Tailored Nanomaterials: Tungsten Carbide-Embedded Copper Sulphide for Antimicrobial Applications

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**Abstract:** Background: This research centres on developing and studying tungsten carbide-incorporated copper sulphide nanocomposites designed to improve their effectiveness against microbes.Materials and methods: Results: Tungsten carbide-embedded copper sulphide nanoparticles were analysed for their antifungal activity against Candida albicans and Aspergillus. The nanoparticles effectively inhibited the growth of both microorganisms, with higher concentrations of A11(H) resulting in larger inhibition zones against Candida albicans, consistent with results for Aspergillus. Various analytical techniques, including FTIR, XRD, UV-DRS, TEM, HR-TEM, and SAED, provided essential insights into the structural and optical properties of the nanoparticles. This understanding is critical for advancing their applications. Conclusions: Tungsten carbide and copper sulphide nanoparticles are promising for use in antifungal applications, including antibacterial coatings, antibiotic delivery systems, diagnostics, and vaccines. Addressing challenges such as maintaining antimicrobial effectiveness, managing costs, and navigating intricate fabrication methods is crucial for progressing antimicrobial nanomaterials, with innovations like integrating nanoparticles into polymer matrices playing a key role.

**Keywords:** Nanotechnology, nanoparticles, antibacterial properties, easy regeneration, microstructure

# INTRODUCTION

In recent years, the alarming rise of antibiotic-resistant bacteria has become a critical threat to public health around the world. As traditional antibiotics lose their effectiveness, it is essential to urgently seek out and develop alternative strategies to effectively combat bacterial infections. The health of our communities depends on our ability to adapt and innovate in this fight against resistance. [(Konwar et al., 2022)](https://paperpile.com/c/x6ryVm/WSRew). Nanostructures, a significant advancement stemming from the Industrial Revolution, have significantly influenced a variety of industries. They offer a range of valuable properties, including enhanced strength, improved chemical reactivity, increased conductivity, high surface-to-volume ratios, and the potential for customized functionality. [(Cao, 2004)](https://paperpile.com/c/x6ryVm/hHkMq). Inorganic nanoparticles exhibit promising antibacterial properties, making them a valuable alternative to organic antibiotics. Their enhanced resilience under extreme conditions, such as elevated temperatures and pressures, highlights their potential for various applications. This superior stability positions inorganic materials as an increasingly attractive option in the fight against bacterial infections. [(Lian et al., 2020; Wang et al., 2017)](https://paperpile.com/c/x6ryVm/55JWh+zcxZ) The exploration of nanoparticles (NPs) as alternatives to traditional antibiotics for targeting bacterial infections is gaining interest. Nanotechnology has the potential to provide significant benefits, including the development of antibacterial coatings for medical materials and implantable devices, improved antibiotic delivery systems, enhanced bacterial detection for diagnostics, and formulation of antibacterial vaccines to manage bacterial populations. [(Wang et al., 2017)](https://paperpile.com/c/x6ryVm/zcxZ) Although there have been advancements in the use of nanoparticles, significant challenges remain in effectively applying them while ensuring their antimicrobial properties are preserved.[(Balderrama-González et al., 2021)](https://paperpile.com/c/x6ryVm/94GyJ). Tungsten carbide and copper sulfide nanoparticles are recognized as promising candidates for antibacterial agents. The recent global pandemic has increased interest in developing advanced technologies for antimicrobial surface coatings, highlighting the necessity for innovative solutions in infection control. [(Yimeng et al., 2023)](https://paperpile.com/c/x6ryVm/C9GTQ).Bacteria, fungi, and viruses can transmit practically all human diseases via contaminated surfaces. Antimicrobial coatings are essential to manage and stop the spread of the COVID-19 pandemic, particularly at this time.The incorporation of antimicrobial nano-compounds into materials to effectively reduce microbial adhesion and eliminate microorganisms is an essential and strategic approach that presents growing challenges.

Tungsten is a transition metal found in the d-block of the periodic table, with an atomic number of 74. It can exist in its pure form, as well as in compounds such as tungsten oxide and tungsten carbide. Tungsten's oxyanion shares similarities with vanadate and molybdenum. Research has indicated that tungsten may have a biological function in certain prokaryotes.[(Matharu et al., 2020)](https://paperpile.com/c/x6ryVm/kYjDN).

Tungsten carbide (WC) nanoparticles have chemical and mechanical properties. They are a grey-black solid with a density of 8.64 gm/cm3 (Metric) and a molar mass of 195.86 g/mol. The tensile strength is better when 2% weight of WC particles is added, while the flexural strength is maximum at 2% weight. A higher weight percentage of particles leads to a decrease in both tensile and flexural strengths. The chemical symbol is WC. Tungsten-based nanoparticles are emerging as a powerful solution in the field of antibacterial agents. Their potential antibacterial properties, combined with significant advantages over traditional organic agents—such as enhanced stability, reduced toxicity, and the ability to target multiple biomolecules—position them as a superior choice. Moreover, when tungsten-based nanoparticles are combined with antibiotics or other nanoparticles, they demonstrate a marked increase in antibacterial activity, further highlighting their effectiveness in this domain. [(Modi et al., 2022)](https://paperpile.com/c/x6ryVm/b6VIx). Tungsten carbide coatings can be applied to various surfaces, including medical devices and tools, to make them more resistant to microbial growth. The hard and durable nature of tungsten carbide makes it suitable for coating materials that come into frequent contact with bacteria or other microorganisms. [(Micallef et al., 2020)](https://paperpile.com/c/x6ryVm/hVbe3)

Copper has been used for centuries for its capability to suppress the growth of different microorganisms.Copper Sulfide nanomaterial shows excellent antioxidant activity and has remarkable catalytic efficiency towards pollutants.[(Narasaiah et al., 2023)](https://paperpile.com/c/x6ryVm/Y5ZQb).CuS nanoparticles reduced bacterial colonisation and promoted wound healing through re-epithelialization and collagen deposition by demonstrating antibacterial activities against Staphylococcus aureus and Escherichia coli. [(Liang et al., 2021)](https://paperpile.com/c/x6ryVm/18CrE). At around 1.6 K, copper sulphide may be readily converted into superconductors and has good metallic characteristics. CuS nanoparticles perform significantly better than bulk material in terms of their physical, chemical, structural, and surface characteristics.In the field of biomedicine, copper sulphide nanoparticles have shown promise in applications such as photothermal therapy and bioimaging .

Copper sulfide (CuS) is a naturally abundant mineral known for its diverse phases, which exhibit varying stoichiometries. These phases range from covellite (CuS, where the stoichiometric ratio x = 1) to chalcocite (Cu₂S, where x = 2). The material is notable for its semiconducting properties, with band gap values spanning from 1.3 eV in its narrower-gap phases to 2.4 eV in its wider-gap forms, making it significant for various electronic and optoelectronic applications.[(Al-Jawad et al., 2021)](https://paperpile.com/c/x6ryVm/Ch2Yx) Copper sulfide, with the formula CuxSy, manifests in various forms such as covellite (CuS), villamaninite (CuS2), chalcocite (Cu2S), and digenite (Cu9S5). Notably, CuS and Cu2S are critical phases in the realm of nanotechnology, underscoring their essential role in driving advancements in this field. Copper sulphide is being explored as a photocatalyst due to its environmental friendliness, cost-effectiveness, non-toxicity, easy regeneration, biocompatibility, chemical stability, and unique optical and electrical properties.[(Ajibade & Oluwalana, 2021; Al-Jawad et al., 2021; Jung et al., 2023)](https://paperpile.com/c/x6ryVm/D6mv6+Ch2Yx+q4egW)CuS nanoparticles can have various stable, metastable, and intermediate compositions and structures between the two common sulphide end members, Cu2S (chalcocite) and CuS (covellite).[(Al-Jawad et al., 2021; Jung et al., 2023)](https://paperpile.com/c/x6ryVm/D6mv6+Ch2Yx).Tungsten carbide embedded with copper sulphide creates a material with exceptional mechanical strength, electrical and thermal conductivity, and chemical stability[(Martínez et al., 2020)](https://paperpile.com/c/x6ryVm/FHqkO).The synthesis of tungsten carbide-embedded copper sulfide is accomplished through mechanical alloying, sintering, and the application of either chemical vapor deposition (CVD) or physical vapor deposition (PVD) [(Tiwari & Jain, 2023)](https://paperpile.com/c/x6ryVm/q5mEH)[(Graf et al., 2023)](https://paperpile.com/c/x6ryVm/zgy7r).

Tungsten carbide (WC) embedded copper sulphide (CuS) nanoparticles exhibit unique chemical and mechanical properties. The composite consists of tungsten carbide (WC), which has a high melting point, extreme hardness, and excellent corrosion resistance[(Kurlov & Gusev, 2013)](https://paperpile.com/c/x6ryVm/YSb0y). Changes in copper's lattice parameter, which show the interaction between tungsten and carbon, are responsible for the phases' solubility in the composite[(Chidambaram et al., 2022)](https://paperpile.com/c/x6ryVm/M0DyE).[(Ajay, Sasikala, et al., 2022)](https://paperpile.com/c/x6ryVm/Z58Al).X-ray diffraction and scanning electron microscopy are essential techniques for thoroughly characterizing the microstructure and phase shifts of the composite, providing valuable insights into its properties and performance

[(Harsha & Subramanian, 2022)](https://paperpile.com/c/x6ryVm/Qtz3k)[(Deepika et al., 2022)](https://paperpile.com/c/x6ryVm/C61Hg)[(Solanki et al., 2022)](https://paperpile.com/c/x6ryVm/VGApK).

The incorporation of tungsten carbide reinforcement significantly enhances the mechanical properties of the composite, particularly in terms of hardness, tensile strength, and wear resistance [(Dharman et al., 2021)](https://paperpile.com/c/x6ryVm/1pFHE).The in situ formation of tungsten carbide within the copper matrix composite is achieved through mechanical alloying, resulting in a nanostructured copper tungsten carbide composite with improved mechanical properties [(Yusoff & Zuhailawati, 2022)](https://paperpile.com/c/x6ryVm/nYksO). Copper, being an excellent conductor, makes the composite suitable for electrical applications[(Ajay, Rakshagan, et al., 2022)](https://paperpile.com/c/x6ryVm/4vBMM)

[(Ajay, Suma, et al., 2022)](https://paperpile.com/c/x6ryVm/791v7) [(Katyal et al., 2021)](https://paperpile.com/c/x6ryVm/9n9sS). The incorporation of tungsten carbide into the copper sulphide matrix offers enhanced mechanical properties and potential applications in various fields[(Pedzich, 2012)](https://paperpile.com/c/x6ryVm/ijgZB)The article presents several challenges related to compatibility, cost, and fabrication complexity. Notably, tungsten carbide is a costly material, which may contribute to a significant increase in the overall expense of the composite [(Neha et al., 2021)](https://paperpile.com/c/x6ryVm/H8d8B)[(Maliael et al., 2021)](https://paperpile.com/c/x6ryVm/eQhEy)[(Lakshmi, 2021)](https://paperpile.com/c/x6ryVm/5xHdW). Additionally, the use of copper sulfide further elevates this cost.[(“Copper Sulfides and Their Composites for High-Performance Rechargeable Batteries,” 2022)](https://paperpile.com/c/x6ryVm/NN55) The composite material's conductive properties make it suitable for batteries and other energy storage devices. The process involves mechanical alloying, compaction and heating of the mixed powders, and chemical vapour deposition or PVD techniques[(Jabin et al., 2021)](https://paperpile.com/c/x6ryVm/4mLYA)[(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/x6ryVm/RMBgr) [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/x6ryVm/2peaa)

One very appealing way to increase the activity of the nanoparticles and make the antimicrobial agents more usable is to disperse the nanoparticles in a polymer matrix[(“Copper Sulfides and Their Composites for High-Performance Rechargeable Batteries,” 2022; Wang et al., 2017)](https://paperpile.com/c/x6ryVm/NN55+zcxZ).This review provides a comprehensive exploration of the potential applications of antimicrobial nanomaterial coatings[(Sabarathinam & Madhulaxmi, 2021)](https://paperpile.com/c/x6ryVm/a5KyF)[(Sushanthi et al., 2021)](https://paperpile.com/c/x6ryVm/qOBq)[(Harsha et al., 2022)](https://paperpile.com/c/x6ryVm/LOveU). It also acknowledges the challenges associated with preserving their antimicrobial properties, thereby setting the stage for further research and development in this important area.

# MATERIALS AND METHODS

## SYNTHESIS OF TUNGSTEN CARBIDE

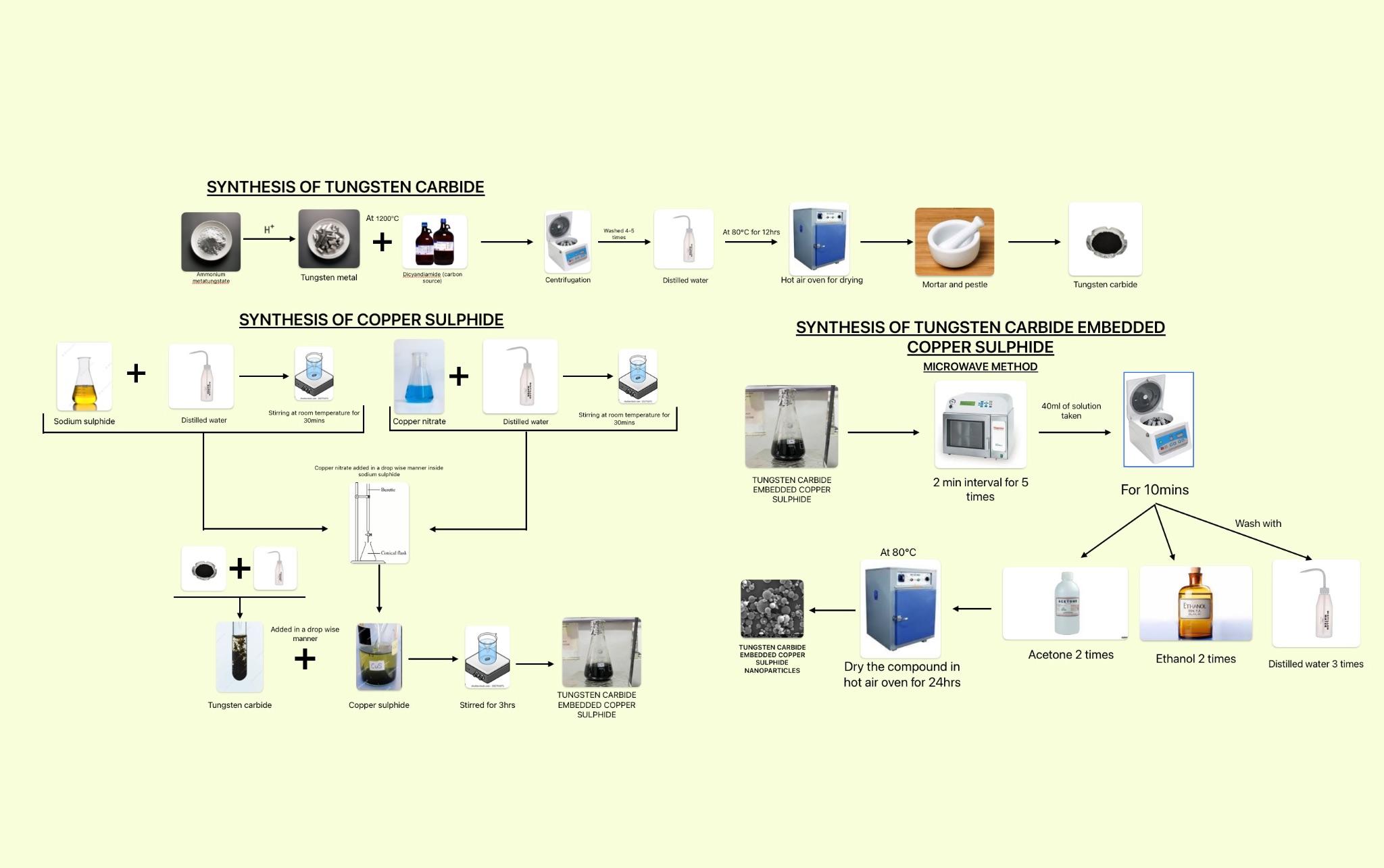
Tungsten carbide nanomaterials were synthesised by adding 0.5g of ammonium metatungstate, which was then reduced to elemental tungsten in the presence of hydrogen gas. The hydrogen gas acted as a reducing agent, enabling the conversion of the tungsten compound to tungsten metal. Subsequently, the reduced tungsten was reacted with the necessary amount of dicyandiamide, a carbon source, at high temperatures of 1200°C. The carbon atoms from dicyandiamide reacted with the tungsten atoms to form tungsten carbide nanoparticles.The mixture was subjected to washing with distilled water four to five times, followed by drying at a temperature of 80°C for a duration of twelve hours.

## SYNTHESIS OF COPPER SULPHIDE

Copper sulphide nanoparticles were synthesised by adding 2.3443g of copper nitrate (Cu(NO3)2: 0.25M) which was then prepared by dissolving the substance in 50 ml of distilled water. It was then stirred for a duration of 30 minutes at room temperature to ensure complete mixing.2.068 g of sodium sulfide (Na2S: 0.53 M) was dissolved in 50 mL of distilled water and stirred for 30 minutes at room temperature. Copper sulfide was then formed using a dropwise method.

## MICROWAVE METHOD

The procedure involves taking a conical flask containing a solution and microwaving it at 2-minute intervals 5 times.Centrifuge 40 ml of the solution for 10 minutes. Wash the precipitate three times with distilled water, two times with ethanol, and two times with acetone. Dry the compound in a hot air oven at 80°C for 24 hours.

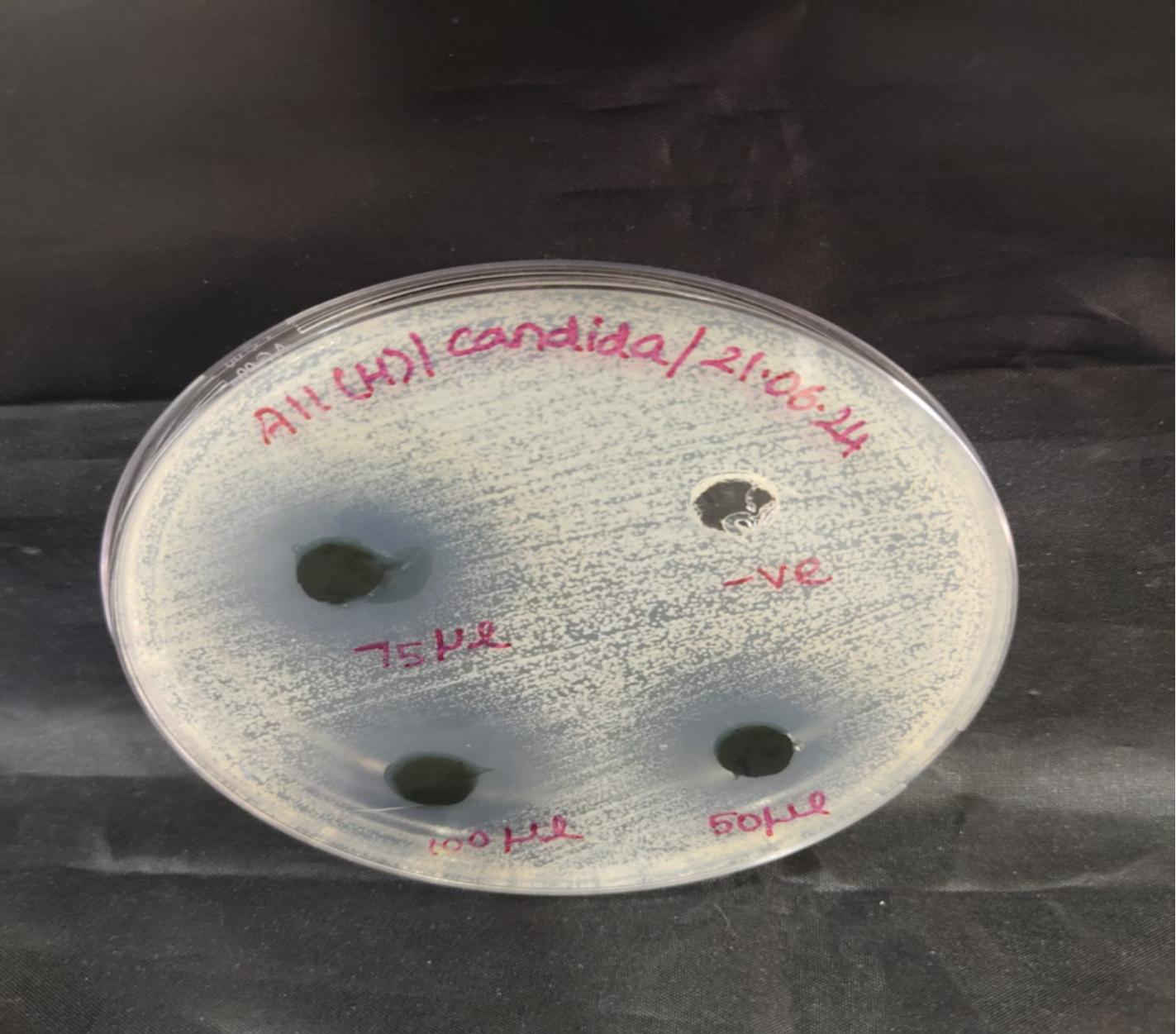


**Figure 1:** A Symmetric diagram illustrating the synthesis of Tungsten carbide, copper sulphide and tungsten carbide embedded copper sulphide nanoparticles.

# RESULTS

## ANTIFUNGAL ACTIVITY

The antifungal effectiveness of Tungsten carbide-embedded copper sulphide nanoparticles against Candida albicans(fig 1) and Aspergillus( fig 2) was investigated. The tungsten carbide-embedded copper sulphide nanoparticles demonstrated efficacy in inhibiting the growth of microorganisms. The data interpreted that As the concentration of A11(H) increases from 50 µL to 100 µL, the diameter of the inhibition zone also increases. This indicates that higher concentrations of A11(H) are more effective in inhibiting the growth of Candida albicans which is similar to the result obtained against Aspergillus.



**Figure 2:** antifungal activity assay, likely involving the measurement of inhibition zones against Candida albicans using different concentrations of a substance referred to as A11(H).

The data is interpreted as follows:

**Table 1:** The data interpretation for the antifungal activity assay against Candida albicans

|  |  |
| --- | --- |
| CONCENTRATION OF  A11(H) | CANDIDA  ALBICANS |
| 50 µL | 17mm |
| 75 µL | 20mm |
| 100 µL | 22mm |
| NEGATIVE CONTROL | 10mm |

## ANTI-FUNGAL ACTIVITY OF TUNGSTEN CARBIDE-COPPER SULPHIDE AGAINST ASPERGILLUS

**Table 2:** The data interpretation for the antifungal activity assay against Aspergillus.

|  |  |
| --- | --- |
| CONCENTRATION OF A11(H) | ASPERGILLUS |
| 50 μL | 12mm |
| 75 μL | 15mm |
| 100 μL | 17mm |
| NEGATIVE CONTROL | 10mm |



**Figure 3:** antimicrobial activity assay, specifically testing the effect of various concentrations of A11(H) on Aspergillus by measuring the inhibition zones.

## Fourier Transform Infrared Spectroscopy

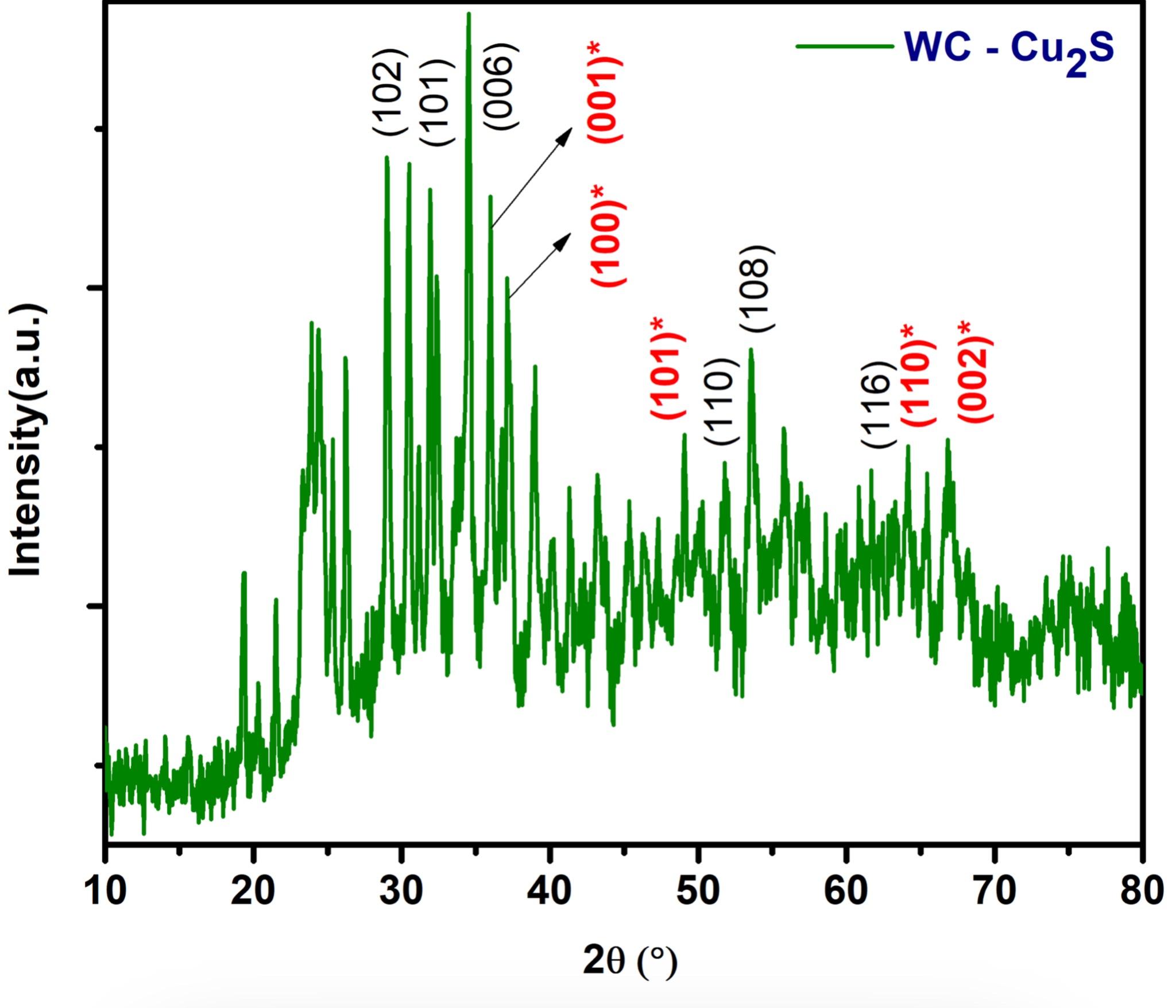
FTIR spectroscopy is an established analytical technique utilized to identify the functional groups present in a compound. This method operates on the principle of measuring the absorption of infrared light at specific wavenumbers, thereby providing valuable insights into the molecular composition and structure of substances. The FTIR peaks indicate the presence of hydroxyl groups with strong peaks at 3671.42 cm⁻¹ and 3562.39 cm⁻¹, along with aliphatic or aromatic hydrocarbons indicated by the peak at 2980.43 cm⁻¹. Additionally, the peaks at 1246.02 cm⁻¹ and 1008.79 cm⁻¹ suggest C-O stretching typical of ethers or esters, while the peak at 831.94 cm⁻¹ points to out-of-plane C-H bending associated with aromatic compounds.



Figure 4: FTIR (Fourier-transform infrared) spectrum graph. Displaying the transmittance percentage (%T) as a function of wavenumber (cm⁻¹).

## X-ray diffraction

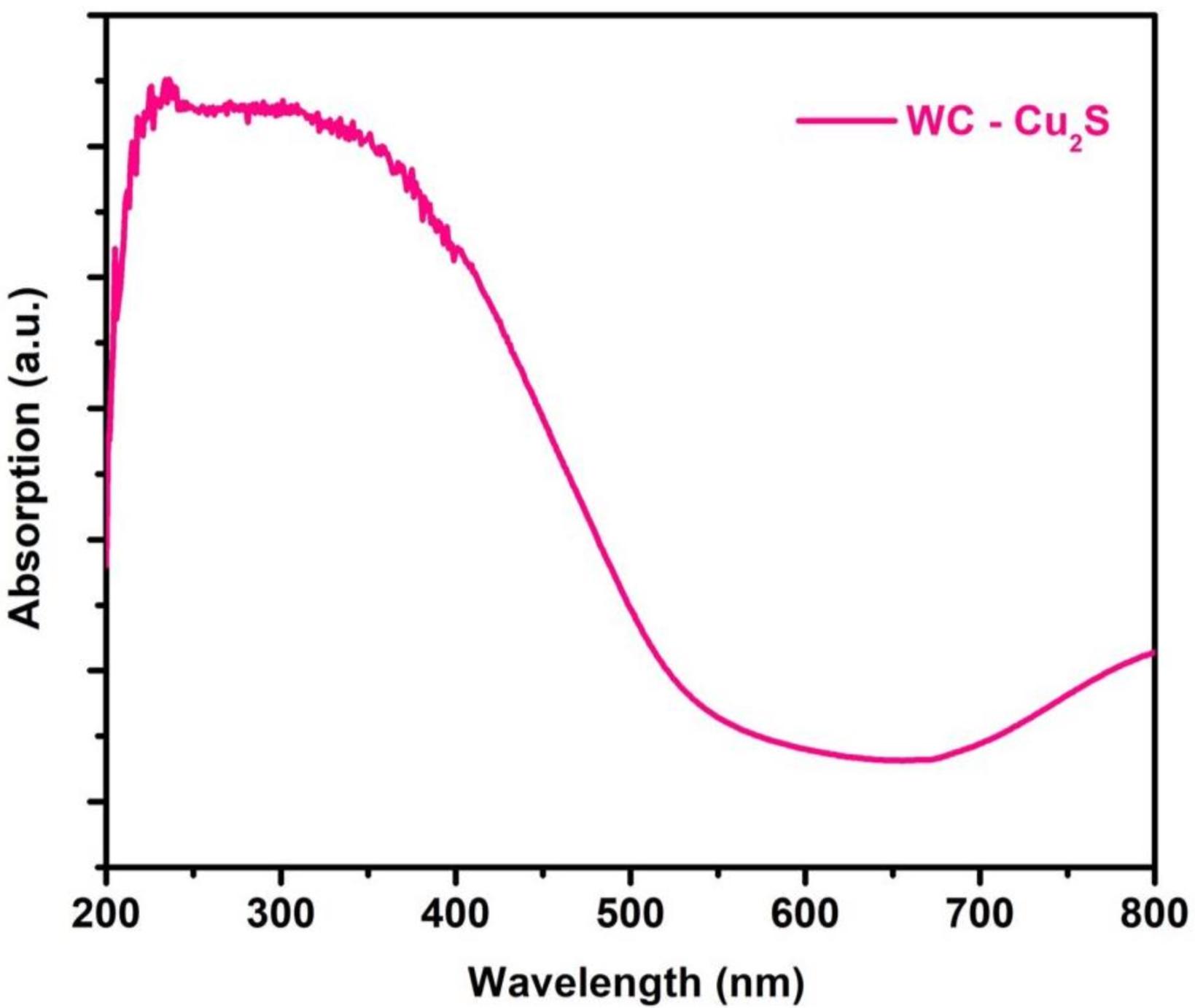
X-ray diffraction (XRD) is primarily used to identify and analyse the crystalline phases in materials, providing insights into their structure and composition. It helps in determining crystal structures, measuring internal stresses, and characterising thin films and nanomaterials. The XRD data reveals a series of diffraction peaks that indicate the sample's crystallographic structure. The 2θ values range from 19.34° to 66.83°, suggesting multiple crystalline phases. Significant intensity peaks, such as those at 123.84 and 190.64, indicate strong crystallinity, while the d-spacing values, ranging from 1.39 Å to 4.59 Å, help identify specific crystallographic planes. Overall, the presence of numerous peaks suggests a polycrystalline sample with a mixture of phases or orientations.



**Figure 5:** XRD analysis of tungsten carbide embedded copper sulphide.

## UV-DRS SPECTRA

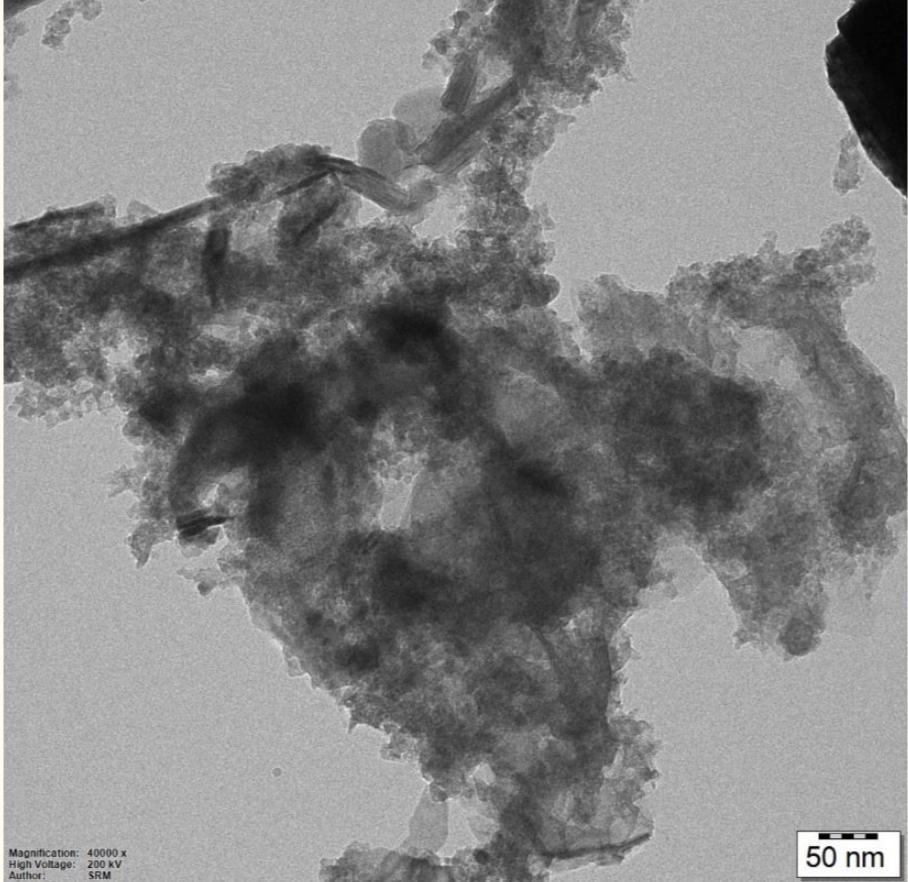
UV-Vis DRS is a technique used to study the light absorption properties of solid samples, providing insights into electronic transitions within materials. The absorption spectrum, shown in the graph, has the x-axis representing wavelengths from 200 to 800 nm and the y-axis indicating absorption in arbitrary units. The magenta line labelled “WC - Cu2S” illustrates the absorption spectrum for tungsten carbide (WC) and copper sulfide (Cu2S),The peak observed near 300 nm highlights an important electronic transition from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO), providing insights into the molecule's electronic structure. This technique is essential for determining the optical properties, purity, and concentration of compounds in materials science and chemistry.



**Figure 6:** UV-DRS spectra of Tungsten carbide embedded copper sulphide

## Transmission electron microscopy

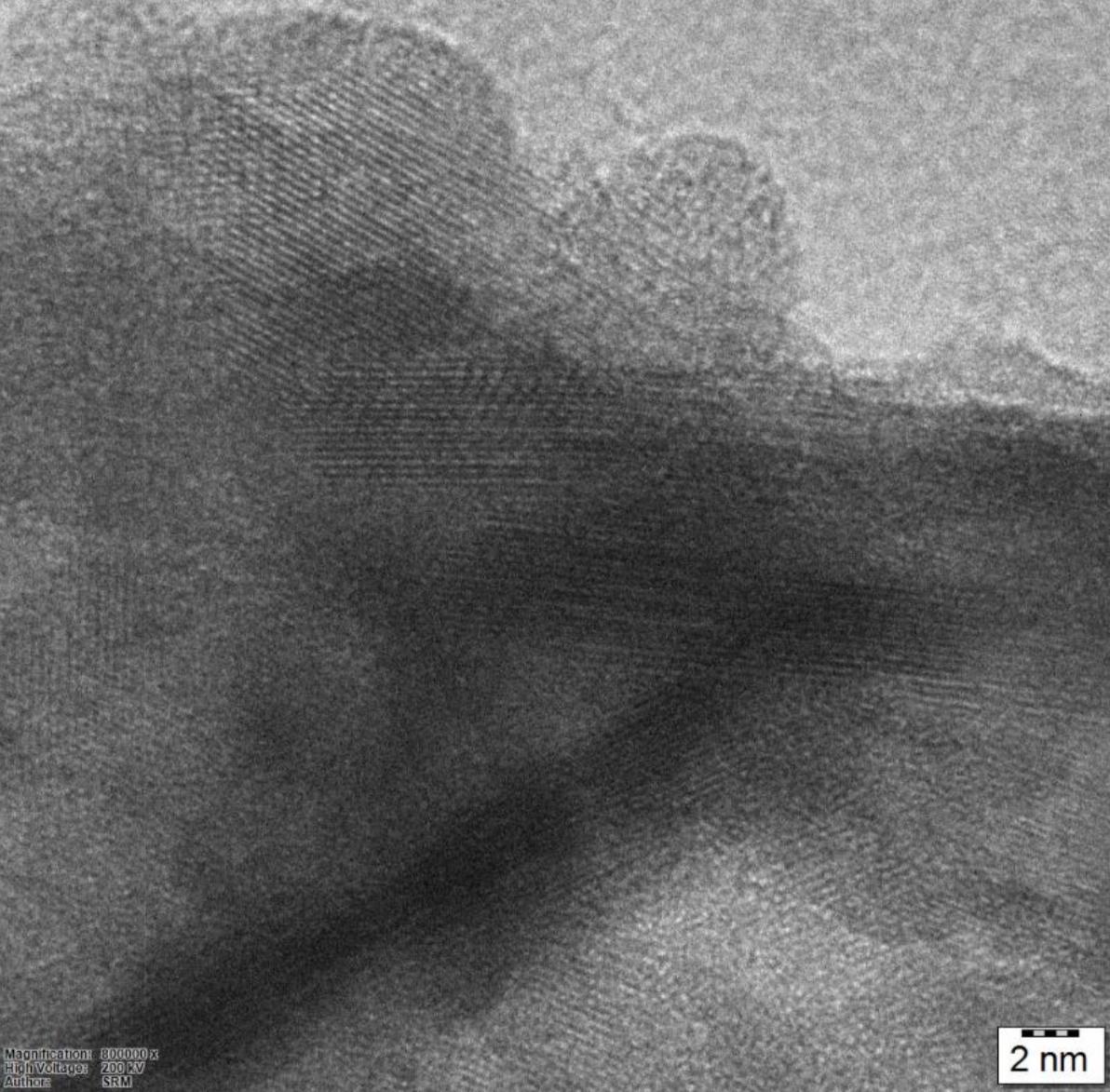
A potent method for describing nanomaterials and other microscopic structures is transmission electron microscopy (TEM) analysis. It offers precise information about the shape, size, structure, and composition of the materials in addition to high-resolution imaging. Here, The TEM image,(Fig 6) taken at a magnification of 40,000x with a scale bar of 50 nanometers, shows a cluster of irregularly shaped nanoparticles with varying opacity, indicating differences in composition or thickness.



**Figure 7:** TEM analysis of tungsten carbide embedded copper sulphide

## High-Resolution Transmission Electron Microscopy

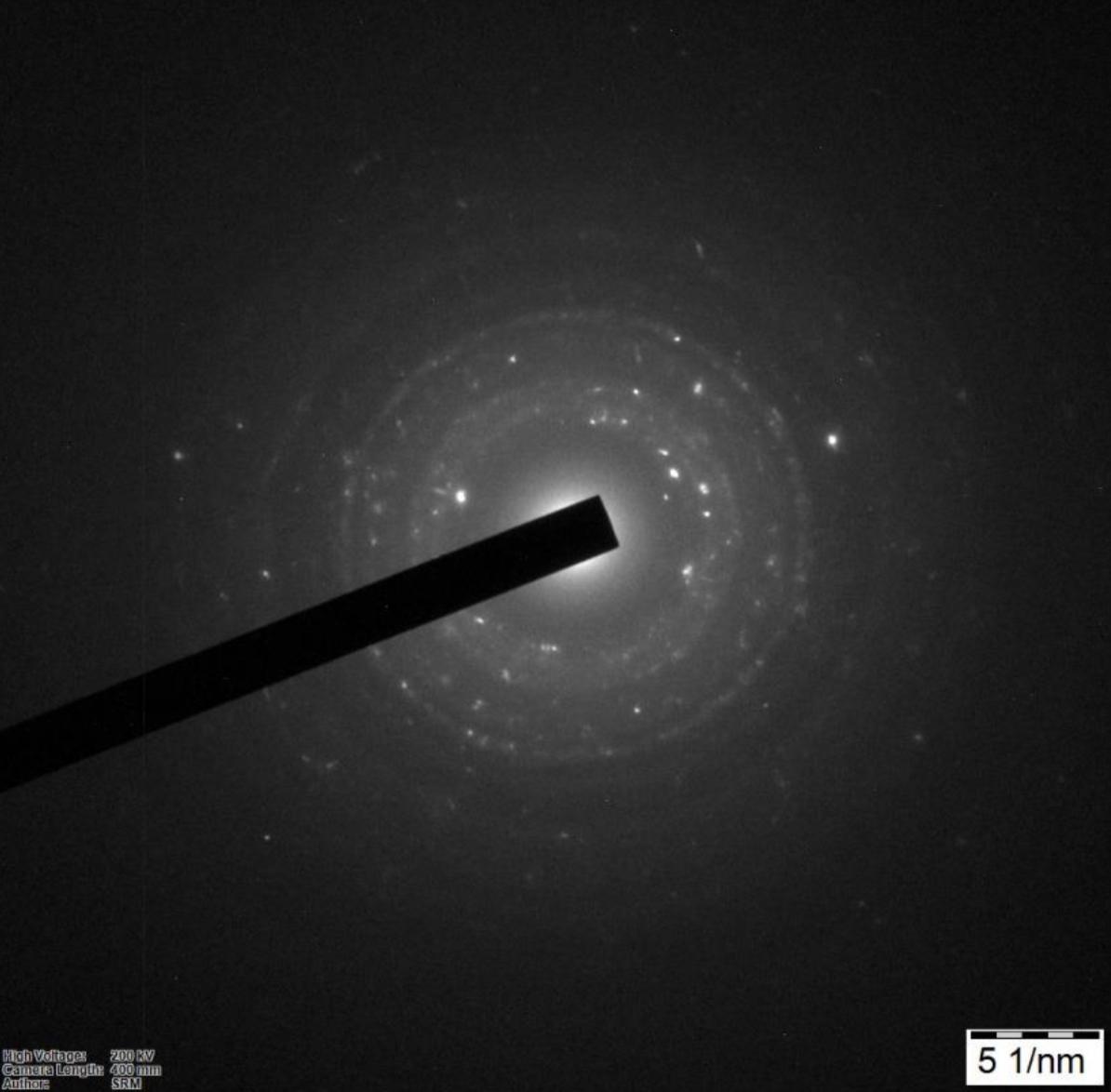
HR-TEM offers atomic-level resolution, enabling access to highly detailed and precise information about the samples. Here, the scale bar showcases 2 nanometers highlighting the high resolution of the microscopy technique.



**Figure 8:**HR TEM analysis of tungsten carbide embedded copper sulphide

## Selected area electron diffraction

Selected Area Electron Diffraction (SAED) is an essential technique for analyzing the nanoscale crystallographic structure of materials, effectively complemented by Transmission Electron Microscopy (TEM).Crystal structures and lattice properties may be determined using SAED patterns. The scale marker "5 1/nm," which here signifies spatial frequency in reciprocal space, is represented by the SAED.



**Figure 9**: SAED analysis of Tungsten carbide embedded copper sulphide

# DISCUSSION

Tungsten carbide-embedded copper sulphide nanoparticles demonstrate antifungal action by releasing copper ions in aqueous environments, disrupting cellular processes in fungi. Studies reveal that tungsten carbide nanoparticles exhibit wide-ranging virucidal activity, highlighting their potential as effective antimicrobial agents.[(Pfaff et al., 2019)](https://paperpile.com/c/x6ryVm/NGXkU)The presence of tungsten carbide enhances structural stability, leading to a sustained release of copper ions and increased antifungal efficiency [(Al-Enazi et al., 2023)](https://paperpile.com/c/x6ryVm/qevyE) Interaction with biological systems generates reactive oxygen species, causing oxidative stress and damage to fungal cells. [(Dai et al., 2024)](https://paperpile.com/c/x6ryVm/KvFxB)The nanoparticles' high surface area and small size promote effective penetration, membrane disruption, and inhibition of critical cellular processes, making them promising candidates for antifungal treatments.[(Ahmed & Anbazhagan, 2017)](https://paperpile.com/c/x6ryVm/yzNLB) The elucidation of these mechanisms simplifies the task of combating germs and developing novel materials resistant to them. This research highlights the potential application of copper nanoparticles in medical and environmental contexts,creating a strong foundation for future growth of new antibacterial materials and agents. [(Lakshmi 2021)](https://paperpile.com/c/x6ryVm/1wFGJ).

In a study utilizing Tungsten oxide nanoparticles, it was observed that Gram-positive bacterial species exhibit higher susceptibility to antimicrobial alternatives compared to Gram-negative species.[(Matharu et al., 2020)](https://paperpile.com/c/x6ryVm/kYjDN) The observed discrepancy can be attributed to differences in cell wall structures. Gram-positive bacteria feature a relatively permeable peptidoglycan layer, which facilitates the penetration of antimicrobial agents. Conversely, Gram-negative bacteria have an outer membrane that may contribute to their reduced susceptibility. [(Egan, 2018)](https://paperpile.com/c/x6ryVm/aNDON)

Based on the findings regarding the antifungal activity of A11(H), it is clear that as it progresses concentration of A11(H) increases,the size of the inhibition zone expands considerably.This suggests that higher concentrations of A11(H) demonstrate enhanced effectiveness in inhibiting Candida albicans and Aspergillus. Additionally, findings from various studies indicate that natural compounds such as clove and oregano essential oils have shown inhibition zones ranging from 15 mm to 30 mm against Fusarium species, depending on the concentration tested. [(“Biological Effects of Essential Oils – A Review,” 2008; Egan, 2018)](https://paperpile.com/c/x6ryVm/aNDON+aZQxw) Similarly, curcumin has exhibited inhibition zones ranging from 11 mm at 50 µg/mL to 22 mm at 200 µg/mL against Aspergillus niger.[(“Biological Effects of Essential Oils – A Review,” 2008; Egan, 2018; Trigo-Gutierrez et al., 2021)](https://paperpile.com/c/x6ryVm/aNDON+aZQxw+iEcDo) These findings provide support for the notion that certain natural compounds can achieve significant antifungal activity comparable to the observed effects of A11(H).

In a study by Ramesh et al. (2020), the cutting-edge FTIR analysis of silver nanoparticles revealed compelling evidence. The strong peaks around 3400 cm⁻¹ signify the remarkable O-H stretching from hydroxyl groups, while the 1620 cm⁻¹ peaks indicate aromatic C=C stretching. This underscores the pervasive nature of hydroxyl groups in similar nanoparticle studies, emphasising their pivotal role in both stabilisation and reactivity. [(“Antibacterial Activity and Spectroscopic Characteristics of Silver Nanoparticles Synthesized via Plant and in Vitro Leaf-Derived Callus Extracts of Mucuna Pruriens (L.) DC,” 2022)](https://paperpile.com/c/x6ryVm/wGboM) Moreover, the work of Patil et al. (2021) presents equally compelling FTIR spectra of nanocomposites derived from essential oils, showcasing peaks at 3700 cm⁻¹ for hydroxyl groups and 2800-3000 cm⁻¹ for aliphatic C-H stretching,Investigating The existence of active moieties that contribute to the antibacterial properties of the materials is essential. The observed C-O stretching around 1300 cm⁻¹ indicates a promising level of functionalization, similar to that found in ethers or esters, which could enhance the effectiveness of these materials. [(Nigam et al., 2020; Patil et al., 2021)](https://paperpile.com/c/x6ryVm/H1wHj+SBYXr) The FTIR outcomes from the current study echo the findings from other research, confirming the prevalence of hydroxyl groups, hydrocarbons, and C-O stretching in various nanoparticle and nanocomposite systems. Undoubtedly, these functional groups are pivotal to shaping the chemical properties and potential applications of the materials under scrutiny.Tungsten carbide-embedded copper sulfide nanomaterials possess distinctive structural and Chemical nature that show great potential for effectively addressing microbial growth. The combination of tungsten carbide's mechanical stability and copper sulphide's antimicrobial properties, particularly through the release of bioactive copper ions, enhances the effectiveness of these nanoparticles against a wide range of microbes. In research conducted by Li et al. (2017), the significance of copper ions in disrupting microbial cellular processes is emphasised, while the structural integrity provided by tungsten carbide may support continuous antimicrobial activity [(Li et al., 2017; Ma et al., 2022)](https://paperpile.com/c/x6ryVm/tyLVP+or8Cg).The generation of reactive oxygen species (ROS) during interactions with biological systems plays a critical role in the antimicrobial mechanism. By inducing oxidative stress, ROS can effectively damage proteins, lipids, and DNA within microbial cells. Research conducted by Huang et al. (2018) and Rahman et al. (2024) highlights the promising potential of metal-based nanoparticles in combating microbial infections through this oxidative pathway. This suggests that further exploration and development of these nanoparticles could lead to more effective treatments in the fight against microbial diseases. [(Rahman et al., 2024)](https://paperpile.com/c/x6ryVm/6mxcZ). Moreover, the capacity of tungsten carbide-embedded copper sulfide nanoparticles to disrupt microbial cell membranes through mechanisms like increased permeability underscores their potential as effective antimicrobial agents. This disruption results in the release of cellular contents and subsequent cell death, as indicated in similar studies focused on metal oxide nanoparticles. [(Singh et al., 2021)](https://paperpile.com/c/x6ryVm/YizQm)

The versatility of these nanomaterials for diverse applications, including surface coatings, wound healing, and drug delivery systems, underscores their significance in addressing the growing challenge of antimicrobial resistance [(Galdino et al., 2022)](https://paperpile.com/c/x6ryVm/Uzuwb). As nanotechnology progresses, ongoing research into optimising synthesis methods and understanding the underlying mechanisms of action will enhance the development of innovative antimicrobial solutions tailored for both medical and industrial applications.

## LIMITATIONS

This study, like all scientific research, has certain limitations that provide valuable opportunities for growth and improvement(Chehelgerdi et al., 2023). One important area for further exploration is the long-term stability and potential cytotoxicity of the synthesized nanomaterials. Addressing these aspects could enhance our understanding and application of these materials in the future.Understanding the biocompatibility and potential side effects of these materials is essential for their safe and effective application in antimicrobial settings (Saadh et al., 2024). Furthermore, additional studies focusing on the mechanism of action of the tungsten carbide-embedded copper sulphide nanomaterials against various microbial strains could greatly enhance the article's value. Understanding the molecular-level interactions of these nanomaterials with pathogens can yield valuable insights for optimising their antimicrobial efficacy and specificity. Additionally, exploring the potential development of resistance by microorganisms to these nanomaterials over time is a crucial aspect that warrants attention in future research.

# FUTURE SCOPE

The research into tailored nanomaterials for antimicrobial applications shows significant promise for addressing the growing concern of antimicrobial resistance. Further exploration could focus on utilising these nanomaterials in various settings, such as medical devices, wound dressings, and environmental disinfection. Additionally, examining the scalability and cost-effectiveness of producing tungsten carbide-embedded copper sulphide nanomaterials on a larger scale could facilitate their practical implementation in real-world antimicrobial strategies.

# CONCLUSION

Tungsten carbide and copper sulphide nanoparticles, in particular, have emerged as strong candidates for antifungal applications. These materials can be utilised in antibacterial coatings, antibiotic delivery systems, diagnostics, and vaccines. Despite their potential, challenges such as maintaining antimicrobial properties, high costs, and fabrication complexities remain. Addressing these challenges through innovations in synthesis and application methods, like embedding nanoparticles in polymer matrices, is crucial for the future of antimicrobial nanomaterials.

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