Synergistic Antimicrobial Effect of Tungsten Carbide and Cobalt Sulfide Hybrid Materials

S Smrithi1 , Sakeen safrin1,a)

1Smrithi Medical Centre, Chennai, Tamilnadu, India

**Corresponding Author:** a)[sakeenasafrin17@gmail.com](mailto:sakeenasafrin17@gmail.com)

**Abstract:** Nanoparticles, with at least one dimension between 1-100 nm, show characteristics due to their small partial size and large surface area. Nanoparticles' special properties allow them to be used in a variety of industries, including electronics, medicine, and cosmetics. Nanoparticles have been created using a variety of techniques, such as physical, chemical, and biological ones, to enhance their characteristics for various uses. A lot of emphasis has been placed on increasing the hardness and stability of tungsten carbide, which is used for industrial purposes, as well as the high electrical conductivity and catalytic properties of cobalt sulfide. The antimicrobial use of nanoparticles has a wide range of possibilities in medicine, agriculture, and food safety because they reduce infection rates, improve public health, and are environmentally friendly. To study the synergistic antimicrobial effect of tungsten carbide and cobalt sulfide hybrid materialsCobalt sulfide is fabricated by dissolving cobalt nitrate and sodium sulfide in water to create the solutions A and B, respectively. These are mixed dropwise to obtain cobalt sulfide precipitates. Tungsten carbide is generated by reducing ammonium metatungstate with hydrogen and reacting the tungsten metal product with dicyandiamide at high temperatures. The tungsten carbide is then mixed with cobalt sulfide to give tungsten carbide cobalt sulfide (WCCoS) nanoparticles. By using microwave-assisted synthesis and calcination, the WCCoS nanoparticles are created to improve their properties. The final WCCoS nanoparticles exhibit antimicrobial properties and exhibit potential for biomedical applications.The synergistic antimicrobial effect of tungsten carbide and cobalt sulfide hybrid materials was investigated using various characterization techniques. XRD confirmed crystalline phase formation, while UV-Vis spectroscopy indicated electronic interactions between components. FTIR analysis validated chemical bonding, and TEM/HRTEM revealed nanoscale morphology with uniform distribution. SAED confirmed crystallinity, supporting the material’s structural integrity. Antifungal activity tests demonstrated significant inhibition, highlighting the hybrid’s potential for biomedical applications.Tungsten Carbide (WC) and Cobalt Sulfide (CoS) hybrid materials were found to possess greatly enhanced antibacterial activity compared with the single component alone. The hybrid material exhibited broad-spectrum antimicrobial activity due to its larger specific surface area, accelerated electron transport, and stronger catalytic activity. Moreover, the material has good stability and biocompatibility, which makes it a good candidate for use in the field of biomedicine. We encourage future studies to further investigate the possible mechanisms of action, long-term stability, in-vivo safety, and efficacy of these materials for therapeutic use.

**Keywords:** Tungsten carbide, Cobalt sulphide, antimicrobial , synergistic properties

# INTRODUCTION

Nanoparticles are particles with a single dimension of 1 to 100 nm. Depending on the size and surface functions of the particle, they display a variety of characteristics.[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/ohd33s/ZYmtd+M2Wj9+dlPge).Nanoparticles can be used in a variety of fields, including electronics, cosmetics, and both diagnostic and therapeutic medical applications, thanks to their small size and huge surface area.[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/ohd33s/ZYmtd+M2Wj9+dlPge) The number of items that either contain or require nanoparticles (NP) for their manufacturing and use increased 25-fold between 2005 and 2010, demonstrating the tremendous advancements in nano-based technology over the past few decades.[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/ohd33s/ZYmtd+M2Wj9+dlPge).Their distinct general qualities, namely in relation to particle size, surface area, surface reactivity, charge, and shape, are possibly what made this advancement possible to their equivalents in bulk or dissolved form. Examining tunneling microscopy, scanning transmission electron microscopy, and tandem electron microscopy are a few techniques that can examine nanomaterials with atomic resolution, which has increased interest in and focus on nanotechnology[(Lu et al., 2025)](https://paperpile.com/c/ohd33s/rejf).Antimicrobial nanoparticle synthesis processes have advanced in recent decades as a result of its use in healthcare and industrial applications. The general characteristics of nanoparticles are entirely determined by the synthesis method used, which also determines the size and shape of the NPs. Physical, chemical, and biological (sometimes referred to as "green") synthesis techniques are the three categories of synthesis procedures. The evaporation method ,condensation method, magnetron sputtering, mechanochemical processing (MCP), microwave-thermal method, photoreduction process, and pulsed laser ablation are the most common methods to synthesize nanoparticles. In the same way, there are numerous techniques for synthesizing nanoparticles chemically, including the atomic layer deposition technique, chemical reduction technique, chemical vapor deposition, electrochemical anodization technique, hydrolysis, hydrothermal technique, precipitation–hydrothermal technique, reverse micellar process, sol–gel technique, solution-based synthesis, solvothermal technique, and the sonochemical technique[(Reindl et al., 2025)](https://paperpile.com/c/ohd33s/IDYw). Carbon-based NPs are being quickly utilized in numerous biomedical applications like drug delivery, gene therapy, and imaging. Carbon nanotubes (CNTs), which represent a major category of these NPs, consist of single-walled (SWCNTs) and multi-walled (MWCNTs) types. The unique physicochemical characteristics of CNTs render them powerful candidates for a variety of applications in biomedical areas, including drug and gene delivery, biosensors, and tissue engineering applications. They also exhibit high stability and possess particular surface chemistry that enhances drug loading capacity. Nevertheless, the safety of CNTs remains uncertain since they have been demonstrated to be harmful to healthy tissues after prolonged exposure. Tungsten, which has an atomic number of 74, is classified as a d block element. Tungsten exists in its pure form as well as in tungsten carbide and tungsten oxide forms. Research has shown that tungsten has a biological function in some prokaryotes and serves as a cofactor for various enzymes that participate in biochemical reactions. The Ren et al. patent, which highlights the virucidal effectiveness of tungsten nanoparticles, especially when combined with other strong antimicrobial agents, led to investigations into tungsten's antiviral and antibacterial properties[(Serpell et al., 2016)](https://paperpile.com/c/ohd33s/9X9R).Tungsten carbide, a variant of tungsten, is well-known for its hardness and wear-resistant qualities. This makes it the most preferred metal for abrasives and cutting tools. It remains stable at a temperature of 2,870°C. With a density of about 15.6 g/cm2, it possesses considerable strength and durability. Additionally, tungsten carbide exhibits high electrical and thermal conductivity. Due to its remarkable properties, it is often utilized in industrial applications subjected to extreme temperatures[(Choi et al., 2018)](https://paperpile.com/c/ohd33s/XkuX).Cobalt is considered to be the first catalyst produced from a non-precious metal. Cobalt is obtainable in forms such as cobalt sulfide, cobalt nitrate, cobalt oxide, etc. Cobalt sulfide (CoS) is a dark, semiconducting substance that is insoluble in water and possesses a hexagonal crystal structure.. It serves as a catalyst for hydrogenation processes and is also employed in qualitative inorganic analysis. Metal sulfides such as cobalt sulfide have attracted significant interest due to their excellent electrical conductivity, reliable stability, minimal toxicity, straightforward fabrication, and most notably, low cost[(Khizar et al., 2024)](https://paperpile.com/c/ohd33s/2ywO). The specific capacitance of cobalt sulfide is recognized to be double that of their metal hydroxides and metal oxide equivalents. Metal sulfide exhibits an enhancement in capacitance that results from substituting lower electronegative oxygen with sulfur. Some of their physical properties, including porous nature, rough structure, crystalline structure, and high density, support the movement of ions during the charge−discharge process. Antimicrobial effects refer to the capacity of a substance to destroy or hinder the growth of microorganisms such as bacteria, fungi, and viruses.[(Ganapathy 2021; Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/ohd33s/jlIi+vxOH+OMqDZ).These effects are crucial in medicine, agriculture, and various industries to prevent and treat infections, primarily to ensure food safety, and to uphold hygiene. Antimicrobial agents have demonstrated significant benefits across various fields, particularly in the last 4 to 5 years[(Harini et al., 2024)](https://paperpile.com/c/ohd33s/jP34). One major benefit is their function in decreasing infection rates by restricting bacterial growth in healthcare environments, which has been especially vital during the COVID-19 pandemic.[(Jain & Verma, 2022; Marya et al., 2022)](https://paperpile.com/c/ohd33s/5zfsc+BHDH7) The development of new antimicrobial surfaces can prevent the transmission of hospital-acquired infections (HAIs). Another benefit is the application of antimicrobial coatings on medical devices, which has diminished biofilm formation and device-related infections[(Lam et al., 2006)](https://paperpile.com/c/ohd33s/Mc1p). In agriculture, antimicrobial peptides are being utilized to manage plant pathogens and decrease reliance on chemical pesticides. Antimicrobial packaging in the food industry has extended the shelf life of products and enhanced food safety.[(Wadhwani et al., 2022)](https://paperpile.com/c/ohd33s/HWR6b) Advancements in nanotechnology have resulted in the creation of nanoparticles possessing strong antimicrobial characteristics, providing innovative solutions for drug-resistant infections.[(Solanki et al., 2023)](https://paperpile.com/c/ohd33s/sU9MS) Furthermore, the application of probiotics and prebiotics as natural antimicrobial substances has garnered significant interest for their ability to support healthy gut function and avert gastrointestinal infections. [(Chokkattu et al., 2023)](https://paperpile.com/c/ohd33s/XekIb) These developments emphasize the continuous strides and vital significance of antimicrobial agents in enhancing public health, agriculture, and food safety[(Serpell et al., 2016; “Synergistic Effect of Bimetallic Cobalt-Based Sulfide Enhances the Performance of ZnSe Photocatalytic Hydrogen Evolution by Z-Scheme,” 2023)](https://paperpile.com/c/ohd33s/9X9R+7LDl).

# MATERIALS AND METHODS

## Synthesis of Cobalt Sulfide

### Solution A

Cobalt: Cobalt nitrate (2.9103 g, pink in appearance) was synthesized by adding 50 mL distilled water at room temperature and stirring for 30 min to ensure complete dissolution of the cobalt nitrate. This produced a homogeneous solution (referred to as Solution A) in which the cobalt nitrate was completely dissolved in the course of its solubility in water, resulting in a clear and uniform solution required for the following step.

### Solution B

At the same time, sodium sulfide, which is naturally yellow, is used as a sulfide source and is dissolved in an equivalent amount of 50 ml distilled water, also at 300K and equal in 30 minute horizons, with the same stirring method to ensure dissolution rates of 100%. This solution, defined as Solution B, is as essential as the cobalt(II) salt in the formation of cobalt sulfide, when combined with Solution A.

## Combining Solutions A and B

The two solutions were then cautiously mixed in a beaker by drop-wise addition. When the two solutions were fully combined, a color change to black was observed visibly, which is indicative of the formation of cobalt sulfide (CoS).[(Muthuswamy Pandian et al., 2022)](https://paperpile.com/c/ohd33s/5D24v) It was important to do this step in such a slow and controlled method so that the reaction rate was manageable.[(Adel et al., 2023)](https://paperpile.com/c/ohd33s/sV2WM) If it was too fast, there would be side products and if too slow, the pure cobalt sulfide precipitate would not form. This black precipitate is a vital part of the process for the following steps in the synthesis of the tungsten carbide cobalt sulfide nanoparticles.

## Synthesis of Tungsten Carbide

Ammonium metatungstate is first reduced to tungsten metal via hydrogen (H₂), utilizing 0.5 grams ammonium metatungstate during the first step of the tungsten carbide synthesis process. The reduction of ammonium metatungstate involves controlled reduction, necessitating the reaction to be controlled and the tungsten metal to be reduced. Using hydrogen as a reducing agent is beneficial because it transforms the tungsten ions in the ammonium metatungstate to metallic tungsten, which is required prior to the formation of tungsten carbide to occur.[(Laghari et al., 2023; Ramakrishnan et al., 2023)](https://paperpile.com/c/ohd33s/0wLM3+y4t9Y).

## Formation of Tungsten Carbide

The reduced metal of tungsten will then react with dicyandiamide in a high temperature environment of 1200°C, dicyandiamide was use as the carbon source; the carbon atoms from dicyandiamide will react with the tungsten atoms resulting in tungsten carbide (WC) formation. This high temperature reaction guarantees the construction of an extremely strong tungsten carbide structure characterised by its well-documented hardness and durability. The reaction mixture is then washed with water for 4 to 5 minutes to get rid of any unreacted materials, alongside any impurities. After washing, the mixture is dried for 12 hours, giving or producing to the final product – pure tungsten carbide powder.

## Combining Tungsten Carbide with Cobalt Sulfide

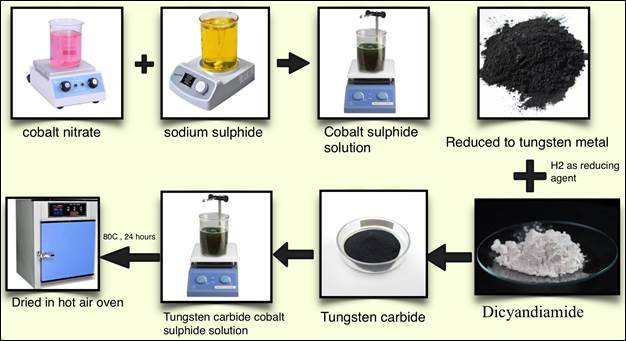
To make tungsten carbide cobalt sulfide (WCCoS) nanoparticles, you need to mix tungsten carbide with a cobalt sulfide solution. First, you create the cobalt sulfide solution by dissolving the cobalt sulfide precipitate you made earlier in 25ml of water. Next, you add the tungsten carbide to this solution. You then stir this mixture for 3 hours without stopping. This long stirring process helps to coat the tungsten carbide particles with cobalt sulfide. The result is a composite material that has better properties than its individual components.

## Microwave-Assisted Synthesis

The mixture is then subjected to a microwave-assisted synthesis process. The microwave irradiation is applied for a total of 10 minutes, with 2-minute intervals to prevent overheating and ensure uniform heating.[(Sreevarun et al., 2023)](https://paperpile.com/c/ohd33s/QKS9u) Microwave synthesis is known for its efficiency and ability to produce nanoparticles with well-defined sizes and shapes. After microwave treatment, the mixture is centrifuged and washed with distilled water, ethanol, and acetone to remove any residual impurities. The precipitate is then dried at 80°C for 24 hours to obtain the final tungsten carbide cobalt sulfide nanoparticles.[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/ohd33s/dmMql+3iH6f)

## Calcination Process

To further improve the properties of the nanoparticles, a calcination process is carried out. The dried precipitate is subjected to calcination at 300°C for 3 hours. Calcination helps to enhance the crystallinity and stability of the nanoparticles, making them suitable for various applications, including antimicrobial treatments for tooth pain alleviation.[(Ganapathy 2021)](https://paperpile.com/c/ohd33s/Lwfcs) The final product is tungsten carbide cobalt sulfide nanoparticles with intrinsic antibacterial properties and biocompatibility, offering promising potential for biomedical applications.

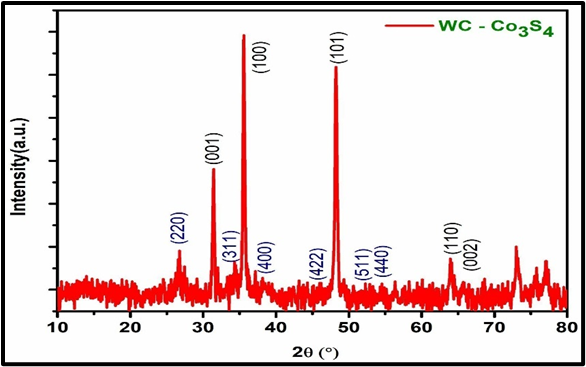


**Figure 1:** A schematic illustration of the synthesis of the hybrid material WC-Co3S4.

# RESULT AND DISCUSSION

## XRD Analysis

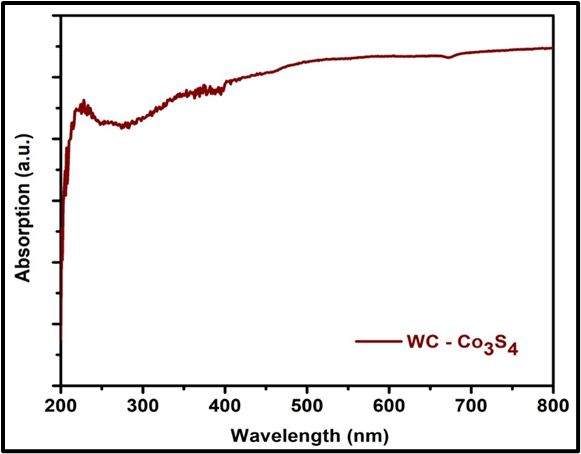
The X-ray diffraction (XRD) patterns of the as-obtained Co3S4 are shown in figure 1. The character diffraction peaks of Co3S4 (red curve) was detected 26.6°, 31.3°, 38.0°, 47.3°, 50.2° and 55.0°, which could be similar to the (220), (311), (400), (422), (511) and (440) crystal planes of the Co3S4 with good crystallinity (JCPDS No. 42-1448), respectively. Similarly, the X-ray diffraction patterns of tungsten carbide are shown in fig 1. The character diffraction peaks of WC (red curve) was detected 31°, 37°, 48°, 65° and 68°, which could be similar to the (100), (100), (101), (110) and (002) crystal planes of the Co3S4 with good crystallinity (JCPDS 20-1315), respectively. The higher peaks of tungsten carbide show that tungsten carbide is high in crystalline nature. In another similar study, The XRD diffraction peaks of Co3S4 and Ni12P5 in composite catalyst Ni12P5/ Co3S4 were only of Co3S4 and Ni12P5 without other impurity peaks[(Nuhu et al., 2025)](https://paperpile.com/c/ohd33s/2Bak). It was clear that Co3S4 peaks are only very slightly reduced following Ni12P5 arrival. High dispersion and a little amount of Ni12P5 turned it into a weak peak. These results demonstrated that the structure of the Co3S4 lattice remained unchanged when Ni12P5 was added to modify the material. The XRD of tungsten carbide microspheres for the molar ratio of 1.1x101 was discussed in another study that used WC. X-ray diffraction was used to corroborate the WC stoichiometry and the lack of any trace of W2C by comparing with the referenced patterns of WC and W2C. The WC domain size is approximately 11 nm when the Scherrer formula is applied to XRD[(Ahmed et al., 2025)](https://paperpile.com/c/ohd33s/8hCH).



**Figure 2.** XRD patterns of WC- Co3S4 hybrid materials

## UV - Vis DRS Spectrum

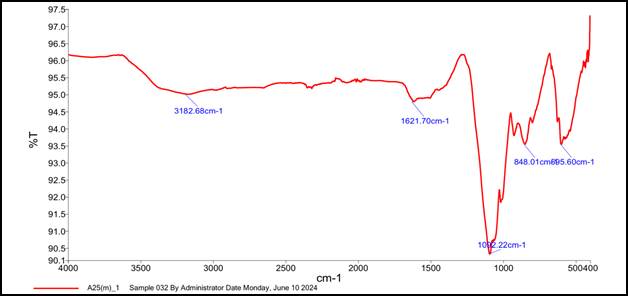
In order to study the light absorption properties of pure samples and nanocomposite samples, we studied the UV–vis diffuse reflectance spectra. Their band gaps can be estimated by formula (Eg = 1240/λ), and the results correspond to Figure 3. UV-DRS research showed that WC- Co3S4 hybrids absorb light well, contributing to their activity. ROS generation is essential for microbial inactivation. A similar study using cobalt sulfide discussed the absorption edges of pure Co3S4, Ni12P5 and composite catalyst 8% Ni12P5/Co3S4 are at about 423, 413 and 450 nm. The band gaps of these materials were calculated according to the formula (Eg = 1240/λ). Compared to Co3S4, a red shift appeared in clear Co3S4, when 8% Ni12P5 was incorporated in pure Co3S4 photocatalyst (Fig. 5a). This can be attributed to co-sensitization, synergistic effect of 8%Ni12P5-Co3S4, or a combination of these two factors. Absorption of light for the composite catalysts, 8% Ni12P5/Co3S4, varied greatly. This plot shows a comparison of light absorption of the composite catalyst of 8% Ni12P5 with all structures. There are three bands with a wavelength of 393 nm, corresponding to the energy required for excitation from one to another state (Figs. 5f−h). From the band gap diagrams in Fig. 5e, it follows that the Co3S4 has an energy band gap of 2.93 eV, the energy band gap between Ni12P5 and the Co3S4 system is 3.00 eV, and that for the 8% Ni12P5/Co3S4 is 2.75 eV. Bands in the diagram show these are less diffused in Ni12P5 and 8% Ni12P5/Co3S4 when compared with Co3S4. The band gap of the Co3S4/Ni12P5 and 8% Ni12P5/Co3S4 in the diagram was determined, both are 3.0 eV. It can be seen from the data that the band gap of the 8% Ni12P5/Co3S4 composite catalyst decreased. The results show that more composite catalysts broadens the light response range and has comparatively high absorption in the visible light region. This is because 8% Ni12P5 was added to Co3S4. The results show that the 8%Ni12P5 concentrations at Co3S4 are greater and the absorption hump extends significantly. This proves that Co3S4 has best light absorption in composites.



**Figure 3.** UV–Vis diffuse reflectance spectra of WC- Co3S4 hybrid materials.

## FTIR Analysis

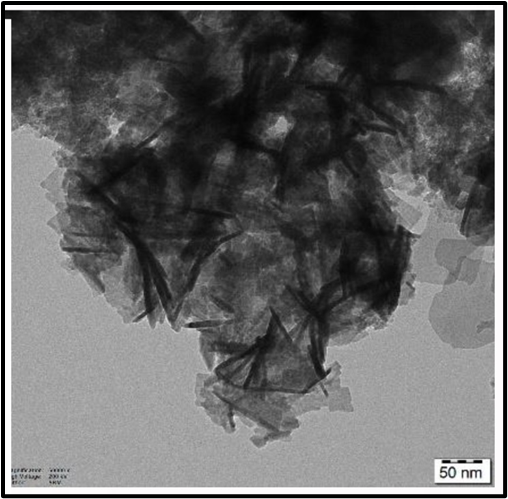
The x-axis represents wavenumber (cm-1), indicating the energy of the absorbed infrared radiation, while the y-axis represents transmittance (%), showing the amount of light passing through the sample in Figure 4. The spectrum shows an intricate arrangement of peaks and troughs, reflecting the vibrational modes of the chemical bonds found in the molecule. Through the examination of the positions and strengths of these peaks, one can determine the functional groups present in the molecule. For instance, the broad peak around 3300 cm-1 suggests the presence of an O-H bond, possibly indicating an alcohol or carboxylic acid group. The peaks near 1700 cm-1 are characteristic of carbonyl groups (C=O), commonly found in aldehydes, ketones, or carboxylic acids. Other peaks in the spectrum can provide further information about the molecular structure, such as the presence of C-H bonds, aromatic rings, and other functional groups.The FTIR spectra were utilized in a related investigation to describe hexadecylamine-capped cobalt sulfide nanoparticles that were made by altering the reaction's temperature. Hexadecylamine confined to cobalt sulphide nanoparticles and non-bounded hexadecylamine were compared using their FTIR spectra. FTIR spectra of non-bounded hexadecylamine and cobalt sulfide nanoparticles capped with hexadecyl amine made by adjusting the temperature. Except cobalt sulphide nanoparticles synthesized at 80 °C, same vibration frequency features were detected as described in the section on the influence of concentration. The lack of N-H stretching-related frequencies in the FTIR spectra may be because hexadecylamine was unable to bind to the complex employed to create the nanoparticles at this temperature. This demonstrates that cobalt sulfide nanoparticles could not be formed at this temperature.



**Figure 4.** FTIR of WC- Co3S4 hybrid composites

## TEM of WC- Co3S4 sample

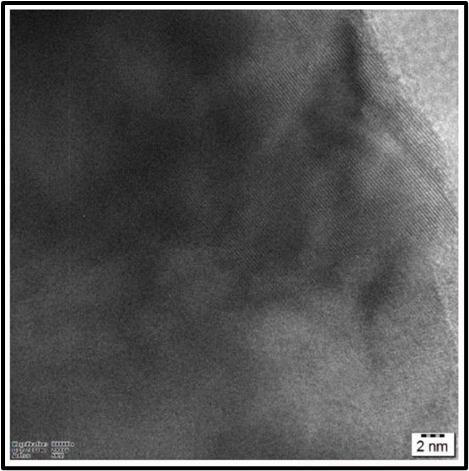
Transmission Electron Microscopy (TEM) is an effective method that delivers high-resolution images of the internal composition of materials at the nanoscale. In a similar study, the results showed that the TEM images of the cobalt sulfide prepared at 190, 210 and 230°C, respectively. It indicated that the nanostructure of cobalt sulfide showed less agglomeration and more 2D nanosheets can be prepared by increasing the vulcanization temperature. These results are inconsistent in Figure 5.



**Figure 5.** TEM image of WC- Co3S4 hybrid

## HRTEM Analysis of WC- Co3S4 sample

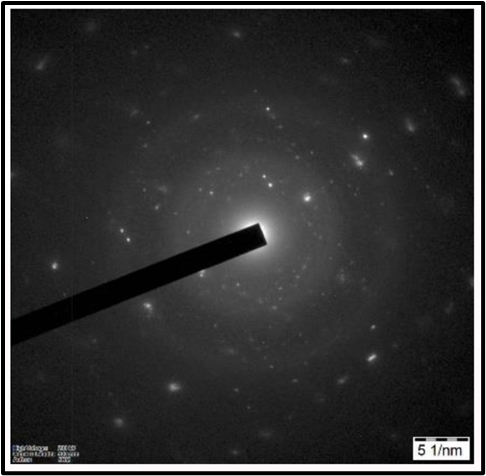
HRTEM is a powerful tool for atomic-scale imaging and structural analysis of materials. Its ability to provide detailed insights into the arrangement of atoms makes it indispensable for research in materials science, nanotechnology, and various applied sciences. By revealing the atomic structure, HRTEM helps in understanding the fundamental properties of materials and guiding the design of new materials with enhanced performance. In a comparable investigation, the microstructure of both materials was further examined using HRTEM.[(Muthuswamy Pandian et al., 2022; Ramakrishnan et al., 2023)](https://paperpile.com/c/ohd33s/5D24v+0wLM3). The first figure illustrates the microstructure of the nano-bud-like NiCo2S4 at high resolution, indicating that the nano-bud is made up of many interconnected nanoparticles. It shows a lattice fringe with an interplanar distance of 0. 28 nm, which is attributed to the (311) plane of NiCo2S4. On the other hand, the HRTEM image in Figure 2 demonstrated that the nano-mesh-like NiCo2S4 consists of nanosheets with numerous void spots or pits, which may enhance the penetration of electrolyte and improve electrochemical performance. The HRTEM image in Figure. 6 displays two sets of lattice spacings of 0. 28 and 0. 33 nm, which correspond to the (311) and (200) planes of NiCo2S4, respectively.



**Figure 6.** HRTEM image of WC- Co3S4 hybrid

## SAED Analysis of WC- Co3S4

SAED patterns provide information about the crystal structure of the material. The positions and intensities of the diffraction spots are directly related to the atomic arrangement and symmetry of the crystal lattice.By analyzing these patterns, researchers can determine the crystal system (e.g., cubic, hexagonal, tetragonal), lattice parameters, and space group of the material(Rafi et al., 2024). The value "5 1/nm" suggests that the spacing between these crystal planes is approximately 0.2 nanometers (nm), calculated as the reciprocal of 5 nm⁻¹ (1/5 = 0.2 nm). In a comparative analysis, the selected area electron diffraction (SAED) pattern shows a series of concentric rings that are in close alignment with the crystalline planes of Co(OH)2, CoO, and Co3O4. The activated Co-WB/NF catalyst is covered by layer-structured hexagonal nanoplates that possess a relatively narrow size distribution. The average size and thickness of the nanoplates are roughly 400 nm and 50 nm, respectively in figure 7.



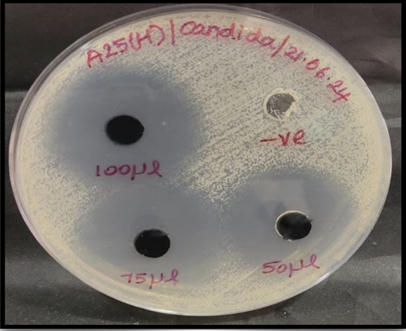
**Figure 7.** SAED image of WC- Co3S4 hybrid

## ANTIFUNGAL ACTIVITY

Different concentrations of an antifungal agent were used to study the Candida Albicans species, and this particular plate contains a visual representation of the results. The petri dish had clear zones around areas where antifungal agents were applied revealing their effectiveness in inhibiting fungal growth (Tuluwengjiang et al., 2024). In this experiment three different volumes – 100µL, 75µL and 50µL were tested and zones of inhibition were witnessed around each point of application. The biggest zone is around the 100 µL application which means that it was more potent in preventing fungal growth at that concentration. -VE means negative control which does not show any zone of inhibition, indicating that it was only caused by the agent but not other factors. Thus, higher concentrations of WC- Co3S4 showed better control of fungal growth in Figure 8.

|  |  |
| --- | --- |
| **CONCENTRATION OF WC- Co3S4** | **CANDIDA ALBICANS** |
| 50 µL | 31mm |
| 75 µL | 34mm |
| 100 µL | 36mm |
| Negative control | 10mm |

Table 1: Concentration

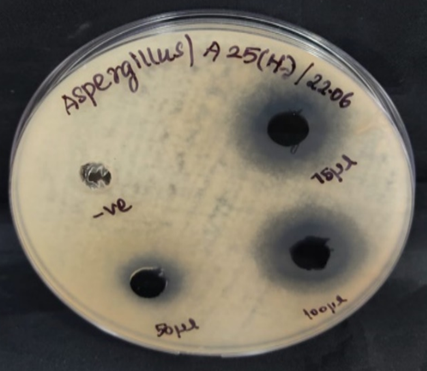


**Figure 8.** Antifungal activity on *Candida Albicans*

The picture shows the results of an experiment testing how effective a certain agent is against Aspergillus species. In this dish, several different volumes of antifungal agent (100mL, 75mL and 50mL) were put, and its effectiveness is clearly shown in the form of the inhibition zones around each drug application site. The clear areas show where the growth of fungus has stopped because of the presence of antifungal agent. The largest zone of inhibition occurs at 100 µL followed by that from 75 µL and then 50µl applications suggesting that with increasing volume there was more activity against fungi on a dose basis.There is no zone of inhibition for a negative control (-VE), which indicates that observed antifungal activity is only due to agent and not external factors as such. Results show that this WC- Co3S4 hybrid agent has potential for inhibiting Aspergillus growth with the larger dosages mimicking greater inhibitions.This improved activity of WC- Co3S4 agent against a wide variety of fungal strains showed the hybrid's broad-spectrum antimicrobial potential in Figure 9.

|  |  |
| --- | --- |
| **CONCENTRATION OF WC- Co3S4** | ***ASPERGILLUS*** |
| 50 µL | 13mm |
| 75 µL | 24mm |
| 100 µL | 26mm |
| Negative control | 10mm |

Table 2: Concentration



**Figure 9.** Antifungal activity on *Aspergillus*

# CONCLUSION

In this study, we looked at the antibacterial properties of tungsten carbide (WC) and cobalt sulfide (CoS) hybrid materials. Our results show that when WC and CoS are combined, their antibacterial activities are greatly improved above each compound alone. Broad-spectrum antibacterial action against a variety of diseases, including fungus and bacteria, was demonstrated by the hybrid material. The hybrid material's distinct physicochemical characteristics, such as its larger surface area, better electron transport abilities, and higher catalytic activity, are responsible for its greater efficacy. These characteristics enhance the mortality of microbial cells by rupturing microbial cell membranes and producing reactive oxygen species (ROS). Furthermore, the hybrid material displayed good stability and biocompatibility, making it a promising candidate for various biomedical applications, including coatings for medical devices and components in antimicrobial formulations. In conclusion, the synergistic combination of tungsten carbide and cobalt sulfide offers a potent antimicrobial solution with potential applications in combating microbial infections. Future studies should focus on the detailed mechanisms of action, long-term stability, and in vivo efficacy of these hybrid materials to further validate their potential for clinical use.0

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