Sodium Sulfate (Na_2SO_4) Detection Using Graphene Coated Microfiber

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Abstract. We investigate the coating of graphene onto the silica microfiber sensor for sodium sulfate measurement at room temperature. The graphene obtained from graphene-polylactic acid filament was coated onto the microfiber based on drop casting methods. In this work, the graphene acts as cladding to interact with analyte as well as functions to trap either sodium cation or sulfate anion and increases the effective refractive index of the cladding. The sensor has a good sensitivity of 0.82 dBm/% and resolution of 1.16 %. The sensitivity and resolution of the sensor were increased by the coating of graphene layer.

INTRODUCTION

Sodium sulfate is used to dry organic liquids. As a filler in powdered home laundry detergents. As a fining agent which removes small air bubbles from molten glass. Glauber's salt, the decahydrate was used as a laxative which removes the certain drugs such as acetaminophen from the body. Although sodium sulfate is generally regarded as non-toxic, it should be handled with care. The dust can cause temporary asthma or eye irritation; this risk can be prevented by using eye protection and a paper mask. Therefore, detection and monitoring of sodium sulfate is very essential.

Many chemical sensors have been proposed to detect sodium sulfate based on various approaches including electrochemical conductivity [1], fluorescence [2], selective ion electrode and ion channel [3], voltammetry [4] and capillary zone electrophoresis (CZE) [5]. Among these sensors, fluorescence device presents many advantages since luminescence measurement are usually very sensitive and low cost. However, this detection method has several technical difficulties.

Recently, graphene has attracted much interest due to its unique characteristics such as high surface area, fast electron mobility and excellent electrical conductivity [6-8]. It also has attractive properties such as zero band gap, high electron mobility, ballistic transport, low electrical noise, and low resistivity [9]. The ongoing exploration on electrical, physical, chemical and mechanical properties contributes to a development of a wide range of new applications for graphene such as sensors, optoelectronic devices and nanocomposite material. For instance, the electrical properties of graphene, which are extremely sensitive to chemical doping and charge transfer effects by various molecules can be applied for sensing applications. It is reported that the graphene has a great potential to be used as sensing elements and tools for biochemical analysis as well as sensor for gases, biochemical sensing, and relative humidity [10-12].

In this research, we proposed a sensitive and simple fiber sensor based on a silica optical microfiber coated with graphene as a probe for the measurement of different concentrations of sodium sulfate in de-ionized water. The silica microfiber was fabricated using a flame brushing technique and it was used as a sensor by immersing the tapered area in sodium sulfate solution. The performance of the sensor was demonstrated with and without the graphene coating.

EXPERIMENTAL ARRANGEMENT

A silica microfiber was fabricated from a single mode fiber (SMF corning 28) by using a well-known flame brushing technique. The experimental setup for the flame brushing method is shown in Fig. 1. The optical silica microfiber has a length of 3 cm. The prepared graphene solution was then deposited onto the silica microfiber at a tapered region by using drop coating method. Then, the device was left to dry for 1 h.

The experimental setup for the sodium sulfate sensor using a silica microfiber coated with graphene as a probe. In the experiment, an amplified spontaneous emission (ASE) source operating at 1550 nm region was used as a light source in conjunction with an Optical Spectrum Analyzer (OSA) with resolution 0.2 nm for the measurement. The room temperature in this work was kept constant at 25 °C to eliminate the temperature influence on the silica microfiber [12]. The experimental setup were conducted on a vibration-free table to prevent any mechanical vibration's influence. Throughout the experiments, both sensor probes were immersed into the sodium sulfate solutions with varied concentrations from 1% to 7%. The small working range was selected to observe experimentally the response of the sensor to small changes in the concentration of the sodium sulfate solution. Refractive index for each sodium sulfate with different concentration were also recorded by abbe refractometer.

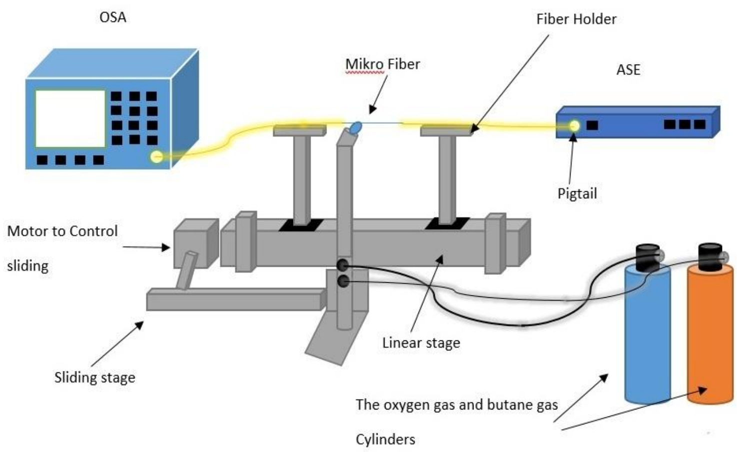


FIGURE 1. Schematic diagram of the fabrication setup for the silica microfiber using a flame brushing technique.

RESULTS AND DISCUSSIONS

The refractive index of the sodium sulfate at different concentrations of solution from 1% to 7% is shown in the Figure 2. As the refractive index of the sodium sulfate solution increases from 1.336 to 1.354.

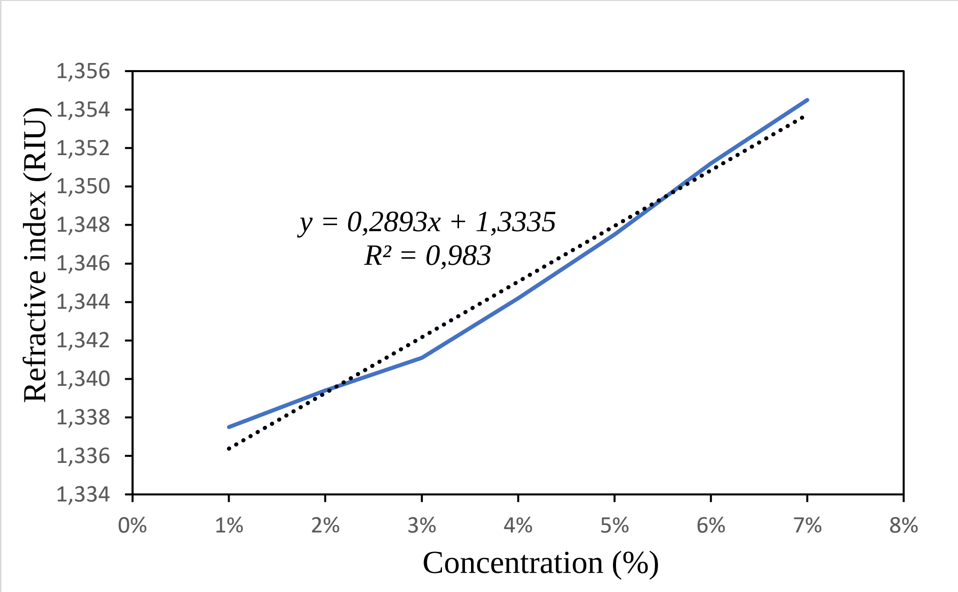


FIGURE 2. Refractive index against sodium nitrate concentrations.

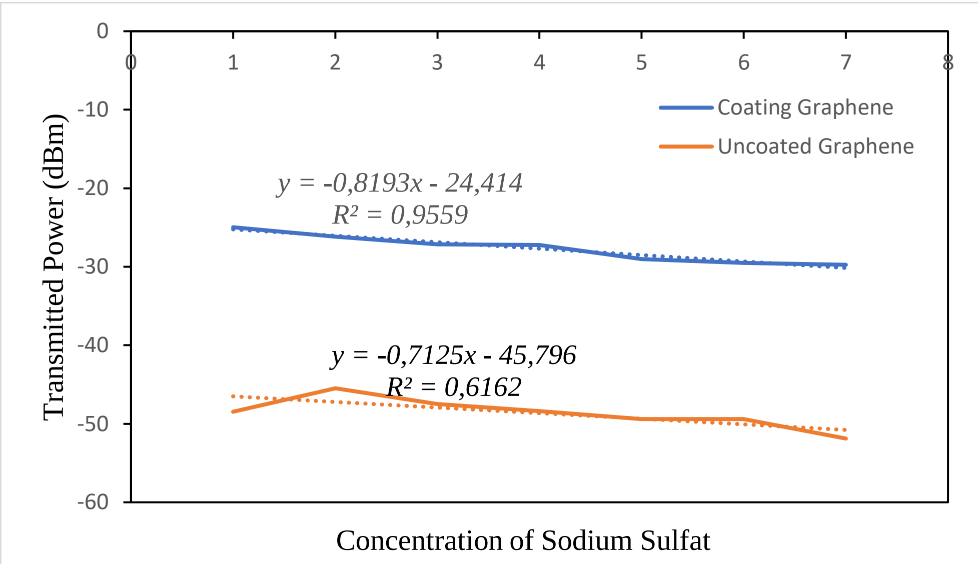


FIGURE 3. Output power against sodium sulfate concentration for the proposed sensor.

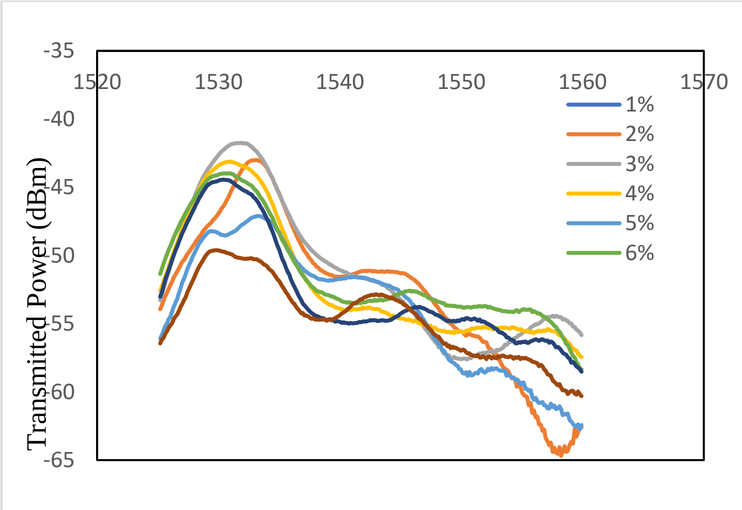
Figure 3 shows the measured output power responses for the proposed sensor at different sodium sulfate concentrations for both microfiber sensor probes with and without the graphene coating. As shown in Fig. 3, without the graphene layer, the output power decreases from −24.97 dBm to −29.27 dBm as the sodium sulfate concentration increases from 1% to 7%. The reduction of the output power is due to the reduction of the core and cladding index contrast since the refractive index of the microfiber sensor increases as the concentration of sodium sulfate increases. Therefore, it will reduce the light-guiding capability of the structure and thus allows more photons to escape from the microfiber. Transmission property and evanescent wave absorption of cladded multimode fiber tapers was theoretically described in ref. [13]

Meanwhile the output power of the sensor with graphene layer decreases from −45.45 dBm to −51.5 dBm. Compared to the uncoated graphene sensor, the graphene coated silica microfiber has significantly higher sensitivity. Without the graphene coating, the sensitivity of the sensor is estimated to be 0.71dB/% with slope linearity of more than 78% and resolution of 2.35%. With the proposed microfiber sensor with graphene coating, the sensor sensitivity is significantly increased to 0.82 dB/% with a better slope linearity of 96% and resolution of 1.16%. Performance of the sensor is summarized in Table 1.

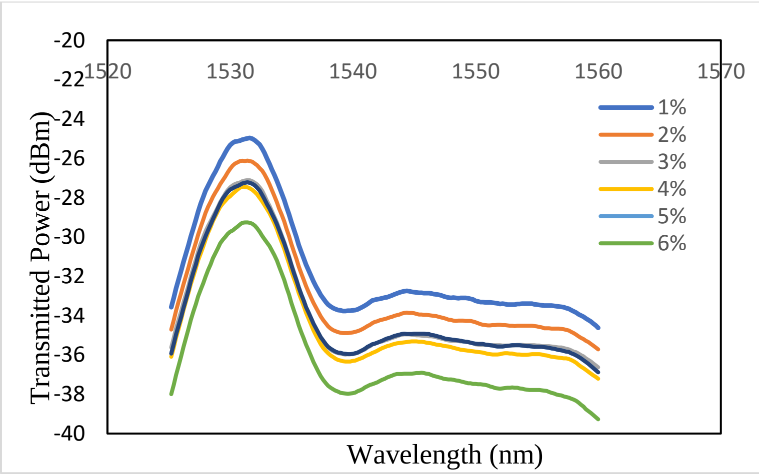
TABLE 1: Performance of the proposed sensor

Parameter	Uncoated graphene	Coated graphene
Sensitivity (dBm/%)*	0.71	0.82
Linearity (%)	78	0.96
Standard Deviation (dBm)	1.68	0.95
Resolution (%)*	2.35	1.16

*(%volume)



(a)



(b)

FIGURE 4. Transmission spectra of the proposed sensor for different concentrations of sodium sulfate (a) uncoated microfiber and (b) a coated microfiber with graphene.

Figure 4(a) and (b) show the transmission spectra of graphene coated and uncoated silica microfiber device, respectively after its immersion in sodium sulfate solution with various concentrations. As shown in Fig. 4(a), there is strong cladding modes interference pattern after immersing in sodium sulfate solution. However, the extinction ratio of the interference comb is significantly reduced as the probe is coating with graphene as shown in Figue 4(b). It could be happened because decreasing in the reflection at the microfiber due to the decrease in the index contrast between two medium. The stability of the sensor was obtained by measuring the output power against time for the silica microfiber coated with graphene as recorded for a duration of 900 s as shown in the Figure 5.

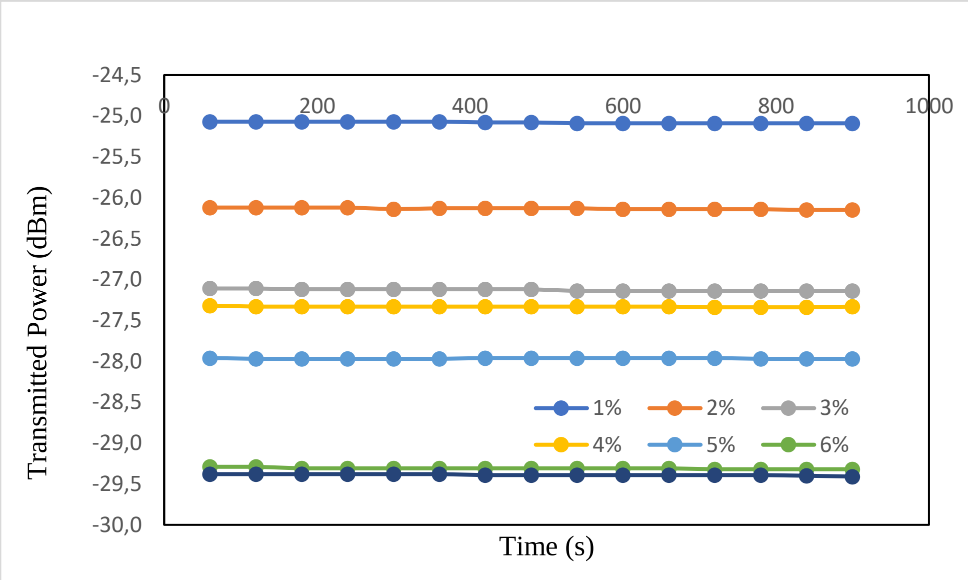


FIGURE 5. Stability of the silica microfiber with a graphene coated for sodium sulfate detection.

CONCLUSIONS

A low cos and simple optical sensor was successfully demonstrated as a device to detect various sodium sulfate concentrations. The silica microfiber probe fabricated by flame brushing technique has a waist diameter of 6 µm with tapering length of 3 cm and integrated with graphene as a sensing layer. As the solution concentration of the sodium sulfate varies from 1% to 7%, the output power of the sensor decreases linearly with a sensitivity of 0.82 dBm/% and linearity of more than 97%. The results show that graphene coated silica microfiber are promising for the refractive index sensing of sodium sulfate solution with high sensitivity, stability and repeatability.

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