the output port was connected to an optical spectrum analyzer (OSA) (Anritsu: MS9710C) for output power recording in dBm. Subsequently, the formaldehyde liquid was dropped evenly onto the MLR from concentration level 0% to 5% and the output power variation was monitored. The recorded data were collected few times so that the reproducibility of the proposed sensor can be ensured.

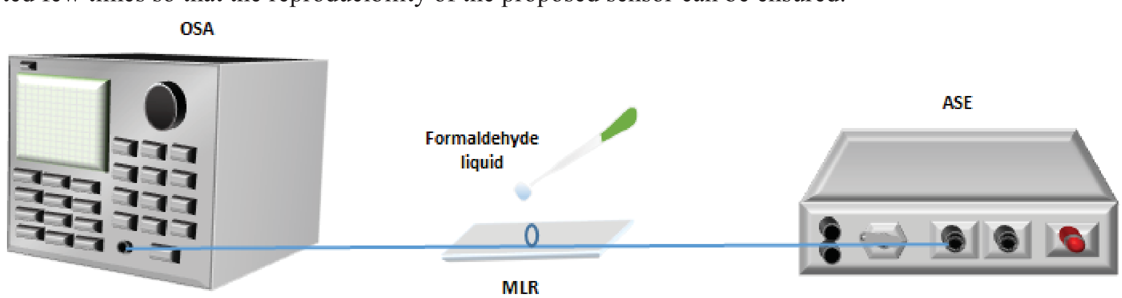

FIGURE 2. Setup for the sensing experiment

The amount of molecules, which were absorbed by the surface of MLR's cladding increases as concentration level is increased from 0% to 5%. This replaces the air medium with other analyte which increase the refractive index (RI) of the cladding. Refractive and evanescent field is correlated each other to determine the sensing performances. As the liquid concentrations increases, greater amount of evanescent wave appeared around the sensing region. This modulate the output light intensity with respect to the concentration level. More scattering losses occurrence were observed which lead to the increment of the transmission losses due to the surface absorption [16][17]. In case of MLR, reduction of light transmission become more significant due to resonator loss which was absent in the straight microfiber. This is because when the light oscillates in the MLR, it magnifies the loss and reduces the output power. Therefore, the reduction of transmitted light significantly changes output power, which in turn improves the sensitivity of the proposed sensor [18][19].

RESULT AND DISCUSSION

WGM of the MLR in 5% concentrations of formaldehyde is shown in Fig. 4. The data was recorded in the wavelength range of 1550nm to 1560nm because the existence of sharp and clear resonation around the region. The resonating wavelength changes as the different formaldehyde liquid concentrations level increase. Sharp resonance dip can be observed for the 5% concentration level. A high quality resonator was found where the Q-factor was $>10^5$ for all concentrations. The Q-factor was calculated based on the formula of $\lambda/\Delta\lambda$. Here, λ is the resonance wavelength while $\Delta\lambda$ is a Full-Width-Half-Maximum (FWHM) linewidth of the resonant wavelength. It increased from 7.774×10^5 to 7.99×10^5 when the concentration level raised from 0% to 5% as shown in Fig. 5. The increasing Q-factor because resonating behavior would change if any change to outer environments of the MLR [7]. Any environment changes would varies the refractive index as the liquid level concentrations increase [5].

The trendline graph of the proposed sensor towards formaldehyde liquid concentrations level is shown in Fig. 6**.** The output power reduced proportionally as the concentrations level increase. As aforementioned, the RI of the MLR increases as the concentrations level increases due to the surface absorption of water molecules [18]. In addition, light oscillation phenomenon inside the MLR magnifies the loss and increase the sensitivity. Eventually the intensity of guided light inside the MLR steadily reduced as the liquid concentrations changed [19]. Thus, MLR produced more stable transmitted output power as compared to the SmF especially at 0%, 1% and 3% concentration level in previous work [20].

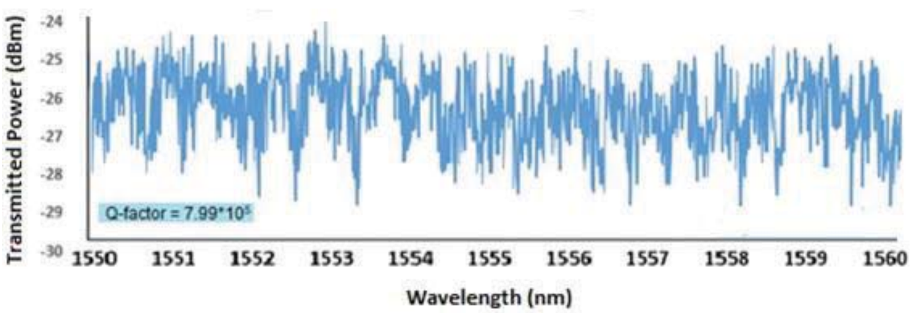

FIGURE 4. Whispering Gallery Mode (WGM) at 5% liquid concentrations level

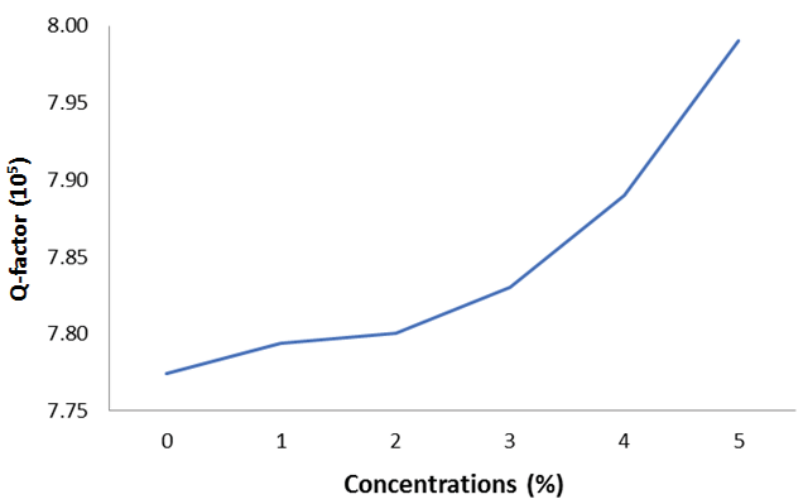

FIGURE 5. Q-factor when the formaldehyde liquid concentration increase

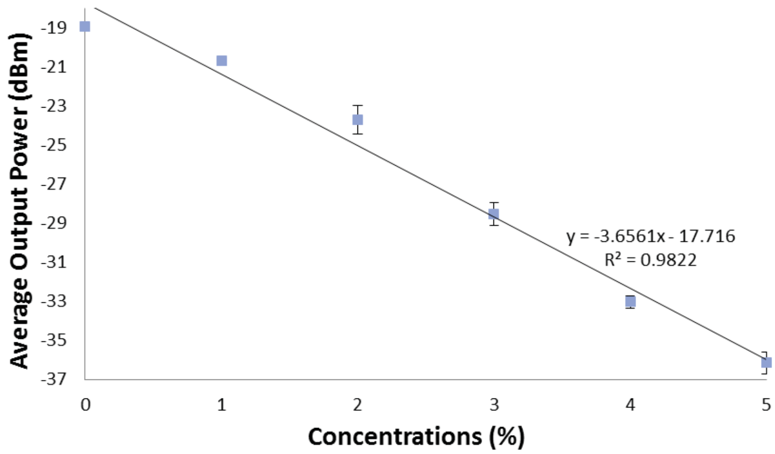

FIGURE 6. The trend line response towards formaldehyde liquid concentration level

Table 1 summarizes the sensing performances of the proposed sensor. The linearity and the sensitivity of the MLR is 99.1% and 3.6561 dBm/% respectively. A low standard deviation with 0.0757dBm leads to a small resolution of 0.0207%. It is also found that the Q-factor increases as the concentration level increases because of the variation of effective refractive index.

TABLE 1. Sensing performance of the formaldehyde liquid sensor

Parameters	MLR
Linearity (%)	99.10%
Sensitivity (dBm/%)	3.6561
Standard Deviation (dBm)	0.0757
Resolution (%)	0.0207

CONCLUSION

A workable formaldehyde sensor has been demonstrated using micro-loop resonator. The MLR produce significant sensing performances in terms of sensitivity, linearity, resolution and standard deviation when exposed to the variation concentration levels of the formaldehyde liquid. This is due to the magnified power loss of the MLR which improve the sensing performance. It has benefit of reducing the hassle during the fabrication process due to the absent of coating procedure. The results show the better sensitivity was observed. Besides, it has numbers of advantages in term of sensitivity, simplicity, small size and low cost. This adhere a requirement in several applications such as human health and toxic gases monitoring.

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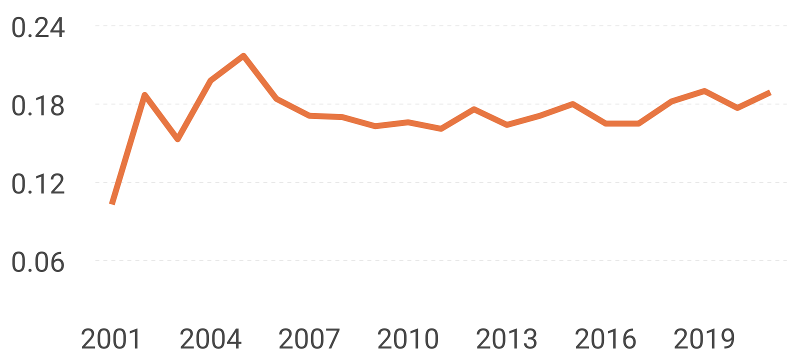

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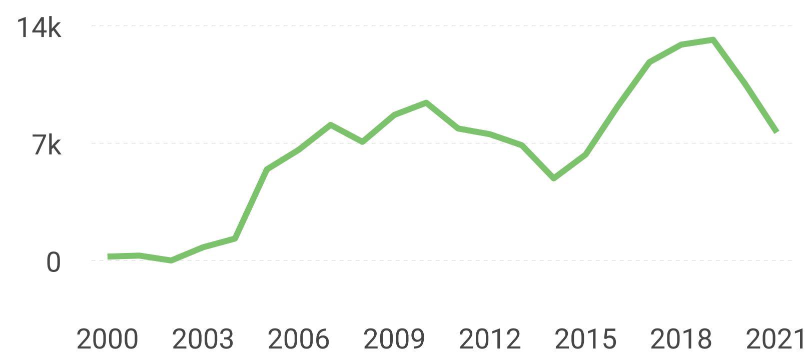

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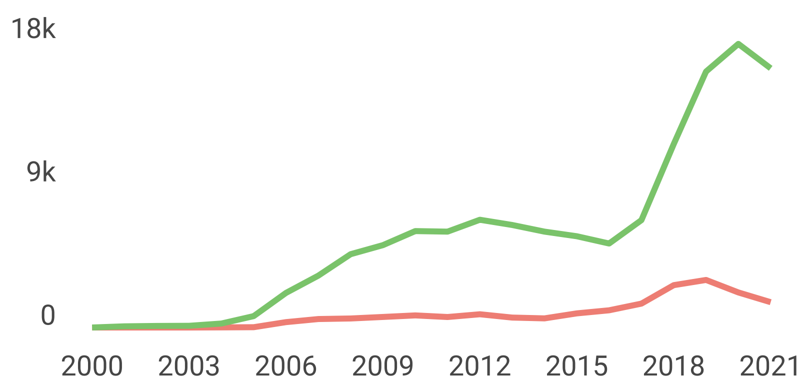

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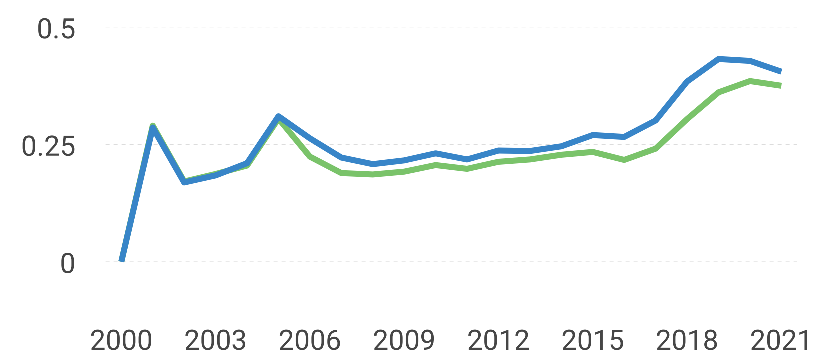

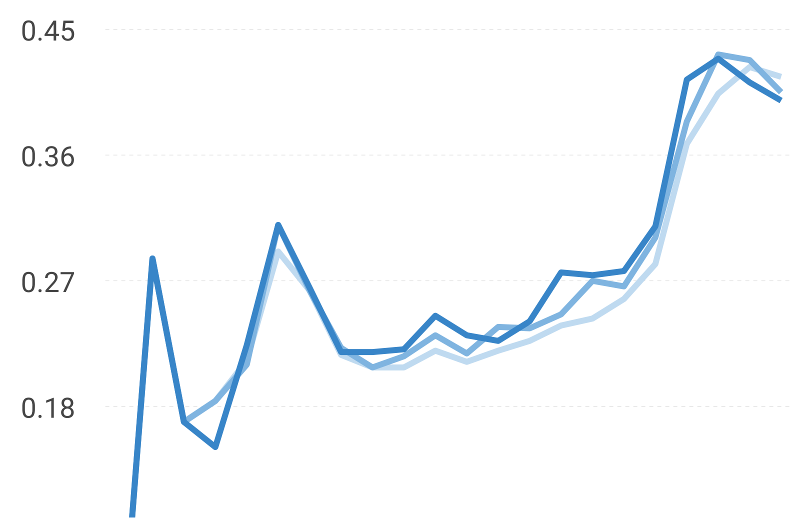

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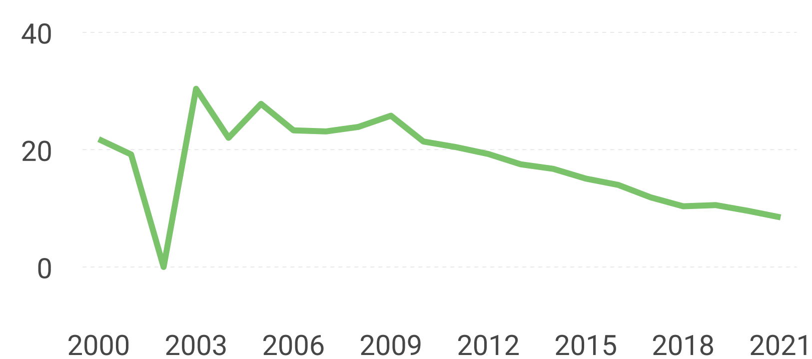

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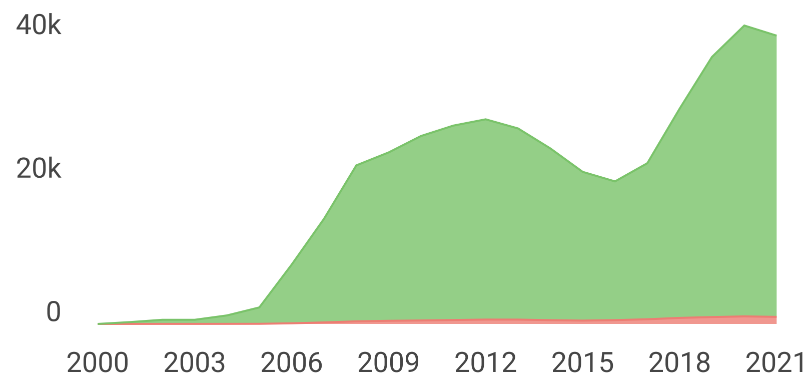

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