Edible oils adulteration analysis by fiber optic multimode displacement sensor

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A fiber optic sensor has been developed to detect the adulteration in edible oil, particularly coconut oil. In this paper, the sensing mechanism uses MMF-MMF based on displacement sensors by employing the lateral offset method. The distance offset set were 4.42 μm, 7.49 μm, and 7.83 μm. The refractive index for pure coconut oil, paraffin oil, and palm oil are found to be 1.4481, 1.4585, and 1.4634 respectively. The sensitivity of each sensor was determined by referring to the highest offset distance of each fiber. Upon completion, the highest sensitivity was observed for 7.83 μm lateral offset distance which is 0.406 dBm/mol for palm oil detection and 0.437 dBm/mol for paraffin oil detection. The experimental results proved that the larger the offset distance, the higher the sensitivity of the fiber sensor.

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1. Introduction

Recently, the use of fiber optic has garnered considerable attention in sensor systems due to numerous advantages it offers due to its small and thin size, biological inertness in nature, and safety due to the absence of electric current at the sensing point [1]–[3]. Fiber optic is in high demand in wide applications such as medical, science, telecommunication networking, automotive, and other various industry [4]. Moreover, fiber optic also can be used as a sensor to measure strain, temperature, pressure, concentration, and different quantities by modifying the fiber optic itself [5]–[8].

Over the past two decades, fiber optic sensors have been used for contamination detection in food products [9]–[11]. Edible oil such as coconut oil plays an important role in people's lives, and it is commonly used in tropical areas. Moreover, coconut oil is not only used for cooking but also medical and industrial purposes. Since pure coconut oil is well known for its smell, flavour, antioxidants, medium-chain fatty acids, vitamins, and is easily digestible, it is very much prone to adulteration. The most found adulterants are paraffin oil and palm oil. Petroleum, paraffin, paraffin oil, and propylene glycol are all derivatives of mineral oil that dissolve the natural oil of the skin, and hence skin becomes more dehydrated [12]–[14]. In addition, liquid paraffin is indigestible and prolonged, and extremely hazardous to human health as it can ultimately lead to several health problems such as liver disorders or even cancer [15], [16]. Monitoring of the quality of cooking oil is essential at the distribution point for the prevention of adulteration, in which the purity of coconut oil can be preserved.

Gas chromatography [17], dielectric technique [18], and electronic nose technology [19] are conventional employs for analysing adulterants in oil. Gas chromatography is more efficient and sensitive, and it can measure multiple components. However, is loss-prevention detection, which is costly and complicated. The electronic nose method is non-destructive and simple yet is predominantly used to detect some volatile substances. Therefore, in this paper, a multimode fiber optic sensor based on the lateral offset displacement method was proposed for the first time for the examination of adulteration of edible oils, which focuses on the detection of paraffin and palm oil in coconut oil. In the structure of the proposed device, a simple technique of field intensity measurement was used that solved the mentioned conventional sensor problems.

2. Methodology

A few samples of edible oil products comprising pure coconut oil added with paraffin and palm oils were used for the adulterant's measurement. The objective was to evaluate the effect of adding paraffin and palm oils as adulterants to the pure coconut's oils purity.

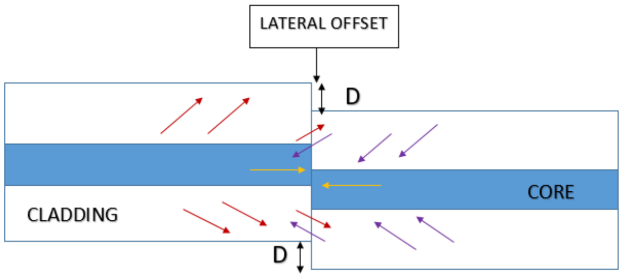

Fig. 1. Schematic Diagram of Lateral Offset

The sensor's probe was developed based on lateral displacement as shown in Fig. 1. In this paper, a fusion-splicing method is used in developing and designing the fiber sensor. Several types of structure can be used in the fusion-splicing method including waist enlargement structure and lateral offset structure. In this research, the lateral offset or lateral misalignment, which is the largest contributor to the total loss in a fiber connection [3], [20], was employed to fabricate the sensor' probe. Using this method, the end surfaces of the fiber optic cable are positioned adjacent or abutting each other or abutting each other with their longitudinal axes parallel [21]. Lateral offset is the failure of the cross-sections of the two fiber cores to perfectly overlap that can cause power loss while transmitting the light inside the fiber. The connections imperfection will have caused the loss in light transmission and commonly manipulated as the sensing region in sensor design. The light from a lead-in fiber, in particular, will be spread into the core and cladding of the sensing fiber, and thus detection is established through the interaction of the cladding modes with the surrounding material [12].

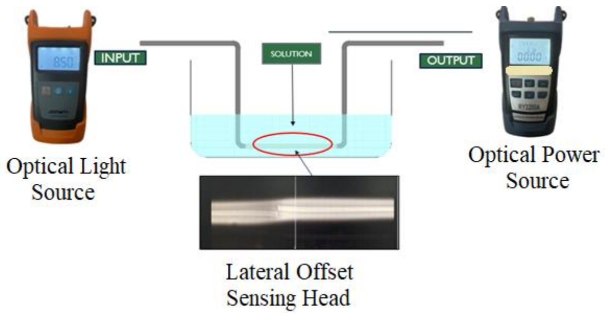

Fig. 2. Experimental Setup (color online)

Fig. 2 depicts the experimental setup based on multimode fiber (MMF) working around 850 nm. As a sensing part, the fiber sensor head is fabricated at the MMF center based on the lateral offset splicing method. MMF used is this work due to thicker diameter than single mode fiber (SMF) and able to carry multiple wavelengths. For sensor applications, MMF is a more cost-effective option than single-mode optical fibre. The lateral offset distance was varied to study the effect of the misalignment gap on the overall sensor performance. The samples of the coconut oil adulterated with different paraffin and palm oils concentrations were then prepared for the adulterant test measurements. Optical Power Meter (OPM) will be used to measure the sensor response towards the optical signal loss which a light input source working at the wavelength of 850 nm is connected to the lead-in fiber of the sensor. For refractive index (RI) measurement, the sensor is tested with a refractometer.

A. Sensing head region fabrication process

The main process involved in the sensing head development is the fiber optic fusion splicing which is done by using SUMITOMO TYPE-36 fusion splicer. Four different misalignments of 0µm, 4.42µm, 7.49µm, and 7.83µm are investigated by varying the offset distance. The captured images of spliced offset section from the splicing machine are shown in Fig. 3, Fig. 4 and Fig. 5, observed using Axioskop 2 MAT Image Analyzer. All fiber cables lengths were fixed to 1 m.

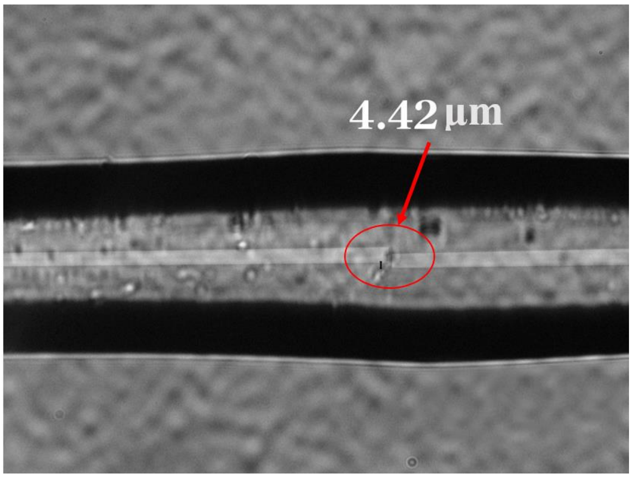

Fig. 3. Recorded Image from Image Analyzer for 4.42 µm lateral offset

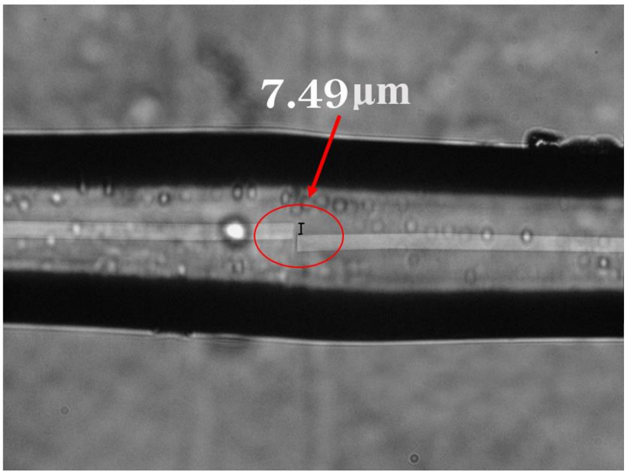

Fig. 4. Recorded Image from Image Analyzer for 7.49 µm lateral offset

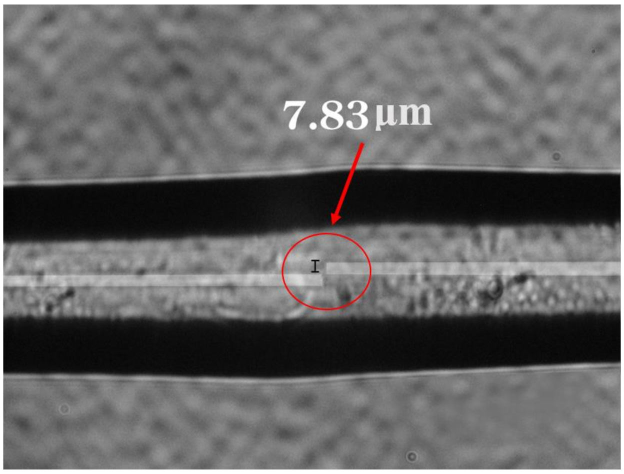

Fig. 5. Recorded image from image analyzer for 7.83 µm lateral offset

3. Results and discussion

Thirteen solution samples were prepared for the test to measure the refractive index, volume, concentration, and the number of mol of each solution. These samples consist of pure coconut oil, palm oil, paraffin oil, five sample solutions of coconut oil and palm oil mixture, and five sample solutions of coconut oil and paraffin mixture. The volume of the coconut oil is set to 20 ml, while for the coconut-palm oil mixture solutions, 10 ml, 8 ml, 5 ml, 3 ml, and 1 ml palm oil was added into the 20 ml coconut oil. Similarly, for the coconut-paraffin oil mixture, 20 ml coconut oil was mixed with the above-mentioned paraffin volumes. The initial refractive index value of pure coconut oil, paraffin oil, and palm oil are found to be 1.4481, 1.4585, and 1.4634 respectively by using a digital refractometer.

Fig. 6 shows the refractive index value for different oil mixture concentrations for coconut-palm oil mixture and coconut-paraffin oil mixture based on the volume of adulterants added to the coconut oil. As the volume of adulterants increases, the RI is increasing as well. Pure coconut oil has a refractive index of 1.4481. Therefore, it is observed that adding adulterants to the coconut oil changes the RI value of the mixture. Light can be absorbed by the atoms or molecules that comprise the analyte sample when the EW interacts directly with the external medium in the presence of analytes, in this case, the concentration of palm oil and paraffin oil. As a result, because the absorption spectra of different analytes differ, absorption phenomena can be used to quantify samples and concentrations of analytes. As a result, optical fibre sensor based on absorption phenomena are highly dependent on the external medium RI, which influences the measured output power directly.

In addition, the graph shows that the slope of the refractive index of palm oil with coconut oil is steeper than the slope of coconut oil with paraffin oil because palm oil has similar physical and chemical properties to coconut oil, and it bends similarly to coconut oil [13]. The slope of the line graph represents the sensitivity of the fiber when interacting with specific aqueous solutions. The steeper slope represents the higher fiber sensor sensitivity. Based on the graph, the sensitivity of palm oil is 0.9 µ RIU/% and 0.6 µRIU/% for paraffin oil.

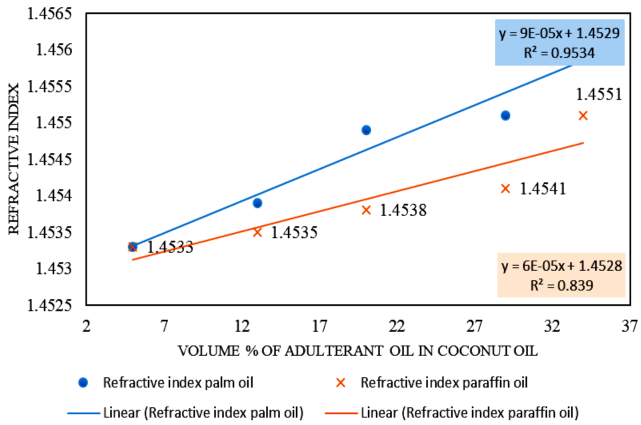

Fig. 6. Refractive index of the volume percentage of palm oil and paraffin oil in coconut oil (color online)

The result was verified with Sheeba et al. [22] in which the results obtained have a similar trend. From the study, it is also shown that as the number of adulterants increases, the refractive index of the medium surrounding the sensor head increases, while the output intensity decreases. This is also consistent with the Clausius-Mosetti equation, which states that the output power decreases as the RI increases [6].

a) Analysis of coconut oil adulteration due to palm oil

To study the effect of coconut oil adulteration due to palm oil existent, five mixture concentrations were tested which is 0.019 mol/g, 0.018 mol/g, 0.016 mol/g, 0.015 mol/g, and 0.015mol/g, prepared with the coconut-palm oil volume percentage ratio of 95/5, 87/13, 80/20, 71/29 and 66/34, respectively. The offset distance was varied, and the output power was observed and summarize as in Table 1. It shows that a longer offset gap will produce higher power loss with method lateral offset distance, in which for example, for 7.83 µm offset, the output power for 66% of coconut oil mixed with 34% of palm oil with the number of mol 0.014 mol/g experienced -37.29 dBm loss, compare to -36.05 dBm for 4.42µm offset at the same number of mol. To summarize, the higher the volume of adulterant oil in coconut oil, the higher the output loss will be produced.

Table 1. Output power for coconut/palm oil mixture with 0µm,4.42 µm, 7.49 µm, and 7.83 µm lateral offset

	Power(dBm)			
Number of mole(mol)/ Lateral Offset (µm)	0	4.42	7.49	7.83
0.0286	-28.15	-32.04	-35.96	-38.00
0.0273	-28.24	-33.50	-36.08	-38.17
0.0262	-28.35	-34.86	-36.5	-38.34
0.0227	-28.46	-35.72	-36.65	-38.98
0.0213	-28.64	-36.24	-37.26	-39.78

Fig. 7 portrays the output power (dBm) versus the number of moles (mol) for coconut-palm oil mixture (calculated based on the percentage of coconut-palm oil volume). From the graph, the sensitivity obtained for 0 µm, 4.42 µm, 7.49 µm and 7.83 µm offset is 0.095 dBm/mol, 0.193 dBm/mol, 0.394 dBm and 0.406 dBm/mol, respectively. The result also shows that for the same adulterant volume, a linear decrease of output intensity was observed as the lateral offset increases. The output power loss shows that the larger distance has a higher output power loss. Therefore, the larger the offset distance, the higher the output power loss will produce for the lateral offset method, however in terms of sensitivity, it produces a more sensitive device. In order to validate the modeling results, the adjusted coefficient of determination (R^2) was also emphasized in the analysis. R^2, which provides an assessment of the strength of the correlation between the model and the response variable, is widely used to determine the accuracy of models, in which the R^2 value is used to determine the degree of fit [23]. The R^2 value observed was 83%, 98%, 94%, and 95 % for 0 µm, 4.43 µm, 7.49 µm, and 7.83 µm lateral offset, respectively. The R^2 value of more than 90% for lateral distance larger than 0 µm shows good accuracy of the model.

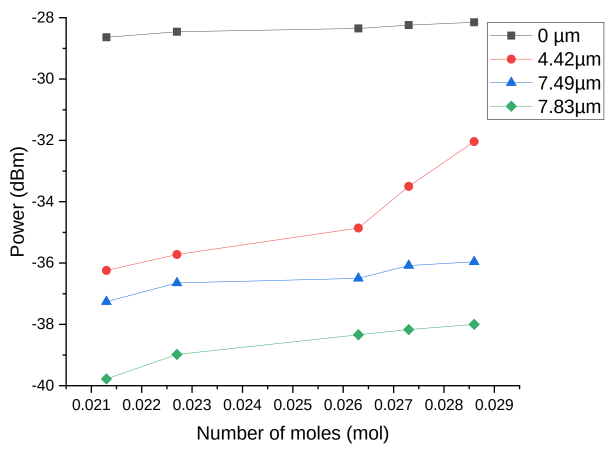

Fig. 7. Graph of output power (dBm) vs the number of mole (mol) of coconut –palm oil mixture for various lateral offset distance (color online)

b) Analysis of coconut oil adulteration due to paraffin oil

For coconut oil adulteration due to paraffin oil contamination, five samples were prepared as in Table 2. The volume percentage ratio for coconut/paraffin oil mixture prepared was 95/5, 87/13, 80/20, 71/29, and 66/34, with the mole concentration of 0.0286 mol, 0.0273 mol, 0.0262 mol, 0.0227 mol, and 0.0213 mol, respectively.

Table 2. Output power for coconut/paraffin oil mixture with 0µm,4.42 µm, 7.49µm, and 7.83µm lateral offset

	Power(dBm)			
Number of mole(mol)/ Lateral Offset (µm)	0	4.42	7.49	7.83
0.019	-28.42	-35.30	-35.36	-35.51
0.018	-28.64	-35.46	-35.77	-36.27
0.016	-28.77	-35.52	-36.28	-36.53
0.015	-28.79	-35.89	-36.63	-36.77
0.014	-28.82	-36.05	-36.90	-37.29

The output power observed was summarized in Table 2. It shows the longer lateral offset will produce higher power loss, for example, for the lateral offset of 7.83 µm, the power received is -37.29 dBm as compared to -28.82 dBm for no lateral offset (measured for 0.014 mol). It can also be observed that with the same lateral offset, as the number of moles increases, the power received will be reduced. In other words, the higher the volume of paraffin oil in coconut oil, the higher the output loss will produce.

Fig. 8 shows a relationship between the output power (dBm) and the number of moles (mol) of coconut-paraffin oil mixture for various lateral offsets. From the graph, the sensitivity obtained for 0 µm, 4.42 µm, 7.49 µm and 7.83 µm is 0.12 dBm/mol, 1.06 dBm/mol, 0.317 dBm/mol and 0.437 dBm/mol, respectively. Therefore, even the output power was reduced as the longer lateral distance was employed, the sensitivity of the sensor was improved. Therefore, the larger gap of offset distance the higher the sensitivity of the sensor based on the lateral offset method, which is consistent with the results obtained for the coconut-palm oil mixture. The results were aligned with the theoretical concept as described in [8], where the study explained that as misalignment between two fibers is increased, the light entering the cladding will gradually increase. Hence, the fiber will experience higher energy loss. The more light leaks into the sensing region, the capability of the sensor to detect any changes in the surrounding materials will be enhanced. For oil adulteration due to the paraffin oil, the R^2 value is reduced as the lateral offset becomes larger. The observed R^2 were 98%, 96%, 94%, and 89% for 0 µm, 4.43 µm, 7.49 µm, and 7.83 µm lateral offset, respectively. Again, the adjusted R^2 value of more than 90% shows good accuracy of the model.

From both Fig. 7 and Fig. 8, it can be concluded that the sensitivity of the sensor for paraffin oil detection is better than palm oil. This is due to palm oil has the similarity characteristics to coconut oil and it easily blends. Hence, adulteration detection becomes rather difficult, especially when the adulterant has similar chemical characteristics to the original oil [16].

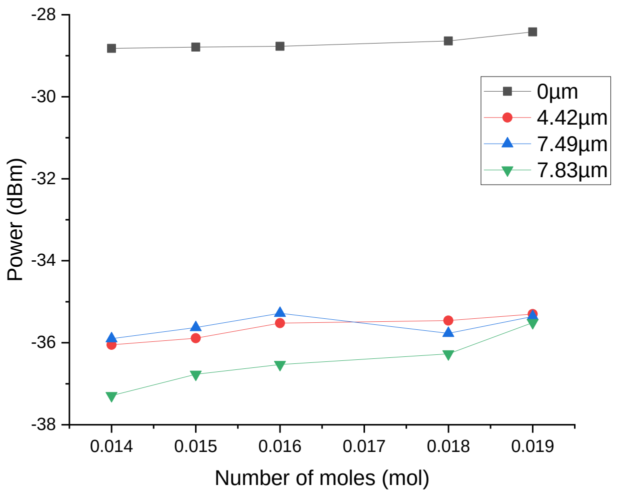

Fig. 8 Graph of output power (dBm) versus the number of moles (mol) coconut oil with paraffin oil with all distance (µm) by using MMF-MMF (color online)

4. Conclusion

In conclusion, a simple, compact, and high sensitivity fiber sensor based on the lateral displacement method has been proposed and experimentally demonstrated. The performance of the sensor device in responding to coconut oil adulteration was investigated and analysed for two different types of adulterant oils, which are palm oil and paraffin oil. It is observed that the sensor performance in detecting paraffin oil adultery demonstrates higher sensitivity. Upon completion, the sensitivity of the sensor towards mixture concentration measured for palm oil and paraffin oil is 0.406 dBm/mol for palm oil detection and 0.437 dBm/mol for paraffin oil detection for 7.83 µm lateral offset, respectively. The significant findings which are based on experimental analysis should make as an important reference in designing an improved fiber optic sensor for quality improvement applications. Furthermore, the proposed design we establish in this paper can be used for remote, real-time, high precision, and early warning monitoring of adulteration in many sensing applications including in the medical sector, food industry, oil, and gas companies, etc.

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References

[1] S. S. K. Hazura Haroon, J. Adv. Rev. Sci. Res. **1**, 1 (2017).
[2] N. M. Razali, A. N. Mazlan, M. F. Salebi, H. Mohamed, S. Ambran, Telkomnika **17**(5), 2445 (2019).
[3] S. K. I. Hanim Abdul Razak, Hazura Haroon, Anis Suhaila Mohd Zain, J. Telecommun. Electron. Comput. Eng. **10**(2–2), 23 (2018).
[4] M. N. S. Hazura Haroon, Siti Khadijah Idris, M. Yusri Yusoff, Anis Suhaila Mohd Zain, Hanim Abdul Razak, Fauziyah Salehuddin, J. Telecommun. Electron. Comput. Eng. **10**(2–5), 131 (2018).
[5] K. Fidanboylu, H. S. Efendioğlu, H. S. Fiber Opt. Sensors and their Applications, Keynote Address, 5th International Advanced Technologies Symposium (IATS'09, 1-6 (2019).
[6] Hazura Haroon, A. Kareem, Optoelectron. Adv. Mat. **13**(5–6), 290 (2019).
[7] A. S. M. Z. Hanim Abdul Razak, Nur Hidayah Sulaiman, Hazura Haroon, Microw. Opt. **60**(4), 920 (2018).
[8] W. F. S. Xu, H. Chen, Opt. Laser Technol. **141**, 107174 (2021).
[9] S. Hao, O. S. Lian Zhu, Mengling, W. Z. Zuo, Ningning Luo, Iulin Shi, X. He, A. Z. Chen, OSA Contin. **2**(4), 1148 (2019).
[10] T. R. K. A. J. Kumar, N. M. Gowri, R. V. Raju, G. Nirmala, B. S. Bellubbi, Pramana-Journal Phys. **67**(2), 383 (2006).
[11] E. O. Samuel T. Ebong, Godfrey T. Akpabio Ekaette S. Attai, Helen, Int. J. Res. Stud. Sci. Eng. Technol. [IJRSSET] **1**(4), 68 (2014).
[12] N. F. Baharin, A. I. Azmi, A. S. Abdullah, M. Y. Mohd Noor, Opt. Laser Technol. **99**, 396 (2018).
[13] W. A. Salah, M. Nofal, J. Sci. Food Agric. **101**(3), 811 (2021).
[14] S. Popa et al. , Sci. Rep. **10**(1239), 16100 (2020).
[15] T. M. Libish et al., Optik **122**(21), 1939 (2011).
[16] A. C. M. R. Pandiselvam, M. R. Manikantan, S. V. Ramesh, S. Beegum, Indian Coconut J. **Nov 2019** (2019).
[17] S. V. R. S. Srinivasulu, Int. J. Innov. Technol. Explor. Eng. **8**(8S3), 615 (2019).
[18] M. R. O. M. S. Firouz, Sens. Bio-Sensing Res. **11**, 33 (2016).
[19] F. T. P. Kadiroglu, F. Korel, J. Am. Oil Chem. Soc. **88**(5), 639 (2011).
[20] "9 Uses of Fiber Optic Cables," 2021.
[21] W. B. Spillman, E. Udd, Field Guide to Fiber Optic Sensors **FG34,** (SPIE) (2014).
[22] P. R. M. Sheeba, M. Rajesh, C. P. G. Vallabhan, V. P. N. Nampoori, Meas. Sci. Technol. **16**(11), 2247 (2005).
[23] K. Dass, S. R Chauhan, Materials and Manufacturing Processes **27**, 531 (2012).

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