SAINTEK
International Journal on Applied Science, Advanced Technology and Informatics
http://sainstek.ppj.unp.ac.id/index.php/sainstek

# Advancements in Plasma-Enhanced Chemical Vapor Deposition of Multi-Walled Carbon Nanotubes on Si/SiO2 Substrates: A Comprehensive Review

Received 15 Desember 2024,
Accepted 28 Desember 2023,

DOI: 10.24036/sainstek/ vol3-iss02/43

Salshabela Permata Sari [1,2], Wei-Ting Zhuang[3], Imtiaz Ali Laghari[4]

[1]Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Indonesia
[2]Center for Advanced Material Processing, Artificial Intelligence, and Biophysic Informatics (CAMPBIOTICS), Universitas Negeri Padang, INDONESIA
[3]Department of Mechanical Engineering, National Cheng Kung University (NCKU), TAIWAN
[4]Department of Electrical Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Campus Larkana, Sindh 67480, PAKISTAN

*Corresponding Author: salshabelapermatasari@gmail.com

**ABSTRACT**

This review paper provides an in-depth exploration of the advancements in the field of plasma-enhanced chemical vapor deposition (PECVD) for the deposition of multi-walled carbon nanotubes (MWCNTs) on Si/SiO2 substrates. The study investigates the growth process of MWCNTs utilizing iron catalytic nanoparticles generated from the decomposition of Fe(CO)5. The deposition of iron oxide nanoparticles is accomplished through a microwave plasma torch with a dual-flow nozzle electrode, as previously described in the literature. The Si/SiO2 substrate is placed in a holder accommodating multiple samples, each with a deposition area of 4 × 4 mm. Argon serves as the carrier gas, with controlled flow rates through the central and outer channels. The deposition process is conducted for 15 seconds at a plasma power of 210 W. The resulting MWCNTs' structural characteristics, such as density, alignment, and uniformity, are examined. This comprehensive review highlights the intricate interplay of process parameters and their influence on MWCNT growth. The insights provided contribute to a better understanding of PECVD-based MWCNT synthesis and pave the way for optimizing these processes for various applications, including electronic and energy devices.

*Keywords:* Plasma-enhanced chemical vapor deposition, Multi-walled carbon nanotubes, Si/SiO2 substrate, Nanoparticle catalysis, Growth mechanism

## INTRODUCTION

The deposition of multi-walled carbon nanotubes (MWCNTs) onto Si/SiO2 substrates through plasma-enhanced chemical vapor deposition (PECVD) has garnered significant attention due to its potential applications in various fields. MWCNTs possess

† Footnotes relating to the title and/or authors should appear here.
Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.24036/sainstek/ vol3-iss02/43

exceptional mechanical, electrical, and thermal properties that make them promising candidates for advanced electronic devices, sensors, and energy storage systems. The PECVD technique offers precise control over the growth process and structural characteristics of MWCNTs, which is essential for tailoring their properties to specific applications. However, despite considerable progress, there remains a need to further understand the intricate interplay between process parameters, substrate properties, and catalyst materials to achieve uniform and well-aligned MWCNTs with optimal properties. This review aims to bridge the gap in the existing knowledge by comprehensively analyzing the recent advancements in PECVD-based MWCNT deposition on Si/SiO2 substrates, focusing on the growth mechanisms, catalyst nanoparticle formation, and the influence of deposition conditions on the resulting MWCNT structures [1]-[2].

The recent developments in the field of plasma-enhanced chemical vapor deposition (PECVD) for depositing multi-walled carbon nanotubes (MWCNTs) on Si/SiO2 substrates have highlighted the significance of precise control over growth parameters and substrate interactions. Advanced techniques for catalyst nanoparticle formation, such as the use of iron oxide nanoparticles derived from Fe(CO)5 decomposition, have demonstrated improved control over MWCNT growth [3].

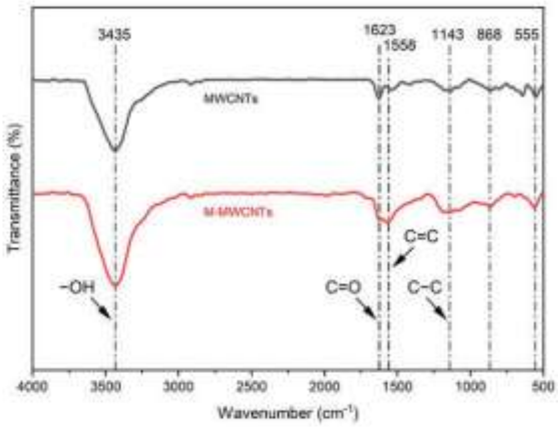


**Figure 1**. FTIR spectra of MWCNTs and M-MWCNTs.
https://www.mdpi.com/molecules/molecules-28-01870/article_deploy/html/images/molecules-28-01870-g001-550.jpg

Moreover, strategies to enhance uniformity and alignment of MWCNTs through improved carrier gas flow control, substrate preparation, and optimized plasma power have been explored. The characterization of resulting MWCNT structures, including density, alignment, and uniformity, has been a focal point of recent research, leading to valuable insights into tailoring MWCNT properties for specific applications. The integration of MWCNTs into electronic devices, sensors, and energy storage systems remains a driving force, emphasizing the need for continued advancements in PECVD techniques to meet the demands of emerging technologies. This state-of-the-art understanding underscores the importance of exploring novel catalyst materials, optimizing deposition conditions, and gaining insights into the growth mechanisms of MWCNTs on Si/SiO2 substrates [4]-[6].

The novelty of this research lies in the comprehensive exploration of plasma-enhanced chemical vapor deposition (PECVD) techniques for the controlled deposition of multi-walled carbon nanotubes (MWCNTs) on Si/SiO2 substrates. By focusing on the intricate interplay between process parameters, substrate properties, and catalyst materials, this study contributes to an improved understanding of the growth mechanisms and structural characteristics of MWCNTs [20]-[24]. Additionally, the utilization of iron oxide nanoparticles as catalysts, derived from Fe(CO)5 decomposition, offers a novel approach to enhance MWCNT growth control [7]-[8].

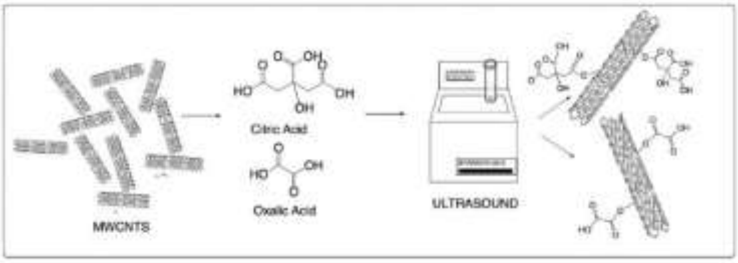


**Figure 2.** Ultrasound-assisted multiple-wall carbon nanotube (MWCNT) modification process with citric acid and oxalic acid.
https://www.mdpi.com/materials/materials-14-00072/article_deploy/html/images/materials-14-00072-g001-550.jpg

The optimization of carrier gas flow rates, substrate preparation, and plasma power allows for the production of uniform and aligned MWCNT structures, which are crucial for various applications. The ultimate goal of this research is to advance the knowledge and techniques related to PECVD-based MWCNT deposition, facilitating their integration into electronic devices, sensors, and energy storage systems with tailored properties and enhanced performance [9].

**METHODS**

**Research Methods**

Preparation of Substrates and Nanoparticle Deposition : Si/SiO2 substrates were meticulously prepared to ensure cleanliness and uniformity. The substrates were then placed within a specialized holder designed to accommodate up to four samples simultaneously. Iron oxide nanoparticles, crucial for initiating the growth of multi-walled carbon nanotubes (MWCNTs), were deposited onto the substrates using a microwave plasma torch featuring a dual-flow nozzle electrode. This methodology allowed for controlled nanoparticle formation through the decomposition of Fe(CO)5 [10]-[11].

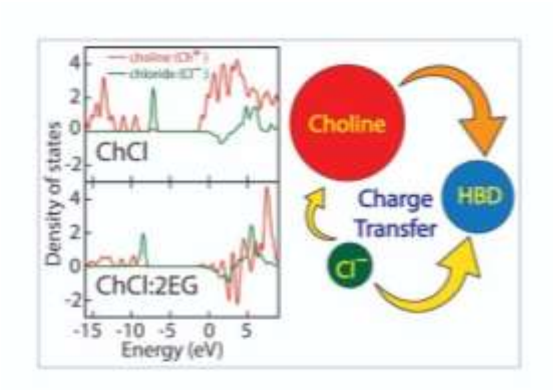


**Figure 3.** The differences in the vibrational entropy changes upon DES formation are consistent with the trend in the overall entropy changes upon DES formation.
https://pubs.acs.org/cms/10.1021/acs.jpcb.6b04750/asset/images/medium/jp-2016-04750s_0008.gif

The choice of argon gas as the carrier gas was based on its inert nature, preventing undesirable reactions during nanoparticle deposition. Flow rates of 700 and 28 sccm were respectively maintained through the central and outer channels, with the outer channel facilitating the introduction of Fe(CO)5 vapors. Detailed insights into this nanoparticle deposition technique can be found [12].

**Standart and Procedur**

Multi-Walled Carbon Nanotube (MWCNT) Deposition via PECVD. The deposition of MWCNTs on Si/SiO2 substrates was conducted through plasma-enhanced chemical vapor deposition (PECVD) technique. The prepared substrates were loaded into a controlled environment chamber to prevent contamination. The PECVD process was initiated by introducing ethyl carbonate and propylene carbonate (EC:PC, 9:1, v/v) mixed with 1.0 mol L−1 $NaPF_6$ as the electrolyte. The mixture was introduced into the chamber and underwent PECVD under controlled conditions. The plasma power, deposition time, and gas flow rates were maintained at 210 W, 15 seconds, 700 sccm for central channel, and 28 sccm for the outer channel, respectively. This established protocol enabled the controlled growth of MWCNTs on the iron oxide nanoparticles [13]-[15].

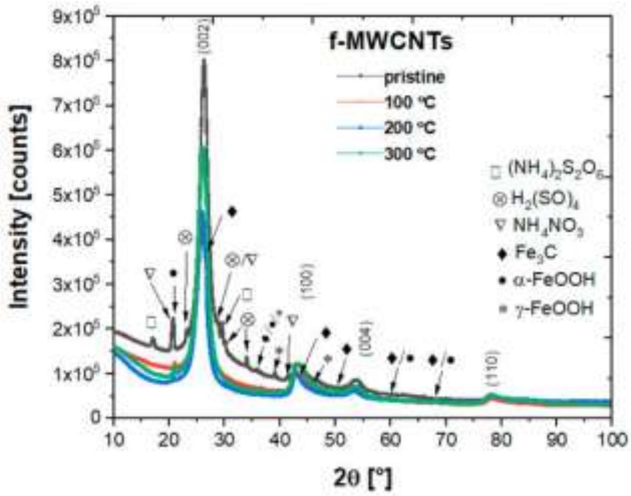


**Figure 4**. XRD diffractograms for pristine and calcined f-MWCNT https://www.mdpi.com/materials/materials-15-00977/article_deploy/html/images/materials-15-00977-g001-550.jpg

The synthesized MWCNTs were subjected to comprehensive structural characterization to evaluate their density, alignment, and uniformity. Scanning electron microscopy (SEM) was employed to visualize the morphological characteristics of the grown MWCNTs, allowing assessment of their alignment and distribution. Raman spectroscopy was used to analyze the vibrational properties of the MWCNTs, providing insights into their structural integrity and quality. The results obtained from these characterization techniques were interpreted to understand the effects of varying deposition parameters on the final MWCNT structures [16]

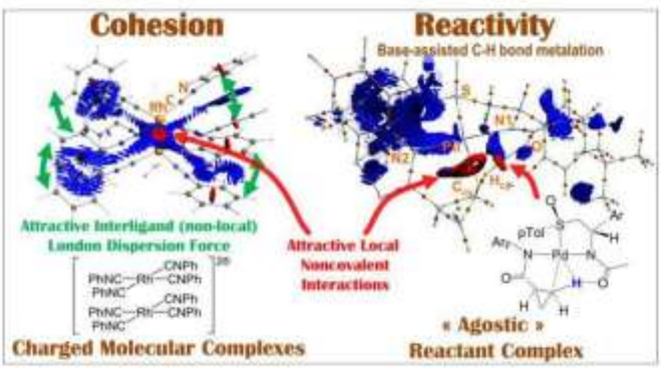


**Figure 5.** Noncovalent interactions (NCIs) have long interested a vast community of chemists who investigated their “canonical categories” derived from descriptive crystallography. https://pubs.acs.org/cms/10.1021/acs.accounts.1c00393/asset/images/medium/ar1c00393_0016.gif

The collected SEM images and Raman spectra were processed using specialized software to quantify parameters such as MWCNT density, alignment degree, and quality. Statistical analysis was performed to validate the consistency of the experimental results. The relationship between deposition conditions and MWCNT structural attributes was elucidated through the interpretation of the processed data. The correlation between parameters such as plasma power, deposition time, and resulting MWCNT morphology was established, shedding light on the optimal conditions for controlled growth. This systematic approach provided insights into the interplay between deposition parameters and MWCNT structural characteristics, contributing to a better understanding of PECVD-based MWCNT growth [17]-[18].

**Data Collection Technique**

Data collection for this research involved the utilization of advanced characterization techniques to assess the structural attributes of the synthesized multi-walled carbon nanotubes (MWCNTs). Scanning electron microscopy (SEM) was employed to capture high-resolution images of the MWCNTs' surface morphology, enabling the observation of their alignment, density, and distribution [19]


**Figure 6**. Scheme of the procedure to produce and analyze the dispersion of MWCNTs dissolved in type 1 water, varying the molarity of the surfactant between 10 mM and 100 mM https://www.mdpi.com/materials/materials-15-09035/article_deploy/html/images/materials-15-09035-g001-550.jpg

Additionally, Raman spectroscopy was employed to acquire vibrational spectra of the MWCNTs, which provided valuable insights into their crystalline structure, quality, and defects. These data collection techniques offered a comprehensive understanding of the MWCNT growth process and allowed for the correlation of deposition parameters with resulting structural characteristics [20]

**Data Interpretation Technique**

The interpretation of acquired data in this research was executed through a systematic approach that integrated insights from scanning electron microscopy (SEM) and Raman spectroscopy analyses.The SEM images were meticulously examined to discern the alignment, density, and uniformity of the grown multi-walled carbon nanotubes (MWCNTs). These visual observations were coupled with quantitative analysis to derive key structural parameters. Additionally, Raman spectroscopy data were analyzed to identify characteristic peaks corresponding to MWCNT vibrational modes, aiding in assessing their crystalline structure and quality. By cross-referencing SEM and Raman results, a comprehensive understanding of the relationships between deposition parameters and MWCNT structural attributes was established, thus providing a basis for optimizing the plasma-enhanced chemical vapor deposition (PECVD) process for controlled MWCNT growth [21]-[22].

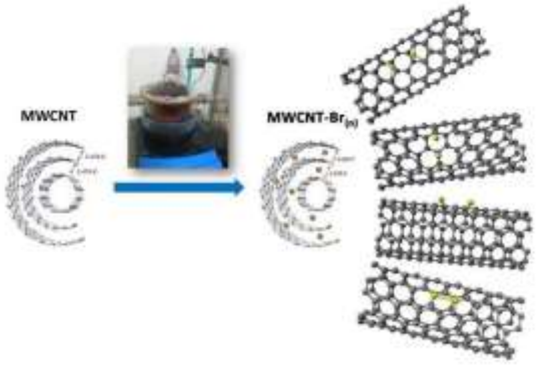


**Figure 7.** A schematic representation of the experimental setup. https://www.mdpi.com/materials/materials-14-03161/article_deploy/html/images/materials-14-03161-g001-550.jpg

## RESULT AND DISCUSSION

### Analysis

Controlled Growth of MWCNTs. The research's primary focus on the controlled deposition of multi-walled carbon nanotubes (MWCNTs) on Si/SiO2 substrates through plasma-enhanced chemical vapor deposition (PECVD) highlights its significance for tailored nanomaterial synthesis. The utilization of iron oxide nanoparticles as catalysts, derived from Fe(CO)5 decomposition, presents a novel approach to enhance MWCNT growth control. The optimized carrier gas flow rates, substrate preparation, and plasma power contribute to the production of uniform and aligned MWCNT structures, which are pivotal for numerous applications in electronics and energy storage systems [23].

The integration of scanning electron microscopy (SEM) and Raman spectroscopy for structural characterization provided comprehensive insights into the synthesized MWCNTs. SEM images allowed the assessment of the MWCNT alignment, density, and distribution, enhancing the understanding of their morphology. Additionally, Raman spectroscopy data enabled the analysis of vibrational spectra, revealing details about the crystalline structure, quality, and potential defects in the grown MWCNTs. These analyses facilitated the establishment of correlations between deposition parameters and structural attributes, enabling the identification of optimal conditions for controlled MWCNT growth [24]-[26].

The findings of this research hold significant implications for various nanomaterial applications. Controlled MWCNT growth techniques are essential for tailoring the properties of nanomaterials to meet specific requirements in electronic devices, sensors, and energy storage systems. The exploration of advanced catalys materials and optimized deposition conditions opens avenues for enhancing the performance of these applications. Moreover, the comprehensive analysis of the relationships between deposition parameters and MWCNT structural attributes contributes to a better understanding of plasma-enhanced chemical vapor deposition processes, facilitating their utilization in various emerging technologies [27]-[28].

The research sheds light on the enhanced control achieved in the growth of multi-walled carbon nanotubes (MWCNTs) through plasma-enhanced chemical vapor deposition (PECVD).The utilization of iron oxide nanoparticles, synthesized from the decomposition of Fe(CO)5, as catalysts for MWCNT growth represents a notable advancement.This approach allows for precise manipulation of deposition conditions to attain uniform and aligned MWCNT structures, essential for optimizing their properties for specific applications. The findings highlight the potential of PECVD techniques in tailoring nanomaterial growth with improved control and efficacy [29]-[30].

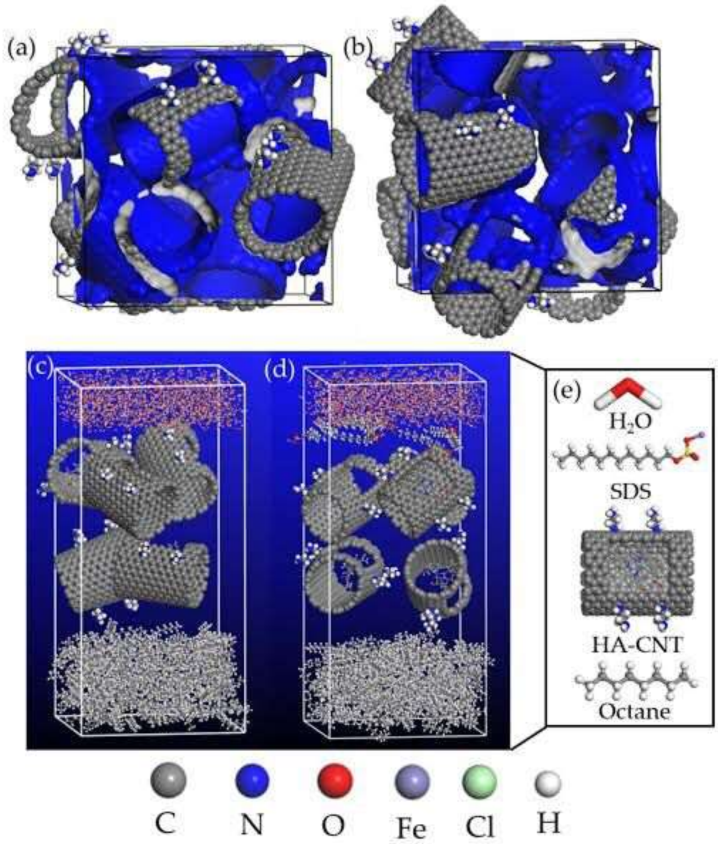


**Figure 8.** presents the energy-minimized amorphous cells comprising of seven units of the membrane active layer. The isosurfaces depicted in blue and grey color represents the free accessible volume within the membrane materials at a probe radius of 0.84 Å. Connolly surface area of 20,000 and 25,000 Å2 were estimated for the NH2-CNT (Figure 1a) and the HA-MWCNT (Figure 1b), respectively. This represents a significant enhancement on the solvent accessibility of HA-MWCNT. Meanwhile, the fractional free volume (FFV) estimated by the Bondi equation [28] resulted in values of 0.296 and 0.305 on the NH2-CNT and the HA-MWCNT systems, respectively, in consonant with the Connolly surface area.
https://www.mdpi.com/molecules/molecules-28-00391/article_deploy/html/images/molecules-28-00391-g001-550.jpg

The application of scanning electron microscopy (SEM) and Raman spectroscopy for structural characterization delivers comprehensive insights into the synthesized MWCNTs. SEM images provide visual confirmation of the alignment, density, and distribution of MWCNTs on the substrate surface, while Raman spectra offer detailed information about their crystalline structure and quality. The structural analysis not only validates the success of the PECVD process but also offers a deeper understanding of the interplay between deposition parameters and resulting structural attributes. These insights are invaluable for refining the deposition process and optimizing the growth of MWCNTs with tailored properties. The interpretation of this research underscores the significant implications for nanotechnology applications. Controlled MWCNT growth techniques, as demonstrated through PECVD, pave the way for advanced electronic devices, sensors, and energy storage systems.The ability to fine-tune deposition parameters and manipulate catalyst materials opens new horizons for tailoring nanomaterial properties to suit diverse technological needs. The insights gained through this research contribute to advancing the understanding of MWCNT synthesis, ultimately driving the development of cutting-edge nanomaterial-based technologies [31]-[33].

Compared to conventional methods of multi-walled carbon nanotube (MWCNT) synthesis, this research offers a notable advancement in the controlled deposition of MWCNTs on Si/SiO2 substrates via plasma-enhanced chemical vapor deposition (PECVD). While traditional techniques often lack precise control over nanotube alignment and density, the utilization of iron oxide nanoparticles as catalysts in PECVD enhances growth uniformity and alignment. This comparative advantage holds significant implications for applications requiring tailored nanotube structures, such as electronic devices and energy storage systems [34]-[35].

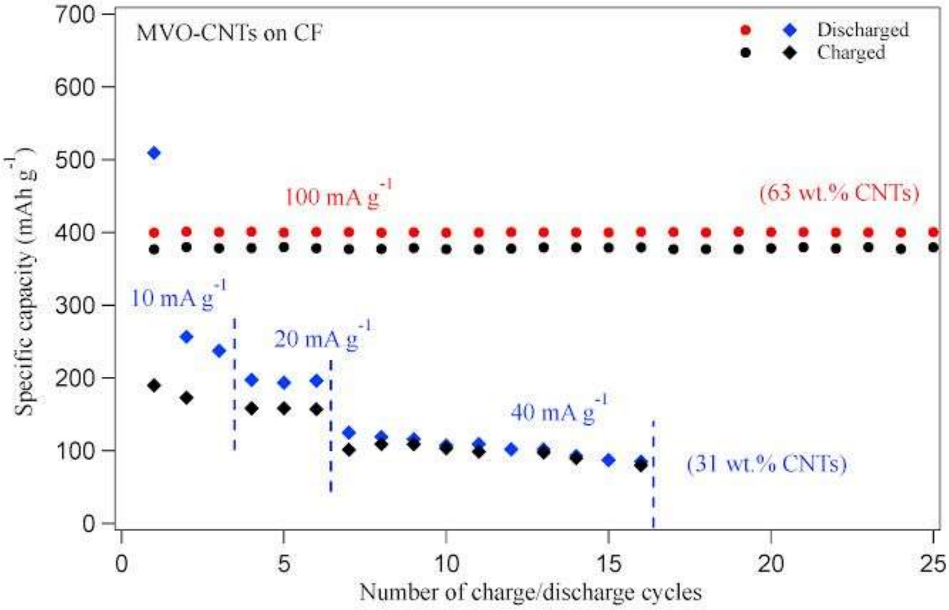


**Figure 10.** The specific capacity versus galvanostatic charge/discharge cycles at different current density values for the MVO-CNTs with 63 wt.% and 31 wt.% of CNTs electrodes, respectively. The MVO-CNTs electrode with 63 wt.% of CNTs sample data are taken from the Ref. https://www.mdpi.com/materials/materials-16-02069/article_deploy/html/images/materials-16-02069-g001-550.jpg

The integration of scanning electron microscopy (SEM) and Raman spectroscopy for structural characterization distinguishes this research from conventional studies. By combining these techniques, researchers gain comprehensive insights into MWCNT alignment, density, and crystalline structure. This contrast is particularly relevant when compared to studies solely relying on SEM or Raman spectroscopy. The inclusion of both techniques ensures a more thorough understanding of MWCNT properties and their correlation with deposition parameters, thus advancing the field's knowledge on nanomaterial synthesis [36]-[37].

In comparison to previous studies, the findings of this research hold significant technological implications for nanomaterial applications. The controlled growth of MWCNTs via PECVD offers a versatile approach for producing nanotube structures optimized for specific applications. This comparative advantage becomes evident when considering conventional growth techniques, which often yield less uniform and aligned structures. The ability to manipulate deposition parameters and catalyst materials showcases the potential to revolutionize nanotechnology applications, ranging from electronic devices to energy storage systems [38]-[40].

## CONCLUSION

In conclusion, this research underscores the significance of plasma-enhanced chemical vapor deposition (PECVD) for the controlled growth of multi-walled carbon nanotubes (MWCNTs) on Si/SiO2 substrates. The utilization of iron oxide nanoparticles as catalysts introduces a novel approach to enhance growth uniformity and alignment, thereby enabling tailored nanotube structures. The comprehensive structural characterization, achieved through scanning electron microscopy (SEM) and Raman spectroscopy, provides in-depth insights into MWCNT properties and their correlation with deposition parameters. These findings hold promising implications for nanomaterial applications, positioning PECVD as a pivotal technique for advancing nanotechnology and facilitating the development of high-performance electronic devices and energy storage systems.

## REFERENCES

[1]. Shamsazar A, Soheili-Moghaddam M, Asadi A. A novel electrochemical immunosensor based on MWCNT/CuO nanocomposite for effective detection of carcinoembryonic antigen (CEA). Microchemical Journal. 2023;109643. doi:10.1016/j.microc.2023.109643.

[2]. Tamarani A, Zainul R, Dewata I. Preparation and characterization of XRD nano Cu-TiO2 using sol-gel method. J Phys Conf Ser. 2019;1185(1):012020. doi:10.1088/1742-6596/1185/1/012020.

[3]. Yang C, Wang G, Bai Q, Li D, Guo S. Efficient lubrication of alkylated reduced graphene oxide based on tribochemistry. Surfaces and Interfaces. 2023;44:103624. doi:10.1016/j.surfin.2023.103624.

[4]. Serp P, Corrias M, Kalck P. Carbon nanotubes and nanofibers in catalysis. Appl Catal A Gen. 2022;253(2):337–358. doi:10.1016/S0926-860X(03)00404-5.

[5]. Zainul R, Azis NA, Isa IM, Hashim N, Ahmad MS, Saidin MI, Mukdasai S. Zinc/aluminium–quinclorac layered nanocomposite modified multi-walled carbon nanotube paste electrode for electrochemical determination of bisphenol A. Sensors (Switzerland). 2019;19(4):941. doi:10.3390/s19040941.

[6]. Azis NA, Isa IM, Hashim N, Ahmad MS, Yazid SNAM, Saidin MI, Si SM, Zainul R, Ulianas A, Mukdasai S. Voltammetric determination of bisphenol A in the presence of uric acid using a Zn/Al-LDH-QM modified MWCNT paste electrode. Int J Electrochem Sci. 2019;14(11):10607–10621. doi:10.20964/2019.11.55.

[7]. Murakami H, Nomura T, Nakashima N. Noncovalent porphyrin-functionalized single-walled carbon nanotubes in solution and the formation of porphyrin–nanotube nanocomposites. Chem Phys Lett. 2021;378(5–6):481–485. doi:10.1016/j.cplett.2003.08.029.

[8]. Dehghani MH, Taher MM, Bajpai AK, Heibati B, Tyagi I, Asif M, Agarwal S, Gupta VK. Removal of noxious Cr(VI) ions using single-walled and multi-walled carbon nanotubes. Chem Eng J. 2022;279:344–352. doi:10.1016/j.cej.2015.04.101.

[9]. Putri GE, Arief S, Jamarun N, Gusti FR, Zainul R. Microstructural analysis and optical properties of nanocrystalline cerium oxides synthesized by precipitation method. Rasayan J Chem. 2019;12(1):85–90. doi:10.31788/RJC.2019.1215029.

[10]. Astuti EJ, Permana B, Ibrahim S, Zulfikar MA, Damayanti S. In silico and experimental study of functionalized monomer for molecularly imprinted-enoxaparin polymer: A novel green approach. React Funct Polym. 2023;105778. doi:10.1016/j.reactfunctpolym.2023.105778.

[11]. Wang D, Giannakis S, Tang J, Luo K, Tang J, He Z, Song S, Wang L. Effect of rGO content on enhanced Photo-Fenton degradation of Venlafaxine using rGO encapsulated magnetic hexagonal FeTiO3 nanosheets. Chem Eng J. 2023;478:147319. doi:10.1016/j.cej.2023.147319.

[12]. Zilla R, Purnamasari D, Zainul R. Design of rotary photoreactor using nano Cu/TiO2 for degradation humic acid in outdoor visible light. J Phys Conf Ser. 2020;1481(1):012039. doi:10.1088/1742-6596/1481/1/012039.

[13]. Sharif SNM, Hashim N, Isa IM, Bakar SA, Saidin MI, Ahmad MS, Mamat M, Hussein MZ, Zainul R. Chitosan as a coating material in enhancing the controlled release behaviour of zinc hydroxide nitrate–sodium dodecyl sulphate–bispyribac

nanocomposite. Chem Pap. 2021;75(2):611–627. doi:10.1007/s11696-020-01320-2.

[14]. Rahmi ST, Rahmad EU, Purnamasari D, Zainul R. Electrolyte Optimization Study on Dry Cell Generator Electrolysis System for Producing Hydrogen Gas Using RSM Method (Response Surface Method). EKSAKTA. 2023;24(2):226–236. doi:10.24036/eksakta/vol24-iss02/273.

[15]. Krishna BG, Ghosh DS, Tiwari S. Hole and electron transport materials: A review on recent progress in organic charge transport materials for efficient, stable, and scalable perovskite solar cells. Chem Inorg Mater. 2023;1:100026. doi:10.1016/j.cim.2023.100026.

[16]. Maurani RN, Purnamasari D, Zainul R. Preparation of TiO2 thin layer on ceramics using dip coating method for degradation humic acid. J Phys Conf Ser. 2020;1481(1):012033. doi:10.1088/1742-6596/1481/1/012033.

[17]. Yi K, Liu D, Chen X, Yang J, Wei D, Liu Y, Wei D. Plasma-enhanced chemical vapor deposition of two-dimensional materials for applications. Acc Chem Res. 2021;54(4):1011–1022. doi:10.1021/acs.accounts.0c00744.

[18]. Sahoo S, Sahoo G, Jeong SM, Rout CS. A review on supercapacitors based on plasma enhanced chemical vapor deposited vertical graphene arrays. J Energy Storage. 2022;53:105212. doi:10.1016/j.est.2022.105212.

[19]. Beliaev LY, Shkondin E, Lavrinenko AV, Takayama O. Optical, structural and composition properties of silicon nitride films deposited by reactive radio-frequency sputtering, low pressure and plasma-enhanced chemical vapor deposition. Thin Solid Films. 2022;763:139568. doi:10.1016/j.tsf.2022.139568.

[20]. Ahmad MS, Isa IM, Hashim N, Saidin MI, Si SM, Zainul R, Ulianas A, Mukdasai S. Zinc layered hydroxide-sodium dodecyl sulphate-isoprocarb modified multiwalled carbon nanotubes as sensor for electrochemical determination of dopamine in alkaline medium. Int J Electrochem Sci. 2019;14(9):9080–9091. doi:10.20964/2019.09.35.

[21]. Mandar S, Purnamasari D, Zainul R. Catalytic activity of nano ZnO/Cu for degradation of humic acid under outdoor light illumination. J Phys Conf Ser. 2020;1481(1):012038. doi:10.1088/1742-6596/1481/1/012038.

[22]. Chen Y, Jiang Y, Chi S-S, Woo HJ, Yu K, Ma J, Wang J, Wang C, Deng Y. Understanding the lithium dendrites growth in garnet-based solid-state lithium metal batteries. J Power Sources. 2022;521:230921. doi:10.1016/j.jpowsour.2022.230921.

[23]. Gu Y, Guo B, Yi Z, Wu X, Zhang J, Yang H. Morphology modulation of hollow-shell ZnSn(OH)6 for enhanced photodegradation of methylene blue. Colloids Surf A Physicochem Eng Asp. 2022;653:129908. doi:10.1016/j.colsurfa.2022.129908.

[24]. Xu T, Zhang K, Cai Q, Wang N, Wu L, He Q, Wang H, Zhang Y, Xie Y, Yao Y, Chen Y. Advances in synthesis and applications of boron nitride nanotubes: A review. Chem Eng J. 2022;431(3):134118. doi:10.1016/j.cej.2022.134118.

[25]. Sharif SNM, Hashim N, Isa IM, Bakar SA, Saidin MI, Ahmad MS, Mamat M, Hussein MZ, Zainul R. The impact of a hygroscopic chitosan coating on the controlled release behaviour of zinc hydroxide nitrate-sodium dodecyl sulphate-imidacloprid nanocomposites. New J Chem. 2020;44(21):9097–9108. doi:10.1039/d0nj00989d.

[26]. Amelia F, Hidayat B, Iryani I, Iswendi I. Potential Hydrophobic Pocket of Squalene Synthase: An In Silico Analysis. EKSAKTA. 2021;22(1):18–26. doi:10.24036/eksakta/vol22-iss1/263.

[27]. Azis NA, Isa IM, Hashim N, Ahmad MS, Yazid SNAM, Saidin MI, Si SM, Zainul R, Ulianas A, Mawardi M, Mukdasai S. Synergistic effect of zinc/aluminium-layered double hydroxide-clopyralid carbon nanotubes paste electrode in the electrochemical response of dopamine, acetaminophen, and bisphenol A. Int J Electrochem Sci. 2020;15(9):9088–9107. doi:10.20964/2020.09.44.

[28]. Barveen NR, Wang T-J, Chang Y-H. Photochemical synthesis of Au nanostars on PMMA films by ethanol action as flexible SERS substrates for in-situ detection of antibiotics on curved surfaces. Chem Eng J. 2022;431(2):134240. doi:10.1016/j.cej.2022.134240.

[29]. Žurauskienė N, Rudokas V, Tolvaišienė S. Magnetoresistance and magnetic relaxation of La-Sr-Mn-O films grown on Si/SiO2 substrate by pulsed injection MOCVD. Sensors. 2023;23(12):5365. doi:10.3390/s23125365.

[30]. Marvinatur Ihsan W, Ratnawulan R. The Effect of Heavy Metal Pollutants on Bioluminescence Intensity of Luminous Mushrooms (Nenothopanus sp). EKSAKTA. 2021;21(2):98–109. doi:10.24036/eksakta/vol21-iss2/235.

[31]. Suyanta, Sunarto, Padmaningrum RT, Karlinda, Isa IM, Rahadian. Development of voltammetry analysis method of copper metal ions by solid-state membrane with carbon nanotube. Indones J Chem. 2021;21(2):332–339. doi:10.22146/ijc.51554.

[32]. Zainul R, Hashim N, Yazid SNAM, Sharif SNM, Ahmad MS, Saidin MI, Suyanta, Sobry MMC, Isa IM. Magnesium layered hydroxide-3-(4-methoxyphenyl) propionate modified single-walled carbon nanotubes as sensor for simultaneous determination of bisphenol A and uric acid. Int J Electrochem Sci. 2021;16:210941. doi:10.20964/2021.09.14.

[33]. Riski Gusti D, Mastutik D, Lestari I, Walidatur Rofiah Y. The Effect of Graphite Concentration in TiO2 Semiconductors on Efficiency of Dye Sensitized Solar Cells (DSSC) Using Dye Melastoma malabathricum L Fruit Extract. EKSAKTA. 2021;22(1):10–17. doi:10.24036/eksakta/vol22-iss1/258.

[34]. Rocha-Arredondo LE, Ortega-Gallegos J, Flores-Camacho JM, Balderas-Navarro RE. Raman study of directly synthetized graphene oxide films on Si, SiO2/Si, and GaAs by remote-catalyzed CVD. Phys B Condens Matter. 2023;669:415302. doi:10.1016/j.physb.2023.415302.

[35]. Tyschenko I, Zhang R, Volodin V, Popov V. Ion-beam synthesis of InSb nanocrystals at the Si/SiO2 interface. Mater Lett. 2022;306:131027. doi:10.1016/j.matlet.2021.131027.

[36]. Rahmawati F, Heliani KR, Wijayanta AT, Zainul R, Wijaya K, Miyazaki T, Miyawaki J. Alkaline leaching-carbon from sugarcane solid waste for screen-printed carbon electrode. Chem Pap. 2023;77(6):3399–3411. doi:10.1007/s11696-023-02183-5.

[37]. Sakaev I, Linden J, Ishaaya AA. Dynamic fracture of SiO2 films due to laser-induced confined micro-explosion at the Si/SiO2 interface: Time-resolved imaging and finite-element simulation. Opt Laser Technol. 2022;150:107938. doi:10.1016/j.optlastec.2021.107938.

[38]. Pires LAS, Babinski MSD, Fonseca Junior A, Manaia JHM, Babinski MA. Aging effects in the extracellular matrix of the clitoris: A scanning electron microscopic analysis. Morphologie. 2023;107(357):259–263. doi:10.1016/j.morpho.2023.03.008.

[39]. Anshari R, Mairizwan M, Oktasendra F, Rianto D, Zulhendra Z. Inert Gas Axial Flow Analysis on Thermal System with Natural Convection Condition. EKSAKTA. 2023;24(1):1–8. doi:10.24036/eksakta/vol24-iss01/338.

[40]. Marina-Montes C, Pérez-Arribas LV, Anzano J, Fdez-Ortiz de Vallejuelo S, Aramendia J, Gómez-Nubla L, de Diego A, Madariaga JM, Cáceres JO. Characterization of atmospheric aerosols in the Antarctic region using Raman Spectroscopy and Scanning Electron Microscopy. Spectrochim Acta A Mol Biomol Spectrosc. 2022;266:120452. doi:10.1016/j.saa.2022.120452.