Bridging Nanoarchitectures: Unraveling Antimicrobial Properties of Ti3C2-Copper Phosphate Nanocomposite

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**Abstract:** Nanoarchiture is involved with the generation of potential materials with useful properties. Ti3C2 is known for its antimicrobial and antifungal properties. Understanding their synthesis and characterization can be used in enhancing their properties. Copper phosphate has the property to inhibit the growth of various microorganisms which promise in the development of medical coatings. So a combination of both compounds can bring out a better nanocomposite.The study aims to identify the antimicrobial properties of titanium carbide copper phosphate nanocomposite and the application of the materials in the fields of medicine.The nanocomposite was prepared by the preparation of titanium carbide and copper phosphate separately which was then mixed to form the combination followed by microwave method and calcination. A magnetic stirrer beaker, burette hot air oven centrifuge and muffle furnace was used. The XRD investigation verified TiC's crystalline structure. Strong absorption in the ultraviolet area was seen in the UV-DRS spectra, suggesting possible photocatalytic capabilities. Metal-oxygen bonds and functional groups were detected by FTIR spectra. High crystallinity in a multilayer structure was seen in TEM and HR-TEM pictures. The crystalline nature of the nanoparticles was verified by SAED patterns. Tests for antifungal activity against Aspergillus species and Candida albicans showed dose-dependent inhibition, demonstrating the antibacterial efficiency of the nanoparticles. Due to their notable crystalline characteristics and potent antibacterial activity, the produced titanium carbide nanoparticles are appropriate for use in environmental and medicinal contexts. It will take further research to realize their full potential in a variety of disciplines.

**Keywords:** Nanocomposite, Titanium carbide, Copper phosphate, Antimicrobial, Antifungal activity, XRD, UV DRS, FTIR, TEM, HR-TEM, SAED.

# INTRODUCTION

Nano architecture describes the planning and building of structures at a nanoscale of 1 to 1000 nm. This field includes ideas from several fields like physics, chemistry, biology and engineering to build useful materials and devices with precise control over their atomic and molecular arrangement. With the help of nanotechnology, nanoarchitecture can create structures that are very different from their macro scale equivalent in terms of their specific features and capabilities. A nanoarchitecture-related study by [(Zhang *et al.*, 2020; Rauwel *et al.*, 2024)](https://paperpile.com/c/IX2g9U/0cBv+pR4z) on Pine Cone-inspired micro cages has combined features that allow for exceptional anti-infection and bone regeneration. These features include super hydrophilicity, superior structural stability, and pH-triggered, intelligent across-shell transport of bioactive silicate nanoplatelets (sizes >100 nm) and emerging antimicrobial silver nanoparticles. The design and development of multifunctional encapsulation and delivery carriers for use in environmental and medicinal applications is given fresh insight by this work. The application of nanoarchitecture is in various fields like material science electronics and medicines, especially for drug delivery systems. As highlighted by[(Soni and Pareek, 2023)](https://paperpile.com/c/IX2g9U/tkIT), the exploration of bioactive constituents from natural sources, such as precious herbs and plants, presents a promising avenue for addressing the escalating concerns related to antimicrobial resistance.

Nanoparticles are well known for their physical and chemical characteristics which result in a strong anti-microbial action. Several nanoparticle kinds including titanium dioxide zinc oxide gold Silver and copper oxide have been thoroughly investigated for their antibacterial properties. These particles can interact with microbial cells and multiply including rupturing cell membranes interfering with cellular function producing reactive oxygen species (ROS) that injure cell components and possibly penetrate cells to damage the internal structures. Since nanoparticles are tiny they can effectively combat both planktonic free floating and biofilm-associated microorganisms by penetrating biofilms which are protective coatings produced by bacteria. Moreover, the research on anthocyanin-rich fruits, as noted in[(no date)](https://paperpile.com/c/IX2g9U/QwKz), underscores the significance of utilizing natural compounds with antimicrobial and antiviral properties in the fight against infectious diseases, including those caused by emerging pathogens like SARS-CoV-2. Antimicrobial packaging made of nanoparticles emphasizes the importance of active substances in prolonging food freshness and preventing undesirable changes[(Bose *et al.*, 2023)](https://paperpile.com/c/IX2g9U/XDdQ).

Nanocomposite formed by the combination of nanoparticles within a matrix material is explored for their anti-microbial properties offering a multifaceted approach to compacting microbial threats. By the integration of the nanoparticles with other materials nanocomposites achieve enhanced antimicrobial activity due to the ability of the nanoparticle to release ions or generate reactive oxygen species upon contact with bacteria. The antimicrobial activity of nanocomposite is advantageous in medical and environmental activity where microbial contamination produces a potential risk. The incorporation of nanoparticles in biobased matrices has shown promising antibacterial and antioxidant properties, essential for food preservation[(Stefanis *et al.*, 2023)](https://paperpile.com/c/IX2g9U/CCtX). Nanocomposite is used for wound dressing surgical implants and medical devices to prevent infection and improve patient outcomes in the field of medical medicine. Nanocomposite represents a promising avenue for developing advanced material that is capable of comparing microbial threats across diverse sectors. Two-photon polymerisation (TPP) enables the precise fabrication of tailored nano- and microstructured architectures with unique mechano-antibacterial properties, mimicking natural nano topography like that of cicada wings [(Tan *et al.*, 2024)](https://paperpile.com/c/IX2g9U/fKmY)

Antimicrobial applications benefit significantly from the advanced properties of nanocomposites[(Sharma et al., 2024)](https://paperpile.com/c/IX2g9U/cpDd),[(Ahmad and Ansari, 2022)](https://paperpile.com/c/IX2g9U/Bcnn). These innovative materials, such as graphene-based nanocomposites, offer unique advantages due to their large surface area, biocompatibility, and potent antimicrobial activity. By harnessing nanocomposite properties, researchers can develop novel antimicrobial strategies that mitigate the risk of antibiotic resistance emergence while improving therapeutic outcomes in clinical applications. Metal-oxide nanocomposites are produced using various methods for the application of antimicrobial activity, as well as the variables that can affect such activities and the main inhibition mechanisms of these materials[(Birhanu, Afrasa and Hone, 2023)](https://paperpile.com/c/IX2g9U/a7Lf). The utilization of nanocomposites represents a promising avenue for addressing the pressing challenges of microbial infections in various biomedical settings. The engineering of antimicrobial nanomaterials appears to be one of the most promising solutions, due to the various processes underlying the antimicrobial mechanisms that include reactive oxygen species (ROS) production, ion diffusion, nanomaterial uptake, and interaction with the pathogen [(Rauwel et al., 2024)](https://paperpile.com/c/IX2g9U/0cBv)

Titanium carbide MXene (Ti3C2), has gained attention for its excellent antimicrobial properties. MXenes are two-dimensional nanomaterials consisting of transition metal carbides, nitrides, or carbonitrides, and Ti3C2 has shown promise in combating bacterial infections. Research conducted by[(Zhang *et al.*, 2022; Bose *et al.*, 2023)](https://paperpile.com/c/IX2g9U/XDdQ+vK3E) found that Ti3C2 exhibits strong antimicrobial activity against both gram-positive and gram-negative bacteria due to its high surface area and ability to generate reactive oxygen species. Findings by[(Kolypetri *et al.*, 2023)](https://paperpile.com/c/IX2g9U/i6Au) in a recent study suggest that exploring new materials like Ti3C2 could provide innovative solutions for antimicrobial challenges. Furthermore, [(Goki *et al.*, no date)](https://paperpile.com/c/IX2g9U/eLz1) emphasize the importance of understanding the physicochemical properties of antimicrobial agents, such as AMPs, in developing effective treatments. The transformative potential of harnessing natural sources for antimicrobial solutions, and the exploration of Ti3C2 antimicrobial attributes unveils a novel avenue in sustainable antibacterial applications[(*Website*, no date a)](https://paperpile.com/c/IX2g9U/75uy).

Copper phosphate, a compound known for its antimicrobial properties, has gained attention in recent years due to its ability to inhibit the growth of various microorganisms. Cu3(PO4)2 forms nanoparticles with small size, responsible for the efficient catalytic action of the nanocomposite material[(‘Ultrasmall CuS-BSA-Cu3(PO4)2 nanozyme for highly efficient colourimetric sensing of H2O2 and glucose in contact lens care solutions and human serum’, 2020)](https://paperpile.com/c/IX2g9U/1YvT). Copper complexes, such as CuHABH, have demonstrated antibacterial and antibiofilm activities against a range of bacteria, as evidenced by[(Sykuła *et al.*, 2022)](https://paperpile.com/c/IX2g9U/mXwx). If appropriately customized, Cu3(PO4)2 has the potential to produce cytotoxic effects and could have a bright future in anticancer therapy[(Laha *et al.*, 2012)](https://paperpile.com/c/IX2g9U/NlkJ). The antimicrobial properties of copper phosphate hold great potential for applications in various industries. Through its ability to inhibit the growth of bacteria and fungi, copper phosphate has shown promise in the development of antimicrobial coatings for medical devices, food packaging, and other surfaces. Additionally, the low toxicity of copper phosphate compared to other antimicrobial agents makes it an attractive option for use in consumer products.

Ti3C2 (titanium carbide MXene) and copper phosphate together provide a synergistic strategy that maximises the benefits of each material's distinct qualities for improved biological applications, especially in antibacterial techniques. Ti3C2, which is well-known for its mechanical strength, electrical conductivity, and biocompatibility, offers an effective matrix for the addition of antimicrobial compounds. On the other hand, by releasing copper ions that damage bacterial membranes and biological processes, copper phosphate exhibits strong antibacterial activity. These combined factors make Ti3C2 copper phosphate nanocomposite a promising candidate for antimicrobial applications in medical devices, environmental remediation, and other related fields. With ongoing advancements in nanotechnology and material science, the Ti3C2 copper phosphate nanocomposite holds great potential for combating bacterial infections and improving public health in the future.

# MATERIALS AND METHODS

## Preparation Of Titanium Carbide

Titanium carbide is synthesized by the elimination of aluminium from Ti3AlC2. Titanium aluminium carbide is added to hydrofluoric acid of 20 ML at 40°C in a beaker. The mixture is stirred in a magnetic stirrer at 410 rpm for 24 hours. The elimination of aluminum called etching of aluminum is done here. It is then heated to remove the aluminium layer faster and is centrifuged. The centrifuge solution is then washed to remove the acidity as the pH will be near one or two. It is washed with distilled water until pH 7 is obtained and then washed with ethanol two times to remove other contamination. The obtained precipitate is then dried at 80°C in a hot air oven for 24 hours. The black-coloured Ti3C2 is ready and stored.

## Preparation Of Copper Phosphate

Copper Phosphate is prepared using solution A and solution B. Solution A is prepared by the mixture of 2.3443 g of copper nitrate into 50 ML of distilled water in a beaker. The solution is mixed in a magnetic stirrer for 30 minutes. Solution B is prepared by the addition of disodium hydrogen phosphate of 2.2713 g into 50 ML distilled water in a beaker. The solution is also mixed for 30 minutes in a magnetic stirrer. Solution C is formed by solution B in the burette and added drop by drop to solution A. The solution is then stirred for one hour to form precipitation which changes the color of the solution to milky blue.

## Preparation Of Titanium Carbide Copper Phosphate

1 g of Titanium Carbide is dispersed into 25 ML of distilled water and stirred for 20 minutes in a beaker. Add the solution into solution C drop by drop while stirring, the milky blue changes to black. The solution is then stirred for three hours. The combination is formed.

## Microwave Method

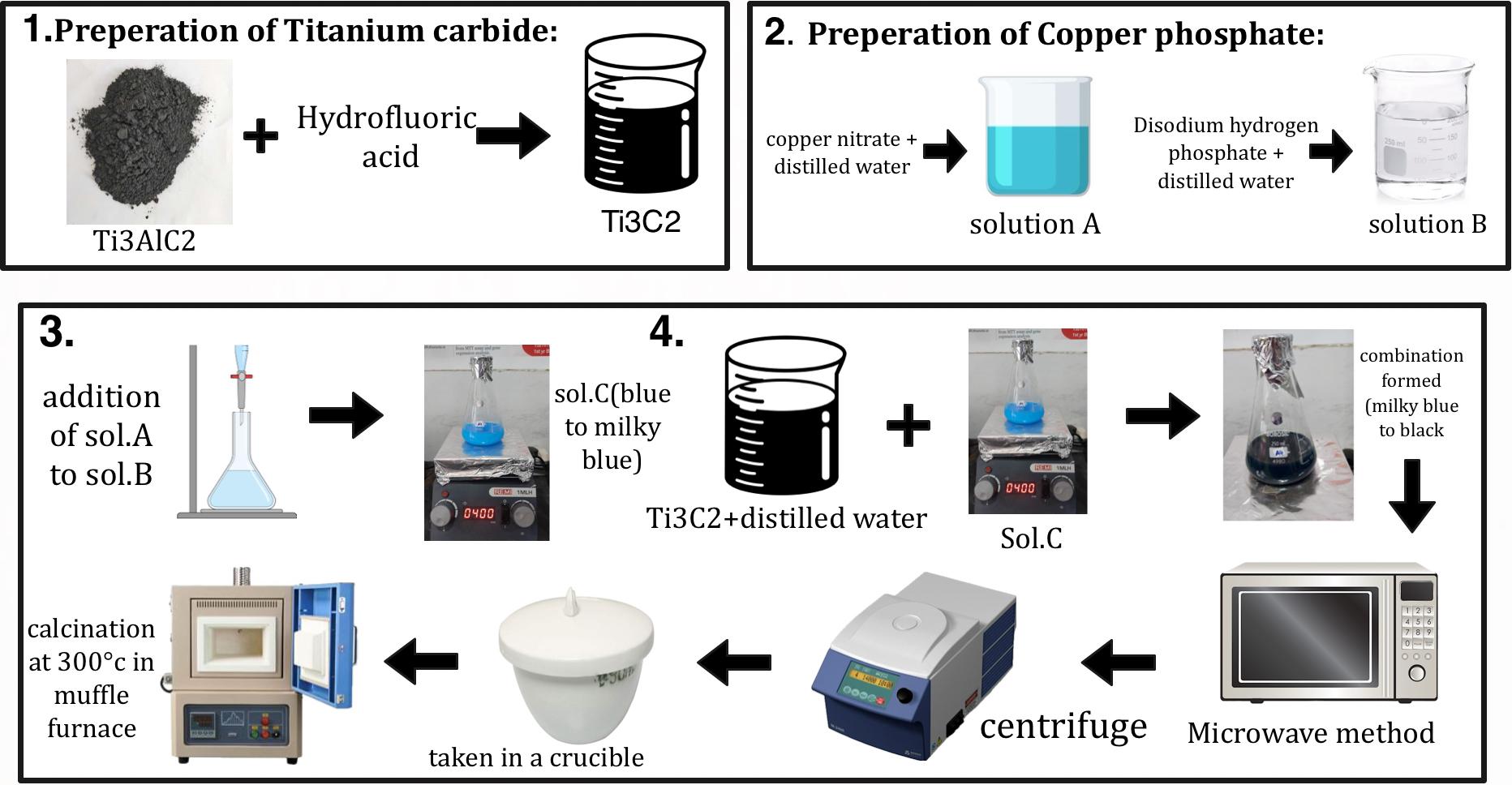


Figure 1: Methodology

Place the conical flask in the microwave and set it for two minutes. Take it out after two minutes, heat is produced in the flask, shake it and again put it back into the microwave. Repeat the process five times for 10 minutes. Cool down the solution and centrifuge it. Centrifuge it three times with water, two times with ethanol, and two times with acetone and then write it at 80°C for 24 hours. The calcination process is done then by using a muffle furnace at 300°C for three hours the product is taken in a crucible. The final product is then ground using a Mortar and pestle and the final product is ready and packed.

# RESULTS AND DISCUSSION

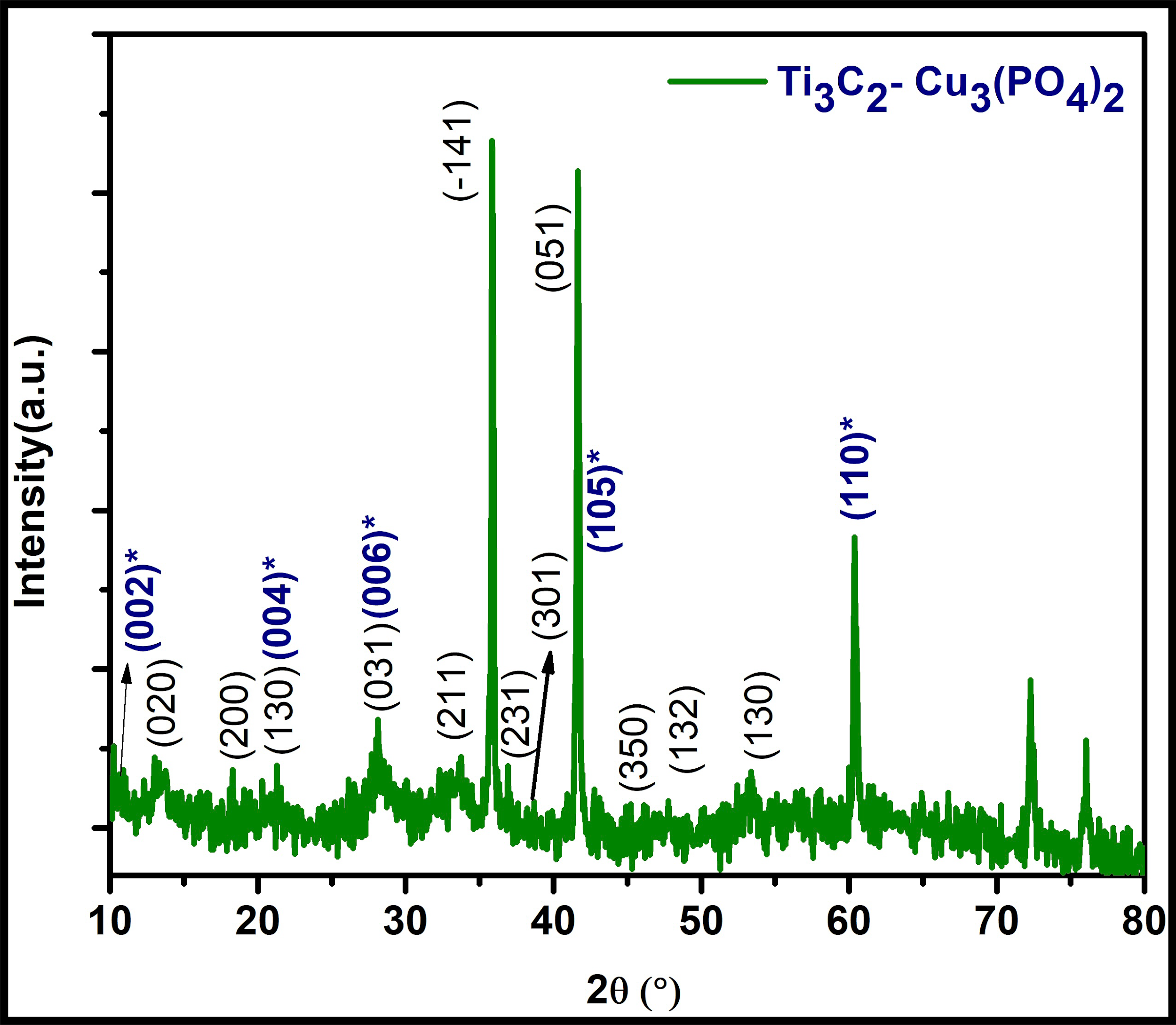
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Figure 2: XRD analysis of titanium carbide copper phosphate

The x-ray diffraction analysis gives information about the crystalline structure and phase composition of titanium carbide copper phosphate. The X-axis shows the angle of diffraction measured in degrees and the Y-axis shows the intensity of diffraction measured in arbitrary units. The peaks in the graph define the crystallinity of the sample. These well-defined peaks can be used to confirm the structural characteristics and purity of the synthesized nanocomposite. The crystalline city of the compound shows a peak at 35° value of 141a.u. Intensity.

The XRD pattern shows the peaks at particular 2θ angles indicating a well-ordered crystalline structure. The identified peaks coincide with multiple crystallographic planes, such as (002), (004), (200), and (105). It is clear from earlier research that the Ti3C2Tx MXene film was effectively synthesized based on the results of the XRD and SEM investigations. MXene films improved osteogenic differentiation in vitro and were highly cytocompatible, according to the cellular studies. [(Zhang, Fu and Mo, 2019)](https://paperpile.com/c/IX2g9U/3Jb2)This is further confirmed by the findings of related research on transition metal carbides and phosphates, which also produce sharp peaks indicating high crystallinity and phase purity. The XRD pattern in recent studies reveals that the widened peaks of TiC arise and the diffraction peaks of Ti3C2 entirely vanish, indicating the phase change of 2D Ti3C2 nanosheets to TiC, which plays a major role in increasing the antimicrobial property [(Barsoum, 2019)](https://paperpile.com/c/IX2g9U/aZ3E).In particular, studies on Ti₃C₂ MXenes typically show similar peak patterns, indicating the material's structural integrity and efficient production.

The ultraviolet-visible diffuse reflectance spectroscopy spectrum gives information about the optical absorption of titanium carbon copper phosphate in the graph. The X-axis represents the wavelength in nanometres and the Y-axis represents absorption in arbitrary units. The spectrum represents the strong absorption in the ultraviolet region which extends into the visible region. The material has a strong absorption at a peak of 270 nm.

The UV DRS spectra show absorptions in the UV region with a visible region extension. Since each MXene has unique absorption peaks at certain wavelengths, the UV–vis absorption spectrum is frequently used to assess the level of oxidation in MXenes. [(Shahzad *et al.*, 2016)](https://paperpile.com/c/IX2g9U/WRIl) Materials with broad absorption have potential for use in photocatalysis and optoelectronics. Previous studies on Ti₃C₂ MXenes and similar composites have demonstrated comparable UV-Vis absorption properties. This indicates that the electronic structure of the Ti₃C₂ - Cu₃(PO₄)₂ composite effectively facilitates charge transfer processes, a benefit for catalytic applications.

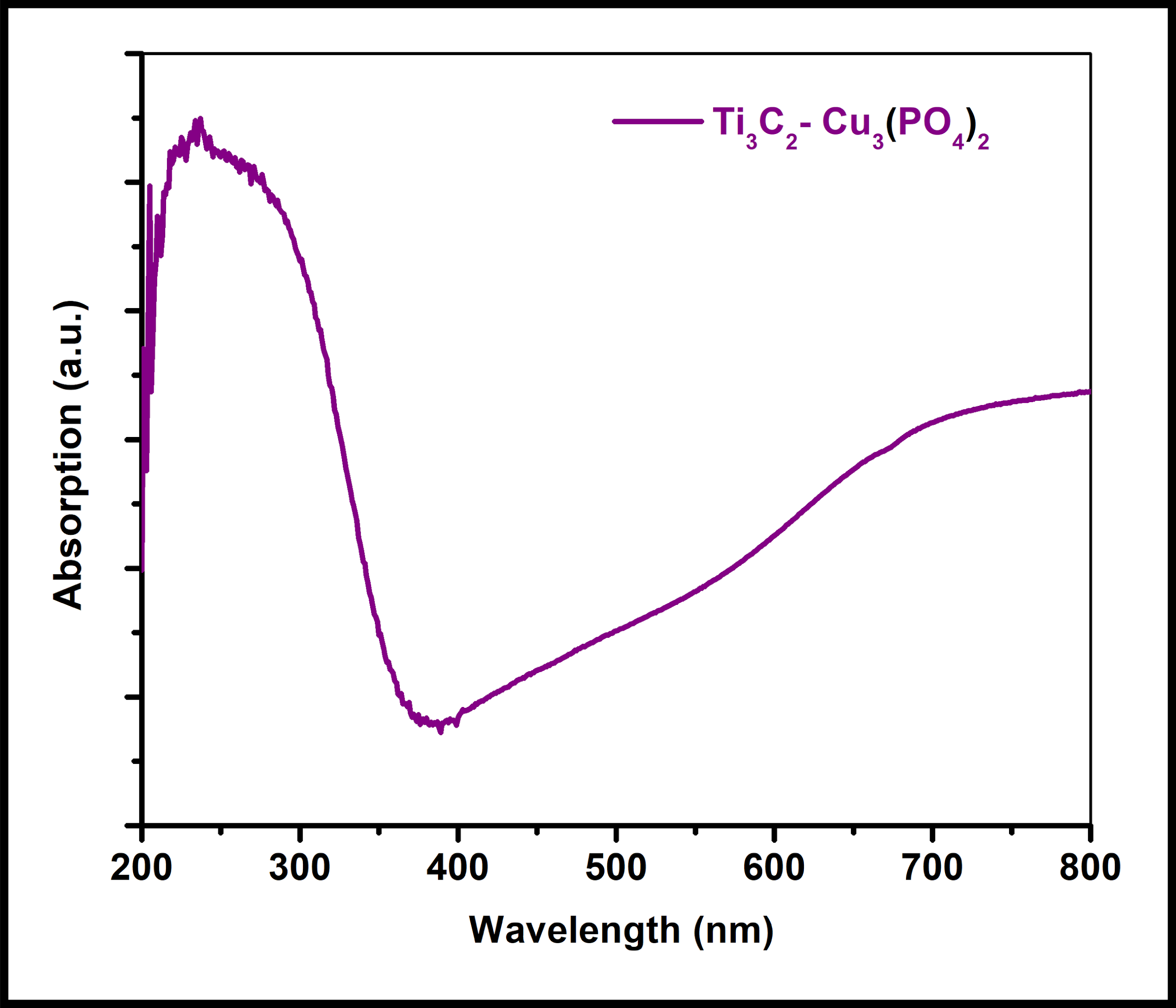
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Figure 3: UV DRS Spectra of titanium carbide copper phosphate

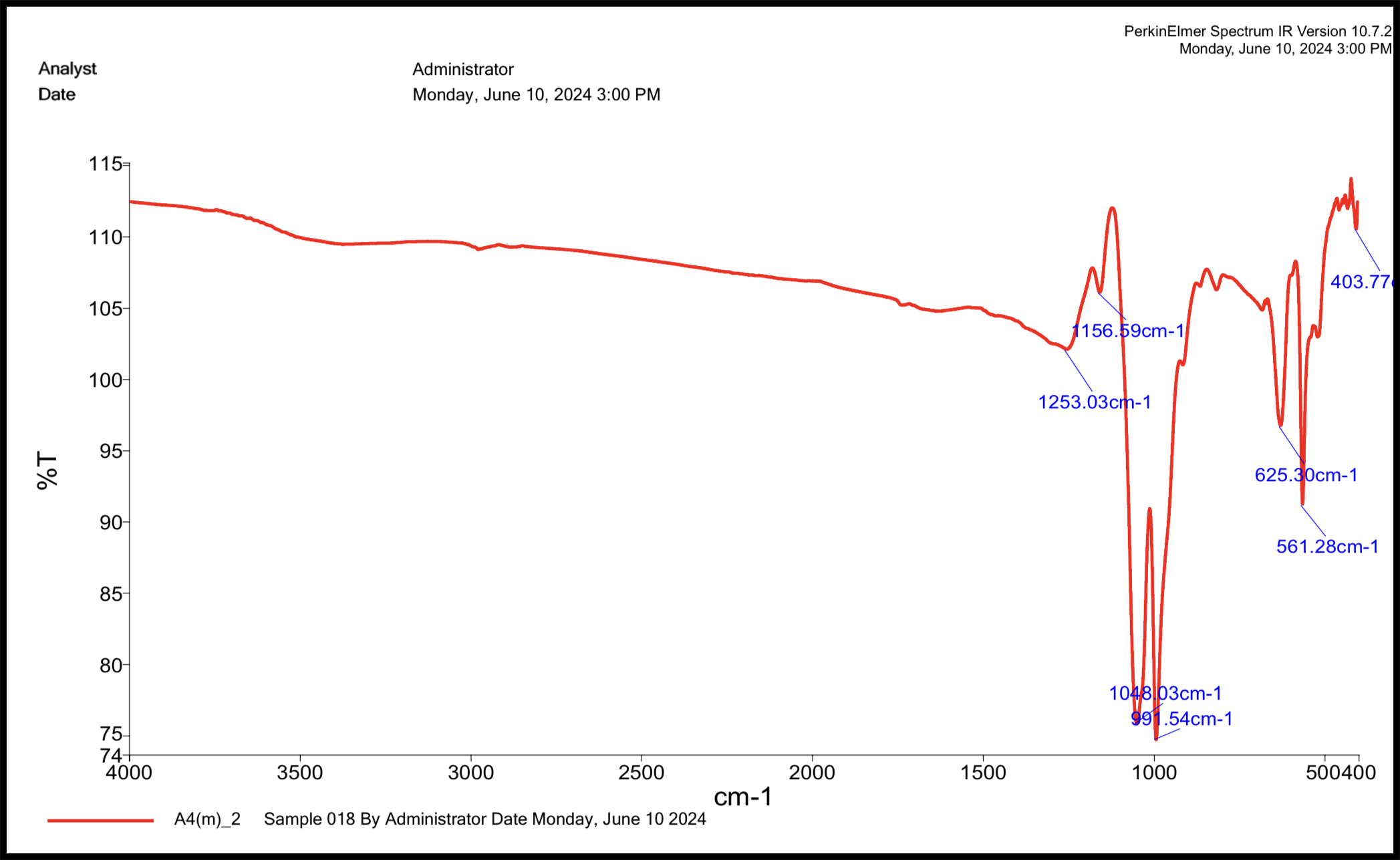
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Figure 4: FTIR of titanium carbide copper phosphate

Fourier transform infrared spectroscopy spectrum displays the infrared absorption band of the titanium carbide copper phosphate. The X-axis shows the wave number measured in the inverse centimetre Y-axis indicates the percentage of infrared light transmitted through the sample. The key absorption band at the infrared level helps in identifying functional groups and molecular structures in the material. FTIR is crucial for identifying the chemical composition. The peaks are mainly at 1255 cm^-1, 1635 cm^-1, and 2360 cm^-1, indicating the presence of phosphate and hydroxyl groups, as well as metal-oxygen bonds in the sample.

The FTIR spectrum shows important absorption bands of Ti₃C₂ - Cu₃(PO₄)₂. These bands represent various chemical bonds and functional groups. The branch-like species forming at the margins are confirmed to be TiO2 crystals with a stable structure by the FTIR image from earlier research. [(Iqbal *et al.*, 2021)](https://paperpile.com/c/IX2g9U/JLSj) These bands match the vibrational modes frequently found in phosphates and carbides of transition metals. The presence of metal-oxygen and metal-carbon bonds, which are crucial for the material's structural and functional properties, is evident in comparable FTIR spectra from investigations on similar materials.

Transmission electron microscopes give a high-resolution view of the morphology at the nanoscale of the material. The image shows the size of the structure in nanometers ( 100 nm), its shape and the distribution of particles which shows the layered sheet-like structure of the material. This gives the fine structural details of the material's nanoscale architecture

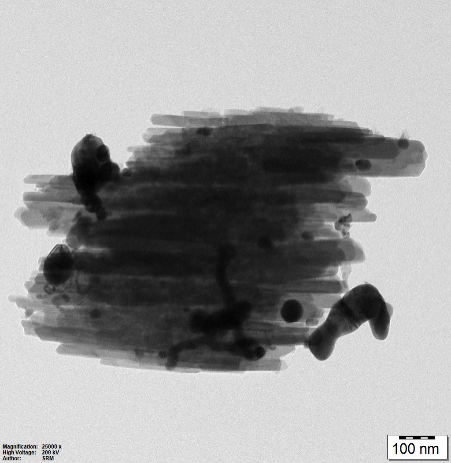
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Figure 5: TEM of titanium carbide copper phosphate

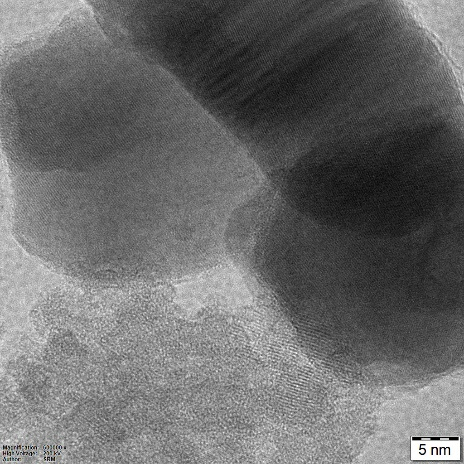


Figure 6: HR TEM of titanium carbide copper phosphate

The highest-resolution transmission electron microscope shows the well-defined lattice fringes which indicates a high degree of crystallinity at the atomic level of the material. It mainly indicates the size of the atomic scale features in nanometres (5nm).

The TEM and HR-TEM images demonstrate a layered or sheet-like structure with noticeable lattice fringes indicating a high degree of crystallinity. These structural properties are consistent with previous studies on MXenes and related composites, which often exhibit similar nanoscale morphologies. HR-TEM measurement was carried out by investigations to clarify the morphology of the CD/TiO2 nanocomposite. The study's HR-TEM images proved that there were nanoparticles with an average size of less than 20 nm. The picture shows that the CDs were evenly distributed over the surface of the rod-shaped TiO2 nanoparticles. The high-resolution image clearly shows lattice fringes. [(Falara *et al.*, 2024)](https://paperpile.com/c/IX2g9U/GntB) The presence of well-defined lattice fringes in HR-TEM images further supports the ordered atomic arrangement, which is necessary for the material to function. Additionally, the SEM findings by [(*Website*, no date b)](https://paperpile.com/c/IX2g9U/T4i5)showed that the composite nanoparticle sizes varied but were often less than 100 nm, confirming the creation of nanocomposite systems.

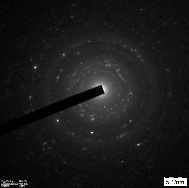
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Figure 7: SAED of titanium carbide copper phosphate

The selected area electron diffraction gives the series of diffraction spots which confirms the crystalline nature of the material The results provide more details on the phase and structure of the crystal in addition to confirming its crystalline nature. Each of these discoveries offers a comprehensive understanding of the material's internal structure.

The crystalline form of the sample is confirmed by the clear diffraction spots seen in SAED. High crystallinity and phase purity are shown by the pattern's symmetry and sharpness. The SAED patterns in studies were described in a work on the synthesis of titanium carbide nanoparticles, which showed unique diffraction spots suggestive of crystalline TiC phases. A vacuum carbothermal reduction technique was used in the preparation, followed by hydrogen treatment, other characterization techniques directly impact the antimicrobial effectiveness of TiC nanoparticles by influencing their surface properties, reactivity, and interaction with microbial cells. [(Xie *et al.*, 2017)](https://paperpile.com/c/IX2g9U/D83A) These results support the effective synthesis and structural integrity of the Ti₃C₂ - Cu₃(PO₄)₂ composite and are consistent with SAED patterns described in earlier investigations on transition metal carbides and phosphates. Another research article discusses the morphology and crystallography of TiC using transmission electron microscopy (TEM) and SAED, highlighting the cubic structure of TiC and confirming its crystallinity [(Niu *et al.*, 2020)](https://paperpile.com/c/IX2g9U/pAzA)

## Antifungal activity of titanium carbide copper phosphate

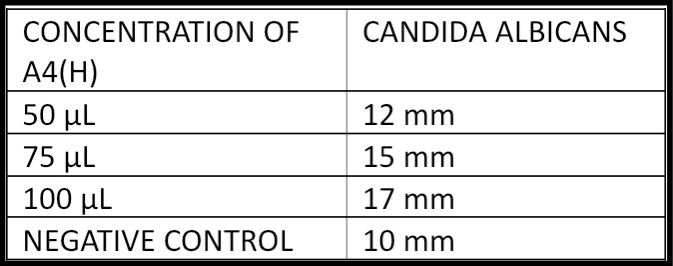
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Figure 8: Antifungal Activity Of Candida Albicans

The plate shows antifungal activity of the material against candida albicans at different concentrations. This result shows inhibition zones at different concentrations. The result indicates dose-dependent antifungal activity with the higher concentration leading to larger inhibition zones confirming the antifungal property.

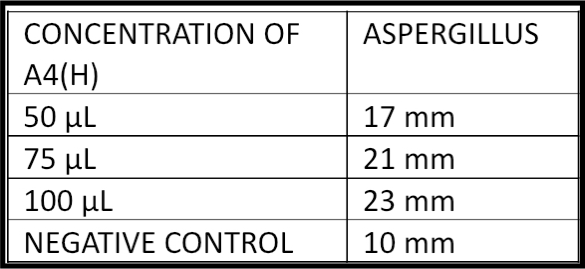
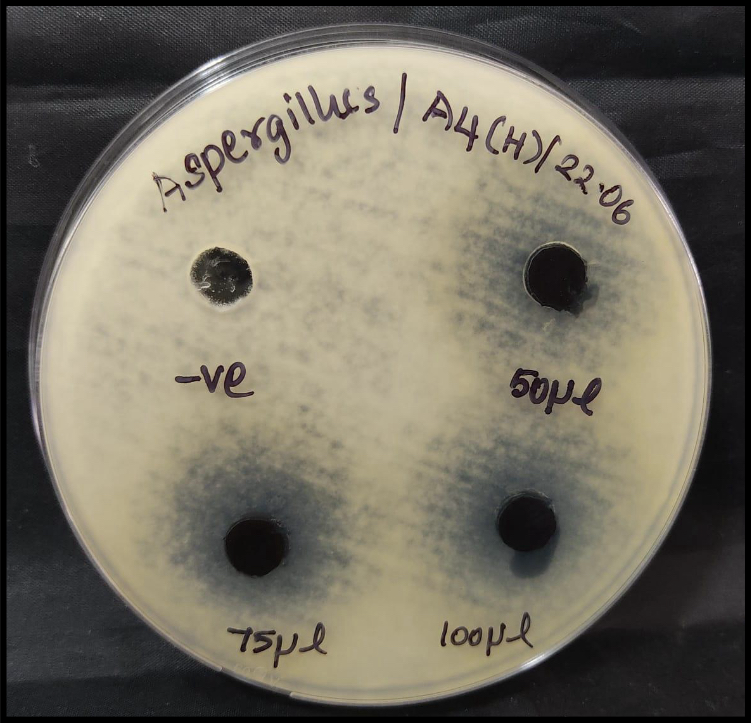
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Figure 9: Antifungal Activity Of Aspergillus

The plate shows antifungal activity of material against aspergillus at different concentrations. The result indicates dose-dependent antifungal activity with higher concentrations leading to larger inhibition zones confirming the antifungal property of the material.

The findings from the antifungal activity test are important because they show that A4(H) can stop the growth of both Candida albicans and Aspergillus(Chehelgerdi et al., 2023). The higher the concentration of A4(H), the better it works. For Candida albicans, the stopping zones ranged from 12 mm to 17 mm, and for Aspergillus, they ranged from 17 mm to 23 mm. This is a big deal compared to other antifungal treatments made from metal phosphates and MXenes. CuO-Zs-NPs showed better effectiveness against Fusarium root rot in both laboratory and greenhouse studies than both commercial fungicides "Kocide 2000" and Biocide under both in vitro and in vivo circumstances, according to the results [(*Website*, no date c)](https://paperpile.com/c/IX2g9U/ghVO) which makes copper a potential antimicrobial material (Saadh et al., 2024). Previous studies have shown that copper-based compounds and MXenes have strong germ-fighting abilities because they can make reactive oxygen and mess up germ cells. The MXene nanocomposite showed considerable antifungal action against isolated fungi from soil and water environments, where its activity was greater than that of other chemicals against tested fungi Aspergillus ssp. and Candida sp., according to the results of the article[(‘Robust advantage of MXene/g-C3N4 loaded on Fe2WO6/BiIO4 nano-platform for chemo-peroxidase colourimetric detection of uranyl ions, antifungal properties, photocatalytic degradation of p-chlorophenol, and eco-toxicity studies’, 2024)](https://paperpile.com/c/IX2g9U/MgYn).

The research found that combining Ti₃C₂ and Cu₃(PO₄)₂ makes them work even better together, fighting off a wider range of germs and being more effective. Research done by[(Rajavel *et al.*, 2019)](https://paperpile.com/c/IX2g9U/ebwC) indicates that the surface moiety and the stacked layer separation are key determinants of Ti3C2Tx's fatal bacterial potency. Ti3C2Tx-coated PVDF membranes are a useful tool for successfully inactivating Escherichia coli. Of more significance, however, is their ability to inhibit the formation of biofilms on the active membrane surfaces, hence offering a high potential for antibiofouling. This work enhances the potential for bioapplication of Ti3C2Tx-based antimicrobial surface coatings and offers helpful directions for their future development.

# CONCLUSION

Ti₃C₂-Cu₃(PO₄)₂ has been thoroughly analysed using a variety of methods, such as XRD, UV-DRS, FTIR, TEM, HR-TEM, and SAED. These methods have shown the compound's distinct crystalline structure, important UV-Vis absorption characteristics, and potent antifungal action. These results demonstrate the promise of Ti₃C₂ - Cu₃(PO₄)₂ for applications in photocatalysis, optoelectronics, and antimicrobial treatments. They also correlate well with results from earlier studies on similar materials. This composite's combination of structural and functional qualities makes it a viable option for additional research and possible industrial uses. These properties are attributed to the unique structure and synergy between Ti3C2 and copper phosphate, which enhance their ability to disrupt microbial cell walls and interfere with cellular processes.

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