Articles

Physical Society of Indonesia

Journal of the Physical Society of Indonesia **1(2)**, 116-122 (2025)

https://doi.org/10.35895/jpsi.1.2.116-122.2025

Synthesis and Characterization of $ZnO@SiO_2$ Composite for Microwave Absorber Applications

Muhammad Fauzan[1], Aditia Nur Bakti[2], Elvina Trivida[2], Nova Nur Elisa Dewi[1], Djoko Triyono[3], Iwan Sugihartono[1*]**

[1]Physics Study Program, FMIPA, Universitas Negeri Jakarta, Jl. Rawamangun Muka, Jakarta, 13220, Indonesia
[2]Research Center for Testing Technology and Standards, National Research and Innovation Agency, Banten, 15314, Indonesia
[3]Physics Department, FMIPA, Universitas Indonesia, Kampus UI Depok, Depok, 16424, Indonesia

(September 05, 2025; revised October 10, 2025; accepted 11, 2025; published online October 13, 2025)

This study aims to synthesize $ZnO@SiO_2$ composites via biosynthesis using *Moringa oleifera* leaf extract and to investigate the effect of different SiO_2 contents (pure ZnO, 1%, 3%, and 5% by weight) on their structural and microwave absorption properties, with ZnO prepared from a $Zn(NO_3)_2 \cdot 4H_2O$ precursor and calcined at 450 °C for 2 hours. The synthesized samples were characterized using X-ray Diffraction (XRD) and a Vector Network Analyzer (VNA). XRD results confirmed that all samples exhibited a hexagonal wurtzite crystal structure with space group $P6_3mc$ and showed no secondary phases. The crystallite size decreased with increasing SiO_2 content, indicating nanoparticle formation and reduced crystallinity. VNA measurements showed that the $ZnO@SiO_2$ sample with 3% SiO_2 exhibited the best microwave absorption performance, with a minimum reflection loss (RL) value of –2.0251 dB at a frequency of 6.125 GHz. These results suggest that the 3% composition achieved better impedance matching and enhanced absorption efficiency.

Keywords: *$ZnO@SiO_2$, biosynthesis, moringa oleifera, microwave absorption*

1. INTRODUCTION

The rapid development of advanced technology, particularly in defense and communication systems, has increased the demand for materials capable of mitigating electromagnetic interference (EMI) and reducing radar detection (Mathur et al., 2020). Radar Absorbing Materials (RAMs) play a crucial role in stealth technology by converting incident electromagnetic waves into thermal energy through dielectric and/or magnetic loss mechanisms, thereby minimizing reflected signals (Taryana et al., 2019). Among potential RAM candidates, zinc oxide (ZnO) has attracted significant interest due to its wide bandgap (~3.4 eV), high dielectric activity, non-toxicity, and environmental friendliness (Du et al., 2021). However, pure ZnO often suffers from particle agglomeration and limited structural stability, which can reduce its absorption efficiency. To address these limitations, silica (SiO_2) is introduced as a coating material to form a core–shell $ZnO@SiO_2$ structure. SiO_2, being an amorphous dielectric, can improve impedance matching, enhance particle dispersion, and induce interfacial polarization, thereby boosting microwave absorption performance (Yang et al., 2023). Conventional synthesis methods for $ZnO@SiO_2$ often involve hazardous chemicals and high energy consumption, raising environmental concerns. In contrast, green synthesis approaches utilizing plant extracts have emerged as sustainable alternatives, offering eco-friendly, low-cost, and biocompatible processes (Ahmed et al., 2017). Moringa oleifera leaves are particularly promising as a reducing and stabilizing agent due to their high content of bioactive compounds such as flavonoids, phenolics, and terpenoids, which can facilitate the reduction of metal ions and prevent nanoparticle aggregation (Sugihartono et al., 2024; Guda et al., 2023).

Contact Author: *Iwan-Sugihartono@unj.ac.id; ** adit006@brin.go.id

Previous studies have demonstrated that plant-mediated biosynthesis can produce nanoparticles with desirable structural and functional properties for various applications, including photocatalysis, sensing, and electromagnetic wave absorption (Asmathunisha & Kathiresan, 2012; Iravani, 2011). This study aims to synthesize $ZnO@SiO_2$ composites via biosynthesis using *Moringa oleifera* leaf extract and to investigate the effect of different SiO_2 contents (pure ZnO, 1%, 3%, and 5% by weight) on their structural, and microwave absorption properties. The synthesized materials were characterized using X-ray Diffraction (XRD) to determine crystal structure and crystallite size, and Vector Network Analyzer (VNA) for evaluating microwave absorption performance. The findings are expected to contribute to the development of environmentally friendly and cost-effective RAMs with optimized structural and electromagnetic properties for defense and EMI shielding applications.

2. METHOD

Moringa oleifera leaves were washed with distilled water, dried at room temperature for 7 days, ground into powder, and sieved. A total of 25 g of the powder was boiled in 250 mL of distilled water at 80 °C for 30 minutes, then filtered to obtain the extract. A zinc nitrate hexahydrate [$Zn(NO_3)_2{\cdot}4H_2O$] solution with a concentration of 0.8 M was prepared and heated to 80 °C while being stirred. Moringa oleifera extract was added dropwise, and the pH was adjusted to 10 using NaOH. The mixture was stirred for 30 minutes to form a $Zn(OH)_2$ precipitate. The precipitate was washed with distilled water and ethanol, dried at 80 °C for 12 hours, and calcined at 450 °C for 2 hours to produce ZnO powder. The $ZnO@SiO_2$ composite was prepared by mixing 2 g of ZnO powder with SiO_2 powder at variations of (pure ZnO, 1%, 3%, and 5% by weight) in a mixture of 160 mL ethanol and 40 mL distilled water. The mixture was stirred for 30 minutes, and the pH was adjusted to 9–10 using NaOH. Stirring was continued for 4 hours at room temperature. The resulting precipitate was washed with distilled water and ethanol, dried at 80 °C for 12 hours, and ground into fine powder. X-ray Diffraction (XRD) was used to determine the crystal structure, and a Vector Network Analyzer (VNA) with the coaxial-line method in the frequency range of 4.3–8.5 GHz was used to measure microwave absorption properties.

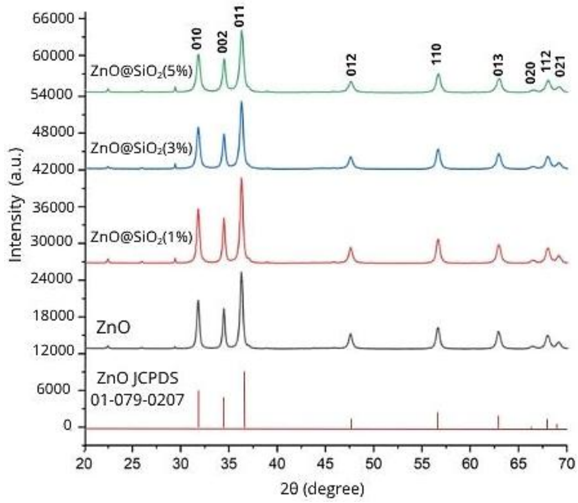

Figure 1. X-Ray Diffraction (XRD) pattern of $ZnO@SiO_2$ nanoparticle synthesis results with variations in SiO_2 concentration of (pure ZnO, 1%, 3%, and 5% by weight).

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 XRD

Figure 1 shows the X-ray diffraction (XRD) pattern of $ZnO@SiO_2$ material with variations in SiO_2 concentration of (pure ZnO, 1%, 3%, and 5% by weight). The diffraction pattern displays the highest intensity peaks on the (100), (002), and (101) planes, which are characteristic of the wurtzitetype hexagonal crystal structure of ZnO. The XRD pattern does not show any additional peaks indicating a second phase or other impurity compounds. This indicates that the addition of SiO_2 does not change the main structure of ZnO and does not form new compounds. This finding is in line with the results of research by Godavarti et al. (2019), which stated that phase purity can be identified from the absence of foreign peaks in the diffraction pattern.

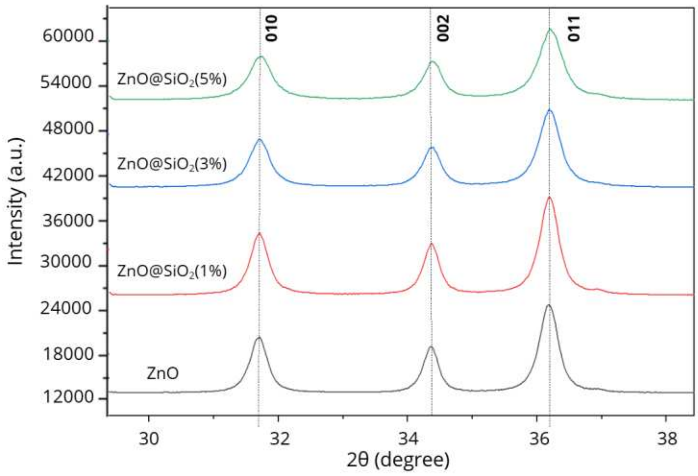

Figure 2. Diffraction angle shift of ZnO & $ZnO@SiO_2$ nanoparticles with variations in SiO_2 concentration of (1%, 3%, and 5%).

Based on Figure 2, the diffraction peaks for the (010), (002), and (011) planes of ZnO and the $ZnO@SiO_2$ composite (1%, 3%, and 5%) appear at similar 2θ angles, indicating that the addition of SiO_2 does not significantly change the d-spacing of the crystal planes. This indicates that the ZnO crystal structure remains stable after modification with SiO_2. XRD analysis was performed using HighScore Plus software, with reference data from JCPDS No. 01-079-0207, which refers to the hexagonal wurtzite ZnO structure. All samples exhibit diffraction patterns consistent with a hexagonal polycrystalline crystal structure, with the space group $P6_3mc$.

Table 1. Structural parameters of $ZnO@SiO_2$ nanoparticles with (SiO_2: pure ZnO, 1%, 3%, and 5% by weight).

Sampel	**Structural Parameters**				
	2θ (°)	**Crystallite Size (nm)**	**d-spacing (Å)**	**FWHM (°)**	**Micro Strain (%)**
			hkl (010)		
ZnO	31.6631	37.25478	2.82357	0.3628	0.373641
$ZnO@SiO_2$ **(SiO_2: 1%)**	31.672	31.76192	2.8228	0.3864	0.381694
$ZnO@SiO_2$ **(SiO_2: 3%)**	31.6732	27.57151	2.82269	0.4392	0.441636
$ZnO@SiO_2$ **(SiO_2: 5%)**	31.6886	16.02429	2.82136	0.5138	0.355121
			hkl (002)		
ZnO	34.3246	33.08549	2.61048	0.3628	0.318229
$ZnO@SiO_2$ **(SiO_2: 1%)**	34.3336	27.0398	2.60984	0.3864	0.30785
$ZnO@SiO_2$ **(SiO_2: 3%)**	34.336	22.1056	2.60964	0.4392	0.336006
$ZnO@SiO_2$ **(SiO_2: 5%)**	34.3526	14.95951	2.60842	0.5138	0.271795
			hkl (011)		
ZnO	36.1505	50.40537	2.48271	0.3628	0.365447
$ZnO@SiO_2$ **(SiO_2: 1%)**	36.1604	44.34186	2.48205	0.3864	0.384994
$ZnO@SiO_2$ **(SiO_2: 3%)**	36.1662	39.66764	2.48159	0.4392	0.448642
$ZnO@SiO_2$ **(SiO_2: 5%)**	36.1788	19.88283	2.48083	0.5138	0.40339

The decrease in crystallite size with increasing SiO_2 addition indicates that SiO_2 particles are able to inhibit the growth of ZnO grains, resulting in smaller and more finely distributed particles.

Table 2. Lattice parameters of $ZnO@SiO_2$ nanoparticles (SiO_2: pure ZnO, 1%, 3%, and 5% by weight).

Lattice Parameters	Sampel			
	ZnO	**$ZnO@SiO_2$ (SiO_2: 1%)**	**$ZnO@SiO_2$ (SiO_2: 3%)**	**$ZnO@SiO_2$ (SiO_2: 5%)**
a = b (Å)	3.2496	3.2489	3.2488	3.2482
c (Å)	3.2496	5.204	5.2038	5.203
c/a	1.601791	1.601772	1.60176	1.60181
α = β (°)	90	90	90	90
γ (°)	120	120	120	120
Volume (Å³)	47.6023	47.5708	47.5661	47.5412

3.1.2 VNA

Based on VNA measurements (Figure 3), the maximum and minimum RL values were obtained for the four samples, namely ZnO and $ZnO@SiO_2$ (SiO_2: 1%, 3%, and 5%), as shown in Table 3. The table shows that all samples exhibit microwave absorption capabilities, although the best absorption performance was obtained with the $ZnO@SiO_2$ (3%) composition. The $ZnO@SiO_2$ sample showed the largest minimum RL value, at -2.0251 dB at a frequency of 6.125 GHz, indicating the highest microwave absorption capacity. This indicates that the addition of 3% SiO_2 is the optimum composition in the $ZnO@SiO_2$ system for microwave absorption at that frequency. Conversely, a decrease in absorption performance occurred with the addition of 5% SiO_2, which could be caused by particle agglomeration or an imbalance in the material's microstructure.

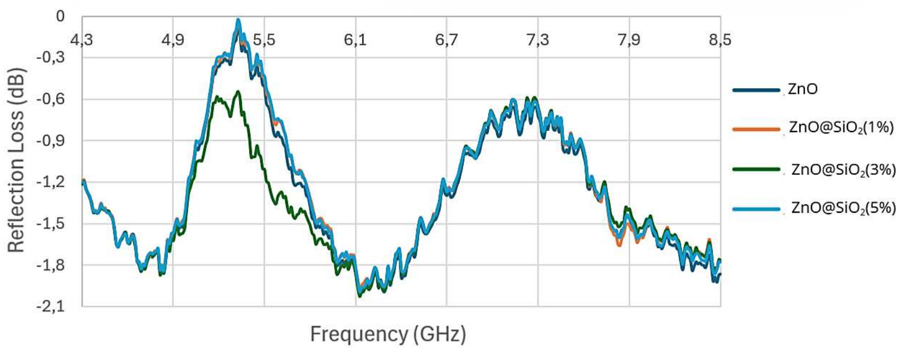

Figure 3. The relationship curve between the RL value and the frequency range of 4.3Ghz - 8.5Ghz for each sample, namely pure ZnO, and ZnO with the addition of SiO_2 of 1%, 3%, and 5%.

Table 3 Lattice parameters of ZnO & $ZnO@SiO_2$ nanoparticles (1%, 3% and 5%).

	Frequency (GHz)	**ZnO**	**$ZnO@SiO_2$ (SiO_2: 1%)**	**$ZnO@SiO_2$ (SiO_2: 3%)**	**$ZnO@SiO_2$ (SiO_2: 5%)**
RL min (dB)	6.125	-1.9971	-1.9697	-2.251	-1.9934
RL max (dB)	5.325	-0.0842	-0.036	-0.5433	-0.0252

Figure 4 shows a comparison graph of the absorption levels of $ZnO@SiO_2$ (SiO_2: SiO_2: pure ZnO, 1%, 3%, and 5% by weight) and SiO_2/CNT (SiO_2: 0.5%, 1%, 2%), ZIF, 1% Ni/ZIF-67. To evaluate the microwave absorption performance of the $ZnO@SiO_2$ nanocomposite, a comparison was made with several comparative materials that had previously been studied at BRIN in 2024, namely SiO_2/CNT materials (with variations of 0.5%, 1%, and 2%), ZIF, and 1% Ni/ZIF-67.

The VNA results show that the $ZnO@SiO_2$ sample with a composition of 3% has the best microwave absorption performance, with a RL value of 2.0251 dB at a frequency of 6.125 GHz, demonstrating the best performance, among variations of ZnO & $ZnO@SiO_2$ (SiO_2: 1%, 5%), and other comparison materials such as SiO_2/CNT (SiO_2: pure ZnO, 1%, 3%, and 5% by weight), ZIF, 1% Ni/ZIF-67. This study shows that the best microwave absorption (RL) performance is in $ZnO@SiO_2$ with 3%

SiO_2. This indicates that the combination of this composite with a ZnO@SiO_2 core-shell structure is able to well combine the absorption strength of ZnO with the stability and smoothness of the morphology of SiO_2. This composite produces a good combination.

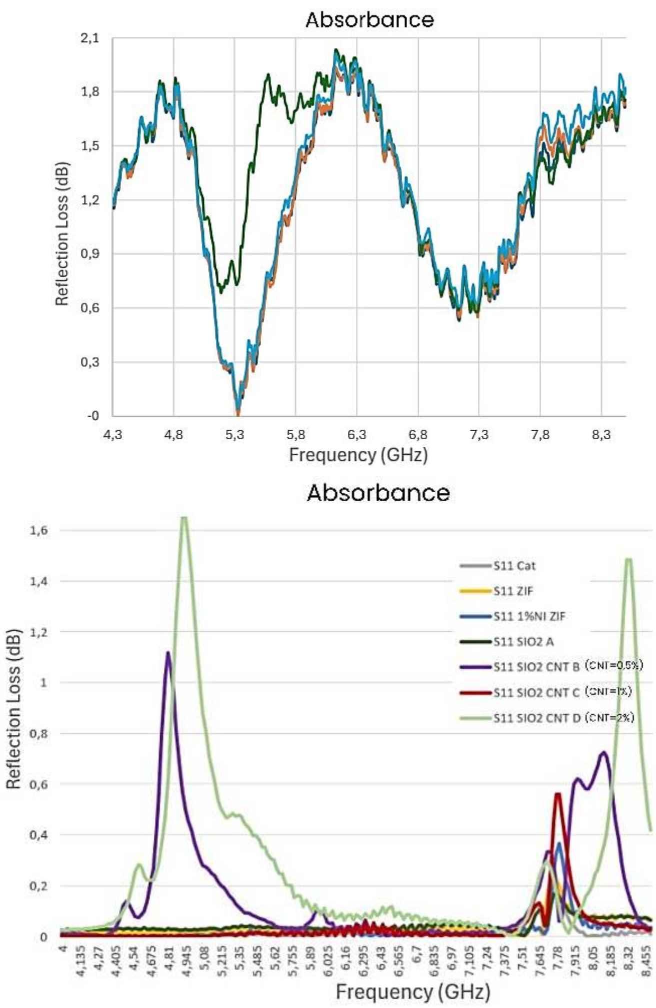

Figure 4. VNA Graph (S11 Parameter).

Table 4. Maximum and minimum RL values for ZnO & ZnO@SiO_2 (SiO_2: pure ZnO, 1%, 3%, and 5% by weight) S11 Parameter.

	Frequency (GHz)	ZnO	ZnO@SiO_2 (SiO_2: 1%)	ZnO@SiO_2 (SiO_2: 3%)	ZnO@SiO_2 (SiO_2: 5%)
|RL min| (dB)	6.125	1.90484	1.935826179	2.03368	2.00917

Table 5. Maximum and minimum RL values for SiO_2/CNT.

	Frequency (GHz)	SiO_2/CNT (CNT: 2%)
|RL min| (dB)	4.9	1.675

3.2 Discussion

Based on the research data, the addition of varying SiO_2 concentrations in the ZnO@SiO_2 composite significantly influences the crystal structure, and microwave absorption capability of the resulting material. XRD characterization results indicate that all samples—both pure ZnO and

$ZnO@SiO_2$ with 1%, 3%, and 5% SiO_2—exhibit diffraction patterns characteristic of the hexagonal wurtzite crystal structure with a $P6_3mc$ space group, without the presence of secondary phases. This confirms that the biosynthesis method using Moringa oleifera leaf extract did not alter the primary ZnO phase (Du et al., 2021). Crystallite size calculations using the Scherrer equation revealed a decreasing trend with increasing SiO_2 concentration. This reduction in crystallite size indicates finer particles, which can enhance the material's active surface area (Yang et al., 2023). This phenomenon is consistent with the role of SiO_2 as a shell in the core–shell structure, preventing excessive ZnO agglomeration and resulting in better particle dispersion. VNA measurements demonstrated that the sample with 3% SiO_2 achieved the best minimum Reflection Loss (RL) value of -2.0251 dB at a frequency of 6.125 GHz. This result indicates improved impedance matching and more effective interaction between the microwaves and the material surface. The presence of the SiO_2 layer is presumed to induce interfacial polarization, which enhances the dielectric loss mechanism and thereby strengthens microwave absorption. Thus, the XRD, SEM, and VNA data collectively support that varying SiO_2 concentrations affect both the structural and electromagnetic properties of $ZnO@SiO_2$ composites, with the 3% SiO_2 composition proving to be the optimum formulation in this study.

4. CONCLUSION

$ZnO@SiO_2$ composites synthesized via a biosynthesis method using *Moringa oleifera* leaf extract successfully retained the hexagonal wurtzite ZnO crystal structure without forming secondary phases, while the addition of SiO_2 reduced crystallite size, indicating the formation of nanoscale particles and preventing excessive agglomeration. Among the variations tested, the 3% SiO_2 sample exhibited the best microwave absorption performance with a minimum RL value of -2.0251 dB at 6.125 GHz, demonstrating improved impedance matching and higher absorption efficiency. These results indicate that a 3% SiO_2 composition optimally enhances both the structural and electromagnetic properties of $ZnO@SiO_2$, making it a promising, environmentally friendly, and cost-effective candidate for microwave absorber applications.

ACKNOWLEDGEMENT

This research was supported by the facilities, scientific, and technical support National Research and Innovation Agency through E- Layanan Sains (ELSA) BRIN.

REFERENCE

Mathur, P., Raman, S. (2020). Electromagnetic Interference (EMI): Measurement and Reduction Techniques. *J. Electron. Mater.* **49**, 2975–2998 https://doi.org/10.1007/s11664-020-07979-1

Taryana, Y., Azwar, M., Sudrajat, N., & Wahyu, Y. (2019). Electromagnetic Wave Absorbing Material in the Radar Frequency Range. *Indonesian Journal of Ceramics and Glass*, 28(1), 1-29.

Sugihartono, I., Azzahra, R.O.A., Yudasari, N., Budi, E., Fahdiran, R., Indrasari, W., Tiam, T.S., Mohar, R.S., Isnaeni, Triyono, D., Kurniadewi, F., & Budi, A.S. (2024). Physical properties and antioxidant activity of ZnO nanoparticles synthesized by Moringa oleifera leaf extract at different pH values. *Journal of Ceramic Processing Research*, 25(4), 557–562.

Du, B., Cai, M., Wang, X., Qian, J., He, C., & Shui, A. (2021). Enhanced electromagnetic wave absorption property of binary ZnO/NiCo2O4 composites. *Journal of Advanced Ceramics*, 10(4), 832-842.

Godavarti, U., Mote, V. D., Reddy, M. V. R., Nagaraju, P., Kumar, Y. V., Dasari, K. T., and Dasari, M. P. 2019. Precipitated cobalt doped ZnO nanoparticles with enhanced low temperature xylene sensing properties. *Physics B: Condensed Matter*, 553. https://doi.org/10.1016/j.physb.2018.10.034

Guda, S., Bharani, K., Matukumalli, U. R., Mekala, L., Donga, D. V. H., & Banothu, A. (2023). Phytochemical analysis and total antioxidant potential of Moringa oleifera leaf extract. *The Pharma Innovation Journal*, SP-12(9), 1736–1739.

Yang, P., Ye, W., Ruan, H., Li, R., Shou, M., Yin, Y., Huang, X., Zhang, Y., & Luo, J. (2023). Core–shell structured silica-coated iron nanowires composites for enhanced electromagnetic wave absorption properties. *International Journal of Molecular Sciences*, 24(10), 8620.

Ahmed, S., Annu, Chaudhry, S. A., & Ikram, S. (2017). A review on biogenic synthesis of ZnO nanoparticles using plant extracts and microbes: A prospect towards green chemistry. *Journal of Photochemistry and Photobiology B: Biology*, 166, 272–284.

Asmathunisha N, dan K Kathiresan. 2012. Biointerfaces a Review on Biosynthesis of Nanoparticles by Marine Organisms. *Colloids and Surfaces B*. 103: 283-287.

Iravani S. 2011. Green Chemistry Green Synthesis of Metal Nanoparticles Using Plants: Green Chemistry. 13: 2638-2650.