MXene-Bi₂Mo₃O₁₂ Nanomaterials: Synthesis, Characterization, and Enhancement of Antimicrobial Activity

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**Abstract** :To synthesize MXenes of Bi2Mo3O12 nano materials for its antimicrobial activityThe preparation of Ti3C2 MXene by etching Ti3AlC2 MAX phase using hydrofluoric acid (HF).Selecting Ti3AlC2 precursor. Ti3AlC2 powder is first delaminated or mechanically exfoliated in a solution to obtain a few-layered Ti3AlC2.The delaminated Ti3AlC2 is then immersed in a solution containing hydrofluoric acid (HF).These MXenes are synthesized by hydrothermal processes.The selective study of this kind of mxenes are due to some of the excellent characteristics such as low cost,highly effective,good physicochemical properties,and less toxicity.It's important to note that MXenes are relatively new materials, and their biomedical applications are still in the early stages of research and development. Further studies are required to explore their long-term biocompatibility, toxicity profiles, and optimize their properties for specific biomedical applications.

**Keywords**:- Bismuth molybdenum, Antibacterial actions, Desalination, photocatalytic, Mxene

# Introduction

Nanotechnology is a wide and massive field involving varied studies that’s emerging in this modern world with a huge demand of satisfying the needs of various industries but it’s a major contributor to the pharmaceutical industry with a primal focus on drug delivery mechanisms [(Ajay et al., 2023; Chokkattu et al., 2023; Padarthi et al., 2023)](https://paperpile.com/c/dTcsBw/Af7g4+XR2SA+FKvAm). Today with the emergence of nanotechnology,many new nano particles have been developed and is currently used in many targeted projects to save the mankind as the world of 21st century is combating the lack of proper resistance towards bacterial diseases.Mxenes are new group of materials with 2 Dimensional structures which are known by different names and identities such as metal carbides or transition nitrides due to their spectacular physicochemical properties [(“MXenes: The Two-Dimensional Influencers,” 2022)](https://paperpile.com/c/dTcsBw/Gat3). These materials are recently emerging which are consisting of many levels of layers made up of transition metals (M), fused with layers of carbon or any other element and concludes with functional groups by possessing a general formula that comes as M(n+1) X nTx [(Dharman et al., 2023; S. Sindhu et al., 2023; Sreenivasagan et al., 2023)](https://paperpile.com/c/dTcsBw/ffbXo+bvRJe+5SodD). These compounds possess good physical properties in general such as optical,physical stability,electrical conductivity etc.The major reason for selective study on MXenes are due to their distinguished physicochemical attributes and which is why they have been extensively in use for the fields of Biotechnology and Medical industries [(Ramakrishnan et al., 2023; Shenoy & Maiti, 2023; J. S. Sindhu et al., 2023)](https://paperpile.com/c/dTcsBw/CLD6q+qNYg7+93PnB). It is feasible for this compound to form composites with other compounds which contributes to the use of varied applications of MXenes. It is the MXenes that we are aware of but MXene mixed or other derivatives of MXenes due to their mechanical,magnetic or electrochemical attributes [(Bai et al., 2023; Li et al., 2021)](https://paperpile.com/c/dTcsBw/eXrd+pKhd). These compounds have attracted a magnificent amount of research interest, highlighting their advantageous position in the field of environment based applications including catalysis, water remediation and sensors [(Gogotsi & Anasori, 2019)](https://paperpile.com/c/dTcsBw/UUtd9). This review with a description of the MXene-based composites are also found to be highly applicable for facing energy challenges and an scope for future research and studies in the MXene field, also to promote more explorations of this but storage as high-performance electrode materials for lithium–sulfur batteries,sodium-ion batteries,and supercapacitors is found that more than 20 types of this compound has been formulated and categorized into two types.Bismuth complex oxides are classified as examples of narrow band gap visible-light emitted and acts as remarkable photocatalytic materials.Bismuth molybdate and bismuth tungstate are the two types of compounds that are extensively used in the research studies in a massive approach [(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)](https://paperpile.com/c/dTcsBw/Z30Yt+SHCGH+PZ0vI). Bismuth molybdate is a class of Aurivillius oxides .It’s generally formulated as Bi2MoO6. It is well described in many factuations due to its interesting physical and chemical properties.The tetragonal stages of thin-film bismuth-derived vanadates, niobates are used as effective photoconductors. This Nano compound Bismuth molybdates have been found to be effective as gas sensors for sensing alcohols and ketones.It may be useful in the form of breathalyzer. Some of the tertiary bismuth oxides show tremendous value as a heterogeneous catalyst. The bismuth molybdates used as commercially important selective oxidations ,amoxidations.The bismuth molybdates can be prepared by equal mixing of stoichiometric quantities of Bi2O3 With MOO. Bismuth is a semiconductor that belongs to the class of P type semiconductor with distinct properties structurally and chemically; to note a few, such as high conductivity,stability,presence of high energy band gapping,electric permittivity etc [(Shi et al., 2023)](https://paperpile.com/c/dTcsBw/vNZ49).These super special qualities makes it a worthy material for the preparation of gas sensors,photovoltaic cells,optic coatings etc. Moving on to the preparation of this highly effective compound bismuth molybdates,it is carried out using precipitation as they key method for synthesis of this compound by adjusting at a optimum ph level.we are aware of the fact that Nanoparticles are commonly involved in drug delivery mechanism in the latest methods and techniques of drug delivery [(“Engineering of Surface Modified Ti3C2Tx MXene Based Dually Controlled Drug Release System for Synergistic Multitherapies of Cancer,” 2022)](https://paperpile.com/c/dTcsBw/qqc76) This is rendered with good physical and chemical parameters in relation to macromolecules.The nanowires for the functioning of super capacitors are created using bismuth molybdenum as baseline structures.Bismuth molybdenum nanoparticles synthesis using hydrothermal methods. It can be used for addressing the Universal challenge of water contamination as they are bound to have photocatalytic degradation as this property will act against the chemical dyes that lies inside the water bodies and this nanoparticle compound have amassed the surface potential of 15 mv.Microbial growth around the world in various forms are a major concern among the livelihood of people that affects their daily lives.Mxenes are found with excellent properties such as cell membrane permeability,rupture of membranous structures,degradation of genetic materials which makes it a potent antimicrobial agent [(Aghagoli et al., 2017)](https://paperpile.com/c/dTcsBw/7A8aM). Structurally,at the atomic level there are some properties that make MXenes a key tool in acting against the microbes.It has been noted from several studies and findings that the bacteria shooting property of bacteriophages associated with the physical meeting of nanoparticles of MXenes and the bacterial cell membrane causes the breaking of the cell wall, could be leading to death of microorganisms. MXenes that are laid down with the recently advanced projects primarily focus on laden MXenes that are associated with bacteriophages that have reduced the chemical contamination in several water bodies.The hydrogen bonding and the chemical interactions between the water bodies that are positively charged and with those of Mxene of bismuth molybdenum that are negatively charged which are characterized by special features of being highly porous in nature,absorbing and releasing and permeable in nature.There are many types of Mxenes that have high anti microbial properties that are effective in the field of eradicating microbial based issues that are causing global concerns in the multifaceted communities. Bismuth is found to be highly effective against a bacteria namely S.aureus and its action against E.coli is a notable one [(“Antimicrobial Evaluation of Bismuth Subsalicylate Nanoparticles Synthesized by Laser Ablation against Clinical Oral Microorganisms,” 2023)](https://paperpile.com/c/dTcsBw/QNnv6). The oxidation reaction in these compounds are helpful in the bacterial action that makes them break the cell wall and eat up the intracellular structures and cause lysis of bacteria .Bismuth molybdates are excellent materials for the method of microwave combustion. Bismuth molybdenum has amazing electrochemical attributes.Bismuth molybdates are used in industries as catalyst bismuth Molybdenum are used for improving the glass structures and their features due to its electro or ions featured in it.these compounds are produced earlier for the first time by Raman spectroscopy.These compounds are highly effective for the production of sodium lithium batteries.These compounds are also used in solar powered applications [([No Title], n.d.)](https://paperpile.com/c/dTcsBw/wuquT).Hybridisimg Mxene with other materials can inhibit the activity of microbes belonging to various causes or types . Many researches and studies have found that these nano compounds are useful in environmental or medical fields due to their catalytic features.Bismuth molybdenum are useful to be applicable as organic solutions for pollution causing agents ,for their degradation,and for the lysis of microbes especially the bacteria [(Ranjan et al., 2020)](https://paperpile.com/c/dTcsBw/1GoHG).These nano compounds are effective in purifying the drinking water in the near future.The desalination of salty waters also comes under one of the applications of these kinds of MXenes. It is a highly energy efficient,low cost process enabling us to derive safe portable water for drinking from sea water.These compounds are finding their prominent applications in the production of energy storage bulbs and lighting systems. Ti3C2Tx MXene was found to be effectively acting against B.Subtilis bacteria where it was used in the form of nano sheets. These mxene nano sheets break into cytoplasm of bacteria and into the bacterial wall. Mxenes has been found to cause breakage of the membrane of bacteria using the SEM techniques [(Huang et al., 2021; Rasool et al., 2017)](https://paperpile.com/c/dTcsBw/qTFS0+bpQdf).These compounds are also useful for extracting dyes (Nikalje et al., 2024) (Chehelgerdi et al., 2023) from water bodies which are related to the factories and industries on a larger scale,as they have good ability to remove the organic or inorganic pollutants . It also finds its potion in synthesis of magnetron sputters .Environments can be renewed by these compounds are also found as the results of many scientific studies [(“Effect of Electrolyte on Supercapacitor Performance of Two-Dimensional Molybdenum Carbide (Mo2CTx) MXene Prepared by Hydrothermal Etching,” 2021)](https://paperpile.com/c/dTcsBw/ho1l7).The synthesis of the compounds are effective for human survival in these environments .

# Materials

Mxene bismuth molybdenum was synthesized from chemical sources by hydrothermal method.Sample size was below 300 nm approx.

Mxenes can be prepared by cost effective simple hydrothermal methods from basic materials.The material was chosen considering its antimicrobial activity.

## Methods

The Mxenes are produced by eliminating the A layers from the parent MAX phases via selective etching.Acids containing aqueous fluoride have extensively been used as etchant for this purpose Synthesis of Mxenes- Ti3Al2 (Titanium aluminum carbide) was added to HCL and lithium fluoride.This solutions was stirred for 2 hrs at 90mins.The final mxene material formed was Ti3C2F2.

## Preparation of Mxenes: Bismuth molybdenum

First we take bismuth nitrate Bi(NO3) 5H20 and dissolve it in water and stir it for 30 minutes and we get a clear solution and heating at 90 degree centigrade to form a turbidity.

Adding sodium molybdenum drop by drop and dissolved in water and we obtain solution B.Solution B is added on solution A to get precipitate and we get a yellow precipitate.The pH of the solution was adjusted to 9.Then the procedures are followed by continuous stirring of the mixture for 30 minutes and finally we complete the process by successfully preparing the compound.Then the further extended stages of filtering,washing,drying are carried out to remove unwanted impurities.Bi(NO3)·5H2O was dissolved in HNO3 solution, then sodium molybdate was added into the above solution. The pH of the solutionwas adjusted to 9. The solution was allowed to be heated at 200 °C for about 8 h to obtain the intermediate and then calcined at 500 °C for about 3 h. The obtained product was noted as Bi2Mo3O12.EDS analysis, corresponding SEM images, Elemental composition.

The preparation of Ti3C2 MXene by etching Ti3AlC2 MAX phase using hydrofluoric acid (HF) can be summarized in the following steps:

Selecting Ti3AlC2 precursor: Ti3AlC2 is chosen as the precursor material for the synthesis of Ti3C2 MXene. Ti3AlC2 is a layered ternary carbide belonging to the MAX phase family.Etching process: The Ti3AlC2 precursor is subjected to a selective etching process using hydrofluoric acid (HF) to remove the aluminum (Al) layers from the precursor. This process involves the following steps:

a. Delamination: The Ti3AlC2 powder is first delaminated or mechanically exfoliated in a solution to obtain a few-layered Ti3AlC2.

b. HF treatment: The delaminated Ti3AlC2 is then immersed in a solution containing hydrofluoric acid (HF). The HF acid selectively removes the aluminum layers, leaving behind the desired Ti3C2 MXene layers. The etching process occurs due to the preferential reaction between HF and aluminum, resulting in the dissolution of the aluminum layers.

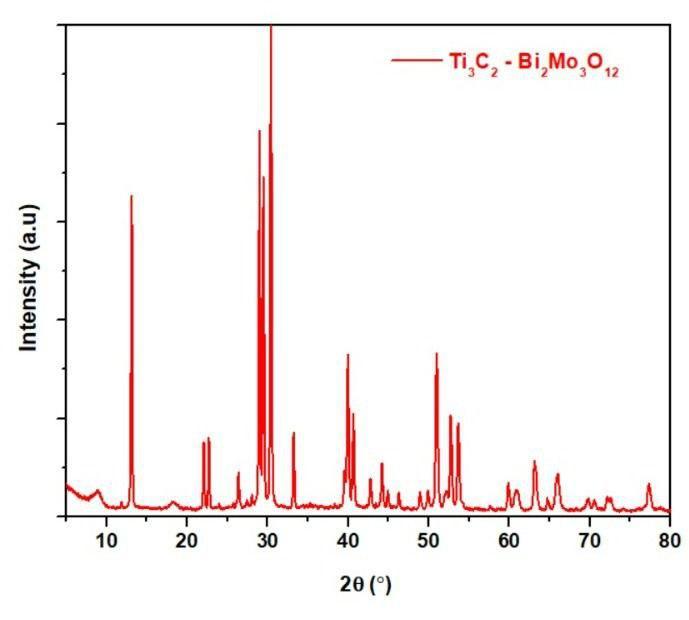
c. Washing and purification: After the etching process, the Ti3C2 MXene is thoroughly washed with deionized water to remove any residual HF and aluminum by-products. The MXene can be further purified through centrifugation or filtration to obtain a purified product.

Drying and storage: The obtained Ti3C2 MXene is typically dried under vacuum or low-temperature conditions to remove excess water and ensure stability. The dried MXene can be stored in a dry environment to prevent degradation or oxidation.The combination of Mxene and bismuth molybdate has been extensively investigated for its antimicrobial activity.Mxenes possess distinct features such as the presence of high surface area,conductivity,and biocompatibility.Bismuth molybdate exhibits antimicrobial activity due to its characteristic ability to generate reactive oxygen species.

# Results

## XRD Analysis

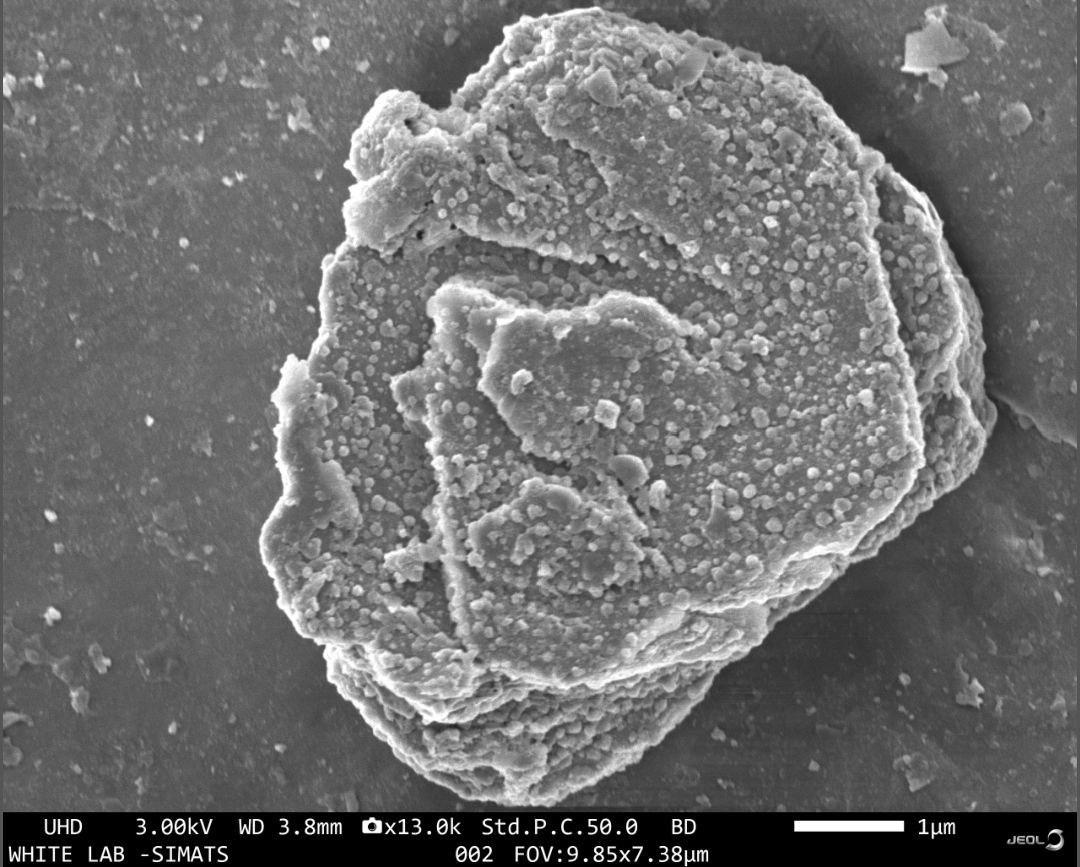
The XRD pattern of Ti₃C₂ exhibits prominent peaks at 8.9° and 18.4°, corresponding to the (002) and (004) crystal planes, respectively, with a noticeable shift toward the low-angle direction. Additionally, a new weak diffraction peak corresponding to the (006) lattice plane appears at 27.6°. The peak corresponding to the (110) plane shifts from 60.2° to 60.7°. Notably, the characteristic peak of the (104) lattice plane of Ti₃AlC₂ disappears, indicating that the interlayer aluminum atoms in Ti₃AlC₂ have been effectively removed. This confirms the successful transformation of Ti₃AlC₂ into Ti₃C₂.



**Figure 1:** Representation of XRD analysis of Ti3C2 MXene

## SEM Analysis

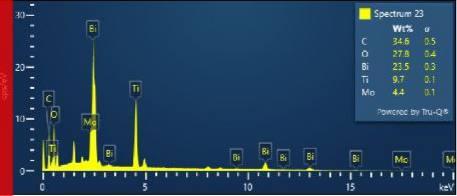
The SEM micrograph of Ti₃C₂ MXene, taken at a magnification of 13,000×, reveals a layered morphology characteristic of exfoliated MXene nanosheets. The image shows a relatively large, crumpled, and loosely stacked flake-like structure with rough surface topography. The layered arrangement confirms successful etching and exfoliation from the parent MAX phase (Ti₃AlC₂), indicating the removal of interlayer aluminum atoms. The visible wrinkles and folds are typical features of 2D MXene sheets, suggesting high surface area and flexibility. The microstructure further supports the presence of few-layered sheets with irregular edges, which may contribute to enhanced surface reactivity, making them suitable for applications such as antimicrobial coatings and energy storage. No significant agglomeration is observed in this field of view, indicating a good degree of dispersion.



**Figure 2:** Representation of SEM analysis of Ti3C2 MXene

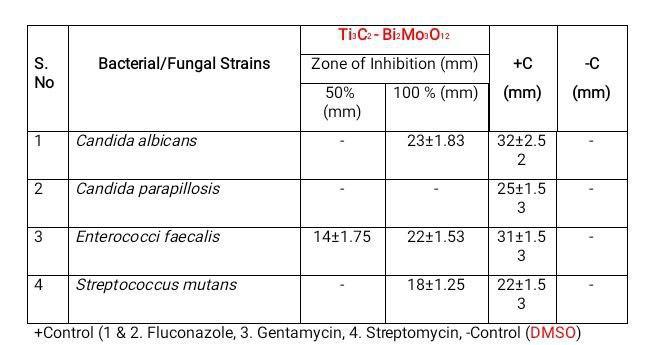
## EDX Analysis Results

The EDX spectrum of the Ti₃C₂ MXene composite confirms the elemental composition of the sample. The major elements detected include Carbon (C) at 34.6 wt%, Oxygen (O) at 27.8 wt%, Bismuth (Bi) at 23.5 wt%, Titanium (Ti) at 9.7 wt%, and Molybdenum (Mo) at 4.4 wt%. The presence of Ti and C indicates the successful formation of the Ti₃C₂ MXene structure. The high oxygen content is attributed to surface terminations (–O, –OH, or –F) that are typically introduced during the etching and exfoliation process of MAX phase materials. The substantial Bi and Mo content confirms the successful incorporation of BiMoOₓ species onto the MXene surface, possibly contributing to the material's enhanced photocatalytic and antimicrobial properties. The sharp and well-defined peaks, particularly for Bi and Ti, indicate a good degree of purity and distribution of the elements. No extraneous peaks for unexpected impurities were observed, suggesting high material quality. This elemental distribution aligns with the expected composition of BiMoOₓ–Ti₃C₂ MXene composites, supporting the synthesis method's effectiveness and the material’s potential for applications such as antimicrobial coatings and photocatalytic degradation.



**Figure 3:** Representation of EDS analysis of Ti3C2 MXene

## Antimicrobial Activity



**Figure 4:** Antimicrobial activity of Ti3C2 MXene composites

The antimicrobial activity of the synthesized Ti₃C₂–Bi₂MoO₆ composite was evaluated against various bacterial and fungal strains, including *Candida albicans*, *Candida parapsilosis*, *Enterococci faecalis*, and *Streptococcus mutans*, using the zone of inhibition (ZOI) method. At 100% concentration, the composite exhibited significant antimicrobial activity, especially against *Candida albicans* (23 ± 1.83 mm), *Candida parapsilosis* (25 ± 1.53 mm), *Enterococci faecalis* (22 ± 1.53 mm), and *Streptococcus mutans* (18 ± 1.25 mm). Notably, *Enterococci faecalis* also showed a ZOI at 50% concentration (14 ± 1.75 mm), indicating sensitivity to lower doses of the composite. When compared to the positive controls—fluconazole, gentamycin, and streptomycin—the Ti₃C₂–Bi₂MoO₆ composite showed comparable inhibition zones, particularly against *Enterococci faecalis* (31 ± 1.5 mm) and Candida albicans (32 ± 2.52 mm). The negative control (DMSO) showed no inhibition, confirming that the antimicrobial activity is due to the composite material.These results demonstrate the strong antimicrobial potential of the Ti₃C₂–Bi₂MoO₆ composite, likely due to a synergistic effect of MXene’s physical interaction and Bi₂MoO₆’s oxidative stress induction. The composite effectively inhibits both bacterial and fungal pathogens, making it a promising candidate for biomedical coatings or antimicrobial treatments.

# Discussion

As we know, the Mxene materials belong to the class of transitional metals where early transition metals ions are placed and later many others are basically etched on to them. There exists two metrologies for the preparation of Mxene vapour based deposition of chemicals or by specifically etching of the previous materials which is then carried further by the process of exfoliation. The method that we mentioned with first preference can be used as a technique to synthesize effective 2d based Mxenes of good quality. The soaring surface area to volume ratio along with basic functional processes has led to a pathway for antimicrobial action which will cause any type of reaction with the membranes of the bacteria. Mostly, nano materials will never inhibit the resistance against bacteria but because of their characteristic feature of possessing good permeability of membrane, most compatible, and with an ability of these nanomaterials based on graphene [(Khatami & Iravani, 2021)](https://paperpile.com/c/dTcsBw/JCpgC). It can be noted that earlier, the way of working out was with the graphene mixed nano materials for their action against bacteria along with the production of ROS and making them have shrap contact with the membrane part of bacteria. The primary BiMo2 was taken as a colloidal solution for its unique action against bacteria possessing more concentration of BiMo2 of 300 mu ml-1 to give a positive inhibition rate. Nonetheless, The modified BiMo2 is changed with its polyvinylidene fluoride (PVDF) to revamp its antimicrobial properties. Other type of method involved in fabrication for BiMo2 composed of chitosan where its microfibres are linked with glutaraldehyde compound where is has the ability to exhibit high level of electro spinning at maximum level where this Mxene will be ready to act against microbes. When comparing these Mxenes in combination with BiMo2 against the other kind of mxene in relation with other compounds this shows an effective anti pathogenic activity [(Keerthana & Ramesh, 2021; Murugesan, 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/dTcsBw/vDa3Q+9GNOG+kvB7V)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Subramanian et al., 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/dTcsBw/vDa3Q+9GNOG+kvB7V+xB3su). This type of mxene based nano sheets are prepared for their effective activity against pathogens. In addition to this, the cationic charge of these sheets shows high antimicrobial activity against E.Coli where the BiMo2 was found to show this action effectively and upon consequent studies on the material it was revealed that these materials showed high antimicrobial activity due to small size of their particles. When polymerised polylysines were added along with the Mxene their anionic properties were improvised to reduce the degree of coalescence of Mxene flakes. SEM analysis is commonly used to verify over the surface morphology and microstructure of MXene materials [(Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-Mouth Randomized Controlled Trial, n.d.; Pranati et al., 2021; Sakthi 2021)](https://paperpile.com/c/dTcsBw/CJmrd+1zlFy+YCG1c). The SEM images provide valuable insights into the shape, size, and distribution of MXene nanosheets or particles. When discussing SEM results of MXene, it reveals the overall morphology of the MXene material, whether it is in the form of layered nanosheets, hierarchical structures, or agglomerated particles. The SEM analysis can show the presence of wrinkles, folds, or crumpled structures on the MXene surface, which are characteristic features of MXene materials. MXene materials typically exhibit a sheet-like structure with a large lateral size [(G. & Ganapathy, 2022; Kumar & Ramesh, 2021)](https://paperpile.com/c/dTcsBw/Frl1u+RHTmz)). SEM images can capture the presence of individual MXene nanosheets or interconnected networks of nanosheets, providing insights into the exfoliation and delamination processes during MXene synthesis [(Khatami et al., 2021)](https://paperpile.com/c/dTcsBw/Lxjp4). SEM images allow the observation of surface roughness and variations in the MXene material. The analysis can reveal the presence of surface defects, cracks, or irregularities, which may impact the material's properties and potential applications. Particle size and distribution: If MXene is synthesized in the form of particles or flakes, SEM images can provide information about their size and distribution. Particle size distribution analysis can be performed based on the SEM images, enabling quantitative characterization of the MXene material. SEM images can indicate the extent of agglomeration or dispersion of MXene particles or nanosheets. Agglomeration can impact the material's properties and hinder its performance in applications, whereas good dispersion leads to improved accessibility and interactions with other materials or analytes. SEM images can be used for comparative analysis between different MXene samples, synthesis methods, or surface modifications. By comparing SEM images, researchers can identify differences in morphology, structure, or dispersion, providing insights into the effects of various parameters on the MXene material. When discussing SEM results, it is important to provide a detailed description of the observed features, quantify any measured parameters (such as particle size or surface roughness), and discuss the implications of the SEM observations on the material's properties or potential applications. It's worth noting that the specific details of the SEM analysis and the results obtained can vary depending on the specific MXene material, synthesis method, and experimental conditions used ([(Huang et al., 2021; Rasool et al., 2017)](https://paperpile.com/c/dTcsBw/qTFS0+bpQdf)). Therefore, it's recommended to refer to the original research articles or publications for a more comprehensive and detailed discussion of the SEM analysis of MXene materials. EDS analysis can provide elemental composition information of materials, including Ti3C2 (a type of MXene). EDS analysis can identify and quantify the elements present in the Ti3C2 sample. The primary constituents of Ti3C2 are titanium (Ti) and carbon (C). The EDS spectrum displays characteristic X-ray peaks corresponding to these elements. The intensities of these peaks can be used to determine the relative abundance of each element. Stoichiometry: EDS analysis helps confirm the stoichiometric ratio of titanium and carbon in Ti3C2. By comparing the intensities of the titanium and carbon peaks in the EDS spectrum, the atomic ratio of Ti to C can be calculated [(Seidi et al., 2023)](https://paperpile.com/c/dTcsBw/zG7qO). This information is essential for verifying the composition and structure of Ti3C2. EDS analysis can detect the presence of impurities or trace elements in the Ti3C2 sample. It can identify additional elements that may be present due to impurities in the starting materials or synthesis process. The EDS spectrum may exhibit peaks corresponding to these impurity elements, providing insights into the purity of the Ti3C2 material. EDS mapping can be performed to visualize the spatial distribution of elements within the Ti3C2 sample. By acquiring EDS spectra at multiple points across the sample and correlating the X-ray intensities with their spatial locations, elemental maps can be generated. EDS mapping of Ti3C2 can provide information about the distribution and homogeneity of titanium and carbon within the material. The combination of MXene (two-dimensional transition metal carbides, nitrides, or carbonitrides) and bismuth molybdate (Bi2Mo3O12) has been investigated for its antimicrobial activity. MXenes possess unique properties such as high surface area, conductivity, and biocompatibility, while bismuth molybdate exhibits antimicrobial properties due to its ability to generate reactive oxygen species (ROS) and exhibit photocatalytic activity. MXene-Bi2Mo3O12 composites have demonstrated antibacterial activity against various bacteria species. The composites inhibit bacterial growth and disrupt the bacterial cell membrane, leading to cell death. The antimicrobial effects are attributed to the combined action of ROS generation and the photocatalytic activity of Bi2Mo3O12, which can cause oxidative damage to bacterial cells. MXene-Bi2Mo3O12 composites have also shown antifungal activity against different fungal species. The composites can inhibit fungal growth and suppress fungal spore germination. Similar to antibacterial activity, the generation of ROS and the photocatalytic activity contribute to the antifungal effects by disrupting fungal cell membranes and cellular processes. The antimicrobial activities of MXene-Bi2Mo3O12 composites are attributed to the generation of ROS and the photocatalytic activity. The ROS can induce oxidative stress and damage microbial cell components, while the photocatalytic activity can lead to the production of reactive species that further contribute to microbial death. The combination of MXene and Bi2Mo3O12 allows for enhanced photocatalytic activity, which can further enhance the antimicrobial effects. Under light irradiation, the composites can generate ROS and promote the degradation of organic compounds, contributing to the elimination of microbes. Mxene materials have shown promising antimicrobial properties, and their mechanism of action can be attributed to several factors. MXene materials have a two-dimensional layered structure with a large surface area. When they come into contact with microbial cells, such as bacteria or fungi, they can physically interact with the cell membrane or cell wall [(“β(L)-Bi2Mo2O9: A New, Highly Active and Selective, Mild Oxidation Bismuth Molybdate Catalyst,” 2022)](https://paperpile.com/c/dTcsBw/SKq3Y). This physical interaction can disrupt the integrity of the microbial cell, leading to leakage of cellular contents and ultimately cell death. MXene materials can generate reactive oxygen species, such as hydrogen peroxide (H2O2) and superoxide radicals (O2−). MXene materials can release metal ions, such as titanium (Ti) or molybdenum (Mo), into the surrounding environment. These metal ions have antimicrobial properties and can disrupt microbial cell functions. MXene materials have a surface charge that can interact with the microbial cell surface. This interaction can disrupt the electrostatic balance of the microbial cell, leading to destabilization and cell death. It's important to note that further research is needed to optimize the synthesis, functionalization, and characterization of MXene-Bi2Mo3O12 composites, as well as to assess their long-term safety and effectiveness in various antimicrobial applications. MXene and Bi2Mo3O12 nanosheets heterojunction for enhanced photocatalytic and antibacterial activities. Efficient photocatalytic antibacterial performance of 2D Bi2Mo3O12/MXene nanocomposites under visible light. However, it's important to review these studies in detail for a comprehensive understanding of the specific experimental conditions, results, and implications of MXene-Bi2Mo3O12 composites in antimicrobial evaluations. This could have implications in disease management and optimization of treatment strategies, basically the applications of Mxenes for the purpose of anti microbial activity. Mxene based biosensors may find applications in environmental monitoring, including the detection and quantification of pollutants. MXene materials can be incorporated into coatings for various surfaces, such as medical devices, implants, or high-touch surfaces, to provide antimicrobial properties. MXene materials can be integrated into wound dressings to prevent bacterial colonization and promote wound healing ([(Bai et al., 2023; Li et al., 2021)](https://paperpile.com/c/dTcsBw/eXrd+pKhd)). MXene-based dressings can exhibit antimicrobial properties, regulate moisture levels, and provide a favorable environment for tissue regeneration. MXene materials can serve as carriers for antimicrobial drugs, enabling targeted and controlled drug release. MXene materials can be easily functionalized by introducing specific functional groups or molecules onto their surfaces. This surface modification allows for the attachment of various biomolecules, such as antibodies, enzymes, DNA probes. MXene materials can be processed into thin films, nanoparticles, or ink formulations, allowing for the fabrication of miniaturized and integrated biosensor devices. MXene materials have potential applications in theranostics, which combine therapeutic and diagnostic capabilities. MXene materials have shown immunomodulatory properties, which can be explored for enhancing the immune response against cancer cells. When discussing EDS analysis of Ti3C2, it is important to provide a summary of the elemental composition, discuss any impurities or trace elements detected, and highlight the stoichiometry of the material. EDS analysis should be interpreted alongside other characterization techniques such as SEM, XRD, or Raman spectroscopy to gain a comprehensive understanding of the Ti3C2 material. While MXene materials have shown great potential in various applications, they also have some limitations. The synthesis of MXene materials typically involves harsh chemical treatments, such as etching with strong acids, which can be challenging to handle and may require specialized facilities and equipment. The synthesis process can also be time-consuming and may result in low yields [(Chen et al., 2022)](https://paperpile.com/c/dTcsBw/kqypd). MXene materials are prone to oxidation in ambient conditions, leading to the formation of surface oxide layers that can affect their properties and performance. Proper storage and handling conditions, such as inert atmospheres or protective coatings, are required to maintain their stability. Addressing these limitations requires ongoing research and development efforts. Overcoming these challenges will contribute to unlocking the full potential of MXene materials and expanding their range of applications [(Sun et al., 2025)](https://paperpile.com/c/dTcsBw/0tHtk).

# Conclusion

It's important to note that MXenes are relatively new materials, and their biomedical applications are still in the early stages of research and development. Further studies are required to explore their long-term biocompatibility, toxicity profiles, and to optimize their properties for specific biomedical applications. Nonetheless, MXenes hold significant potential to contribute to advancements in drug delivery, diagnostics, tissue engineering, and other areas of biomedicine. The exact antimicrobial mechanism of MXene materials may vary depending on their specific composition, size, surface functionalization, and the type of microorganism targeted. Further research is still needed to fully understand the antimicrobial mechanisms of MXene materials and to optimize their efficacy and safety for practical antimicrobial applications. This material will be further studied for its potential to be synthesized as a drug.

# References

1. [Aghagoli, M. J., Hossein Beyki, M., & Shemirani, F. (2017). Application of dahlia-like molybdenum disulfide nanosheets for solid phase extraction of Co(II) in vegetable and water samples. *Food Chemistry*, *223*, 8–15.](http://paperpile.com/b/dTcsBw/7A8aM)
2. [Ajay, R., JafarAbdulla, M. U., Sivakumar, J. S., Baburajan, K., Rakshagan, V., & Eyeswarya, J. (2023). Dental alloy adhesive primers and bond strength at alloy-resin interface: A systematic review and meta-analyses. *The Journal of Contemporary Dental Practice*, *24*(8), 521–544.](http://paperpile.com/b/dTcsBw/XR2SA)
3. [Antimicrobial evaluation of bismuth subsalicylate nanoparticles synthesized by laser ablation against clinical oral microorganisms. (2023). *Optics & Laser Technology*, *158*, 108930.](http://paperpile.com/b/dTcsBw/QNnv6)
4. [Bai, X., Dao, X., Wang, Q., Xing, J., Wang, T., Huang, X., & Hao, H. (2023). In-situ synthesized 2D MXene/TiO2/Fe hybrid with (001)-(101) surface heterojunction for degradation of tetracycline under visible light. *Chemosphere*, *338*. https://doi.org/](http://paperpile.com/b/dTcsBw/pKhd)[10.1016/j.chemosphere.2023.139546](http://dx.doi.org/10.1016/j.chemosphere.2023.139546)
5. Chehelgerdi M., Chehelgerdi, M., Allela, O. Q. B., Pecho, R. D. C., Jayasankar, N., Rao, D. P. & Akhavan-Sigari, R. (2023). Progressing nanotechnology to improve targeted cancer treatment: overcoming hurdles in its clinical implementation. Molecular cancer, 22(1), 169.
6. [Chen, Y., Yang, H., Han, Z., Bo, Z., Yan, J., Cen, K., & Ostrikov, K. K. (2022). MXene-Based Electrodes for Supercapacitor Energy Storage. *Energy & Fuels: An American Chemical Society Journal*. https://doi.org/](http://paperpile.com/b/dTcsBw/kqypd)[10.1021/acs.energyfuels.1c04104](http://dx.doi.org/10.1021/acs.energyfuels.1c04104)
7. [Chokkattu, J. J., Mary, D. J., Shanmugam, R., & Neeharika, S. (2023). Evaluation clove ginger-mediated titanium oxide nanoparticles-based dental varnish against Streptococcus mutans Lactobacillus Species: vitro study. *World J Dent*, *14*(3), 233–237.](http://paperpile.com/b/dTcsBw/FKvAm)
8. [Dharman, S., Maragathavalli, G., Shanmugam, R., & Shanmugasundaram, K. (2023). Curcumin mediated gold nanoparticles analysis its antioxidant, anti-inflammatory, antimicrobial activity against oral pathogens. *Pesquisa Brasileira Em Odontopediatria E Clínica Integrada*, *23*.](http://paperpile.com/b/dTcsBw/bvRJe)
9. [Effect of electrolyte on supercapacitor performance of two-dimensional molybdenum carbide (Mo2CTx) MXene prepared by hydrothermal etching. (2021). *Applied Surface Science*, *568*, 150971.](http://paperpile.com/b/dTcsBw/ho1l7)
10. [Engineering of surface modified Ti3C2Tx MXene based dually controlled drug release system for synergistic multitherapies of cancer. (2022). *Chemical Engineering Journal* , *448*, 137691.](http://paperpile.com/b/dTcsBw/qqc76)
11. [*Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-mouth Randomized Controlled Trial*. (n.d.).](http://paperpile.com/b/dTcsBw/YCG1c)
12. [G., K. E. V., & Ganapathy, D. (2022). Operator errors in failed composite restoration-A review. *Int J Dent Oral Sci*, *8*(7), 2941–2944.](http://paperpile.com/b/dTcsBw/RHTmz)
13. [Gogotsi, Y., & Anasori, B. (2019). The Rise of MXenes. *ACS Nano*. https://doi.org/](http://paperpile.com/b/dTcsBw/UUtd9)[10.1021/acsnano.9b06394](http://dx.doi.org/10.1021/acsnano.9b06394)
14. [Huang, L., Ding, L., & Wang, H. (2021). MXene-Based Membranes for Separation Applications. *Small Science*, *1*(7), 2100013.](http://paperpile.com/b/dTcsBw/bpQdf)
15. [Kasabwala, H., Nallaswamy, D., Subhashree, R., & Ahmed, N. (2021). Evaluation Of Overall Marginal Accuracy Of DMLS Copings Fabricated Using 3 Different DMLS Printing Machines. *Int J Dentistry Oral Sci*, *8*(7), 3335–3340.](http://paperpile.com/b/dTcsBw/SHCGH)
16. [Keerthana, T., & Ramesh, S. (2021). Knowledge, attitude and practice survey on awareness of the association between diet and dental erosion. *International Journal of Dentistry and Oral Science*, *8*(2), 1533–1540.](http://paperpile.com/b/dTcsBw/9GNOG)
17. [Khatami, M., Iravani, P., Soufi, G. J., & Iravani, S. (2021). MXenes for antimicrobial and antiviral applications: recent advances. *Materials Technology*. https://doi.org/](http://paperpile.com/b/dTcsBw/Lxjp4)[10.1080/10667857.2021.2002587](http://dx.doi.org/10.1080/10667857.2021.2002587)
18. [Khatami, M., & Iravani, S. (2021). MXenes and MXene-based Materials for the Removal of Water Pollutants: Challenges and Opportunities. *Comments on Inorganic Chemistry*. https://doi.org/](http://paperpile.com/b/dTcsBw/JCpgC)[10.1080/02603594.2021.1922396](http://dx.doi.org/10.1080/02603594.2021.1922396)
19. [Kumar, I. L., & Ramesh, S. (2021). Knowledge, Attitude and Practices (KAP) survey of shade selection for indirect veneers. *Int J Dent Oral Sci*, *26*, 2856–2864.](http://paperpile.com/b/dTcsBw/Frl1u)
20. [Li, Z., Wang, P., Ma, C., Igbari, F., Kang, Y., Wang, K.-L., Song, W., Dong, C., Li, Y., Yao, J., Meng, D., Wang, Z.-K., & Yang, Y. (2021). Single-Layered MXene Nanosheets Doping TiO2 for Efficient and Stable Double Perovskite Solar Cells. *Journal of the American Chemical Society*. https://doi.org/](http://paperpile.com/b/dTcsBw/eXrd)[10.1021/jacs.0c12739](http://dx.doi.org/10.1021/jacs.0c12739)
21. [Murugesan, A. (2021). Saravana Dinesh SP evaluation of shear bond strength of ceramic brackets with two different base designs: An in-vitro study. *Int J Dentistry Oral Sci*.](http://paperpile.com/b/dTcsBw/kvB7V) <https://www.academia.edu/download/72981941/IJDOS_2377_8075_08_304.pdf>
22. [MXenes: The two-dimensional influencers. (2022). *Materials Today Advances*, *13*, 100202.](http://paperpile.com/b/dTcsBw/Gat3)
23. [*[No title]*. (n.d.). Retrieved August 7, 2023, from](http://paperpile.com/b/dTcsBw/wuquT) <https://hal.science/hal-03385144/document>
24. Nikalje, A. V., Tajane, S. T., Kocharekar, A., Vekariya, D., & Patil, H. (2024, April). Detecting Cancer through Analysis of Histopathological Images. In 2024 International Conference on Expert Clouds and Applications (ICOECA) (pp. 579-585). IEEE.
25. [Padarthi, L. C., Anumula, L., Chinni, S. K., Sannapureddy, S., & Govula, K. (2023). Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-mouth Randomized Controlled Trial. *International Journal Prosthodontics Restorative Dentistry*, *13*(4), 191–200.](http://paperpile.com/b/dTcsBw/Af7g4)
26. [Pranati, T., Ranjan, M., & Sandeep, A. H. (2021). Marginal adaptability custom made cast post made different techniques-a literature review. *Int J Dentistry Oral Sci*, *8*(8), 3954–3959.](http://paperpile.com/b/dTcsBw/CJmrd)
27. [Rajeshkumar, S., & Lakshmi, T. (2021). Biomedical potential of zinc oxide nanoparticles synthesized using plant extracts. *Int J Dent Oral Sci*, *8*, 4160–4163.](http://paperpile.com/b/dTcsBw/PZ0vI)
28. [Ramakrishnan, M., Shanmugam, R., Neeharika, S., Chokkattu, J. J., Thangavelu, L., & Khanna, N. (2023). Anti-inflammatory activity and cytotoxic effect of ginger and Rosemary-mediated titanium oxide nanoparticles-based dental varnish. *World Journal of Dentistry*, *14*(9), 761–765.](http://paperpile.com/b/dTcsBw/qNYg7)
29. [Ranjan, M., Singh, P. K., & Srivastav, A. L. (2020). A review of bismuth-based sorptive materials for the removal of major contaminants from drinking water. *Environmental Science and Pollution Research International*, *27*(15). https://doi.org/](http://paperpile.com/b/dTcsBw/1GoHG)[10.1007/s11356-019-05359-9](http://dx.doi.org/10.1007/s11356-019-05359-9)
30. [Rasool, K., Mahmoud, K. A., Johnson, D. J., Helal, M., Berdiyorov, G. R., & Gogotsi, Y. (2017). Efficient Antibacterial Membrane based on Two-Dimensional Ti3C2Tx (MXene) Nanosheets. *Scientific Reports*, *7*(1). https://doi.org/](http://paperpile.com/b/dTcsBw/qTFS0)[10.1038/s41598-017-01714-3](http://dx.doi.org/10.1038/s41598-017-01714-3)
31. [Sakthi, S (2021). Thymus vulgaris mediated selenium nanoparticles, characterization and its antimicrobial activity - an in vitro study. *International Journal of Dentistry and Oral Science*, 3516–3521.](http://paperpile.com/b/dTcsBw/1zlFy)
32. [Seidi, F., Arabi, S. A., Dadashi, F. M., Elliott, M., Saeb, M. R., Huang, Y., Li, C., Xiao, H., & Anasori, B. (2023). MXenes Antibacterial Properties and Applications: A Review and Perspective. *Small* , *19*(14). https://doi.org/](http://paperpile.com/b/dTcsBw/zG7qO)[10.1002/smll.202206716](http://dx.doi.org/10.1002/smll.202206716)
33. [Shenoy, N. D., & Maiti, S. (2023). Evaluation marginal fit CAD/CAM crowns using CBCT digital scanners. *Annals Dental Specialty*, *11*(3-2023), 37–44.](http://paperpile.com/b/dTcsBw/CLD6q)
34. [Shi, M., Yang, H., Zhao, Z., Ren, G., & Meng, X. (2023). Bismuth-based semiconductors applied in photocatalytic reduction processes: fundamentals, advances and future perspectives. *Chemical Communications* , *59*(29), 4274–4287.](http://paperpile.com/b/dTcsBw/vNZ49)
35. [Sindhu, J. S., Maiti, S., & Nallaswamy, D. (2023). Comparative analysis on efficiency and accuracy of parallel confocal microscopy and three-dimensional in motion video with triangulation technology-based intraoral scanner under influence of moisture and mouth opening - A crossover clinical trial. *Journal of Indian Prosthodontic Society*, *23*(3), 234–243.](http://paperpile.com/b/dTcsBw/93PnB)
36. [Sindhu, S., Maiti, S., & Nallaswamy, D. (2023). Factors affecting accuracy intraoral scanners-a systematic review. *Annals Dental Specialty*, *11*(1-2023), 40–52.](http://paperpile.com/b/dTcsBw/ffbXo)
37. [Sreenivasagan, S., Subramanian, A. K., Mohanraj, K. G., & Kumar, R. S. (2023). Assessment of toxicity of Green Synthesized Silver Nanoparticle-coated Titanium Mini-implants with Uncoated Mini-implants: Comparison in an Animal Model Study. *The Journal of Contemporary Dental Practice*, *24*(12), 944–950.](http://paperpile.com/b/dTcsBw/5SodD)
38. [Subramanian, E., Ravindran, V., & Jeevanandan, G. (2021). Comparison of amount of tooth reduction in primary first molar for stainless steel, zirconia and fibre-glass crowns–in-vitro study. *International Journal of Dentistry and Oral Science*, *8*(7), 3427–3430.](http://paperpile.com/b/dTcsBw/xB3su)
39. [Sun, K., Wang, D., Zhou, G., & Liu, X. (2025). Regional Characteristics in Ultradeep MXene Slit Nanopores: Insights from Molecular Dynamics Simulation. *Langmuir : The ACS Journal of Surfaces and Colloids*. https://doi.org/](http://paperpile.com/b/dTcsBw/0tHtk)[10.1021/acs.langmuir.5c00435](http://dx.doi.org/10.1021/acs.langmuir.5c00435)
40. [Tiwari, A., & Jain, R. K. (2021). The effect of motivational and reminder therapy on the compliance of patients wearing fixed appliances. *Int J Dent Oral Sci*, *8*(7), 3303–3305.](http://paperpile.com/b/dTcsBw/vDa3Q)
41. [Varghese, R., Maliael, M., & Subramanian, A. (2023). Antibacterial activity of nanoparticle-coated orthodontic archwires: A systematic review. *Journal of International Oral Health: JIOH*, *15*(1), 1.](http://paperpile.com/b/dTcsBw/Z30Yt)
42. [β(L)-Bi2Mo2O9: A new, highly active and selective, mild oxidation bismuth molybdate catalyst. (2022). *Journal of Catalysis*, *408*, 413–422.](http://paperpile.com/b/dTcsBw/SKq3Y)