

# 1D-Nano-Scale Porous Silicon (1D-Psi) as Optical Sensor Device

Rashmi<sup>1</sup>, Vivekanand Mishra<sup>2,\*</sup>, Sukriti<sup>3</sup>, Chandni Pathak<sup>4</sup>, Anjali S. Kotian<sup>5</sup>

## Abstract

*This research article embarks on a thorough experimental inquiry into the detection of kerosene adulteration in petrol, employing a sophisticated one-dimensional microcavity of nano-scale porous silicon (1D-PSMC) sensing device. The significance of this investigation stems from the detrimental consequences of petrol adulteration, which not only aggravates environmental pollution but also jeopardizes the functionality and durability of machinery components, thereby posing significant economic and environmental challenges. The 1D-PSMC, designed to function as an optical sensor device, has undergone extensive scrutiny and practical application. Within this study, we meticulously examine the resonance wavelength shift observed in the reflectance spectra of petrol samples containing various concentrations of kerosene adulterants. Impressively, the sensor device demonstrates outstanding efficacy, capable of detecting adulteration levels as low as 0.5% and even discerning minute variations of 0.01% [Table 1]. This remarkable sensitivity underscores the invaluable potential of the 1D-PSMC sensor in real-world applications. Moreover, the article delves into the intricate relationship between wavelength shifts in the reflectance spectra and the diverse concentrations of kerosene present in the petrol samples. By elucidating these correlations, this research contributes significantly to expanding our comprehension of the operational mechanisms of 1D-PSMC sensing devices in combatting petrol adulteration effectively. Consequently, such advancements hold promises for mitigating environmental degradation and preserving machinery efficiency on a broader scale.*

**Keywords:** 1D-PSMC, Petrol, Kerosene, Adulteration, Wavelength Shift, Sensor

### \*Author for Correspondence

Vivekanand Mishra

<sup>1</sup>Assistant Professor, Department of Science, Alliance University, Chandapura-Anekal Main Road, Bengaluru, Karnataka India

<sup>2</sup>Professor, Department of Physics, Institute of Applied Sciences and Humanities, GLA University, Mathura, Uttar Pradesh, India

<sup>3</sup>Assistant Professor, Department of Science, Alliance University, Chandapura-Anekal Main Road, Bengaluru, Karnataka India

<sup>4</sup>Assistant Professor, Department of Science, Alliance University, Chandapura-Anekal Main Road, Bengaluru, Karnataka India

<sup>5</sup>Research Scholar, Department of Science, Alliance University, Chandapura-Anekal Main Road, Bengaluru, Karnataka India

Received Date: March 11, 2024

Accepted Date: April 23, 2024

Published Date: July 31, 2024

**Citation:** Rashmi, Vivekanand Mishra, Sukriti, Chandni Pathak, Anjali S. Kotian. 1D-Nano-Scale Porous Silicon (1D-Psi) as Optical Sensor Device. Journal of Polymer & Composites. 2024; 12(Special Issue 5): S69–S75.

## INTRODUCTION

Practice of fuel adulteration is a widespread threat and is spread over the entire world. Present article is focussed over the implication of one-dimensional microcavity of nano scale porous silicon (1D-PSMC) sensing device to identify the presence of adulterated kerosene in gasoline. Porous silicon was discovered long back around year 1956 but succeeded to gain attention by the researcher only after the demonstration of their optical properties namely, photoluminescence and electroluminescence [1–4]. Porous silicon being full of exceptional properties namely, high-level sensitivity, tiny size, larger surface-to-volume ratio, biocompatibility as well as the compatibility with silicon IC technology makes it the most eligible and potential candidate for the application in the field of sensing devices. In the present work we focused on developing an optical sensor to detect even the minute level of adulteration in a petrol utilizing 1D-

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PSMC. Optical characterisation namely, reflectance measurement study was carried out to detect the adulteration (i.e., the concentration of kerosene) present in petrol. The basic principle involve in the sensing is modification in overall effective refractive index (R.I) of microstructure caused by the introduction of adulterated fuel drops in the pores. in the microstructure total effective refractive index (R.I.) caused by the introduction of tainted fuel droplets into pores.

When the appropriate electrolyte composition and anodization conditions are met, the silicon dissolves not evenly but rather in a way that creates pores on the wafer's surface. The sensors extreme sensitivity is caused by these holes, which also significantly increase the surface-to-volume ratio. The specifications of the applications may guide the design of the pore size [5].

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Several types of biosensors, including humidity, gas, pressure, and pressure sensors, have been developed and well explored by researchers worldwide [6–10].

The original reflectance spectrum of structure changes when fuel is introduced into the pores [11]. This process of sensing is completely reversible, thus helps in saving cost by reusable sensor. Sensor based on the above principle is further utilised for the purpose of identifying kerosene adulteration in petrol.

Kerosene being most utilized adulterant in the fuel sample like petrol and diesel. Kerosene in case of market price stays at the way cheaper side in comparison to the petrol price. So, the mixing of fuels with kerosene is at higher demand as it leads to the monetary profit. Specifically, in India kerosene can be accessed easily and at a much cheaper rate. The government policy made kerosene accessible to those in lower social classes for heating and cooking. The large quantity of kerosene at such a cheaper rate encourages the adulteration on larger and uncontrollable scale. Adulteration directly affects the economy of the country and leads to major contributor towards the pollution. Also, the longer use of adulterated fuel degrades the vehicle engine and reduces its lifetime and efficiency. Machine components lifetime is greatly impacted since adulteration lowers the fuel quality to what is necessary for the cars to operate properly. This could result in engine component failure, raising concerns about safety.

BPL section of society is the majority facing the indirect impact of fuel adulteration. Majority of them relies on kerosene for cooking and other household purposes. The diversion of kerosene in the field of the fuel adulteration, compels them to use the substitute of it for the cooking purpose. So, they are left with no choice other than utilising the biomass as domestic fuel for household purpose. Which in return plays the role of major contributor towards the air pollution, directing to several issues namely, health issues, etc. Researcher are working on the field of the optical adulteration of petrol detection with kerosene [12].

Automobile sector being larger consumer of petroleum products, are the main contributor to the air pollution over the worldwide. Nowadays, the unexpected increase in air pollution is the major concern, as this can lead to the increase in a number of greenhouse gases that cause global warming in the atmosphere. Demand of fuel is growing on a larger and larger scale and till date there is not any efficient and alternative source of fuel for the automobile industry. This causes the increase in the fuel prices. This also encourages the fuel adulteration and is the major issue we are facing. This also acts as a major contributor for increase in the air pollution in an environment. Adulteration effect is not only concentrated to the degradation of the environment but hampers the vehicle's engine performance also. Adulteration of petrol by introduction of kerosene reduces the fuel cost, and thus encourages this

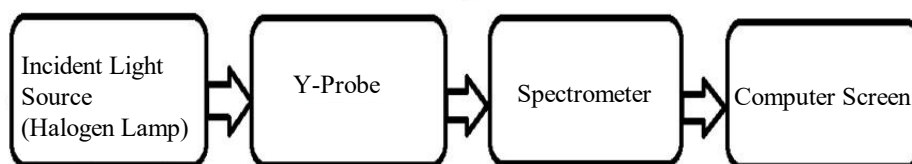
practice of adulteration [13]. The lack of on-the-spot standard checking techniques for adulteration are encouraging these practices. Adulteration in automobile fuels with kerosene or other leads to emission of greenhouse gases which affects public health, is a result of an air pollution indirectly [14]. In India, adulteration of gasoline involves mixing of diesel and petrol in kerosene [15]. Crucial preventive measures for the adulteration involves regular and regulated checking of fuel quality at the distribution points. As it is not easy to detect the adulteration less than 30% due to small volume percent by automobile user, yet for more over 30%, adulteration can be readily identified from the reduction in engine performance [16]. Adulteration detection equipment should be quick responsive, competent, portable, inexpensive and user friendly. Recently, nano material porous silicon (PS) emerged as an unique promising properties material with the application mainly in the refractive index based optical sensing The 1D-PSMC [17, 18]. structure exhibits a pronounced resonance dip in the reflectance spectra and regulates the electromagnetic wave propagation through photonic crystals [19, 20]. The optical detection of adulteration in gasoline is made possible by the unique property of nano-porous silicon refractive index sensing (examined by the reflectance spectra's wavelength shift).

Primary goal of present article is to assess the viability of 1D-PSMC Figure 1, configurations 1D-PSMC structures as optical sensing devices for quantitatively detecting fuel adulteration of kerosene in gasoline using a fibre optic spectrometer. Finally, the testing of these structures as an optical sensor device has been done by examining the resonance wavelength shift in the reflectance spectra of different concentrations of kerosene in petrol. The abrupt increase in the atmospheric pollution from fuel adulteration, where the adulterants play a prominent role in modifying the real chemistry of the base fuel. Also, results in alteration of the combustion dynamics taking place inside the combustion chamber. These as a cumulative result causes overall enhancement in the emission of harmful atmospheric pollutant gases namely, carbon monoxide, nitrogen oxides, hydrocarbons, carcinogenic pollutants, etc.

The machine components lifetime is reduced on exposure to the adulterated fuels as adulteration leads to deterioration in the fuel's quality required to propel the vehicles. Leading to the failure of machine imported parts including engine components and challenges the safety issues associated with it.

Nowadays, lot much significant research works are done on the optical detection of gasoline adulteration using kerosene. Here, we offer a brand-new, one-dimensional, nanoscale porous silicon microcavity sensor that is safer to use with combustible fuels and easier to operate.

Future scope involves the application in different distribution points in order to keep an eye on adulteration practice and uproot it from the grassroot level. The designed sensor utilizes the response of the reflectance spectrum conforming the variation spectrum, occurred due to variation in the refractive index.



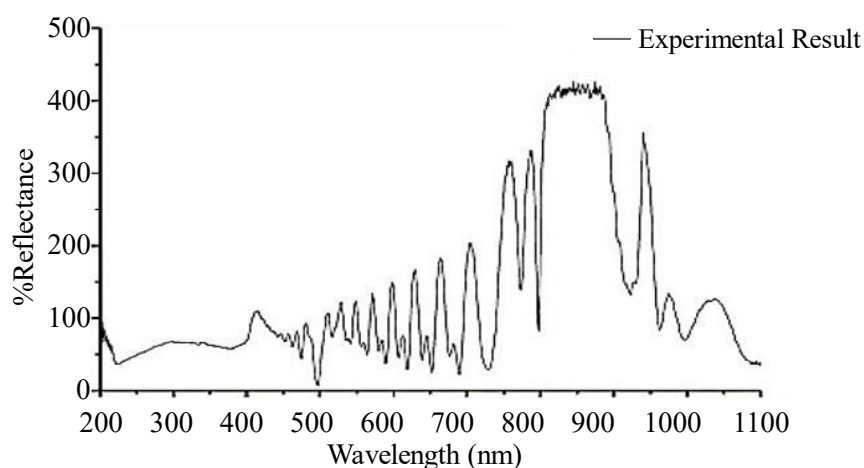
**Figure 1.** Flow chart comprising steps involved for the experimental realization of the feasibility of (1D-PSMC) sensor device.

For the experimental realization of the feasibility of (1D-PSMC) sensor device we have made the flow chart comprising of different steps involved. Initial step involves the illumination of the sensor device utilizing the halogen lamp using a bifurcated fibre probe in a Y form (depicted in the Figure 1). Y-shaped bifurcated fibre probe consists of a central fibre for channelising the incident beam. To collect the reflected beam, a bundle of six fibres is arranged around the core fibre. The spectrophotometer analyses the reflected beam in more detail before displaying the reflectance spectrum on a computer screen.

In the present article, we utilized 1D-PSMC sensor for checking the adulteration of kerosene in the petrol. At the primary stage, the homogeneous mixture of the combination of various ratios of kerosene (0–50%) to gasoline were made in varied proportions. Later, on the above-mentioned solution was introduced dropwise on the 1D-PSMC sensor. Special care was taken in aiming the solution to reach the pores. Afterward, in order to limit the occurrence of reaction in the linear zone, the vary amount of solution was raised to 20  $\mu\text{L}$ . Each measurement was completed, and the apparatus was properly cleaned in isopropyl alcohol (for approximately 05 minutes) followed by rinsing with the de-ionized water (for approximately 02 minutes). Once the device was rinsed, was kept for drying with the intention of total elimination of every molecule of kerosene liquid that was present in the pores.

## RESULTS AND DISCUSSIONS

The optical characterization of the sensor device was carried out utilizing the optical spectrometer. Figure 2 depicts the reflectance spectra of 1D-PSMC, we observed a dip in photonic resonance of the 1D-PSMC close to 800 nm.



**Figure 2.** 1D-PSMC Structure experimental reflectance spectral analysis.

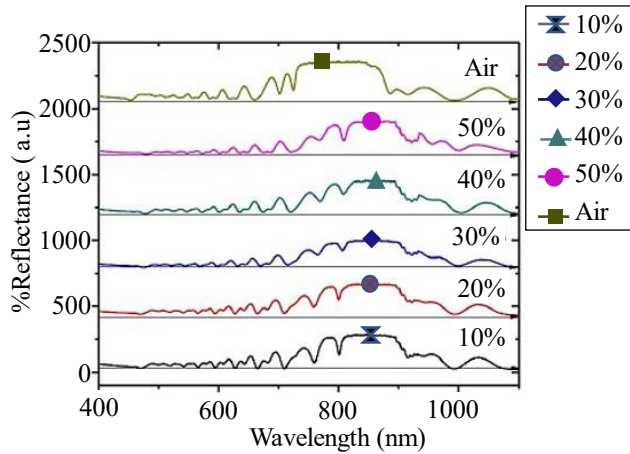
### Kerosene Detection

Table 1 shows the performance of 1D-PSMC sensor device by analyzing the shift of the wavelength in the reflectance spectra for the detection of kerosene in petrol at different concentrations (ranging 0% to 50%). There were differences seen in the reflectance spectra of various kerosene concentrations in gasoline. After analyzing the spectra, we observed that the wavelength in the reflectance spectra shifted toward the higher wavelength regions due to adsorption (shown in Figure 3).

A kerosene-filled porous material enhances its overall refractive index and optical thickness. The extent of wavelength shifts relies solely on the concentration of kerosene. Greater concentrations lead to higher refractive indices within the solution, resulting in more pronounced shifts in wavelength. Subsequently, the mixture is left to dry entirely to ascertain the definitive, stable wavelength shift.

The pores of a sensor device are filled by the molecules of adulterated sample under observation. As a result, pouring of adulterated samples leads to further variation in the structure effective refractive index. The insertion of an analyte into the pores alters the reflectance spectrum since the reflectance spectrum is influenced by the structure's refractive index. This is the fundamental idea behind the 1D-PSMC sensor optical sensing. The variation in the effective refractive index of the structure leads to an increase in the optical thickness of the structure of the sensor device [20, 21]. The optical thickness of the sensor device structure increases because of variations in the structure effective refractive index [22]. The reflectance spectrum shifts because of the overall changing optical thickness, and this shift can be used to calibrate the sensor device. Petrol and kerosene have refractive indices of 1.414 and 1.448, respectively. Because the adulterants and fuels are not entirely volatile, there are always some

leftovers in the pores which, by preventing the reflectance spectrum from returning to its initial position, show that the residues were packed within the pores. After each measurement, devices must be cleaned to guarantee that the reflectance spectrum returns to its initial location.

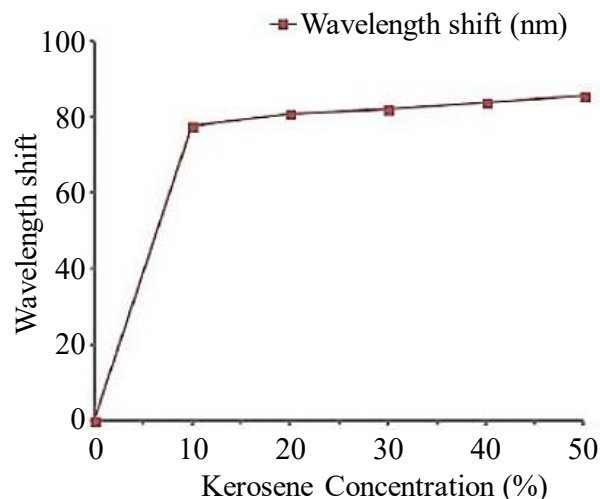


**Figure 3.** Reflectance spectra of gasoline tainted with kerosene at different concentrations.

**Table 1.** Concentration of Kerosene in Petrol and their wavelength shift.

S.N.	Concentration of Kerosene in Petrol (%)	Wavelength Shift ( $\Delta\lambda$ ) (nm)
1	0	0
2	10	77.63
3	20	80.82
4	30	82.03
5	40	83.73
6	50	85.48

Table 1 lists the effective wavelength shift ( $\Delta\lambda$ ) for each concentration of 1D-PSMC derived from its reflectance spectra, and Figure 4 plots the results. Figure 4 represents the smooth linear fitting for the graph between the kerosene concentrations vs. shift in the wavelength. Herein, the structure response was accurately approximated across the range of the wavelength shift in the reflectance spectrum for various kerosene solution concentrations. From the observed parameters we concluded that the 1D-PSMC sensing device is a good indicator for sensing measurement.



**Figure 4.** Plot of wavelength shift vs concentration of kerosene.

## CONCLUSIONS

The utilization of 1D-PSMC structures as optical sensing devices for quantitative detection of kerosene fuel adulteration in gasoline is studied. Device successfully detects concentration of kerosene ranging from 0%–50% Figure 4, in petrol. We observed the variations in the reflectance spectra of varying kerosene percentages in gasoline which results in the shifting of wavelength toward the higher wavelength region in reflectance spectra. We observed that the strength of the wavelength shift is directly proportional to the kerosene concentration. Higher concentration of kerosene results in increase in refractive index of the solution reflecting that the device can detect the adulteration of petrol by the introduction of kerosene easily. The suggested device is matchless in terms of performance and is low-cost optical sensor compared to other existing technologies. Performed experiments reveals that, once the liquid molecule from the porous structure is completely removed, the structure reflectance spectra of the structures quickly revert to their initial waveform. Admirable quality of these structures encourages the development of reversible sensing devices.

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