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MZI Coreless Fiber Sensor Coated with Gold & Graphene for Respiratory Monitoring System

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ABSTRACT

A respiratory monitoring system based on coreless optical fiber is successfully designed and tested. The sensor consists of coreless fiber spliced with single mode fiber on two sides to fabricate Mach-Zehnder Interferometer. The sensor coated with nanogold particles and graphene in the same way to improve the sensor's performance. The sensor was inserted into an oxygen mask tube and then put on the nose and mouth to monitor the respiratory rate for different cases. The result showed that when breathing increased, the intensity of light decreased. The light intensity of breathing at sleeping case was more than at working sport case. The sensor sensitivity was 1748 nm/RIU, and 2593 nm/RIU coated gold and coated gold & graphene. In different cases, we expect the proposed wearable breath sensor could be a valuable and dependable device for respiration rate monitoring.

Keywords: Breathing, coreless optical fiber, graphene, nanogold, oxygen mask

1. INTRODUCTION

Breath could be a preparation of oxygen entering the lungs and coming to the body's cells, as well as the forms that cause carbon dioxide out of the body through the nose and mouth [1]. Respiratory characteristics such as respiratory rate (may be an imperative sign of a human being, this rate depends on the oxygen level within the blood) [2]. Respiratory significance and gas trade can be identified by utilizing the contrasts in temperature, mugginess, and carbon dioxide (CO_2) of respiratory wind current. Too, it is conceivable to screen respiratory exercises by calculating the varieties in thoracic and stomach circumferences [3]. These parameters regularly give vital pointer advance around the mental and physical conditions of an understanding, and nonstop observing is fundamental to degree the crucial parameters of a quiet in clinical or high-risk circumstances [4].

Over the past few years, fiber optic has started to serve as sensors. In addition, numerous kinds of fiber optic sensors were intended to measure various metrics. Optical fibers for sensing applications have many advantages, such as being immune to electromagnetic, accurate, robust, small sizes, non-optical counterparts, and flexible, among which are lightweight, microwave interference, and radio frequency [5]. Some of the optical fiber sensors use as biosensors. The ideal biosensor must respond to small levels of analyses and be able to do so distinguish among sorts based on recognition molecules that are immobilized on its side. Optical sensors rely on the interplay of light and material [6][7][8].

L. M. Hu, et al., 2011[9], demonstrated and proposed by utilizing an altered photonic gem fiber (PCF)-based MZI, in which a collapsed locale is presented at the center point of the PCF to move forward the termination proportion, The proposed altered PCF-MZI strain sensor comprises of a brief segment of index-guiding PCF (LMA-10) which was sandwiched between two SMFs longitudinally.

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Wenjun Zhou, et al., 2011 [10] demonstrated an exceedingly touchy strain sensor by presenting a photonic gem fiber (PCF-MZI) in a depression ring down fiber circle as a detecting component. The MZI was created by joining a brief length of PCF between two single-mode strands with collapsed discuss gaps over a brief locale at two grafting focuses, which permits coupling between center and cladding modes interior of the PCF. It is composed of a brief segment of PCF (LMA-10) This research proposed an active sensor based on SMF – coreless – SMF that provides a Mach - Zehnder Interferometer coated with gold nanoparticles and graphene to produce a very sensitive sensor by using a laser as a source in the visible spectrum.

2. MATERIALS AND METHODS

The sensor structure is based on Mach-Zehnder Interferometer. The fabrication of the interferometer is easy and straightforward since it only includes cleaving and fusion splicing, which can be carried out with common fiber tools and equipment [11].

The conventional single mode fiber was used with coreless fiber with 125 μm in diameter. A short section with a coreless fiber length of 5 cm was used in this sensor; spliced the coreless fiber with SMF from two sides. The taper was fabricated through a conventional fusion splicer and then etched into the fiber by inserting a droplet of hydrofluoric acid (HF) amongst the PCF with 40% concentration.

To produce an active sensor, coated it firstly with gold nanoparticles by using the magnetron sputtering coating process as shown in Figure 1; a target or a metal precursor that was desired to be deposited is bombarded with energetic ions of inert gases (e.g., argon or helium), The forceful collision of these energetic ions with the target ejects target metal atoms into space. These metal atoms are then deposited on the substrate, forming a metallic film. The target was cooled by water, so little radiation heat was generated. We used a 500 v power supply and 27 mA for the current and $8*10^{-1}$ bar for pressure with a gold purity of 99.9% and thickness of 1mm in this process and took the first results. Then coated with graphene because of its high ability to absorb moisture in the same way as coated gold, and also take the results.

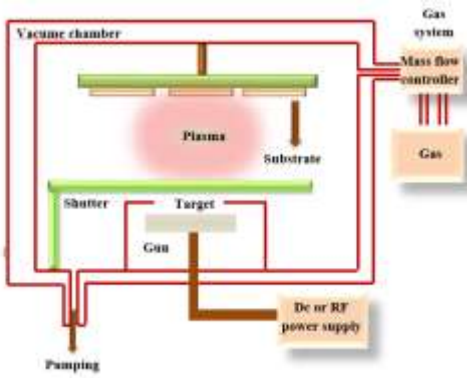

Figure 1. Schematic diagram of a mechanism of magnetron sputter coating machine.

After done all the processes to fabricate the sensor, the setup of the experiment was connected using the red light laser source (650 nm) connected with the fabrication sensor and then connected to the spectrometer, which was connected to a computer to show the data results as shown in Figure 2. The sensor was located inside the tube of the oxygen mask, and the oxygen mask was placed on the person's face, so the inhalation and exhalation were calculated with each breathing process carried out by absorbing the moisture associated with the inhalation and exhalation processes.

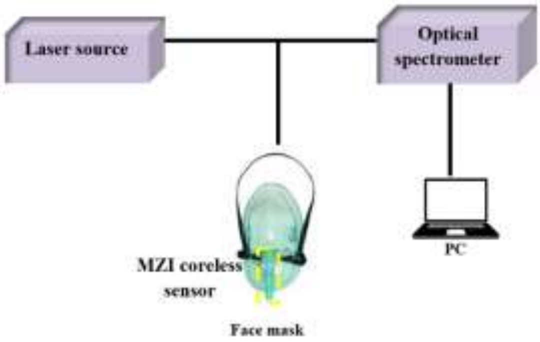

Figure 2. Proposed setup of the sensing structure.

This sensor was first used on normal air and considered a reference; then, it was used on daily human activities, such as sitting, walking, jogging, exercising, and sleeping. The light intensity was calculated in each case using an optical spectrometer, and the transmittance and sensitivity were calculated.

3. RESULTS AND DISCUSSION

3.1. Coated with Nanogold Particles

Firstly, the sensor was tested by measuring different breathing states, and by connecting it to the spectrometer, the light intensity was calculated as a function of wavelength.

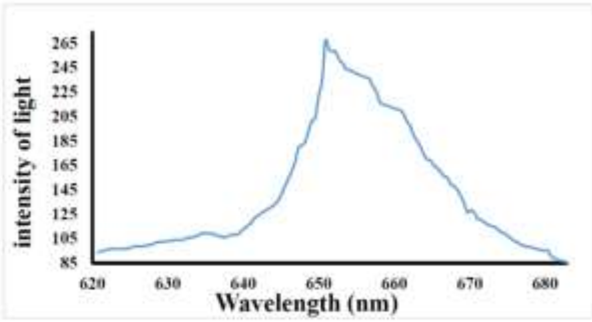

Figure 3. Reference wave of coated nanogold.

Figure 3 showed the reference wave when the air was used; due to the visible spectrum, the wavelength ranges between 620 nm to 680 nm, so the intensity of the laser beam increased gradually from 95.6 as a function of wavelength to 621.69 nm. When reached maximum intensity of 267, the wavelength was 650.89 nm because we used a red laser source, then decreased gradually to the minimum intensity at 679.98 nm.

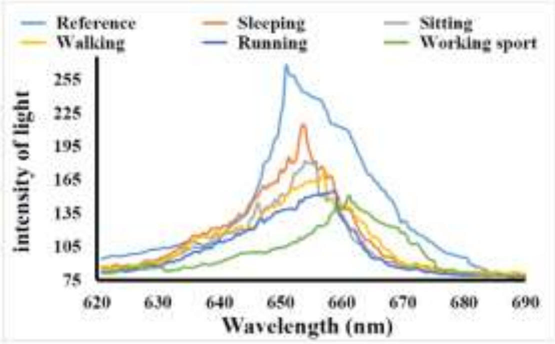

Figure 4. Transmission spectra of 5 cm coreless fiber interferometer coated with nanogold particles with different breathing cases.

As a function of wavelength, the higher the breathing rate, the lower the light intensity. An increase in the breathing rate leads to an increase in the sensor absorption, and thus the resulting intensity decreases. Figure 4 shows the intensity at different respiration states.

The intensity in all cases progressively increased until it reached the highest value at the wavelength of the red laser and then went back down. The intensity was 211.65 at 654.03 nm wavelength for sleeping breathing case. Therefore, the highest intensity in the state of sleep is the lowest respiration rate, approximately ten breaths per minute.

At the normal state of breathing (sitting), the intensity gradually decreased at each state of breathing. In the sitting state.

In the two last cases, it was less intense because running and working sport increased the respiratory rate, which is approximately 30 or more, so the intensity of light at running was 155 at 658.96 nm wavelength. In contrast, the intensity at working sport, considered the lowest and highest respiratory rate, was 151.71 at 661.2 nm wavelength.

The figure of merit (FOM) is a significant parameter used to evaluate the performance of the SPR sensors. A large FOM indicates high detection accuracy. Additionally, it helps to expand the detection limit. FOM can be evaluated as follows:

$$FOM\ (\%\ RH\text{-}1) = SW / FWHM \qquad (1)$$

Where SW is the wavelength sensitivity and FWHM defined as full width half maxima. The FOM for all breathing cases was calculated. As a result of all cases, redshift wavelength has been observed at the higher the respiratory rate and the lower the intensity because, that when increased in respiratory rate wavelength shifting was occurred to red shift, that because of SPR technique, a TM causes the excitation of electron density oscillations known as surface plasmon wave at the metal – dielectric interface. When the energy as well as the momentum of both, the incident light and SPW match, a resonance occurs which results in a sharp dip in the reflected light intensity. So, when coated the sensors with nanogold particles SPR achieved and obtained wavelength shifting because the gold demonstrates a higher shift of resonance parameter to change in refractive index of sensing layer and is chemically stable.

Table 1 Numerical intensity results of the proposed sensor

Breathing cases	Intensity of light	Shifting wavelength	Figure of merit (FOM)
Sleeping	211.65	654.03	0.0211
Sitting	181.47	655.82	0.0176
Walking	170	657.17	0.0152
Running	155	658.96	0.0172
Working sport	151.71	661.2	0.0123

Transmittance (T) is the fraction of incident light that is transmitted. In other words, it's the amount of light that "successfully" passes through the substance and comes out the other side. Figure (5) shows light's transmittance as a wavelength function. So, to calculate transmittance, we used this equation [12],

$$T = I_{out} / I_{in} \quad (2)$$

In is the intensity of incident light, and I_{out} is the intensity of that light after it passes through the sample. Figure 5 shows the opposite of Figure 4 because the measured intensity was divided by the reference intensity. Therefore, the working sport had the highest transmittance at a value of 0.3874 at 651.34 nm. Less transmittance was at sleeping at the value of 0.7006 at 651.79 nm wavelength between them the other cases from running to sitting with a value of 0.5846 at 650.89 nm wavelength for running and 0.4608 at 649.55 nm wavelength for sitting and finally 0.5846 at 560.44 nm wavelength for walking.

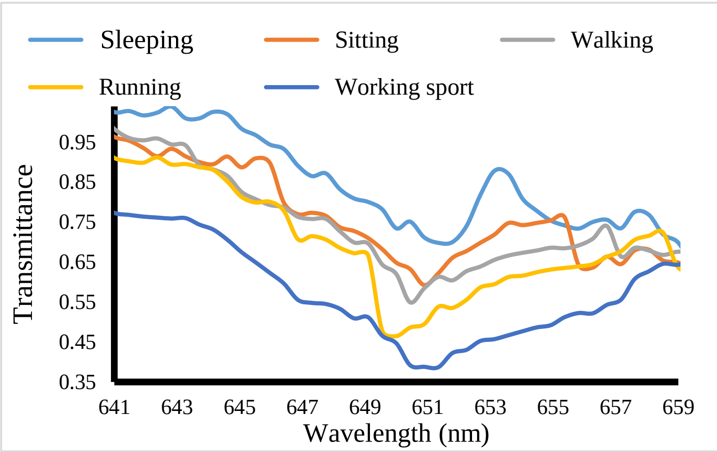

Figure 5. Transmittance spectra of 5 cm coreless fiber interferometer coated with gold nanoparticles with different breathing cases.

Table 2 Numerical transmittance results for the proposed sensor

Breathing cases	Transmittance	SPR wavelength
Sleeping	0.7006	651.79
Sitting	0.5846	650.89
Walking	0.5495	650.44
Running	0.4608	649.55
Working sport	0.3874	651.34

By fabricating the breathing sensor based on humidity absorption and by calculating the shifting wavelength, we calculated the sensitivity of the sensor by using the equation,

$$SW = \Delta\lambda peak / \Delta RH \quad (3)$$

Where SW is the wavelength sensitivity and Δλpeak is the resonance wavelength shift, and ΔRH is the change in the relative humidity.

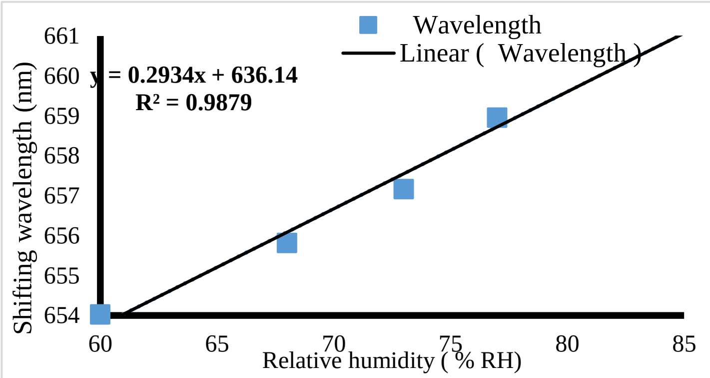

Figure 6. The relation between wavelength and refractive index for the breathing sensor.

So, Figure 6 shows the relation between shifting wavelength and change in analyte RH; by taking the slope of the curve, we calculated the sensor's sensitivity, which was 293.4 pm / % RH. Response time was 2.5 sec.

3.2. Coated with Gold and Graphene

Firstly, calculate the reference wave as a function of wavelength when taking air as a reference. Figure 7 shows the reference wave when coated with the sensor with gold & graphene to improve the sensitivity because the graphene is more able to absorb moisture, and found the wavelength ranges between 630 nm to 690 nm. Hence, the intensity of the laser beam increased gradually from 72.49 at 631.14 nm wavelength, and when reached the maximum intensity of 125.09 at 664.78 nm wavelength because we used a red laser source, then decreased gradually also to the minimum intensity at 689.8 nm wavelength.

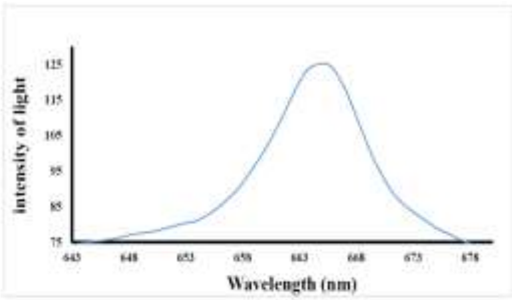

Figure 7. Reference wave of gold & graphene-coated.

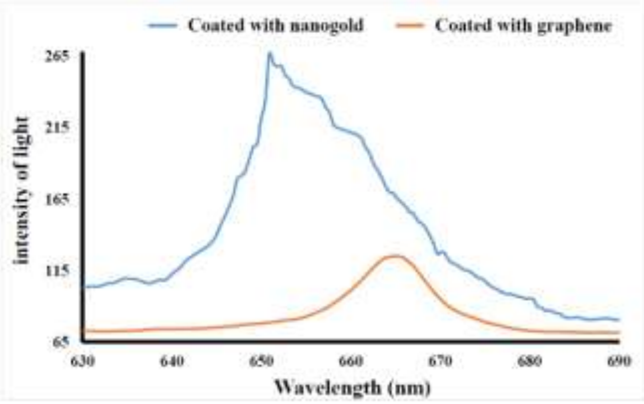

Figure 8. Reference wave for gold and gold & graphene-coated

Figure 8 shows the reference wave of the sensor when coated with gold and coated gold & graphene when compared. The results found the gold & graphene-coated was less intense than just gold because graphene increased the absorption of the sensor, so the intensity decreased.

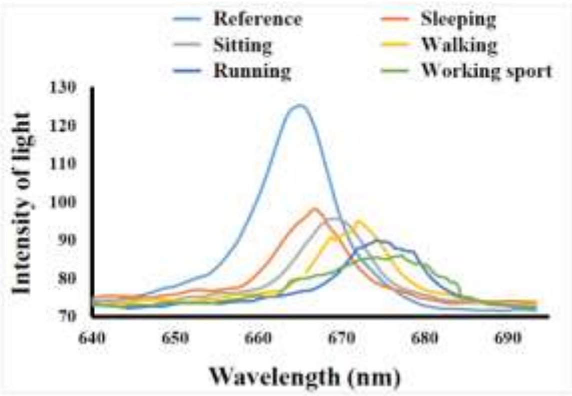

Figure 9. Transmission spectra of 5 cm coreless fiber interferometer coated with gold & graphene with different breathing cases.

Figure 9 shows the different cases of respiration. When taking the sleeping case, the intensity was 98 at 667.02 nm wavelength, and for sitting was 95.62 at 669.25 nm wavelength. For walking and running, 94.49 at 672.38 nm wavelength, 89.7 at 674.62 nm wavelength, respectively, and finally, for working sport was 86 at 677.3 nm wavelength.

Table 3 Numerical intensity results of the proposed sensor

Breathing cases	Intensity of light	Shifting wavelength	Figure of merit (FOM)
Sleeping	98	667.02	0.0313
Sitting	95.62	669.25	0.0322
Walking	94.49	672.38	0.0345
Running	89.7	674.62	0.0372
Working sport	86	677.3	0.0254

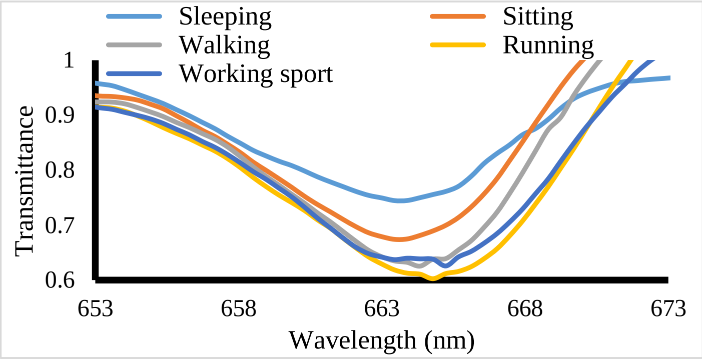

Figure 10. Transmittance spectra of 5 cm coreless fiber interferometer coated with gold & graphene with different breathing cases.

Figure 10 shows the transmission spectra of the sensor when coated with gold & graphene. When taking working sport, the transmission was 0.6402 at 663.44 wavelengths and for sleeping was 0.7442 at 665.78 nm wavelength.

Table 4 Numerical transmittance results for the proposed sensor

Breathing cases	Transmittance	SPR wavelength
Sleeping	0.7442	663.44
Sitting	0.6751	663.88
Walking	0.6390	665.23
Running	0.6025	664.78
Working sport	0.6402	665.78

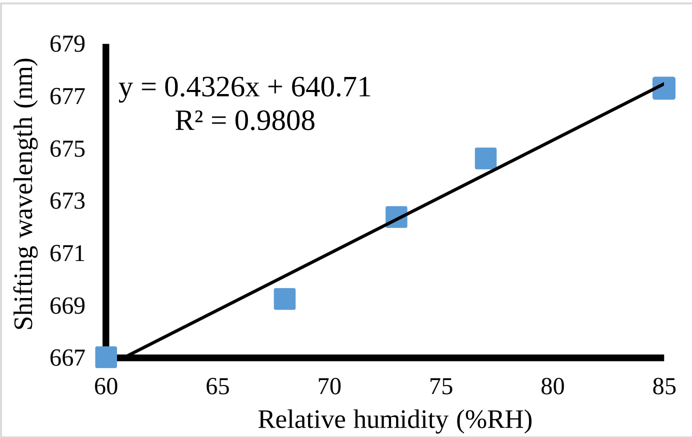

Figure 11. The relation between wavelength and refractive index for the breathing sensor coated with gold & graphene.

So, Figure 11 shows the relation between shifting wavelength and change in analyte RH; by taking the slope of the curve, we calculated the sensor's sensitivity was 432.6 pm / % RH. Response time was 1.2 sec.

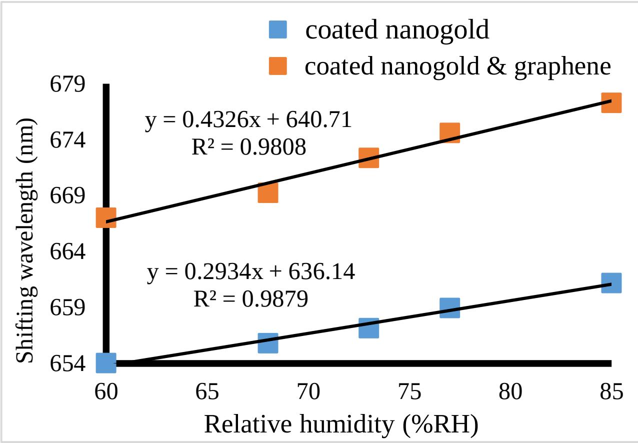

Figure 12. Wavelength shifts vs. refractive index of sensor coated with nanogold and nanogold & graphene.

Figure 12 shows the difference in the sensitivity of the sensor when coated. It is just nanogold particles and nanogold & graphene. It appears that when coated with just nanogold, the sensitivity is less than that coated with nanogold & graphene and the shifting wavelength increased because graphene was used to improve the performance of the sensor due to the ability of graphene to absorb moisture from the air. After all, it is composed of carbon and hydrogen.

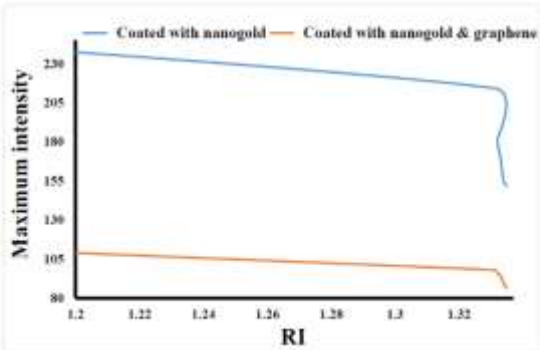

Figure 13. Maximum intensity vs. refractive index of sensor coated with nanogold and nanogold & graphene.

Figure 13 shows the difference between maximum intensity for coating the sensor with just nanogold and with nanogold & graphene. The absorbance of the moisture from air increased when the refractive index or concentration increased, and the intensity decreased. For coated with nanogold particles, the intensity is higher than when coated with gold & graphene, so the absorbance increases when coated the sensor with graphene because the sensor's performance improves.

Table 5 Comparision between nanogold and nanogold & graphene coating sensor

Coated with nanogold							
Breathing case	**intensity**	**shifting**	**FOM**	**Sensitivity**	**Resolution**	**Response time**	**LOD**
Sleeping	211.65	1.34	0.0211	294.3 pm/% RH	0.170 RH	2.5 sec	5.766 nm
Sitting	181.47	1.79	0.0176				
Walking	170	1.35	0.0152				
Running	155	1.8	0.0172				
Working sport	151.71	2.24	0.0123				
Coated with nanogold & graphene							
	Intensity	**shifting**	**FOM**	**Sensitivity**	**Resonsivity**	**Response time**	**LOD**
Sleeping	98	1.97	0.0313				
Sitting	95.62	2.23	0.0322	432.6 pm/% RH	0.115 RH	1.2 sec	2.658 nm
Walking	94.49	3.13	0.0345				
Running	89.7	2.24	0.0372				
Working sport	86	2.68	0.0254				

4. CONCLUSION

A successful respiratory monitoring system was developed based on a coreless fiber MZI interferometer coating with nanogold particles and gold & graphene. The system monitored respiratory rates for various activities based on calculating light intensity. When the respiratory rate increased, the light intensity decreased and made shifting wavelength for each activity. The highest intensity in the sleep state is the lowest rate of respiration; in the sitting and walking states, the intensity decreased because the respiratory rate increased in those cases, and the last states (running and working sports) were less intense. The transmittance of this sensor was also measured. From this research also conclude, the sensor coated with nanogold & graphene was better performance than coated with just nanogold particles because of the graphene is more able to absorb humidity as result of chemical structure that consist of carbon and hydrogen.

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