# Development of a Glucose Meter Using Boric Acid-Modified Carbon Dots as a Fluorescent Probe

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**Abstract**— A glucose meter has been developed utilizing boric acid-modified carbon dots as a fluorescence probe. Boric acid-modified carbon dots produce varying fluorescence emission with varying glucose concentration in water. Boric acid-modified carbon dots mixed with glucose addition was excited by a violet laser (405 nm), then the emission intensity was detected by a photodetector, to be converted to an electrical signal being an input signal for a microcontroller for glucose concentration measurement. The output voltage of the glucose meter is corresponding to the fluorescence emission measured by using a spectrofluorometer with glucose concentration in the boric acid-modified carbon dots.

At present, the detection of glucose, most commonly and already commercially, uses electrochemical methods [1]. However, several methods are currently developed, including optical methods such as photometry or spectrometry. The optical method is based on absorption or emission properties produced when light photons interact with glucose directly or through the media. The optical absorption method has been widely developed but there is no commercial tool based on this method that has been used clinically. The optical emission method, such as fluorescence, has also been developed so far, but it has not yet produced commercial devices to measure the concentration of glucose [2,3]. The fluorescence method is a very promising alternative for developing glucose concentration measurement because of its higher sensitivity and simple configuration.

The development of fluorescence sensors for glucose setection has been developed utilizing boronic acid as a fluorescence probe without enzyme addition [4,5]. Boronic acid has been known to be able to form a complex with glucose to generate specific fluorescence emission [6]. On the other hand, the use of nanomaterials for glucose fluorescence sensors is also being developed [7]. Further development is combining boronic acid with nanomaterials such as carbon dots as a fluorescence probe for glucose detection [7]. Carbon dots have been used as a fluorescence-based sensor probe to detect various chemical compounds such as glucose [8].

Functionalization of carbon dots by complexation with a functional ligand can be constructed as fluorescent biosensors for the detection of glucose without enzyme utilization. In this study, carbon dots were combined with boric acid as a fluorescence probe to detect glucose. Previously, boric acid has been used as a fluorescence probe for glucose detection [9,10]. Boric acid and boronic acid are simple molecules and they can form complexes with glucose to produce specific fluorescence emissions. This work develops a glucose meter based on boric acid-modified carbon dots that were used as a fluorescence probe.

In this work, a carbon dot was synthesized by microwave irradiation of acidic rice husk. A total of 100 g of rice husk was washed with water then dried in the oven for 3 hours at 100$^o$ C. Then, 1 g of clean rice husk was dissolved in 100 ml of 10 M $H_2SO_4$ solution in a small glass and covered with aluminium foil. The precursor was then put in a microwave oven and then irradiated with a power of 600 W for 12 minutes. After that, 1 ml of the precursor was diluted with 10 ml of distilled water. Figure 1 shows a TEM image of the carbon dots sample that has been synthesized from acidic rice husks through microwave irradiation. It can be seen in the TEM image that the carbon dots are evenly distributed in the aqueous sample.

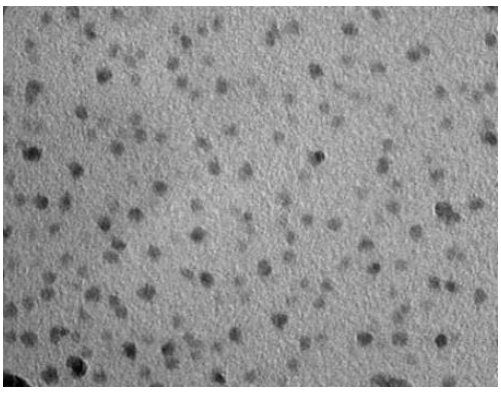

Fig. 1. TEM image of carbon dots produced from rice husk via microwave irradiation in acidic condition.

The effect of adding boric acid on the fluorescence emission characteristic of the carbon dot was tested. This test is done by dissolving boric acid with varied masses,

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namely 0.05 g, 0.1 g, and 0.5 g into 5 mL of carbon dots solution to form a boric acid-modified carbon dots solution. The solution samples were heated on a hot plate at 100ºC for 10 minutes. Furthermore, the samples were diluted with 50 mL of distilled water. The carbon dots solution samples with a varied boric acid content were tested by fluorescence spectroscopy.

Figure 2 shows the fluorescence emissions of boric acid-modified carbon dots solution being inversely proportional to the mass content of boric acid added. The more boric acid is added, the lower is the fluorescence emission of the boric acid-modified carbon dots solution. In accordance with the desired characteristics of the sensor material, a material composition that has inhibitory properties is needed, such as would not be a catalyst when the solution is mixed with glucose. Therefore, the composition of 0.5 g of boric acid dissolved in 5 mL carbon dots is the right composition as a sensor probe for detecting glucose via fluorescence emission.

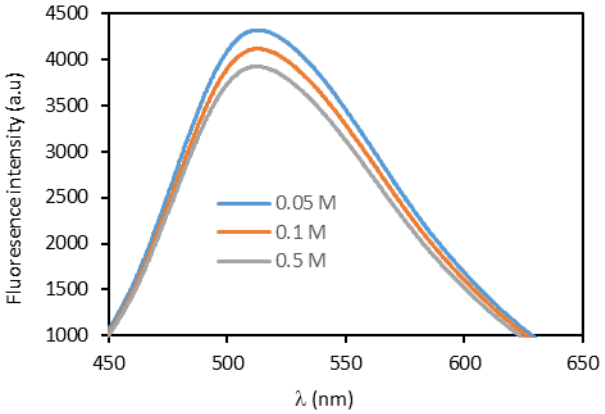


Fig. 2. Fluorescence spectra of the boric acid-modified carbon dots with a varying concentration of boric acid in 5 mL carbon dots.

The implementation of boric acid-modified carbon dots as a glucose sensor was done by studying the effect of glucose addition on fluorescence emission of the boric acid-modified carbon dots. The testing of sensor response was carried out by mixing 3 mL of boric acid-modified carbon dots solution with 3 mL of pure glucose solution with different concentrations, respectively are 0 M; 0.1 M; 0.5 M; 1 M. The test solutions were put into a cuvette then excited with a violet laser light (405 nm) to obtain the fluorescence emission using a spectrofluorometer (Ocean Optic). Fluorescence spectra were analyzed to know the effect of glucose addition on the emission of boric acid-modified carbon dots. The obtained data are used as a basis for developing a glucose meter in this work.

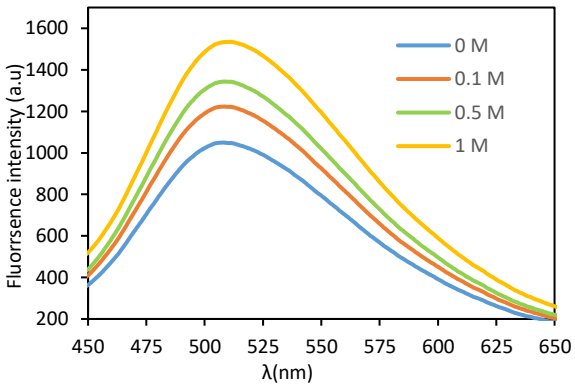


Fig. 3. Fluorescence of boric acid-modified carbon dots with various glucose concentrations.

Figure 3 shows an increase in the fluorescence emission of boric acid-modified carbon dots along with an increase in the glucose concentration given. The measurement results show that fluorescence emission has increased with its highest (peak) intensity occurring at a wavelength of 510 nm. The four emission peaks of the samples tested show an increase in intensity as the added glucose concentration increases. The data of peak fluorescent emission for each glucose concentration is displayed in a curve as shown in Fig. 4. It appears on the curve that there are two response ranges from the fluorescent sensor, namely at low glucose concentrations (below 0.05M), which have a higher slope, and a higher concentration range with a lower curve slope. Based on these data, boric acid-modified carbon dots can be applied as glucose sensors by fluorescence mechanism. The response of varied glucose concentrations to the emission intensity of boric acid-modified carbon dots is used as a basis for developing a glucose meter based on the microcontroller proposed in this work.

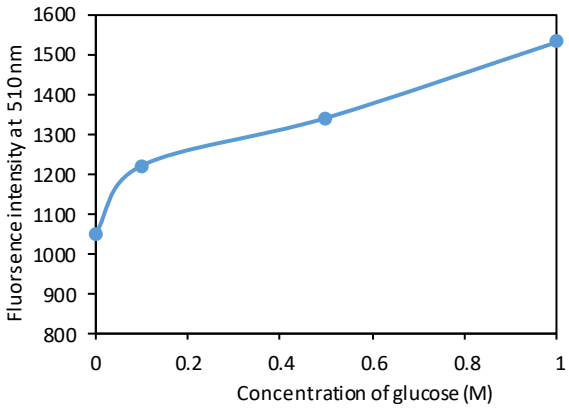


Fig. 4. The curve of fluorescence peaks of boric acid-modified carbon dots with varying concentration of glucose.

The design of the glucose meter was based on the response data of boric acid-modified carbon dots toward glucose, as can be seen in Fig. 4. The components needed

 

to design a glucose meter based on the fluorescence emission of boric acid-modified carbon dots are: a violet laser (405 nm) as an excitation source, photodetector (PD) used to detect fluorescent emission, 9V battery as a power source, Arduino Nano as a microcontroller, and Nokia 5110 LCD module used for displaying the measurement results as voltage data. The schematic circuit of the developed glucose meter is shown in Fig. 5.

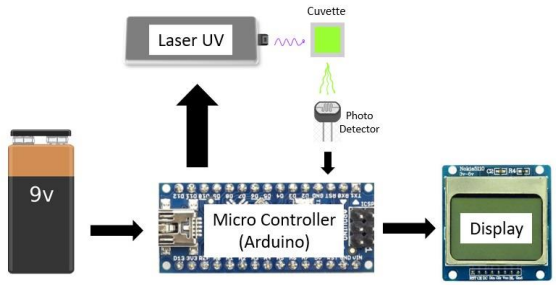


Fig. 5. Scheme of glucose meter based on microcontroller using carbon dots-boric acid fluorescence probe.

The boric acid-modified carbon dots solution with varying concentrations of glucose was placed in a cuvette. Then the complex solution was exposed to violet laser light (405 nm) powered by a battery as an excitation source. The fluorescent emission generated from the excitation process is detected by a photodetector, then converted into an electrical signal. The electrical signal is inputted to the microcontroller to be processed and then displayed on the display as voltage data.

The test results of the glucose meter are displayed in a plot of the curve as shown in Fig. 6. The curve displays the relationship between the sensor output (voltage) with the glucose concentration. The resulting curve pattern is similar to the peak of fluorescent emission data obtained using a spectrofluorometer (Fig. 4). This means that the output voltages of the glucose meter were correlated with the intensity peaks of fluorescence emissions.

The data pattern from the glucose meter (Fig. 6) follows the pattern of the spectrofluorometer data, namely the output voltage registered by the glucose meter and the emission intensity registered by the spectrofluorometer (Fig. 4). The curve of output voltage of glucose concentration has two response ranges of glucose meter data, similar to the spectrofluorometer data, namely a low concentration range (0 - 0.05 M) and a higher concentration range (0.05 - 1 M). It appears that at a low concentration (0 - 0.05 M) the slope of the curve more than at a higher concentration (0.05 - 1 M) indicating that the developed glucose meter has a higher sensitivity in a low concentration range of glucose.

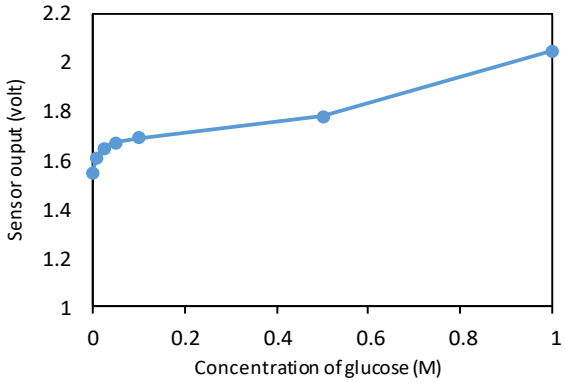


Fig. 6. Output of glucose meter versus glucose concentration.

The sensitivity of both response ranges is determined, based on the slope of both curve ranges, namely the range 0 - 0.025 M and 0.025 - 1 M. The sensitivity for the range 0 - 0.025 M is 3.095 V/M while for the range 0.025 - 1 M it is 0.388 V/M. Thus, the sensitivity at a low concentration (0 - 0.025 M) is ten times greater than that at a higher concentration (0.025 – 1 M).

In conclusion, a glucose meter has been designed that can measure variations in glucose concentration by utilizing the fluorescence response of boric acid -modified carbon dots. The output voltage of this glucose meter varies with glucose concentration and corresponds to the intensity of fluorescence emission produced by the boric acid-modified carbon dots - glucose complex. This glucose meter has high sensitivity at low concentrations of glucose in a range of 0 - 0.025 M.

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## References

[1] H. Teymourian, A. Barfidokht, J. Wang, Chem. Soc. Rev. **49**, 7671 (2020).
[2] D.C. Klonoff, J Diabetes Sci. Technol. **6**(6), 1242 (2012).
[3] J.C. Pickup, F. Hussain, N.D. Evans, O.J. Rolinski, D.J.S. Birch, Biosens. Bioelectron. **20**, 2555 (2005).
[4] H. Fang, G. Kaur, B. Wang, J. Fluoresc. **14**(5), 481 (2004).
[5] T. Kawanishi, M.A. Romey, P.C. Zhu, M.Z. Holody, S. Shinkai, J. Fluoresc. **14**(5), 499-512 (2004).
[6] A.S. Krishna, P.A. Nair, C. Radhakumary, K. Sreenivasan, Mater. Res. Express **3**(1), 055001 (2016).
[7] G.P.C. Mello, E.F.C. Simões, D.M.A. Crista, J.M.M. Leitão, L. Pinto da Silva, J.C.G. Esteves da Silva, Crit. Rev. Anal. Chem. **49**(6), 542 (2019).
[8] X. Shan, L. Chai, J. Ma, Z. Qian, J. Chen, H. Feng, Analyst **139**, 2322 (2014).
[9] J. Dong, S. Li, H. Wang, Q. Meng, L. Fan, H. Xie, C. Cao, W. Zhang, Anal. Chem. **85**(12), 5884 (2013).
[10] Y. Cui, F. Chen, X-B. Yin, Biosens. Bioelectron. **135**, 208 (2019).

 