



Original Article

Joule-lenz Self-heating Synthesis of SnO₂/Au Nanosheets for High-sensitivity Surface-enhanced Raman Scattering Applications

Dai Ngoc Do¹, Tran Van Tan¹, Nguyen Van Phu¹,
Pham Nguyen Hai¹, Nguyen Thi Ha Thu², Bui Thi Huyen Trang¹,
Ngac An Bang¹, Tran Thi Ha³, Nguyen Viet Tuyen^{1,*}

¹*VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam*

²*Air Defence Air force Academy, Doai Phuong, Hanoi, Vietnam*

³*Hanoi University of Mining and Geology, 18 Pho Vien Street, Dong Ngac, Hanoi, Vietnam*

Received 13th June 2026

Revised 4th August 2026; Accepted 8th October 2026

Abstract: SnO₂/Au nanosheets prepared via the Joule–Lenz self-heating method were developed as Surface Enhanced Raman Scattering (SERS) substrates for trace detection. The effects of current intensity and processing time on morphology and Raman enhancement were systematically investigated. Structural and morphological characteristics were analyzed by SEM, XRD, and Raman spectroscopy. Finite element simulations using COMSOL Multiphysics were conducted to elucidate the electromagnetic enhancement mechanism and identify regions of high local field intensity. The results show that the SnO₂/Au nanosheet substrate enables detection of Methylene Blue at concentrations as low as 10⁻¹¹ M and thiram down to 10⁻⁸ M. These findings demonstrate a practical strategy for developing scalable and low-cost SnO₂-based SERS substrates through morphology-controlled nanostructure engineering for trace-level detection applications.

Keywords: SnO₂/Au nanosheets, SERS, COMSOL simulations

1. Introduction

Raman spectroscopy is a non-destructive optical technique with high selectivity and the ability to provide detailed information on the vibrational properties of molecules and solid-state materials [1, 2]. However, its intrinsically weak scattering cross-section severely limits its applicability for trace-level

* Corresponding author.

E-mail address: nguyenviettuyen@hus.edu.vn

<https://doi.org/10.25073/2588-1124/vnumap.5162>

detection. Surface-enhanced Raman scattering has emerged as a powerful approach to overcome this limitation by exploiting localized surface plasmon resonance (LSPR) in nanostructured materials [3-6], enabling orders-of-magnitude enhancement of Raman signals [7-10].

Conventional SERS substrates based on noble metals such as Au and Ag exhibit excellent enhancement performance [11-13]. However, their high cost and limited structural tunability hinder their large-scale and practical applications [14]. Recent efforts have therefore focused on developing alternative platforms, including semiconductor–metal hybrid systems, which can synergistically integrate electromagnetic enhancement [15-17], interfacial charge transfer, and morphology-induced field localization [18, 19]. SnO₂/Au composites are particularly attractive due to their low cost and excellent chemical stability [20-22]. Despite these advantages, a systematic understanding of how fabrication parameters govern the formation of SnO₂-based nanostructures and their corresponding SERS performance remains lacking. Addressing this issue is crucial for the rational design of high-performance, low-cost SERS substrates.

In this work, SnO₂/Au nanosheets were fabricated via a Joule–Lenz self-heating-assisted thermal oxidation process followed by Au sputtering. The effects of key fabrication parameters on structural evolution and SERS performance were systematically investigated. The substrates were evaluated using methylene blue and thiram as probe molecules at ultra-low concentrations. Furthermore, finite element method (FEM) simulations were employed to reveal the distribution of localized electromagnetic fields and to clarify the enhancement mechanism associated with hierarchical nanostructures.

The results demonstrate that the SnO₂/Au nanosheets achieve a detection limit as low as 10⁻¹¹ M, attributed to the synergistic coupling between plasmonic enhancement and high-density “hot spots”. These findings not only provide fundamental insights into structure–property relationships in SnO₂-based SERS substrates but also establish a viable pathway toward scalable, cost-effective platforms for trace-level detection in environmental monitoring, biomedical diagnostics, and food safety.

2. Experimental

SnO₂/Au nanosheets were fabricated via a Joule–Lenz self-heating-assisted thermal oxidation process followed by Au sputtering. Fe wires were cleaned with acetone and ethanol in an ultrasonic bath for 10 minutes in each solvent. Then, a Sn gel layer (98.5% Sn) was coated onto the wire surface. The samples were then connected to electrodes and heated by an electric current of 8.5 A for different durations to facilitate the formation of SnO₂ nanosheets. Subsequently, the SnO₂ nanosheets were coated with Au using a DC sputtering system (JEOL JFC–1200). A sputtering current of 30 mA and deposition times ranging from 20 to 50 s were investigated to optimize the density of Au nanoparticles on the SnO₂ surface.

X-ray diffraction (XRD) was employed to determine the crystal phases and lattice parameters using an Empyrean PANalytical system. Surface morphology was examined by scanning electron microscopy (SEM) using FESEM Nova NanoSEM 450. Elemental composition was analyzed by energy-dispersive X-ray spectroscopy (EDS) integrated with the SEM system. Raman spectra were recorded using a Horiba LabRAM HR800 (He–Ne laser, $\lambda = 632.8$ nm, 50 $\times$ LWD objective). Methylene blue and thiram were used as probe molecules.

3. Results and Discussion

Scanning electron microscopy (SEM) images (Fig. 1) reveal the evolution of the nanoparticle's morphology as a function of annealing time. After 5 h of annealing, the surface exhibits a disordered structure with no clearly distinguishable nanosheet morphology. When the annealing time is increased

to 10 h, nanosheet-like structures begin to emerge (marked by the arrows); however, they are sparsely distributed and show significant non-uniformity in size and orientation. A well-defined and densely packed nanosheet morphology is obtained when the annealing time reaches 20 h or longer. However, when the annealing time is extended to 24 h, the thickness of the nanosheets increases from approximately 20–30 nm to ~100 nm, which may reduce SERS performance due to a decrease in the density of electromagnetic “hot spots”.

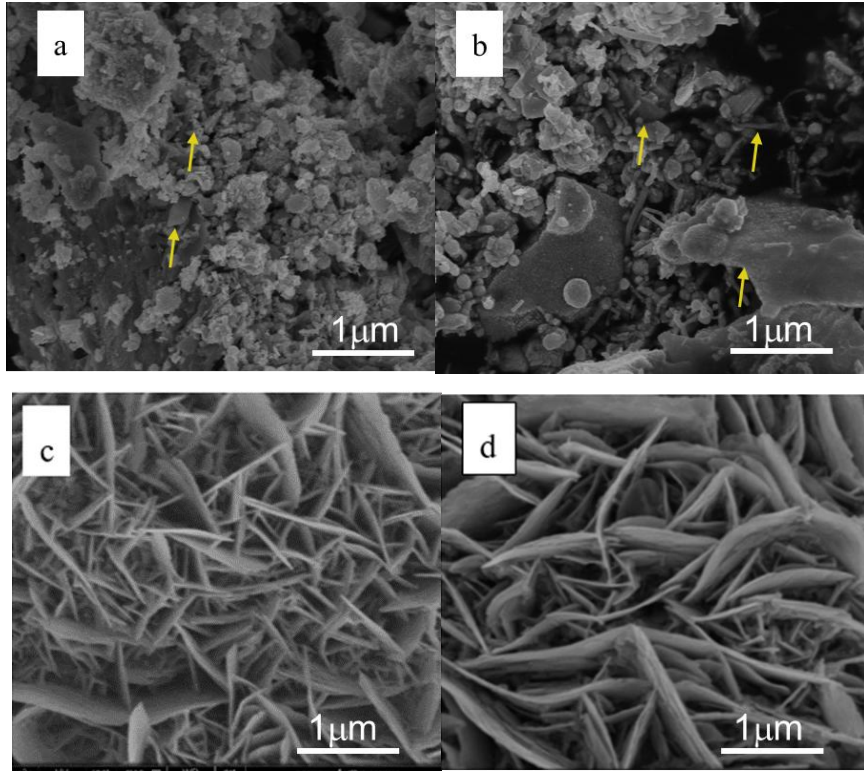


Figure 1. SEM images of SnO₂ samples annealed at a current of 8.5 A: (a) 5 h; (b) 10 h; (c) 20 h; (d) 24 h.

The structural evolution of SnO₂ synthesized at a current of 8.5 A was investigated by Raman spectroscopy. The results show the presence of characteristic vibrational modes of SnO₂, including Eg mode at 472 cm⁻¹, A_{1g} mode at 630 cm⁻¹, and B_{2g} mode at 772 cm⁻¹, along with a peak at 575 cm⁻¹, which is commonly associated with lattice defects [23, 24]. As the annealing time increases, the intensity of the Raman peaks significantly improves, indicating enhanced crystallinity. Notably, the samples annealed for 20 h and 24 h exhibit sharp and well-defined Raman spectra, suggesting that this time range is optimal for the formation of a well-developed crystalline structure of SnO₂. Energy-dispersive X-ray spectroscopy (EDS) confirms the presence of Sn and O elements, as well as Au after deposition, indicating high material purity without significant impurities (Fig. 2b).

To enhance the SERS effect, a thin Au layer was deposited onto the SnO₂ surface via sputtering. The SERS activity was evaluated using methylene blue as a probe molecule at a concentration of 10⁻⁹ M. The results show that a sputtering time of 30 s on the SnO₂ sample annealed for 20 h yields the highest Raman intensity [25], which is approximately 8.5 times higher than that of the sample annealed for 10 h and 1.6 times higher than that of the sample annealed for 24 h. When the sputtering time is too short (<30 s), the Au nanoparticle density is insufficient to generate a significant number of hot spots.

In contrast, it can be understood that excessive sputtering (>30 s) leads to nanoparticle aggregation into larger clusters, reducing the density and effectiveness of hot spots (Fig. 3).

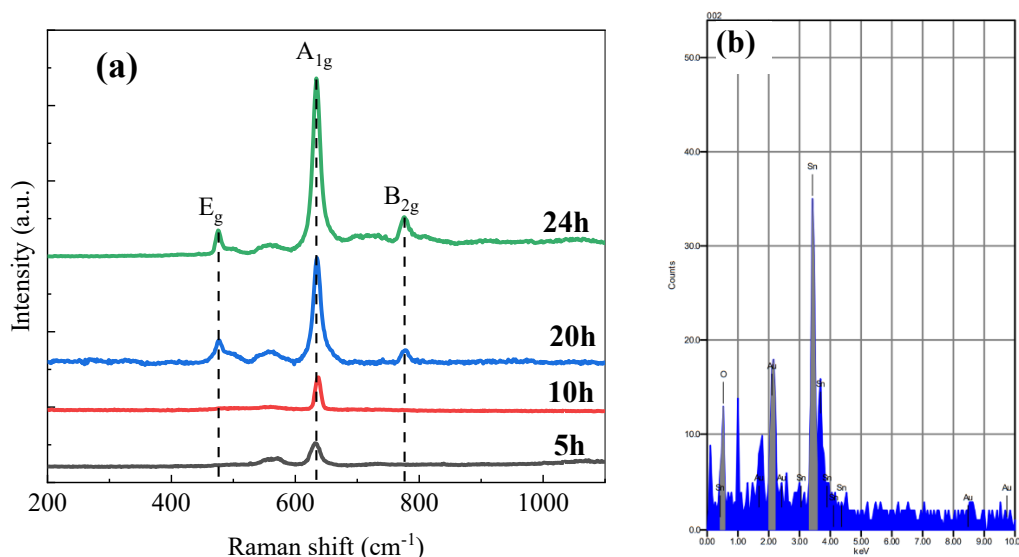


Figure 2. a) Raman spectra of SnO_2 samples annealed at a current of 8.5 A under different durations and b) EDS spectra of the SnO_2/Au nanosheet substrate annealed in 20 h and sputtering Au for 30 s.

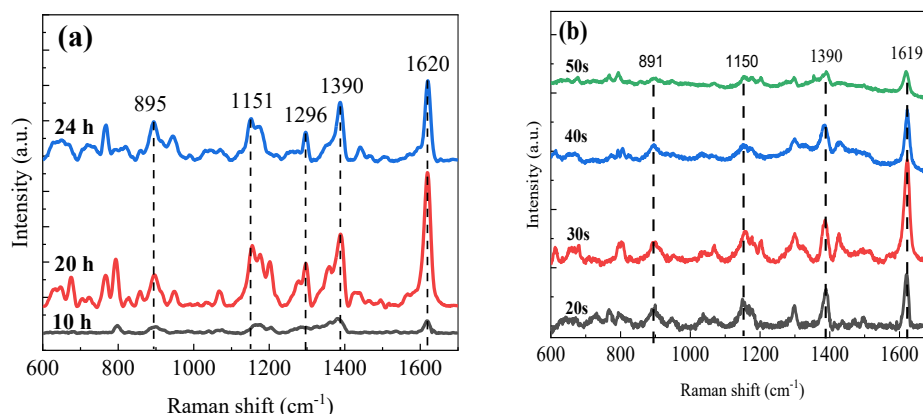


Figure 3. Raman spectra of 10^{-9} M MB measured on SnO_2/Au substrates prepared with different annealing times and sputtering time of 30 s (a) and SnO_2/Au substrates prepared in 20 h with various sputtering time of Au (b).

Under the optimized conditions with annealing time of 20 h and sputtering time of 30 s, the SnO_2/Au substrate exhibits excellent SERS sensitivity. The characteristic Raman peaks of MB can still be clearly detected at concentrations as low as 10^{-11} M, demonstrating competitive sensitivity compared with several previously reported SERS substrates (Table 1). In addition, the substrate demonstrates effective SERS performance for thiram over a wide concentration range (Fig. 4), with characteristic Raman peaks remaining clearly distinguishable down to 10^{-8} M. The systematic decrease in signal intensity with decreasing concentration confirms the sensitivity and reliability of the substrate, highlighting its strong potential for trace-level detection of hazardous chemicals and pesticide residues.

Finite element method (FEM) simulations were carried out using the Electromagnetic Waves, Frequency Domain module in COMSOL Multiphysics to investigate the electric field distribution and elucidate the enhancement mechanism of the fabricated SERS substrates. The optical constants for Au used in the simulations were obtained from [26] with real part ($n = 0.18377$) and imaginary part ($k = 3.4313$) of refractive index for Au. The electric field intensity distribution was calculated under excitation at a wavelength of 632.8 nm, corresponding to the Raman laser source used in the experiments.

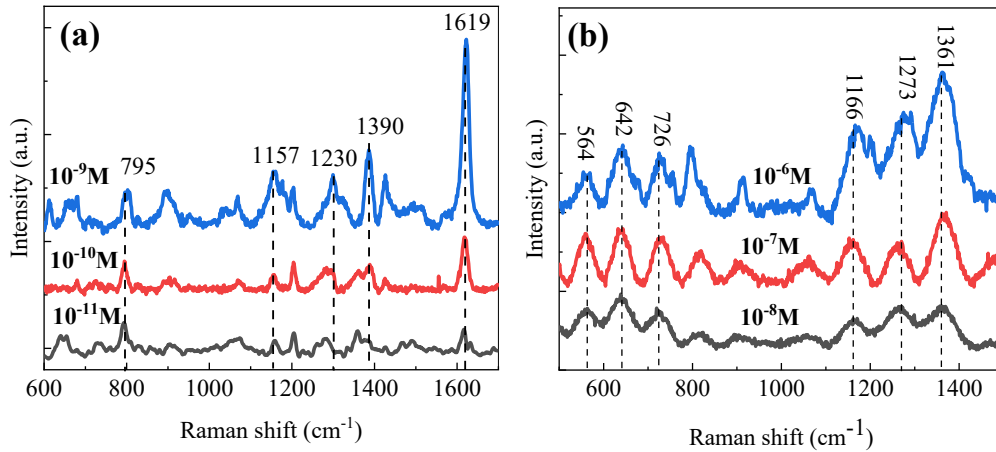


Figure 4. Raman spectra of MB (a) and thiram (b) at different concentrations on SnO_2/Au nanosheets with sputtering time of 30 s.

The simulation results (Fig. 5) demonstrate that the localized electric field distribution strongly depends on plasmonic coupling effects. For an isolated Au nanoparticle excited at a wavelength of 632.8 nm, the electric field is mainly concentrated near the particle surface. When two Au nanoparticles are positioned in close proximity, strong plasmonic coupling occurs in the interparticle gap region, resulting in a pronounced increase in the localized electric field intensity. The electric field intensity of the coupled structure is clearly higher than that of the single-particle configuration, indicating the important role of interparticle coupling in SERS enhancement.

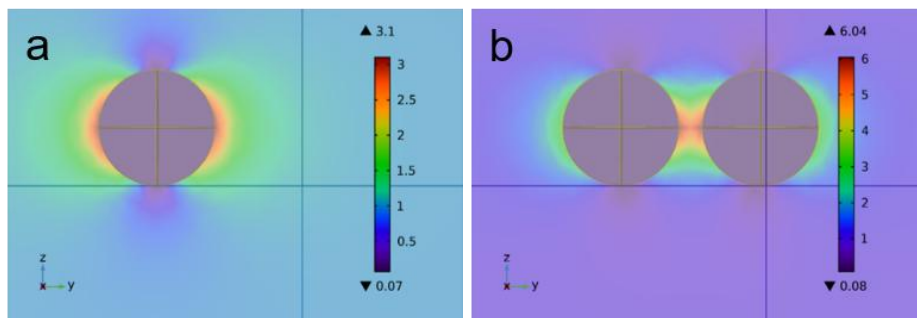


Figure 5. Simulation results of the electric field enhancement on a single Au nanoparticle (a) and a pair of Au nanoparticles in close proximity (b).

For the SnO_2/Au nanosheet substrate, the nanosheet morphology provides a large specific surface area that facilitates a high density of regions with enhanced localized electromagnetic fields compared

with planar surfaces. This structural feature contributes significantly to the improved SERS activity of the substrate. In addition, the deposited Au nanoparticles further enhance electromagnetic field localization through plasmonic interactions between neighboring particles. Furthermore, SnO_2 is an n-type semiconductor with energy band structure facilitating favorable orbital overlap with organic target molecules like MB. Defect sites in SnO_2 like oxygen vacancies create midgap energy levels that support highly efficient electron transfer between the semiconductor and the analyte and hence contribute further to the chemical enhancement process.

Table 1. Comparison of the LOD of MB of the present work with previously reported SERS substrates

Research group	Substrate	Method	MB detection limit
Imran Shaikh et al., [27]	Ag nanoparticles	Spin-coating	10^{-10} M
Xuanhe Li et al., [28]	Au nanoparticles	Microplasma	10^{-11} M
Luis Zamora-Peredo [29]	ZnO/Ag nanoparticles	Hydrothermal method	10^{-9} M
Meruyert Kadir [30]	TiO ₂ /Ag nanotubes	Electrochemical method	10^{-12} M
Thi Ha Tran [31]	CuO/Ag nanowires	Thermal oxidation	10^{-10} M
This work	SnO_2 /Au nanosheets	Joule–Lenz self-heating	10^{-11} M

4. Conclusion

In this study, SnO_2 /Au nanosheet SERS substrates were successfully fabricated using a Joule–Lenz self-heating-assisted oxidation method followed by Au sputtering. The effects of fabrication parameters on structural morphology and SERS performance were systematically investigated. The SnO_2 /Au nanosheet substrate exhibited excellent SERS activity, enabling the detection of MB at concentrations as low as 10^{-11} M and thiram down to 10^{-8} M. Morphological analysis and electromagnetic simulations revealed that the enhanced SERS performance originates from localized electromagnetic field enhancement induced by plasmonic coupling between Au nanoparticles. These findings demonstrate that morphology-controlled SnO_2 /Au nanostructures are promising candidates for the development of low-cost, scalable, and stable SERS substrates. The proposed fabrication strategy provides a practical approach for trace-level detection applications in environmental monitoring, food safety, and biomedical analysis.

Acknowledgments

This research is funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 103.02-2023.100. Phu Nguyen Van was funded by the PhD Scholarship Programme of Vingroup Innovation Foundation (VINIF), Vin University, code VINIF.2025.TS21.

References

- [1] C. E. Harvey, B. M. Weckhuysen, Surface- and Tip-Enhanced Raman Spectroscopy as Operando Probes for Monitoring and Understanding Heterogeneous Catalysis, *Catalysis Letters*, Vol. 145, No. 1, 2015, pp. 40-57, <https://doi.org/10.1007/s10562-014-1420-4>.

- [2] J. B. Wu, M. L. Lin, X. Cong, H. N. Liu, P. H. Tan, Raman Spectroscopy of Graphene-Based Materials and Its Applications in Related Devices, *Chemical Society Reviews*, Vol. 47, No. 5, 2018, pp. 1822-1873, <https://doi.org/10.1039/C6CS00915H>.
- [3] M. Fleischmann, P. J. Hendra, A. J. McQuillan, Raman Spectra of Pyridine Adsorbed at a Silver Electrode, *Chemical Physics Letters*, Vol. 26, No. 2, 1974, pp. 163-166, [https://doi.org/10.1016/0009-2614\(74\)85388-1](https://doi.org/10.1016/0009-2614(74)85388-1).
- [4] D. L. Jeanmaire, R. P. V. Duyne, Surface Raman Spectroelectrochemistry: Part I. Heterocyclic, Aromatic, and Aliphatic Amines Adsorbed on the Anodized Silver Electrode, *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry*, Vol. 84, No. 1, 1977, pp. 1-20, [https://doi.org/10.1016/S0022-0728\(77\)80224-6](https://doi.org/10.1016/S0022-0728(77)80224-6).
- [5] M. G. Albrecht, J. A. Creighton, Anomalous Intense Raman Spectra of Pyridine at a Silver Electrode, *Journal of the American Chemical Society*, Vol. 99, No. 15, 1977, pp. 5215-5217, <https://doi.org/10.1021/ja00457a071>.
- [6] M. Moskovits, Persistent Misconceptions Regarding SERS, *Physical Chemistry Chemical Physics*, Vol. 15, No. 15, 2013, pp. 5301-5311, <https://doi.org/10.1039/C2CP44030J>.
- [7] D. Li, D. Yao, C. Li, Y. Luo, A. Liang, G. Wen, Z. Jiang, Nanosol SERS Quantitative Analytical Method: A Review, *TrAC Trends in Analytical Chemistry*, Vol. 127, 2020, Article 115885, <https://doi.org/10.1016/j.trac.2020.115885>.
- [8] G. McNay, D. Eustace, W. E. Smith, K. Faulds, D. Graham, Surface-Enhanced Raman Scattering (SERS) and Surface-Enhanced Resonance Raman Scattering (SERRS): A Review of Applications, *Applied Spectroscopy*, Vol. 65, No. 8, 2011, pp. 825-837, <https://doi.org/10.1366/11-06365>.
- [9] T. N. Q. Trang, N. T. P. Trinh, N. T. G. Bao, V. T. H. Thu, Hotspot-type Silver-Polymers Grafted Nanocellulose Paper with Analyte Enrichment as Flexible Plasmonic Sensors for Highly Sensitive SERS Sensing, *Journal of Science: Advanced Materials and Devices*, Vol. 8, No. 3, 2023, Article 100597, <https://doi.org/10.1016/j.jsamd.2023.100597>.
- [10] M. Zhang, Z. Wu, Y. Yang, J. Ye, S. Han, Y. Li, Fabrication of Molecularly-imprinted Gold Nanoparticle-Embedded Fe-MOFs for Highly Selective SERS Detection of 17 β -estradiol in Milk, *Analyst*, Vol. 148, No. 11, 2023, pp. 2472-2481, <https://doi.org/10.1039/D3AN00343D>.
- [11] Z. Chen, Y. Sun, J. Shi, W. Zhang, X. Zhang, X. Huang, X. Zou, Z. Li, R. Wei, Facile Synthesis of Au@Ag Core-Shell Nanorod with Bimetallic Synergistic Effect for SERS Detection of Thiabendazole in Fruit Juice, *Food Chemistry*, Vol. 370, 2022, Article 131276, <https://doi.org/10.1016/j.foodchem.2021.131276>.
- [12] S. Lee, H. Dang, J.-I. Moon, K. Kim, Y. Joung, S. Park, Q. Yu, J. Chen, M. Lu, L. Chen, S. W. Joo, J. Choo, SERS-based Microdevices for Use as in Vitro Diagnostic Biosensors, *Chemical Society Reviews*, Vol. 53, No. 11, 2024, pp. 5394-5427, <https://doi.org/10.1039/D3CS01055D>.
- [13] G. Awiaz, J. Lin, A. Wu, Recent Advances of Au@Ag Core-shell SERS-based Biosensors, *Exploration*, Vol. 3, No. 1, 2023, Article 20220072, <https://doi.org/10.1002/EXP.20220072>.
- [14] C. Li, Y. Huang, X. Li, Y. Zhang, Q. Chen, Z. Ye, Z. Alqarni, S. E. J. Bell, Y. Xu, Towards Practical and Sustainable SERS: A Review of Recent Developments in the Construction of Multifunctional Enhancing Substrates, *Journal of Materials Chemistry C*, Vol. 9, No. 35, 2021, pp. 11517-11552, <https://doi.org/10.1039/D1TC02134F>.
- [15] T. T. H. Pham, X. H. Vu, N. D. Dien, T. T. Trang, T. T. K. Chi, P. H. Phuong, N. T. Nghia, Ag Nanoparticles on ZnO Nanoplates as a Hybrid SERS-active Substrate for Trace Detection of Methylene Blue, *RSC Advances*, Vol. 12, No. 13, 2022, pp. 7850-7863, <https://doi.org/10.1039/D2RA00620K>.
- [16] D. T. N. Nga, H. A. Nguyen, N. T. Hoa, N. N. Huyen, N. X. Dinh, T. N. Bach, N. Q. Hoa, A. T. Le, A Zinc Oxide-silver Nanocomposite-based SERS Nanoplatform for Ultrasensitive Ofloxacin Determination in Beef and an Ophthalmic Solution: Effects of ZnO and ZnO Content on Electron Transfer and SERS Enhancements, *RSC Advances*, Vol. 15, No. 12, 2025, pp. 8878-8888, <https://doi.org/10.1039/D5RA00776C>.
- [17] J. Y. Zhou, J. Zhu, G. J. Weng, J. J. Li, J. W. Zhao, Fabrication of SERS Composite Substrates Using Ag Nanotriangles-modified SiO₂ Photonic Crystal and the Application of Malachite Green Detection, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, Vol. 318, 2024, Article 124472, <https://doi.org/10.1016/j.saa.2024.124472>.
- [18] T. H. Tran, T. M. A. Nguyen, V. P. T. Dao, C. D. Sai, T. C. Bach, N. H. Pham, A. B. Ngac, V. T. Pham, T. K. C. Tran, H. Cheong, V. T. Nguyen, Highly Sensitive Characteristic of Surface Enhanced Raman Scattering for CuO/Au Core/Shell Nanowires Substrate, *Ceramics International*, Vol. 48, No. 3, 2022, pp. 3199-3205, <https://doi.org/10.1016/j.ceramint.2021.10.093>.

- [19] V. T. Tran, M. P. Le, N. H. Pham, T. H. Y. Le, V. T. Nguyen, T. H. Pham, T. S. Nguyen, Q. H. Nguyen, V. T. Pham, T. T. Nguyen, C. T. Nguyen, A. B. Ngac, O. Martínez Sacristán, T. H. Tran, Unraveling the Mechanism of Photo-induced Surface Enhanced Raman Scattering on ZnO/Au thin Films, *Applied Surface Science*, Vol. 657, 2024, Article 159785, <https://doi.org/10.1016/j.apsusc.2024.159785>.
- [20] M. S. Choi, H. G. Na, S. Kim, J. H. Bang, W. Oum, S. W. Choi, S. S. Kim, K. H. Lee, H. W. Kim, C. Jin, Synthesis of Au/SnO₂ Nanostructures Allowing Process Variable Control, *Scientific Reports*, Vol. 10, No. 1, 2020, Article 346, <https://doi.org/10.1038/s41598-019-57222-z>.
- [21] J. Fernández-Vidal, A. M. G. Marín, L. A. H. Jones, C. H. Yen, T. D. Veal, V. R. Dhanak, C. C. Hu, L. J. Hardwick, Long-Life and pH-Stable SnO₂-Coated Au Nanoparticles for SHINERS, *The Journal of Physical Chemistry C*, Vol. 126, No. 29, 2022, pp. 12074-12081, <https://doi.org/10.1021/acs.jpcc.2c02432>.
- [22] S. J. Oldenburg, J. B. Jackson, S. L. Westcott, N. J. Halas, Infrared Extinction Properties of Gold Nanoshells, *Applied Physics Letters*, Vol. 75, No. 19, 1999, pp. 2897–2899, <https://doi.org/10.1063/1.125183>.
- [23] H. T. Girão, T. Cornier, S. Daniele, R. Debord, M. A. Caravaca, R. A. Casali, P. Mélinon, D. Machon, Pressure-Induced Disorder in SnO₂ Nanoparticles, *The Journal of Physical Chemistry C*, Vol. 121, No. 28, 2017, pp. 15463-15471, <https://doi.org/10.1021/acs.jpcc.7b04079>.
- [24] H. T. Girao, P. Hermet, B. Masenelli, J. Haines, P. Mélinon, D. Machon, Pressure-Induced Sublattice Disorder in SnO₂: Invasive Selective Percolation, *Physical Review Letters*, Vol. 120, No. 26, 2018, Article 265702, <https://doi.org/10.1103/PhysRevLett.120.265702>.
- [25] C. Li, Y. Huang, K. Lai, B. A. Rasco, Y. Fan, Analysis of Trace Methylene Blue in Fish Muscles Using Ultra-Sensitive Surface-enhanced Raman Spectroscopy, *Food Control*, Vol. 65, 2016, pp. 99-105, <https://doi.org/10.1016/j.foodcont.2016.01.017>.
- [26] P. B. Johnson, R. W. Christy, Optical Constants of the Noble Metals, *Physical Review B*, Vol. 6, No. 12, 1972, pp. 4370-4379, <https://doi.org/10.1103/PhysRevB.6.4370>.
- [27] I. Shaikh, M. A. Haque, H. Pathan, S. Sartale, Spin-Coated Ag NPs SERS Substrate: Role of Electromagnetic and Chemical Enhancement in Trace Detection of Methylene Blue and Congo Red, *Plasmonics*, Vol. 17, No. 5, 2022, pp. 1889–1900, <https://doi.org/10.1007/s11468-022-01671-2>.
- [28] X. Li, L. Lin, W.-H. Chiang, K. Chang, H. Xu, Microplasma Synthesized Gold Nanoparticles For Surface Enhanced Raman Spectroscopic Detection of Methylene Blue, *Reaction Chemistry & Engineering*, Vol. 7, No. 2, 2022, pp. 346-353, <https://doi.org/10.1039/D1RE00446H>.
- [29] L. Z. Peredo, J. I. G. Ramirez, A. C. G. Velasco, J. H. Torres, L. G. González, M. Bizarro, A. B. Rodríguez, Influence of Ag Photodeposition Conditions over SERS Intensity of Ag/ZnO Microspheres for Nanomolar Detection of Methylene Blue, *Nanomaterials*, Vol. 11, No. 12, 2021, pp. 3414, <https://doi.org/10.3390/nano11123414>.
- [30] M. Kadir, R. Nemkayeva, G. Baigarinova, B. Alpysbayeva, A. Assembayeva, V. Smirnov, SERS-active Substrates Based on Ag-coated TiO₂ Nanotubes and Nanograss, *Physica E: Low-dimensional Systems and Nanostructures*, Vol. 145, 2023, Article 115499, <https://doi.org/10.1016/j.physe.2022.115499>.
- [31] T. H. Tran, M. H. Nguyen, T. H. T. Nguyen, V. P. T. Dao, Q. H. Nguyen, C. D. Sai, N. H. Pham, T. C. Bach, A. B. Ngac, T. T. Nguyen, K. H. Ho, H. Cheong, V. T. Nguyen, Facile Fabrication of Sensitive Surface Enhanced Raman Scattering Substrate Based on CuO/Ag Core/Shell Nanowires, *Applied Surface Science*, Vol. 509, 2020, Article 145325, <https://doi.org/10.1016/j.apsusc.2020.145325>.