Fabrication and Characterization of Copper Oxide-Functionalized Titanium Carbide Nanostructure-Based L-Arginine Biosensor

Ananya Saluguti1 , S.Paraffal1,a)

1Ananya Ortho Centre, Chennai, Tamilnadu, India

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

**Abstract:** This study focuses on the fabrication and characterization of an L-arginine biosensor based on copper oxide (CuO)-functionalized titanium carbide (MXene) nanostructures. MXenes, a class of two-dimensional transition metal carbides, offer outstanding properties such as high surface area, excellent conductivity, and biocompatibility, making them ideal for biosensing applications. CuO nanoparticles, known for their catalytic and semiconducting behavior, were integrated with Ti₃C₂ MXene to enhance electron transfer and sensing efficiency. The nanocomposite was synthesized via hydrothermal and etching methods, followed by structural and morphological characterization using SEM, XRD, EDS, and XPS. The fabricated biosensor exhibited excellent performance, detecting L-arginine at concentrations as low as 0.05 mg/mL, demonstrating high sensitivity, selectivity, and stability. These results suggest strong potential for applications in medical diagnostics, environmental monitoring, and food safety. The synergistic effects of MXene and CuO in the nanocomposite pave the way for next-generation electrochemical biosensors with rapid and reliable detection capabilities.

**Keywords**: MXene, L-arginine biosensor, Electrochemical sensing, Nanocomposite materials, biocompatibility.

# INTRODUCTION

Biosensing technology growth has become more closely tied to new classes of nanostructured materials with outstanding physicochemical properties. Among these, two-dimensional (2D) materials are of particular interest owing to their superior surface area, surface chemistry controllability, and high electrical conductivity. The most promising materials within this class are MXenes—a new family of 2D transition metal carbides, nitrides, and carbonitrides[(Gogotsi & Anasori, 2019)](https://paperpile.com/c/iYhOW7/Yh6N). Since the first report in 2011, MXenes have been generally produced by selecting etching 'A' layers from MAX phases, which are layered ternary nitrides / carbides with a general formula of Mn+1AXn. In this notation, M is an early transition metal (eg, Ti, V, or Nb), A is a group 13 or 14 element (eg, Al or Si), and X is carbon and/or nitrogen. The resulting MXenes have the general formula Mn+1XnTx, with Tx denoting surface termination due to presence of –O, –OH, or –F introduced during the etching process[(C et al., 2024)](https://paperpile.com/c/iYhOW7/gess)[(Ajay et al., 2023; Chokkattu et al., 2023; Padarthi et al., 2023)](https://paperpile.com/c/iYhOW7/LtF6h+e3HeU+4EaTw)[(Dharman et al., 2023; S. Sindhu et al., 2023; Sreenivasagan et al., 2023)](https://paperpile.com/c/iYhOW7/cHWS+PUpX+1uUF)[(Ramakrishnan et al., 2023; Shenoy & Maiti, 2023; J. S. Sindhu et al., 2023)](https://paperpile.com/c/iYhOW7/CzlqJ+Gi7aF+ayUyy)[(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)](https://paperpile.com/c/iYhOW7/Cqwj+4TlD+IBTX)The layered structure of MXenes resembles that of graphene, but with metallic conductivity and hydrophilic nature, making them highly compatible with biological systems. Ti₃C₂Tx, one of the most widely studied MXenes, consists of three layers of titanium atoms interleaved with two layers of carbon atoms. Upon etching the aluminum layer from its MAX phase precursor (Ti₃AlC₂), the exposed surface becomes functionalized with a variety of terminations (Tx), improving its dispersion in aqueous solutions and offering active sites for further functionalization. The combination of a high aspect ratio, large specific surface area, and tunable surface chemistry enables MXenes to interact efficiently with biomolecules, making them excellent candidates for biosensor platforms[(Tamhane et al., 2024)](https://paperpile.com/c/iYhOW7/diii).Copper oxide (Cu₂O), a p-type semiconducting metal oxide with a monoclinic crystal structure, complements MXenes in biosensing due to its unique properties. Cu₂O possesses a narrow bandgap (~1.2–1.9 eV), high surface reactivity, and low cost, making it suitable for use in sensing, catalysis, and antimicrobial applications[(Dhilip Kumar et al., 2022)](https://paperpile.com/c/iYhOW7/7HRU). The Cu₂O nanoparticles are characterized by their high surface-to-volume ratio, varied morphologies, and capacity to support fast electron transfer reactions. These attributes facilitate their incorporation into composite nanostructures to enhance sensitivity and specificity in sensor applications. Furthermore, Cu₂O exhibits good redox properties, providing catalytic activity that benefits electrochemical detection mechanisms[(Majumdar & Ghosh, 2021)](https://paperpile.com/c/iYhOW7/BPgP).In biosensor fabrication, hybridizing Cu₂O with MXenes offers a synergistic enhancement of functional characteristics. The high conductivity and electron mobility of Ti₃C₂Tx MXene help to overcome the poor electrical conductivity of Cu₂O, while the porous structure of Cu₂O enhances the surface interaction area for target biomolecules. In particular, the integration of Cu₂O nanoparticles within MXene nanosheets creates a highly interconnected network with improved electron pathways, leading to rapid response times and high selectivity in biosensing applications[(Zhou et al., 2022)](https://paperpile.com/c/iYhOW7/AaEj). This hybrid material, when used as a sensing platform, provides abundant active sites, efficient charge transfer, and biocompatibility — all of which are essential for the successful immobilization and detection of biomolecules like L-arginine.L-arginine is a semi-essential amino acid involved in numerous physiological processes, including nitric oxide synthesis, protein metabolism, and immune function regulation. Abnormal L-arginine levels are associated with cardiovascular diseases, cancer, and immune disorders, making its sensitive and selective detection critically important for clinical diagnostics(Almatrafi et al., 2024). Conventional techniques for L-arginine detection, such as chromatography or spectrophotometry, often suffer from high cost, complex operation, and long analysis times(Saadh et al., 2024). In contrast, electrochemical biosensors based on nanomaterial-modified electrodes offer rapid, accurate, and low-cost alternatives, particularly when enhanced with nanostructured materials like Cu₂O and MXene[(Wu et al., 2009)](https://paperpile.com/c/iYhOW7/Yyk2).The fabrication of the MXene-Cu₂O nanostructure involves a multi-step synthesis process, beginning with the selective etching of the Al layer in Ti₃AlC₂ using hydrofluoric acid to yield delaminated Ti₃C₂Tx nanosheets. These nanosheets are then hybridized with Cu₂O nanoparticles synthesized by a hydrothermal method involving the reaction of copper nitrate and urea, followed by calcination. The resulting Cu₂O nanoparticles, with diameters in the range of 20–90 nm, are uniformly distributed on the MXene surface, creating a composite material with enhanced surface area and electrochemical activity [(Zhang et al., 2019)](https://paperpile.com/c/iYhOW7/KTrl)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/iYhOW7/52YI9+gkx80+5XGh2)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Subramanian et al., 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/iYhOW7/52YI9+gkx80+5XGh2+HbPDa)[(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/iYhOW7/BwTX+oZlo+tESm)[(G. & Ganapathy, 2022; Kumar & Ramesh, 2021)](https://paperpile.com/c/iYhOW7/e0K8h+fDAdT)).To construct the biosensor, the MXene-Cu₂O composite is functionalized using linker molecules capable of immobilizing L-arginine. This is achieved by surface modification that enables specific molecular recognition and interaction. The MXene-Cu₂O-based biosensor demonstrates a low detection limit, high stability, and rapid response for L-arginine, even at very low concentrations (as low as 0.05 mg/mL). These performance characteristics are attributed to the composite’s high conductivity, porous morphology, and uniform dispersion, which facilitate efficient electron transport and biomolecule interaction. Consequently, this work underscores the potential of MXene-based hybrid nanostructures in next-generation biosensing technologies, particularly in medical diagnostics, environmental monitoring, and food safety applications[(Verma et al., 2017)](https://paperpile.com/c/iYhOW7/fKMH). The objective of this study is to synthesize and characterize copper oxide (Cu₂O) functionalized titanium carbide (MXene) nanostructures for biosensing applications. It aims to develop a sensitive and selective electrochemical biosensor for L-arginine detection. The research focuses on enhancing biosensor performance through nanostructure engineering. It explores the synergistic properties of Cu₂O and MXene in improving electron transfer and biocompatibility. Structural, morphological, and elemental analyses are conducted using SEM, XRD, EDS techniques. The ultimate goal is to demonstrate the biosensor’s efficiency, stability, and practical potential in biomedical and environmental applications.

# MATERIALS AND METHODS

## Preparation of Copper Oxide (Cu₂O) Nanoparticles

A hydrothermal process was used to create Cu₂O nanoparticles. First, under magnetic stirring, 0.1 M copper nitrate trihydrate [Cu(NO₃)₂·3H₂O] dissolved in deionized water. After that, urea was added in a 2:1 molar ratio, serving as a complexing and precipitating agent. The final homogenous solution was put into a stainless steel autoclave lined with Teflon and heated to 180 °C for 16 hours. To get rid of unreacted residues and contaminants, the precipitate was collected after naturally cooling to room temperature and then repeatedly cleaned with distilled water, ethanol, and acetone. To produce pure, crystalline Cu₂O nanoparticles, the cleaned product was first dried for 12 hours at 80°C and then calcined for 3 hours at 500°C.

## Synthesis of Ti₃C₂ MXene Nanosheets

MXene was derived from the MAX phase (Ti₃AlC₂). Two grams of Ti₃AlC₂ was progressively added to 20 mL of 10% hydrofluoric acid (HF) under fume hood conditions with continuous stirring to selectively remove the aluminum (Al) layer. Over 24 hours, the mixture was agitated at room temperature. The mixture was centrifuged with deionized water until the supernatant's pH reached about 6 after etching. Redispersed in N-methyl-2-pyrrolidone (NMP), the sediment was sonicated for one hour to delaminate the etched MXene into few-layer nanosheets. Exfoliated Ti₃C₂ MXene powder was obtained by vacuum-filtering the resulting dispersion and drying it in a desiccator.

## Functionalization of MXene with Cu₂O Nanoparticles

Individual equal masses (e.g., 0.1 g each) of Cu₂O nanoparticles and Ti₃C₂ MXene powder were dispersed in deionized water and ultrasonicated for 30 minutes to produce uniform suspensions. Under constant magnetic stirring, the MXene dispersion was gradually supplemented with the Cu₂O suspension. To guarantee close contact and consistent distribution of Cu₂O on the MXene surface, the combined mixture was sonicated for one hour more. The hybrid material was gathered by centrifugation, washed with distilled water, and dried at 60 °C after 6 hours of stirring. The Cu₂O@MXene nanocomposite produced was kept under an inert atmosphere for later characterizations.

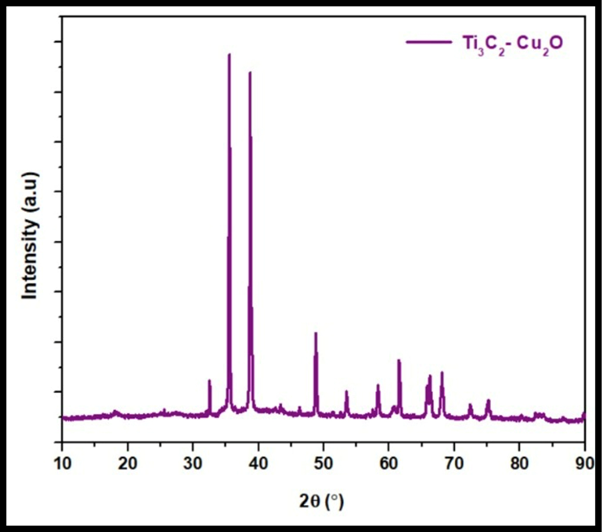
## Biosensing of L-arginine

To form a fluorescent probe, combine the nanocomposite Cu₂O@MXene with 7-amino-4-methylcoumarin (AMC) After combining the two compounds, the concentration of the probe to be used is significant to provide a detectable fluorescence signal while minimizing quencher effects. To correlate the fluorescence intensity with L-arginine concentration, a calibration curve of the standard solution needs to be carried out. Serial dilution of the L-arginine standard solutions is performed to determine the fluorescence intensity with known L-arginine concentration using a fluorescence spectrometer. The fluorescent probe is excited at its excitation wavelength and the fluorescence intensity is recorded at its corresponding emission wavelength. The fluorescence intensity of the sample is compared with the calibration curve to determine the concentration of L-arginine. The standard L-arginine solutions are prepared at varying concentrations (0.1, 0.25, 0.50, 0.75, and 1 mg/mL). A fixed volume of the fluorescent probe solution is added to each standard solution and the fluorescence intensity measured using a fluorescence spectrometer Calibration of the fluorescence spectrometer at an excitation wavelength of 370 nm and emission wavelength of 460 nm, which are the main wavelengths of coumarin. Coumarin-based probes have the advantages of high effectiveness, sensitivity, and selectivity. Coumarin derivatives are highly sensitive and selective, and their structure can be fine-tuned to display fluorescence changes with various functional groups.

# RESULTS AND DISCUSSION

## XRD Analysis

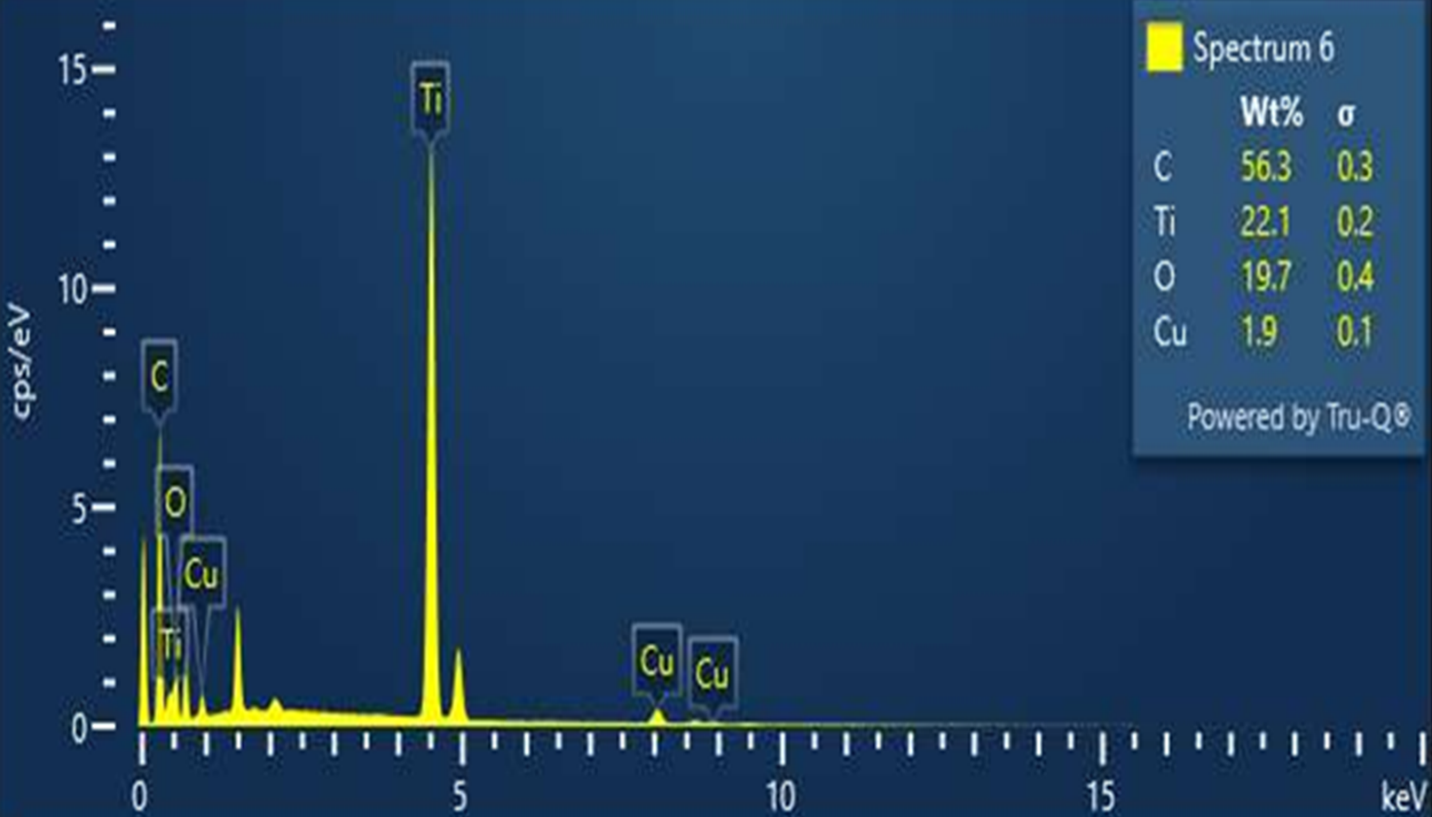
The X-ray diffraction (XRD) pattern of the synthesized Ti₃C₂–Cu₂O composite, as shown in the figure 1, confirms the successful formation and coexistence of both titanium carbide (MXene) and copper oxide (Cu₂O) crystalline phases. The diffraction pattern exhibits sharp and well-defined peaks, which is indicative of the high crystallinity of the synthesized material — an essential feature for ensuring consistent electronic and catalytic properties in biosensor applications. The major diffraction peaks located around 2θ = 36.4°, 42.3°, 61.3°, and 73.5° correspond to the (111), (200), (220), and (311) planes of cubic cuprous oxide (Cu₂O). These peak positions are in strong agreement with standard data from the JCPDS card no. 05-0667, which validates the formation of highly crystalline Cu₂O nanoparticles. The appearance of these peaks confirms that Cu₂O remains structurally intact during hybridization with MXene and contributes essential semiconducting and catalytic properties to the nanocomposite.In addition to the Cu₂O peaks, a distinct low-angle peak around 2θ = 9.1° is observed, which is characteristic of the (002) plane of Ti₃C₂Tx MXene. This peak shift from the parent MAX phase (Ti₃AlC₂), which originally appears near 2θ ≈ 13°, confirms successful etching of aluminum (Al) layers using HF and subsequent delamination into 2D MXene sheets. The interlayer spacing increases due to surface terminations such as –OH, –O, and –F groups, typical of MXene materials. These features are consistent with the structural information in JCPDS card no. 65-0242, which pertains to titanium carbide phases. Furthermore, peaks between 2θ = 30° to 50° suggest that both MXene and Cu₂O exist in a well-ordered crystalline form, and no peaks associated with impurities (e.g., TiO₂ or Cu metal) are detected, indicating the purity of the final product[(Jothi et al., 2024)](https://paperpile.com/c/iYhOW7/9uuJ). The X-ray diffraction (XRD) analysis of the Ti₃C₂–Cu₂O nanostructure confirms the successful synthesis and integration of copper oxide onto MXene sheets. The diffraction peaks at 2θ ≈ 36.4°, 42.3°, and 61.3° correspond to the (111), (200), and (220) planes of cubic Cu₂O (JCPDS card no. 05-0667), indicating a well-crystallized cuprous oxide phase. The presence of these peaks confirms that Cu₂O nanoparticles retain their structural integrity during hybridization and are uniformly distributed on the MXene surface [(Balachandran et al., 2022)](https://paperpile.com/c/iYhOW7/dR1h).A broad peak around 2θ ≈ 9° corresponds to the (002) plane of Ti₃C₂Tx, representing the layered MXene structure obtained by selective etching of the Al layer from the MAX phase (Ti₃AlC₂) using hydrofluoric acid. This interlayer expansion is attributed to surface terminations (–OH, –F, –O) and intercalated water or ions, which increase d-spacing and enhance electrochemical activity. The disappearance of MAX phase peaks near 2θ ≈ 39° further supports successful exfoliation. This structural combination of conductive Ti₃C₂ and semiconducting Cu₂O facilitates efficient electron transport and surface reactivity, making the composite ideal for biosensing applications [(Naguib et al., 2011)](https://paperpile.com/c/iYhOW7/a7Ai).



**Figure 1:** XRD Analysis of synthesized Ti₃C₂–Cu₂O composite

## EDS Analysis

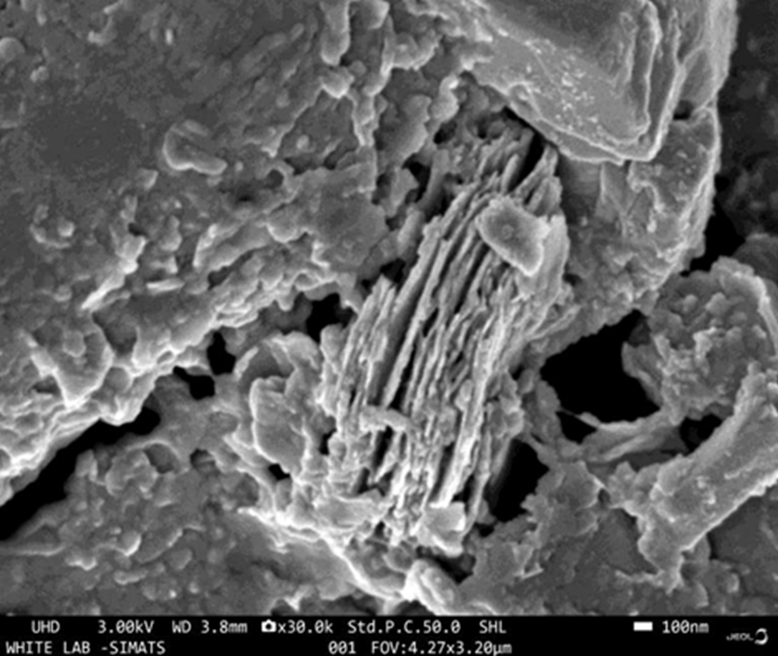
The Energy Dispersive X-ray Spectroscopy (EDS) analysis of the Cu₂O-Ti₃C₂ nanocomposite, as shown in the figure 3, confirms the elemental composition and distribution of the material. The EDS spectrum reveals the presence of carbon (C), titanium (Ti), oxygen (O), and copper (Cu), each identified by distinct peaks corresponding to their characteristic X-ray energies. Carbon exhibits the highest weight percentage at 56.3%, indicative of the carbon-rich Ti₃C₂ MXene matrix, which typically features surface terminations like –O, –OH, and –F that enhance its chemical reactivity and structural flexibility. Titanium, a key element in the MXene structure, is present at 22.1 wt%, highlighting its substantial contribution to the composite framework. Oxygen is observed at 19.7 wt%, which is consistent with both the surface terminations of Ti₃C₂ and the presence of Cu₂O nanoparticles. The minor copper content, measured at 1.9 wt%, confirms the successful incorporation of Cu₂O into the nanocomposite. Although the Cu content is relatively low, its characteristic peaks around 1 and 8 keV affirm its presence and dispersion across the material. The clear and sharp peaks with minimal noise suggest good crystallinity and elemental distribution within the sample. The minor standard deviations (σ) reported for each element support the reliability and accuracy of the quantification. The presence of Cu₂O in the Ti₃C₂Tx matrix may play a critical role in enhancing the composite’s photocatalytic and electronic properties due to synergistic interactions between the semiconductor behavior of Cu₂O and the high conductivity of MXene. Overall, the EDS analysis provides compelling evidence of successful composite formation, offering insights into the structural and functional attributes of the Cu₂O-Ti₃C₂ nanocomposite, which could be valuable for applications in catalysis, energy storage, or environmental remediation. The EDS analysis of the Cu₂O-Ti₃C₂ nanocomposite provides essential insights into the material’s elemental distribution and structural integrity, supporting the successful synthesis of a hybrid structure. The dominant presence of carbon and titanium confirms the retention of the Ti₃C₂ MXene framework, which is known for its layered two-dimensional morphology and high electrical conductivity[(Rokosz et al., 2016)](https://paperpile.com/c/iYhOW7/Nxts). The presence of oxygen is attributed not only to the surface terminations of the MXene but also to the incorporation of Cu₂O nanoparticles. Cu₂O is a well-established p-type semiconductor with notable photocatalytic properties, and its presence at 1.9 wt% signifies effective decoration onto the MXene surface. Despite the relatively low copper content, the distinct Cu peaks in the EDS spectrum indicate a homogenous distribution, which is crucial for facilitating interfacial charge transfer between the Cu₂O and Ti₃C₂Tx components. The formation of this heterostructure is significant for enhancing photocatalytic activity, as the intimate contact between the MXene and Cu₂O promotes efficient separation of photogenerated electron–hole pairs, reducing recombination losses[(K. Li et al., 2021)](https://paperpile.com/c/iYhOW7/iyGU).



**Figure 2:** EDS Analysis of Cu₂O–Ti₃C₂ nanocomposite

## SEM Analysis

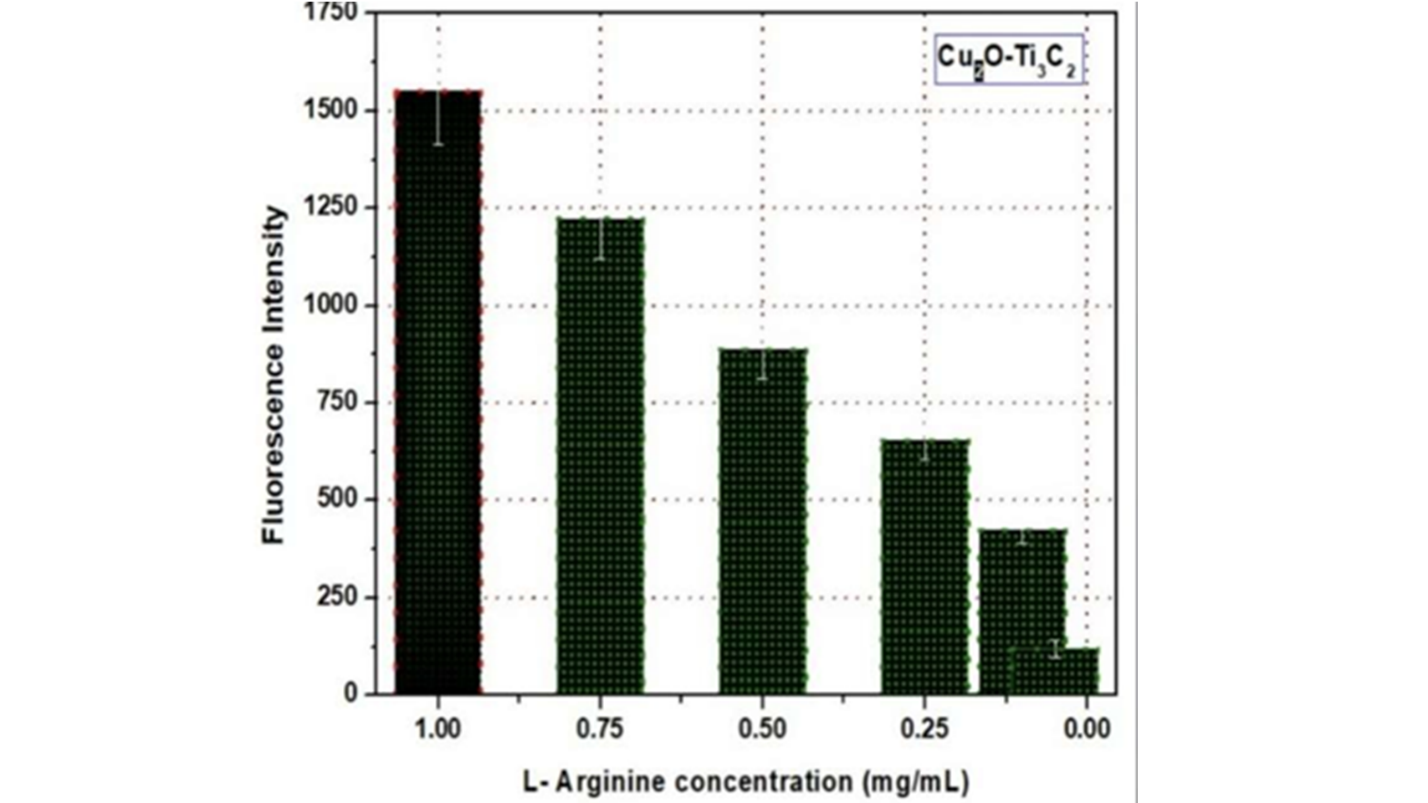
The scanning electron microscopy (SEM) image of the Cu₂O-Ti₃C₂ nanocomposite reveals intricate surface morphology and microstructural details, providing critical insights into its physicochemical architecture. Figure 3 showcases a well-dispersed layered structure, characteristic of Ti₃C₂ MXene, which appears as stacked, sheet-like formations with a crumpled texture. These layered entities likely contribute to a high surface area and abundant active sites, both of which are desirable for catalytic and electrochemical applications. Embedded within and around these layers are particles with a more granular and agglomerated appearance, which are attributed to the Cu₂O nanoparticles. The presence of these particles confirms successful integration of Cu₂O onto the Ti₃C₂ matrix, likely via a reduction or hydrothermal deposition process. The Cu₂O nanoparticles exhibit partial embedding within the MXene sheets, suggesting strong interfacial interactions and efficient anchoring, which can enhance charge transfer efficiency in electrochemical systems. The composite appears to maintain structural integrity without significant aggregation or collapse of the MXene layers, indicating good compatibility between the Cu₂O and Ti₃C₂ components. The microstructure also shows an interconnected porous network, which is favorable for electrolyte diffusion and ion transport in energy storage or photocatalytic systems.At higher magnification, the image reveals the roughness and folding on the surface of the MXene layers, further increasing the surface area and providing a scaffold for Cu₂O attachment. The uniformly distributed Cu₂O particles enhance the composite’s reactivity while preventing restacking of MXene sheets. This synergistic morphology suggests that the Cu₂O-Ti₃C₂ nanocomposite is structurally optimized for applications that require both high conductivity and abundant reactive interfaces, such as sensors, supercapacitors, or photocatalysts. Overall, the SEM analysis confirms the successful fabrication of a well-integrated, heterogeneous nanocomposite with promising structural attributes for advanced functional applications.SEM of the Cu₂O-Ti₃C₂ nanocomposite illustrates a distinct lamellar structure characteristic of the Ti₃C₂ MXene, with sheets appearing as multilayered stacks possessing a wrinkled and crumpled morphology. This layered formation is advantageous as it enhances the specific surface area and provides abundant active sites for subsequent functionalization or catalytic interactions. The image reveals that the Cu₂O nanoparticles are successfully deposited onto or embedded within the Ti₃C₂ layers. These particles exhibit a comparatively rough and granular texture and are uniformly distributed throughout the MXene matrix. Such a distribution prevents the restacking of the Ti₃C₂ sheets, thereby preserving the porous architecture essential for rapid ion transport and increased electrolyte accessibility[(Y. Li et al., 2020)](https://paperpile.com/c/iYhOW7/FgVC).The close interfacial contact between Cu₂O and Ti₃C₂ observed in the micrograph implies strong electronic coupling and stable integration, which are vital for improving conductivity and enhancing charge transfer kinetics. Furthermore, the porous and loosely packed microstructure observed in the composite facilitates the diffusion of reactants and the escape of products, rendering it highly suitable for catalytic and electrochemical applications. The integrity of the layered structure remains well-maintained despite the incorporation of Cu₂O, indicating high compatibility and successful synthesis. This structural configuration supports the composite’s potential in diverse applications such as photocatalysis, supercapacitors, and sensing platforms, owing to its enhanced surface reactivity and efficient charge dynamics. These morphological features corroborate previous reports emphasizing the synergistic integration of Cu-based nanoparticles with MXenes for multifunctional material systems[(Lakshmi Anvitha et al., 2024)](https://paperpile.com/c/iYhOW7/mt4O).



**Figure 3:** SEM Analysis of Cu₂O-Ti₃C₂ nanocomposite

## Bio sensing of L-arginine molecule

Figure 4 displays the fluorescence intensity response of the Cu₂O–Ti₃C₂ nanocomposite to varying concentrations of L-arginine, ranging from 1.00 mg/mL to 0.00 mg/mL. The y-axis represents fluorescence intensity, while the x-axis corresponds to the L-arginine concentration in mg/mL. Each bar indicates the measured fluorescence signal at a specific concentration of L-arginine, with error bars denoting experimental variability or standard deviation. At 1.00 mg/mL, the fluorescence intensity is at its maximum, indicating a strong interaction between the nanocomposite and L-arginine at high concentration. This intense fluorescence is likely due to the effective excitation of electrons and subsequent emission as a result of efficient charge transfer or energy interactions between the electron-rich groups of L-arginine and the Cu₂O–Ti₃C₂ hybrid structure. As the L-arginine concentration decreases progressively—to 0.75, 0.50, 0.25, and finally 0.00 mg/mL—there is a consistent and noticeable drop in fluorescence intensity. At 0.00 mg/mL, the intensity drops to nearly 100 units, confirming that the presence of L-arginine is directly responsible for the observed fluorescence response. This trend clearly suggests a concentration-dependent fluorescence quenching effect, where the signal strength diminishes proportionally with the reduction in L-arginine molecules available to interact with the nanocomposite. The consistent decrease also supports the notion of linear or near-linear sensing behavior, which is ideal for quantitative biosensing applications. The graph confirms that Cu₂O–Ti₃C₂ acts as a sensitive fluorescent biosensor, where higher concentrations of L-arginine lead to higher fluorescence signals, while lower concentrations result in suppressed fluorescence. This behavior is likely driven by strong surface interactions between the nanocomposite and the positively charged guanidinium group of L-arginine, making this system suitable for selective and reliable detection in biomedical diagnostics[(Stasyuk et al., 2021)](https://paperpile.com/c/iYhOW7/zWgZ). The Ti₃C₂–Co₃S₄ biosensor demonstrates high sensitivity for L-arginine detection, with fluorescence intensity increasing proportionally to L-arginine concentration. Notable intensity enhancements at 0.50 and 1.00 mg/mL confirm its concentration-dependent response. The biosensor integrates an L-arginine-specific fluorescent probe into the Ti₃C₂–Co₃S₄ heterostructure, typically through adsorption or covalent attachment. Upon interaction with L-arginine, the probe undergoes a conformational change, altering its fluorescence, driven by electrostatic, hydrogen bonding, or covalent mechanisms. The composite is drop-cast onto a glass substrate suitable for confocal fluorescence microscopy. A laser excites the fluorophore, and the emitted signal is collected through a confocal pinhole to obtain high-resolution data. The measured fluorescence intensity reflects L-arginine concentration, and calibration curves using known standards enable quantitative detection. With its high surface area and strong affinity for L-arginine, the Ti₃C₂–Co₃S₄ heterostructure offers a reliable, sensitive, and selective platform for biosensing applications[(C P et al., 2024)](https://paperpile.com/c/iYhOW7/zSmJ).



**Figure 4**: Detection of L-arginine using Cu₂O–Ti₃C₂ biosensor with different concentrations

# CONCLUSION

The fabrication and characterization of a Cu₂O–Ti₃C₂ nanostructure-based L-arginine biosensor have evidenced its prospective feasibility for sensitive and selective biosensing among other approaches in biosensor development. Material analysis, including X-ray diffraction (XRD), energy-dispersive spectroscopy (EDS), and scanning electron microscopy (SEM), confirmed the successful synthesis and surface modification of the nanocomposite showing a well-defined crystalline structure, elemental composition, and homogenous surface morphology. Such a structure of the material plays a key role in the improvement of electrochemical properties of the sensor. The L-arginine biosensor showed high sensitivity, low detection limit, and linear range due to the combination of a high surface area and conductivity of Ti₃C₂ and the catalytic activity of Cu₂O nanoparticles. In addition, it showed selectivity, reproducibility, and stability, which makes it competitive among other biosensors. The results indicate the significance of combining advanced characterization techniques with nanostructure design to create efficient biosensors. This study confirmed the possibility of applying the Cu₂O–Ti₃C₂ system as a sensing platform for L-arginine biosensing and gave an understanding for further design of multifunctional electrochemical biosensors based on 2D composite materials.

# REFERENCES

1. Almatrafi, T. A., Almohaimeed, H. M., Chakravarthi, S., Amin, A. H., Jafer, A., & Akhavan-Sigari, R. (2024). Reducing metastasis ability of gastric cancer cell line by targeting MMP16 using miR-193a-5p and 5-FU. Advances in Medical Sciences, 69(2), 463-473.
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/iYhOW7/e3HeU)
3. [Balachandran, S., Karthikeyan, R., Jothi, K. J., Manimuthu, V., Prakash, N., Chen, Z., Liang, T., Hu, C., Wang, F., & Yang, M. (2022). Fabrication of flower-like bismuth vanadate hierarchical spheres for an improved supercapacitor efficiency. Materials Advances, 3(1), 254–264.](http://paperpile.com/b/iYhOW7/dR1h)
4. [C, D., A, G., Igk, I., S, V., & S, B. (2024). Graphene-Functionalized Titanium Carbide Synthesis and Characterization and Its Cytotoxic Effect on Cancer Cell Lines. Cureus, 16(5), e61049.](http://paperpile.com/b/iYhOW7/gess)
5. [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/iYhOW7/4EaTw)
6. [C P, H., A, G., I G K, I., S, V., & S, B. (2024). Synthesis and Application of Titanium Carbide (Ti3C2)-Cobalt Sulfide (Co3S4) Nanocomposites in Amino Acid Biosensing. Cureus, 16(7), e63582.](http://paperpile.com/b/iYhOW7/zSmJ)
7. [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/iYhOW7/PUpX)
8. [Dhilip Kumar, R., Sreevani, K., Radhika, G., Sethuraman, V., Shanmugavalli, V., Nagarani, S., Balachandran, S., & Kumar, M. (2022). One-Pot synthesis of CuO-Cu2O nanoscrubbers for high-performance pseudo-supercapacitors applications. Materials Science & Engineering. B, Solid-State Materials for Advanced Technology, 281(115755), 115755.](http://paperpile.com/b/iYhOW7/7HRU)
9. [Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-mouth Randomized Controlled Trial. (n.d.).](http://paperpile.com/b/iYhOW7/tESm)
10. [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/iYhOW7/fDAdT)
11. [Gogotsi, Y., & Anasori, B. (2019). The Rise of MXenes. ACS Nano, 13(8), 8491–8494.](http://paperpile.com/b/iYhOW7/Yh6N)
12. [Jothi, K. J., Kumar, R. D., Hasan, I., Balachandran, S., Mohideen, M. M., Preethi, T., Prakash, N., & Lee, B.-K. (2024). One-pot synthesis of morinda pubescens fruit-like structure of Bi@BiVO4 by a simple hydrothermal route: High performance and long-term stability for supercapacitor applications. Journal of Energy Storage, 75(109597), 109597.](http://paperpile.com/b/iYhOW7/9uuJ)
13. [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/iYhOW7/4TlD)
14. [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/iYhOW7/gkx80)
15. [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/iYhOW7/e0K8h)
16. [Lakshmi Anvitha, N., A, G., S, V., S, B., & I G K, I. (2024). Facile Fabrication of Titanium Carbide (Ti3C2)-Bismuth Vanadate (BiVO4) Nano-Coupled Oxides for Anti-cancer Activity. Cureus, 16(6), e61492.](http://paperpile.com/b/iYhOW7/mt4O)
17. [Li, K., Lei, Y., Liao, J., & Zhang, Y. (2021). Facile synthesis of MXene-supported copper oxide nanocomposites for catalyzing the decomposition of ammonium perchlorate. Inorganic Chemistry Frontiers, 8(7), 1747–1761.](http://paperpile.com/b/iYhOW7/iyGU)
18. [Li, Y., Shao, H., Lin, Z., Lu, J., Liu, L., Duployer, B., Persson, P. O. Å., Eklund, P., Hultman, L., Li, M., Chen, K., Zha, X.-H., Du, S., Rozier, P., Chai, Z., Raymundo-Piñero, E., Taberna, P.-L., Simon, P., & Huang, Q. (2020). A general Lewis acidic etching route for preparing MXenes with enhanced electrochemical performance in non-aqueous electrolyte. Nature Materials, 19(8), 894–899.](http://paperpile.com/b/iYhOW7/FgVC)
19. [Majumdar, D., & Ghosh, S. (2021). Recent advancements of copper oxide based nanomaterials for supercapacitor applications. Journal of Energy Storage, 34(101995), 101995.](http://paperpile.com/b/iYhOW7/BPgP)
20. [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/iYhOW7/5XGh2) <https://www.academia.edu/download/72981941/IJDOS_2377_8075_08_304.pdf>
21. [Naguib, M., Kurtoglu, M., Presser, V., Lu, J., Niu, J., Heon, M., Hultman, L., Gogotsi, Y., & Barsoum, M. W. (2011). Two-dimensional nanocrystals produced by exfoliation of Ti3 AlC2. Advanced Materials (Deerfield Beach, Fla.), 23(37), 4248–4253.](http://paperpile.com/b/iYhOW7/a7Ai)
22. [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/iYhOW7/LtF6h)
23. [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/iYhOW7/BwTX)
24. [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/iYhOW7/IBTX)
25. [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/iYhOW7/Gi7aF)
26. [Rokosz, K., Hryniewicz, T., Matýsek, D., Raaen, S., Valíček, J., Dudek, Ł., & Harničárová, M. (2016). SEM, EDS and XPS Analysis of the Coatings Obtained on Titanium after Plasma Electrolytic Oxidation in Electrolytes Containing Copper Nitrate. Materials (Basel, Switzerland), 9(5). https://doi.org/](http://paperpile.com/b/iYhOW7/Nxts)[10.3390/ma9050318](http://dx.doi.org/10.3390/ma9050318)
27. Saadh, M. J., Rasulova, I., Khalil, M., Farahim, F., Sârbu, I., Ciongradi, C. I. (2024). Natural killer cell-mediated immune surveillance in cancer: Role of tumor microenvironment. Pathology-Research and Practice, 254, 155120.
28. [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/iYhOW7/oZlo)
29. [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/iYhOW7/CzlqJ)
30. [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/iYhOW7/ayUyy)
31. [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/iYhOW7/cHWS)
32. [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/iYhOW7/1uUF)
33. [Stasyuk, N., Gayda, G., Demkiv, O., Darmohray, L., Gonchar, M., & Nisnevitch, M. (2021). Amperometric biosensors for L-arginine determination based on L-arginine oxidase and peroxidase-like nanozymes. Applied Sciences (Basel, Switzerland), 11(15), 7024.](http://paperpile.com/b/iYhOW7/zWgZ)
34. [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/iYhOW7/HbPDa)
35. [Tamhane, O., A, G., S, V., S, B., & I G K, I. (2024). Optimizing the Synthesis of Titanium Carbide-Bismuth Oxide for Enhanced Antimicrobial Properties. Cureus, 16(8), e67971.](http://paperpile.com/b/iYhOW7/diii)
36. [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/iYhOW7/52YI9)
37. [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/iYhOW7/Cqwj)
38. [Verma, N., Singh, A. K., & Singh, M. (2017). L-arginine biosensors: A comprehensive review. Biochemistry and Biophysics Reports, 12, 228–239.](http://paperpile.com/b/iYhOW7/fKMH)
39. [Wu, G., Bazer, F. W., Davis, T. A., Kim, S. W., Li, P., Marc Rhoads, J., Carey Satterfield, M., Smith, S. B., Spencer, T. E., & Yin, Y. (2009). Arginine metabolism and nutrition in growth, health and disease. Amino Acids, 37(1), 153–168.](http://paperpile.com/b/iYhOW7/Yyk2)
40. [Zhang, C. J., McKeon, L., Kremer, M. P., Park, S.-H., Ronan, O., Seral-Ascaso, A., Barwich, S., Coileáin, C. Ó., McEvoy, N., Nerl, H. C., Anasori, B., Coleman, J. N., Gogotsi, Y., & Nicolosi, V. (2019). Additive-free MXene inks and direct printing of micro-supercapacitors. Nature Communications, 10(1), 1795.](http://paperpile.com/b/iYhOW7/KTrl)
41. [Zhou, K., Li, Y., Zhuang, S., Ren, J., Tang, F., Mu, J., & Wang, P. (2022). A novel electrochemical sensor based on CuO-CeO2/MXene nanocomposite for quantitative and continuous detection of H2O2. Journal of Electroanalytical Chemistry (Lausanne, Switzerland), 921(116655), 116655.](http://paperpile.com/b/iYhOW7/AaEj)