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Potential of local material SiO_2 water Hyacinth for semiconductor materials

Sony Hidayat [1*], Ahmad Ziyan Nafis [1], Muhammad Noorman Perdana [1], Upik Nurbaiti [1]
[1]Department of Physics, Faculty of Mathematics and Natural Sciences, Semarang State University, Indonesia

* Corresponding author's e-mail: sonyhidayat777@students.unnes.ac.id

ABSTRACT
This study aims to examine the potential of local SiO_2 material synthesized from water hyacinth biomass waste as a candidate for semiconductor materials. Synthesis was carried out through a calcination process at temperatures above 600 °C to remove cellulose, lignin, and other impurities. Material characterization was carried out using UV-Vis spectroscopy, X-ray Diffraction (XRD), and Raman Spectroscopy. The results of UV-Vis spectroscopy showed that the water hyacinth derived SiO_2 exhibited an unusually reduced optical band gap of approximately 2.3 eV, likely influenced by impurity phases.. XRD tests indicated the presence of two crystal phases, namely the trigonal structure of SiO_2 and the monoclinic structure of the $CaH_{12}O_{17}Si_2U_2$ compound. Raman analysis confirmed the presence of functional groups such as Si, amorphous SiO2, CH_2/CH_3 and vibration signals from irregular sp^2 carbon. This combination of structures is thought to cause a lower band gap value compared to pure SiO_2. This finding indicates that SiO_2 from water hyacinth has potential as an intermediate semiconductor material, although further purification is still needed to increase the purity of the SiO_2 phase.

Keywords:
Band Gap; Local Water Hyacinth Biomass; Semiconductor; SiO_2.

Introduction

The development of semiconductor materials has become increasingly advanced in various fields of technology (Nurhayati et al., 2023). These applications include LEDs, computer chips, and renewable energy technologies. Semiconductors are materials that have unique properties, the energy gap is not too large, between metal and insulator materials (Rasyidi, 2015). One of the materials that is widely used in the manufacture of semiconductors is silicon (Si) because it has a fairly small band gap, around 1.4 eV, and 3-4 eV for silicon dioxide or silica (SiO_2) (Rai et al., 2014; Ücker et al., 2023). Research in the field of semiconductors has been widely carried out, but research that utilizes local organic materials is still not widely studied, especially biomass waste. Therefore, investigating biomass waste as a potential source of advanced materials is important for identifying locally derived alternatives.

According to Hidayat et al (2024) and Junaudi et al (2022), water hyacinth is one of the biomass waste materials that can be synthesized into silica. Water hyacinth is an aquatic weed that grows very quickly and is invasive if its population is not controlled (Kalsum, 2015) (Figure 1). Excessive water hyacinth populations will cause quite serious environmental impacts, such as shallowing of the water ecosystem, reduced water oxygen levels, excessive methane gas in the water ecosystem due to water hyacinth decay, and blockage of water flow due to excessive water hyacinth numbers (Ningsih et al., 2019; Ratnani et al., 2024; Zevriawan et al., 2023). Therefore, the existence of water hyacinth in nature needs to be controlled and utilized wisely. The processing of water hyacinth into handicrafts has been widely carried out by creative economy activists, but other potentials need to be further developed, one of which is for semiconductor materials.

The purification of SiO_2 from water hyacinth is carried out using the calcination method, calcination is a material purification process using a heating temperature in the range of 500°C-1000°C (Usman et al., 2020; Pratama et al., 20230. In this case, calcination is intended to purify

SiO_2 from cellulose, lignin and unnecessary impurities, so that it is expected to produce SiO_2 with high purity. In addition, the calcination process is intended to form a more uniform SiO_2 crystal structure.

(a) **(b)**

Figure 1. (a) Ilustration of Over Population Water Hyacinth on Bengawan Solo River (KOMPAS.COM); (b) Ilustration of Over Population Water Hyacinth on Martapura River (KOMPASIANA.COM).

This study focuses on determining the band gap value of SiO_2 synthesized from water hyacinth, its crystal structure and functional groups. However, this study does not cover the direct application of SiO_2 material, this is also a limitation in the study.

Methods

Synthesis of water hyacinth SiO_2

Figure 2. Extraction Process SiO_2 from Water Hyacinth.

Freshly obtained water hyacinth is cleaned from impurities and then dried under the hot sun. The dried water hyacinth is then burned using conventional methods to obtain its ash (Figure 2). Next, 150 mL of citric acid solution ($C_6H_8O_7$) is added to 48 g of the water hyacinth ash. Soaking is carried out for several minutes with a total mixture temperature of around 50°C using a stirrer heater. Water hyacinth that has been soaked in citric acid solution is then washed with hot water 3 times to remove the citric acid content in it. The residue from washing in the form of water hyacinth ash is then ovened at a temperature of 100°C for 25 minutes. The next step is the purification of SiO_2 using a furnace at a temperature above 600°C. (Hutomo, 2017). Then the synthesis results were tested using UV-VIS to determine the band gap of the material, XRD to determine the crystal structure of the synthesized SiO_2 material, and Raman Spectroscopy to determine the functional groups of the material.

Results and Discussions

Water hyacinth has been synthesized into powder suspected to be SiO2. The powder obtained was then subjected to XRD characterization to see the crystals and validate the presence of SiO2, then strengthened with Raman spectroscopy, then to see the semiconductor properties of the band gap, UV-Vis characterization was carried out (Figure 3).

Figure 3. Results of Extraction SiO_2 from Water Hyacinth.

UV-VIS Analysis

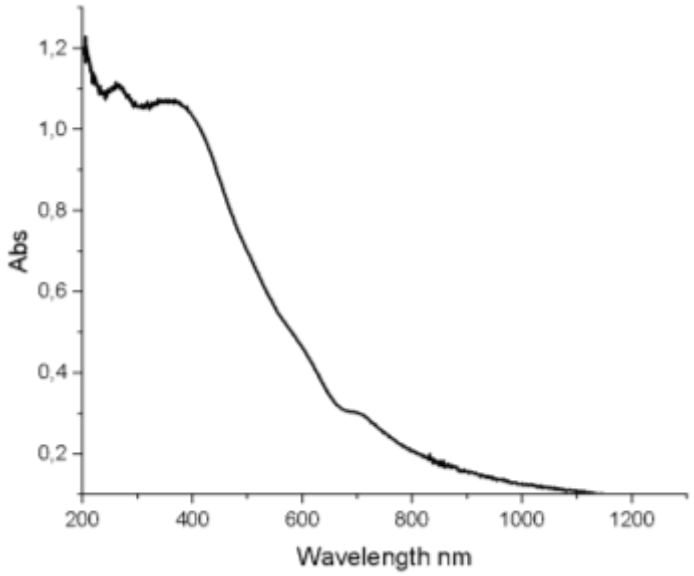


Figure 4. Graph of SiO_2 Absorbance Value of Water Hyacinth

The results of the synthesis of SiO_2 water hyacinth powder were then tested for optical absorbance using UV-VIS Spectroscopy in the testing wavelength range of 200nm-1200 nm. It can be seen that there is one fairly sharp absorbance peak, which indicates an electronic transition from the valence band to the conduction band (Figure 4). The phenomenon of the emergence of one fairly sharp absorbance peak indicates that the SiO_2water hyacinth material has direct band gap characteristics, because indirect band gap materials generally occur two or more energy transitions accompanied by tiered absorbance due to phonon participation (Sharma et al., 2012). In direct band gap materials, electron transitions from the valence band to the conduction band can occur directly without any change in momentum, resulting in one sharp peak in the absorbance spectrum (Muttaqin, 2015). Thus, the water hyacinth–derived SiO_2 appears to exhibit direct band gap behavior (Babyszko et al., 2023). To find out the band gap value, further analysis can be carried out using the tauc plot method with the equation:

$$(\alpha hv)^n = A(hv - E_g)$$

Where is the absorption coefficient, is the photon energy, is a constant, is the band gap energy, is the value for direct transitions, and is for indirect transitions.$\alpha h\nu A E_g n = 2\ n = \frac{1}{2}$.

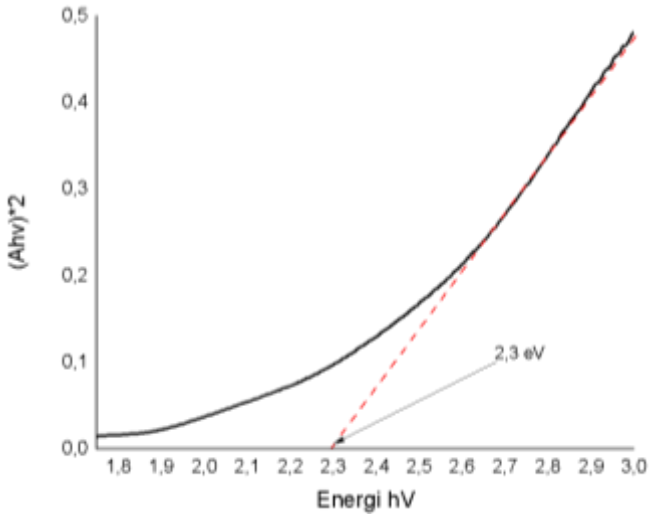


Figure 5. Energy Gap Graph SiO_2 Water Hyacinth Tauc Plot Method

The Tauc plot analysis yielded a band gap value of approximately 2.3 eV (Figure 5). The band gap value of 2.3 eV is included in the category of semiconductors with an intermediate band gap, which is too small for an insulator and too large for a metal conductor, but is ideal for various light-active semiconductor applications such as red-orange LEDs (λ ~540–560 nm) which require materials with a band gap of around 2 eV (Telefunken, 1999). When compared with research by Seguini et al (2011); Hussin (2017), SiO_2 has a band gap of around 3eV-5eV, while SiO_2 synthesized from water hyacinth has a band gap of around 2.3eV. This is likely due to the presence of other elements or compounds that are still present in the SiO_2 from the synthesized water hyacinth. The fairly flat graph curve indicates that the SiO_2 synthesized from water hyacinth is not completely pure, in contrast to the band gap graph of SiO_2 which tends to be almost vertical. Therefore, further analysis is needed with XRD to determine the structure of the crystals in the material, as well as Raman Spectroscopy analysis to determine the presence of other functional groups in the synthesized material.

X-Ray Drifraction XRD Analysis

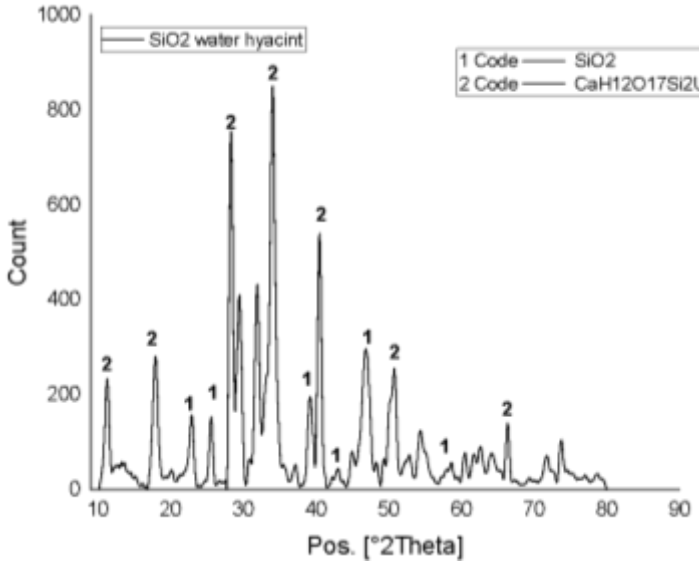
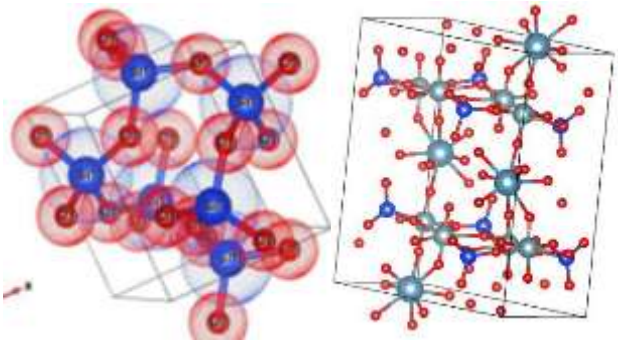


Figure 6. XRD Graph of SiO_2 Water Hyacinth

The results of the synthesis of SiO_2 water hyacinth will then be characterized by XRD (target Cu, λKα = 1.54060 A˚). Testing using XRD aims to determine the crystal phase that appears and to determine the crystal shape formed from the sample.

After the XRD characterization test was carried out, the data obtained were then processed using Match Software with the Crystallography Open Database (COD) 2025 comparative database (Figure 6). The diffraction peaks shown (2 Θ) (code 1): 23; 25.99; 39.02; 43; 46.9; 58.71, are diffraction peaks owned by the SiO_2 crystalline structure, with a trigonal crystal structure, and COD id code: 8103513. The peaks at 2θ = 11.25°, 17.88°, 28.35°, 34.2°, 40.8°, 47.02°, 50.84°, and 66.4° (code 2) correspond to a monoclinic phase indexed in the COD as $CaH_{12}O_{17}Si_2U_2$ (COD ID 9014766). The emergence of crystal structures other than SiO_2 is a by-product of imperfect material synthesis. Basically, the elements Ca, H, and O are indeed found in the structure of organic materials, especially plants, so the emergence of the $CaH_{12}O_{17}Si_2U_2$ crystal system is very common if the purification process is not perfect. To visualize the trigonal SiO_2 and monoclinic $CaH_{12}O_{17}Si_2U_2$ structures, the corresponding COD files were processed using VESTA software(Figure 7).



(a) **(b)**

Figure 7. (a) Crystal structure of SiO_2 , (b) Crystal structure of $CaH_{12}O_{17}Si_2U_2$

Raman Spectroscopy Analysis

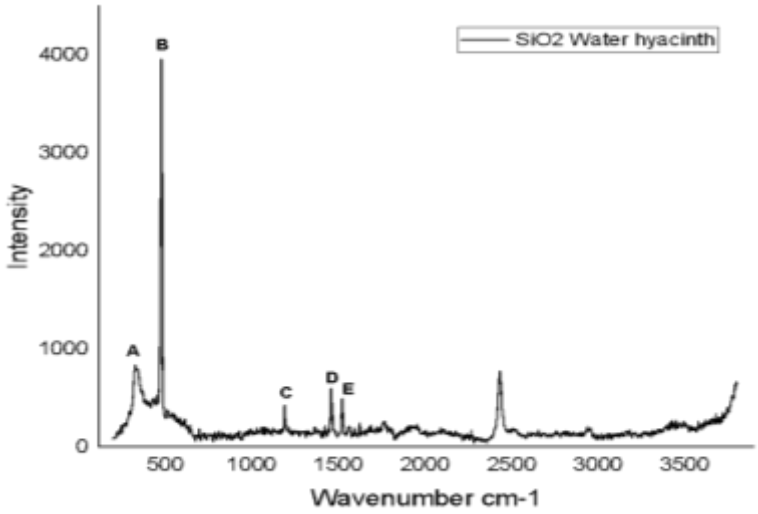


Figure 8. Raman Spectroscopy Graph of SiO_2 Water Hyacinth

The SiO_2 water hyacinth sample was then subjected to Raman Spectroscopy characterization test to see the phase of the compound or other elements in the sample (Figure 8). The Raman characterization test was carried out in the wave number range of 100-4000 cm-1. The Raman spectroscopy graph shows several sharp peaks and quite a lot of noise at several wave number points (Table 1). The appearance of noise is likely due to the camber of the sample used and the appearance of fluorescence phenomena in the sample when exposed to laser light. Fluorescence is a phenomenon where the outermost electrons in the sample compound are excited, and emit light with a higher wavelength than the wavelength of the exciting light. In Raman Spectroscopy testing this often occurs, especially in organic samples, usually this phenomenon appears in the low wave number range of 300-450 cm-1 depending on the sample.

Table 1. Functional Group of SiO_2 Water Hyacinth

Code	Wave Number cm-1	Intensity	Bond
A	336.24	664.68	Fe-S
B	471.89	3962.64	Si-a
C	1100	401	SiO_2
D	1458.33	455.85	CH2/CH3
E	1529.06	408.74	G

According to Galuskina et al (2025) The spectrum peak at wave number 336 cm-1 is related to the symmetric stretching vibration of Fe-S. The appearance of the Fe element in the sample is most likely due to contaminants during the sample refining process. The spectrum peak that appears at wave number 471 cm-1 is a peak indicating the presence of vibrations of the Si-a element which is an amorphous Si compound, as reported by Abed et al (2020). The noise spectrum that appears in the wavelength range of 1100 cm-1 is a spectrum peak indicating the presence of SiO_2 compounds (Abed et al., 2020). Meanwhile, the spectrum peak that appears at wave number 1458 cm-1 is a peak due to deformation of the CH_2/CH_3 compound as reported by research conducted by Zyubin et al in 2018. Peak D at wave number 1529 cm-1 according to research conducted by Galaburda et al (2019); Tan et al (1999); Cho et al (2015) can be associated with the spectrum due to irregular sp2 carbon Graphene (G) vibrations. The emergence of graphen elements or carbon bonds (C) is very natural if the purification process is not perfect, the C element appears from the burning process of water hyacinth which has not completely disappeared during calcination. The results of Raman Spectroscopy testing support XRD and UV-VIS test data showing compounds other than SiO_2, causing a decrease in the band gap value compared to pure SiO_2.

UV-VIS characterization shows that the SiO_2 material synthesized from water hyacinth has direct band gap properties and has a band ap value of 2.3 eV using the touch plot method. The results of the XRD test showed that the synthesized material had 2 types of crystal phases, namely Trigonal SiO_2 and monoclinic $CaH_{12}O_{17}Si_2U_2$. Raman Spectroscopy testing shows the presence of Si, amorphous SiO_2, CH_2/CH_3 and Vibrations of the G element.

Conclusion

The results of the study showed that the SiO_2 compound synthesized from water hyacinth has a type of electron transfer from the conduction band to the valence band of the direct band gap type. In addition, the SiO_2 compound from water hyacinth also has an energy gap of 2.3 eV. This indicates that the synthesized water hyacinth–derived SiO_2 can be classified as an intermediate-band-gap semiconductor. XRD analysis shows 2 crystal structure phases, namely trigonal SiO_2 and $CaH_{12}O_{17}Si_2U_2$ monoclinic. CH_2/CH_3 and Graphene (G) compounds are also still present in the synthesized SiO_2 material. This combination has justified the value of the SiO_2 band gap from water hyacinth 2.3 eV is influenced by other compounds, not purely from SiO_2.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

References

Abed, Mm, & Kiani, A. (2020). Emissivity Study Of Nanofibro-Porous Si/Sio2 Structures Synthesized By Picosecond Pulse Deposition At Varied Laser Scanning Speeds And Repetition Rates. Results In Materials, 8, 100157.

Babyszko, A., Wanag, A., Kusiak-Nejman, E., & Morawski, A. W. (2023). Effect Of Calcination Temperature Of Sio2/Tio2 Photocatalysts On Uv-Vis And Vis Removal Efficiency Of Color Contaminants. Catalysts, 13(1), 186.

Cho, J., Jung, D., Kim, Y., Song, W., Adhikari, Pd, An, Ks, & Park, Cy (2015). Fabrication Of Graphene Pn Junction Field Effect Transistors On Patterned Self-Assembled Monolayers/Substrates. Applied Science And Convergence Technology, 24(3), 53-59.

Galaburda, M., Kovalska, E., Hogan, B.T., Baldycheva, A., Nikolenko, A., Dovbeshko, G.I., ... & Bogatyrov, V.M. (2019). Mechanochemical Synthesis Of Carbon-Stabilized Cu/C, Co/C And Ni/C Nanocomposites With Prolonged Resistance To Oxidation. Scientific Reports, 9(1), 17435.

Galuskina, I.O., Krüger, B., Galuskin, E.V., Krüger, H., Vapnik, Y., Murashko, M., ... & Agakhanov, A.A. (2025). Zoharite,(Ba, K) 6 (Fe, Cu, Ni) 25s27, And Gmalimite, K6□ Fe2+ 24s27—New Djerfisherite Group Minerals From Gehlenite-Wollastonite Paralava, Hatrurim Complex, Israel. Minerals, 15(6), 564.

Hutomo, Dk (2017). Synthesis And Characterization Of Composite Electromagnetic Wave Absorber Based On Upr With Fe3o4 Filler From Iron Sand And Sio2 From Rice Husk (Doctoral Dissertation, Jakarta State University).

Hussin, Shaa (2017). Study The Nanoporous Sio2–Tio2 Doped With Er And La Thin Films Properties Antireflection And Self-Cleaning Applications (Doctoral Dissertation, College Of Science For Women Physics Department Study The Nanoporous Sio2–Tio2 Doped With Er And La Thin Films Properties Antireflection And Self-Cleaning Applications A Thesis Submitted To The Council Of College Of Science For Women, University Of Baghdad).

Hidayat, S., Fianti, F., Nurbaiti, U., & Astuti, B. (2024). Structure And Morphology Of Absorber Material Based On Iron Sand With Sio_2 Fortification From Water Hyacinth. Journal Of Natural Sciences And Mathematics Research, 10(2), 189-199.

Junaudi, A., & Oemiati, N. (2022). Utilization Of Water Hyacinth Ash As An Additive To Increase Concrete Compressive Strength. Bearing: Journal Of Civil Engineering Research And Studies, 7(3), 137-145.

Kalsum, U. (2015). Utilization Of Water Hyacinth As A Color Absorbent In Waste Textile Industry As An Effort To Reduce Water Pollution. Berkala Teknik, 5(1), 786-800.

Muttaqin, Fd (2015). Study Of The Effect Of Annealing On The Properties Of Hydrogenated Amorphous Silicon (A-Si:H) Grown By Pecvd Method (Doctoral Dissertation, Institut Teknologi Sepuluh Nopember).

Ningsih, Yw, Kurniawan, T., Rahmawati, An, Permatasari, Da, Ghunarso, Dah, Pratama, Ra, ... & Widiyatmoko, W. (2019). Public Perception Of Water Hyacinth Plants In Rawa Pening In Banyubiru Village, Semarang Regency. Journal Of Geography, Education And Environment (Jgel), 3(2), 83.

Nurhayati, E., & Angdreas, K. (2023). Semiconductor Industry Investment Development Strategy In Indonesia. Sainstekes Magazine, 10(1), 049-067.

Pratama, Y., & Irfa'i, Ma (2023). Effect Of Temperature And Calcination Time On The Purity Of Bovine Bone-Based Hydroxyapatite Using The Precipitation Method. Journal Of Mechanical Engineering, 11(01), 7-12.

Rai, C., Pandey, P., Parra, M.R., & Haque, F.Z. (2014). Optical, Dielectric And Impedance Studies Of Sio2/Mwcnt Nanocomposite Synthesized Through In-Situ Ultrasonication-Assisted Sol–Gel Method. Journal Of Advanced Physics, 3(3), 194-204.

Rasyidi, M. (2015). Analysis Of Optical Properties Of Sio2-Zno Powder Mixture With Temperature Variation As An Alternative Semiconductor Material In Solar Cells (Doctoral Dissertation, State Islamic University Of Maulana Malik Ibrahim).

Ratnani, Rd, Hartati, I., & Kurniasari, L. (2024). Utilization Of Water Hyacinth (Eichorniacrassipes) To Reduce Cod (Chemical Oxygen Depletion), Ph, Odor, And Color Content In Tofu Liquid Waste. Research And Community Service Report.

Seguini, G., Schamm-Chardon, S., Pellegrino, P., & Perego, M. (2011). The Energy Band Alignment Of Si Nanocrystals In Sio2. Applied Physics Letters, 99(8).

Sharma, D., Gaur, P., Malik, B. P., Singh, N., & Gaur, A. (2012). Intensity Dependent Nonlinear Absorption In Direct And Indirect Band Gap Crystals Under Nano And Picosecond Z-Scan. Optics And Photonics Journal, 2(2), 98-104.

Telefunken, V. (1999). Physics Of Optoelectronic Devices Light-Emitting Diodes.

Ücker, C.L., Almeida, S.R., Maron, Gk, Carreno, Nlv, Morisso, F.D.P., Da Silva Cava, S., & Raubach, C.W. (2023). Using Rice Husk Ash As A Sio2 Source In The Preparation Of Sio2/Nb2o5 And Sio2/Zns Heterostructures For Photocatalytic Applications. Environmental Science And Pollution Research, 30(26), 68477-68488.

Usman, Mr, Nabila, R., & Hakiki, Ln (2020). Calcium Extraction From Green Mussel Shells (Perna Viridis L.) And Batik Mussels (Paphia Undulata B.) By Calcination Method As Effervescent Preparation. Indonesian Journal Of Chemical Research, 8(2), 101-107.

Zevriawan, Ab, Adina, R., Aulia, Nm, Jagadraya, Sp, & Maulid, D. (2023). Processing Of Water Hyacinth Waste Into Eco Enzyme As An Effort To Manage The Environmental Quality Of Jatibarang Reservoir With A Partnership Concept. E-Amal: Journal Of Community Service, 3(3), 175-180.

Zyubin, A., Lavrova, A., Manicheva, O., Dogonadze, M., & Samusev, I. (2018). Dataset Of Single Mycobacterium Tuberculosis Bacteria Cells With Different Antibiotic Susceptibility Obtained By Raman Spectroscopy. Data In Brief, 21, 2430-2434.