

Antioxidant-Assisted Suppression of Oxidation and Sedimentation in $\text{Ti}_3\text{C}_2\text{T}_x$ MXene Dispersions

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Abstract

MXenes, characterized by outstanding electrical conductivity, hydrophilicity and tunable surface chemistry, are becoming an attractive platform for next-generation electronics and memory devices. But the susceptibility of MXene to quick oxidation and low colloidal stability of MXene dispersions are still problematic to achieve long-term stability of devices. In this work, we systematically explored the oxidation stability and sedimentation behavior of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions in various storage conditions and antioxidant stabilized dispersion system. We demonstrated the ability of antioxidant to suppress the oxidation and maintain the dispersion stability by comparing dispersed $\text{Ti}_3\text{C}_2\text{T}_x$ MXene (MXene) with ascorbic acid-treated MXene dispersions. Sedimentation was examined by visual observation and gravimetric analysis as a function of time, while oxidation behavior was investigated by UV-Visible (UV-Vis) spectroscopy, Fourier Transform Infrared (FTIR) spectroscopy, XRD and characterization. The ascorbic acid-treated MXene dispersions exhibited decreased sedimentation rate and better dispersion stability along with superior anti-oxidation compared to untreated MXene dispersions. Moreover, the optimized MXene showed good retention of optical properties indicating reduced degradation during storage. These results indicate that antioxidant stabilization improves the colloidal stability of MXene and suppress oxidation-induced aggregation and it makes MXene more available for long-term electronic and memory devices. Here, we showed a facile, low-cost strategy to improve the colloidal stability of MXenes and the correlation between oxidation behavior and the performance of dispersions.

1. Introduction

One class of 2D transition metal carbides, nitrides and carbonitrides has become the most promising material to realize next-generation electronic and memory devices due to their outstanding electrical conductivity, unique layered structure, hydrophilic surface and tunable physicochemical properties[1]. MXenes has received increasing interest since its discovery in particular the $\text{Ti}_3\text{C}_2\text{T}_x$ material itself is applied in different applications such as energy storage, electromagnetic interference shielding, sensors, catalysis, supercapacitors and memory device. Among them, the remarkable electron transport characteristics and good solution processibility allow MXenes materials an attractive candidate for next-generation electronic and memory device. Among the wide varieties of MXenes compositions, $\text{Ti}_3\text{C}_2\text{T}_x$ MXene was most widely studied due to its good conductivity, excellent flexibility as well as numerous surface functional groups such as -OH, -O, -F, -Cl. These functional groups are responsible for the water dispersing property and for the formation of easy thin film and nano composite for electronics device [2]. Nevertheless, one of the drawbacks limiting widespread applications of MXene is their poor environmental stability and rapid oxidation in ambient conditions[3].

Oxidation of MXene is strongly dependent on environmental condition such as exposure to oxygen, humidity, temperature, pH and storage condition. During the oxidation process $\text{Ti}_3\text{C}_2\text{T}_x$ will be gradually transformed to titanium oxide compounds which are severely detrimental for both electrical conductivity

and mechanical integrity[4]. Oxidation is responsible for the nanosheets aggregation and faster precipitation of MXenes in colloidal solution which results in poor dispersion stability and material property loss. Sedimentation behavior of MXenes dispersion could be a useful indication for colloidal stability and anti-oxidation property. Undegraded and stabilized MXene dispersion appears uniformly suspended with minimal aggregation, while oxidation-induced deterioration would lead to self-assembly and precipitation of MXene nanosheets due to destruction of electrostatic repulsions and structural integrity. Hence, investigation of sedimentation behavior would give an indication of oxidation-induced instability[5].

Various methods has been demonstrated in improving MXene oxidation resistance such as low temperature storage, oxygen-free storage, surface functionalization, antioxidant treatment and polymer stabilization. Antioxidant-assisted stabilization using reducing agents like ascorbic acid becomes more and more popular due to the simple, cost effective and environmentally friendly property. Ascorbic acid is able to scavenge dissolved oxygen and reactive oxygen species to prevent MXene from oxidizing[6].

In this study, the oxidation stability and sedimentation behavior of $\text{Ti}_3\text{C}_2\text{T}_x$ MXenes were systemically investigated under different storing conditions compared with pristine and stabilized $\text{Ti}_3\text{C}_2\text{T}_x$ MXenes by using redox reagent [7]. Time-dependent sedimentation stability measurement and visual analysis, Uv-Vis, FTIR ,XRD and complimentary techniques were used to determine oxidation state and dispersion stability of $\text{Ti}_3\text{C}_2\text{T}_x$. The goal is to develop a simple and economical method to stabilize $\text{Ti}_3\text{C}_2\text{T}_x$ MXene for long term applications in electronics and memory device[8].

2. Materials and Methods

2.1. Materials

The required materials such as Ascorbic acid (Sisco research laboratories (SRL), extra pure, 99.9%), glacial acetic acid (SRL, extra pure, 99.5%), acetone (SRL, extra pure, 99%), isopropanol (SRL, pure, 99%) were procured from different sources and used in this work. Ti_3AlC_2 , MAX phases powder(Carbon ukraine 99.5%) Hydrochloric acid (HCl) Sigma Aldrich (99.9%), Hydrofluoric acid (HF), Lithium chloride (LiCl) TCI Pvt. Ltd. DI Water.

2.2. Synthesis of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene from MAX Phase

The synthesis of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene was carried out using a top-down wet chemical etching method. Initially, an etching solution was prepared using a mixture of hydrochloric acid, hydrofluoric acid, and water in a volumetric ratio of 6:3:1. This etchant selectively removes the aluminum layer from the MAX phase structure[8]. Approximately 1 g of Ti_3AlC_2 powder was gradually added to 20 mL of the prepared etching solution under continuous stirring. The reaction mixture was maintained at 35°C with a stirring speed of 400 rpm for 24 hours [8]. During this process, the aluminum layers present in the MAX phase were removed, resulting in the formation of multilayer $\text{Ti}_3\text{C}_2\text{T}_x$ MXene [9].

The chemical reaction occurring during the etching process can be represented as:



Where T_x represents surface termination groups such as $-\text{O}$, $-\text{OH}$, $-\text{Cl}$ and $-\text{F}$.

After completion of the etching reaction, the mixture was repeatedly washed with deionized water to remove residual acids and by-products. Centrifugation was carried out at approximately 3500 rpm for 45 minutes during each washing cycle. This washing step was repeated until the pH of the solution approached neutral conditions[10]. The obtained sediment consisted of multilayer $\text{Ti}_3\text{C}_2\text{T}_x$ MXene. To obtain few-layer MXene nanosheets, the multilayer $\text{Ti}_3\text{C}_2\text{T}_x$ material was dispersed in an aqueous solution containing 1 g of Lithium chloride dissolved in 50 mL of deionized water. The mixture was stirred at 35°C for approximately 18 hours at 350 rpm. The lithium ions intercalate between the MXene layers, weakening the interlayer interactions and facilitating the separation of individual sheets. Following the intercalation step, the mixture was subjected to centrifugation and washing to remove excess salts [11]. The resulting material formed a viscous MXene paste often referred to as MXene clay. When dispersed in water, this material forms a stable colloidal suspension of $\text{Ti}_3\text{C}_2\text{T}_x$ nanosheets, indicating successful delamination of the MXene layers [12]

2.3. Preparation of Ascorbic Acid Treated MXene

A predetermined amount of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene was dispersed in deionized water to prepare a uniform aqueous suspension, followed by ultrasonication for 30–60 minutes to achieve proper exfoliation and homogeneous distribution of the nanosheets[13]. The prepared MXene suspension was then divided into different experimental groups, namely M_0 (pure MXene as the control sample), M_1 (MXene with 0.5 wt% ascorbic acid), M_2 (MXene with 1.0 wt% ascorbic acid), and M_3 (MXene with 1.5 wt% ascorbic acid). Subsequently, all samples were continuously stirred for 30 minutes to ensure uniform mixing and proper incorporation of the antioxidant within the MXene dispersion[14].

2.4. Sedimentation Behaviour Study

The sedimentation stability of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions was investigated using a simple time-dependent visual sedimentation method. Equal volumes (10 mL) of the prepared dispersions were transferred into transparent glass vials and stored under ambient conditions at room temperature[15]. The sedimentation behaviour was monitored at regular time intervals of 0 h, 6 h, 12 h, 24 h, 3 days, 5 days, 7 days, and 14 days. At each interval, digital photographs were recorded to observe sediment formation, supernatant clarity, and visible color changes in the dispersions. The sedimentation stability was further quantitatively evaluated using the sedimentation ratio (SR), calculated as the ratio of sediment height (H_s) to total dispersion height (H_t), expressed as $\text{SR} = H_s/H_t$. A lower sedimentation ratio indicates improved colloidal stability and reduced aggregation of MXene nanosheets within the dispersion[16].

3. Characterization and Data Analysis

We characterized structural, optical, chemical and electrical properties of $Ti_3C_2T_x$ MXene dispersions to observe their oxidation stability and colloidal stability with varying concentrations of AA. We made use of several characterization techniques (UV-Vis spectroscopy, FTIR, XRD, sedimentation study, electrical conductivity and direct observation) to establish a relationship between oxidation inhibition and colloidal stability and electronic property [17].

3.1. UV-Visible spectroscopy Analysis

UV-Visible spectroscopy was used to evaluate the resistance of oxidation and optical stability of MXene dispersions while they are kept in storage. We recorded spectra using a UV-Vis spectrophotometer in the wave range from 200–800 nm and measured the spectra in the solution where it was dispersed in deionized water. A quartz cuvette of 1cm optical path length was used. The samples were measured on intervals at 0, 1, 3, 5, 7, and 14 days[18].

We used change in absorbance intensity at MXene spectrum region for quantifying the degree of oxidation. The Stability Retention was calculated as below:

$$\%Stability = A_0 / A_t \times 100$$

Where, A_0 : Initial absorbance of fresh MXene; A_t : Absorbance of MXene after storage time t.

Due to the effect of oxidation which lead to degradation of nanosheets and aggregation, we observed that absorbance of all samples decrease significantly with time[19]. However the rate of degradation is depends on the concentration of antioxidant. In the case of without AA (M_0), we observed a significant decrease in the absorbance intensity and the Stability retention of only 42% after 14 days that means the MXene was highly oxidized and the dispersion stability is not good. The improvement of the stability retention is shown in other samples with AA and for M_2 (1 wt% AA) it showed highest stability retention of 81% after 14 days[20].

This can be related to the scavenging activity of ascorbic acid for dissolved oxygen and free radicals that is to limit the surface oxidation of $Ti_3C_2T_x$ nanosheets. However increasing concentration to 1.5 wt% (M_3) does not enhance further performance, it can be because of agglomeration[21].

Table .1

UV–Visible Absorbance Retention (%)

Sample	Day 0	Day 3	Day 7	Day 14
M ₀ (Pure MXene)	100	82	61	42
M ₁ (0.5 wt%)	100	88	80	69
M ₂ (1.0 wt%)	100	93	88	81
M ₃ (1.5 wt%)	100	90	84	76

3.2. Sedimentation behaviour analysis

To evaluate the colloidal stability of MXene dispersion time-dependent sedimentation test was carried out. 10 mL volumes of the dispersion were transferred into clean transparent glass vials and kept at same environmental condition. Sediment formation, clarity of the supernatant and homogeneity of the dispersion was observed for 14 days[22].

Sedimentation stability was evaluated with sedimentation ratio:

$$SR = H_s / H_t.$$

Where, H_t ; total height of the dispersion, H_s ; sediment height

Small sedimentation ratio corresponds to stable colloids

Table.2. Sedimentation Ratio (SR)

Sample	Day 1	Day 3	Day 7	Day 14
M ₀	0.18	0.35	0.61	0.79
M ₁	0.10	0.18	0.34	0.48
M ₂	0.07	0.12	0.24	0.31
M ₃	0.08	0.14	0.28	0.37

M₀, as-synthesized MXene, displays an obvious sediment phenomenon (SR = 0.79 on day 14), representing the extensive aggregation of MXene and the poor colloidal stability. In the contrary, the minimum SR value (0.31) was obtained from M₂, which means the dispersion stability is the highest. We believe the enhanced dispersion stability comes from two aspects. One is less oxidation and the other one is more electrostatic stabilization as mentioned above due to the adding of antioxidant. The higher the oxidation level, the lower the surface functionalization, the easier it is for the MXene nanosheets to aggregate, and thus the higher the sediment ratio[23].

3.3 FTIR Analysis on surface chemical changes and functional groups on oxide surfaces

The functional groups and surface chemical changes due to oxidation was studied using FTIR spectroscopy over the wavenumber range from 400 to 4000 cm^{-1} , of the fresh and aged samples of MXene. It was paid more attention to the oxidation functional groups and Ti-O bonds formed and surface terminations such as -OH, -O, -F. The FTIR spectra show that untreated MXenes and antioxidant-treated MXenes have significant difference of chemical stability[24]. In 3200–3600 cm^{-1} O-H stretching vibration region, there is a dramatically increasing in peak intensity of M_0 (without antioxidant), which corresponds to the forming more OH groups owing to oxidation and moisture, but just a weak peak is obtained in M_2 (ascorbic acid at 1 wt%), so oxidation is suppressed well in this one[25]. Also in 600–700 cm^{-1} Ti-O vibration region, the Ti-O vibration peak intensity is very strong in M_0 because it is easily to form TiO_2 , which is verified by the peak intensity of M_2 is just a weak one. Moreover, in the 1000–1200 cm^{-1} surface functional groups region, the surface groups are destroyed for untreated MXene (indicated by a low peak intensity) but still remained for M_2 [26]. M_0 showed a large boost of Ti-O vibration peak, meaning that severe oxidation has occurred, and titanium oxide species are produced. While the decreasing peak intensity of surface termination means the surface chemistry of MXene deteriorates. On the other hand, the Ti-O formation is very slight for M_2 , while more stable surface functional groups are preserved. This suggests that ascorbic acid is able to resist oxidation by avoiding the formation of oxide and maintaining the terminations[27].

3.4 X-ray Diffraction (XRD) Analysis

XRD was carried out to examine the stability and structural integrity of the aged $\text{Ti}_3\text{C}_2\text{T}_x$ MXene. A 2θ angle from 5–80 was scanned for the diffraction pattern. For fresh MXene samples, a characteristic and sharp (002) diffraction peak was obtained at 6–7; the layered structure of the $\text{Ti}_3\text{C}_2\text{T}_x$ MXene was proved. M_0 shows almost 55% decrease of the (002) peak intensity after being stored for 14 days, which revealed the rapid oxidation process of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene[28]. On the contrary, M_2 had only about 20% decrease of the (002) peak intensity, which is expected to better retain the layered crystalline structure. New oxide related features in the diffraction pattern of M_0 further proved the oxidation toward to titanium oxide phase transformation. The relatively stable diffraction features of antioxidant treated MXene are consistent with the function of ascorbic acid preventing structural integrity from being damaged by oxidation[29].

3.5 Electrical Conductivity Analysis

Electrical conductivity measurements were done to investigate the effect of oxidation and sedimentation on electronic transport properties[30]. Thin film sample prepared from both fresh and aged MXene dispersions was analyzed using four-probe method for conductivity testing.

Table.3. Conductivity Retention

Sample	Initial (S/cm)	Day 14 (S/cm)	Retention (%)
M ₀	1200	552	46
M ₁	1180	802	68
M ₂	1210	1016	84
M ₃	1190	940	79

The unstabilized MXene sample displayed a dramatic decline in conductivity, which is attributed to oxidation causing disruption of conductive paths and subsequent aggregation of nanosheets. M₂ retained 84% of the conductivity value after 14 days, indicating good retention of conductivity with storage. The electrical stability of MXene dispersions is therefore well reflected by sedimentation behavior and UV-Vis results. Suppression of oxidation also means preservation of the electronic properties[31]. Since conductivity of MXene is strongly dependent upon the structure and aggregation of individual nanosheets, dispersion stability is vital for electronic and memory-device applications.

3.6 Correlation between oxidation level, sedimentation and electrical conductivity:

Good correlation was found between the level of oxidation, sedimentation rate and electrical conductivity. Samples with a higher sedimentation ratio had higher rates of oxidation and larger electrical conductivity loss and samples with lower sedimentation ratios have shown to improve optical stability and retain electrical performance better. Higher level of oxidation Higher rate of aggregation Higher sedimentation ratio Lower electrical conductivity M₂ has proved to be the best stabilized system in all the analysis and hence the best amount of ascorbic acid to use for stabilization of Ti₃C₂T_x MXene dispersions is 1wt% [32]. The combination of these analyses shows that by stabilizing the dispersed MXene dispersions with an antioxidant, the level of oxidation was effectively suppressed leading to the enhancement of the stability in dispersion and therefore better retention of electronic properties for memory and electronics applications[33].

Overall, antioxidant-assisted stabilization presents a simple, scalable, and cost-effective strategy to enhance MXene performance for long-term applications in electronics, sensing, and memory devices.

4. Results and Discussion

The oxidation stability and sedimentation behaviour of Ti₃C₂T_x MXene dispersions were systematically investigated under ambient storage conditions with varying concentrations of ascorbic acid as an antioxidant stabilizer[34]. The obtained results reveal a strong correlation between oxidation resistance, colloidal stability, structural integrity, and electrical performance of MXene dispersions over a storage

period of 14 days. The sedimentation behaviour study demonstrated significant differences in dispersion stability between pristine and antioxidant-treated MXene samples[35]. Initially, all dispersions exhibited a homogeneous dark black appearance, indicating uniform nanosheet distribution. However, visible sediment formation and supernatant separation gradually appeared in untreated MXene (M_0), indicating severe aggregation and instability. Quantitative analysis using the sedimentation ratio showed a continuous increase with storage duration, confirming progressive nanosheet settling. Among all samples, M_2 (1 wt% ascorbic acid) exhibited the lowest sedimentation ratio of 0.31 after 14 days compared to 0.79 for pristine MXene, indicating significantly improved colloidal stability. This enhanced stability is attributed to the antioxidant effect of ascorbic acid, which minimizes oxidation-induced surface deterioration and suppresses nanosheet aggregation[36].

The optical stability of MXene dispersions was further examined through UV–Visible spectroscopy. A substantial decrease in absorbance intensity was observed for all samples with increasing storage duration, reflecting gradual oxidation and degradation of MXene nanosheets. However, untreated MXene exhibited the fastest deterioration, retaining only 42% of its initial absorbance after 14 days[37]. In contrast, antioxidant-treated samples showed improved stability, particularly M_2 , which maintained 81% absorbance retention. The improved optical stability can be explained by the reducing nature of ascorbic acid, which scavenges dissolved oxygen and reactive oxidative species, thereby protecting surface termination groups of MXene from oxidation. Interestingly, increasing antioxidant concentration beyond 1 wt% (M_3) did not significantly improve stability, suggesting that an optimum concentration exists for effective stabilization. Structural and chemical characterization using FTIR and XRD further confirmed oxidation suppression in antioxidant-treated samples [39]. FTIR analysis of pristine MXene revealed a strong increase in Ti–O vibration peaks within the range of 600–700 cm^{-1} , indicating the formation of titanium oxide species during storage. Conversely, M_2 showed substantially weaker Ti–O peak intensity, confirming reduced oxidation. Similarly, XRD analysis demonstrated considerable degradation of the characteristic (002) diffraction peak in untreated MXene, with nearly 55% reduction in intensity after 14 days[40]. In comparison, M_2 exhibited only ~ 20% peak reduction, indicating effective preservation of the layered crystal structure. These observations strongly suggest that antioxidant treatment plays a critical role in maintaining both structural integrity and surface chemistry of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene. Electrical conductivity measurements further demonstrated the influence of oxidation on material performance. Pristine MXene showed severe conductivity loss, retaining only 46% of its initial conductivity after storage due to oxidation-induced disruption of conductive pathways and increased aggregation. In contrast, M_2 maintained approximately 84% conductivity retention, confirming superior electronic stability. The improved conductivity preservation directly correlates with reduced oxidation and enhanced colloidal stability observed in sedimentation and UV–Vis analyses[41].

Overall, the results clearly indicate that oxidation is the dominant factor governing MXene instability in aqueous dispersions, leading to aggregation, structural degradation, optical deterioration, and reduced electrical performance. Among all investigated formulations, 1 wt% ascorbic acid (M_2) provided the most effective stabilization, demonstrating an optimal balance between oxidation resistance and

dispersion stability. The findings confirm that antioxidant-assisted stabilization is an efficient strategy for improving the long-term performance of MXene dispersions for electronic and memory device applications[42].

4. Conclusion

In this report, oxidation stability and sedimentation of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions were investigated through the analysis of using different antioxidant concentration of ascorbic acid stabilization under room storage condition. It is shown that oxidation is the most reason for MXene dispersion's deterioration which greatly impacts the colloidal stability, structure and properties (optical and electrical properties) of MXene dispersion during storage.

From the sedimentation tests, pristine MXene (M_0) is aggregated and settled down quickly after a storage period. The poor stability of MXene dispersion is caused by the aggregation of MXene nanosheets during storage due to oxidation. After treating with antioxidant agent, the colloidal stability of MXene dispersion improves, the sedimentation ratio is reduced and the MXene is maintained to homogeneous dispersion state for a longer duration. 1 wt% ascorbic acid treated MXene dispersion shows the best stability. For M_2 dispersion, the sedimentation ratio is the smallest one (0.31 after 14 days), which implies that M_2 is most stable dispersion in resisting the aggregation of MXene nanosheets.

UV-Vis spectrum indicates M_2 have better oxidation resistance as maintained higher optical stability (approx 81% after 14 days) compared to M_0 (approx 42% after 14 days). Also FTIR spectrum confirms oxidation inhibition due to weaker Ti-O vibration peaks on treated samples. XRD pattern indicates better layered structure preservation for treated MXene, the (002) diffraction peaks did not have obvious attenuation. Electrical conductivity was also investigated, it shown that M_2 can preserve 84% of its initial conductivity after 14 days where as M_0 only maintain 46% of its initial conductivity. As there is strong correlation between the degradation in conductivity and the sedimentation ratio of MXene dispersion, sedimentation tests may serve as a cost-effective and simple indirect technique for evaluating the oxidation stability of MXene materials. Overall, this work demonstrates that using antioxidant assisted stabilization technique such as ascorbic acid for MXene dispersion under room condition is one of the simplest, cheapest, environmental friendly and effectively approach for suppressing the oxidation.

This stabilization method holds great potential for promoting the practical application of MXene materials to electronic, sensing, energy storage and resistive memory device. Additional approach such as combined use of polymer wrapping, storage in inert atmosphere or low temperature condition should be considered to prolong the durability of MXene.

Declarations

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The authors declare that no external funding was received for this research work.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. All relevant data generated or analyzed during this study are included within the manuscript file.

Ethics Approval

The current research, titled "Antioxidant-Assisted Suppression of Oxidation and Sedimentation of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene Dispersions," involved the preparation, processing, characterization, and testing of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene-based dispersions for the behavior of oxidation prevention and sedimentation behavior of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions. Only lab-based chemicals and procedures were used for the experiment. No human or human derived biological specimens, tissues, clinical specimens or patient data and private

personal identifiable information was involved. No experiments were done on animals or animal-derived samples were used.

The current research is for the synthesis, post-modification treatment, physio-chemical characterization and evaluation of the stability of inorganic/materials-science samples and thus does not constitute research needing approval of a human research ethics committee, institutional review board or an animal ethics committee. Hence, ethics approval for the current study was not required.

The authors confirm that all experiments were conducted in line with present institutional lab protocol, relevant scientific and safety guidelines and that no human intervention and/or data collection were involved. Ethics Approval: Not applicable.

Consent to Participate

The research conducted within the scope of this project is laboratory-based materials-science study with a specific focus on $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions and antioxidant-assisted suppression of oxidation and sedimentation. Specifically, the work performed involved synthesis and characterization of material samples as well as assessment of various physicochemical and stability-associated parameters of the samples. None of human participants were recruited, enrolled, interviewed, asked for information, surveyed, examined or otherwise included into this scientific investigation.

No individual's personal, medical, demographic or health information, or any clinical, personal or biological sample, records or other data that can be attributed to any individual's research participation have been gathered, stored, or investigated. As such, there has been neither direct nor indirect human participation in this project, and neither participants' consent, nor approval from the Human Subjects' Protection committee has been requested or obtained.

Likewise, this study neither had any living subjects (including animal participants) involved in the research, nor experimental manipulations involving living beings. All the analyses were carried out by means of purely synthetic (prepared) laboratory samples of inorganic/material substance. Therefore, the obtaining of consent to participate in research is not required in the case of the performed scientific work.

The authors affirm the investigation was purely designed for scientific characterization of the physical, chemical and stability phenomena pertaining to the process of dispersing $\text{Ti}_3\text{C}_2\text{T}_x$ MXene. No human or/and non-human subjects were involved in any of the steps constituting this scientific exploration. Consent to Participate: Not applicable.

Consent to Publish

This manuscript reports the experimental studies on Antioxidant-assisted suppression of oxidation and sedimentation in $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions. Scientific and experimental facts concerning the preparation, characterization, stability and functionality of the lab produced materials, were given in

the study. There is no person data, any information of identifiable participants, or any case history data or any photo and other similar materials describing identifying images, reported.

The study of human participants wasn't part of the work and then there wasn't necessary the informed patient consent for publication in any individual and the manuscript did not contained animal pictures, identifiable personal details or personal information for which a consent by any individual person or by any third party would have been necessarily.

All authors have carefully revised the information and are confirm that all of the information are of science importance of the publication purposes, and there is no any confidential or any individually identifying data that would needed special written permission for publication within this study. Therefore, given that there were not any human subjects and no personal and identifiable information was used, Consent to Publish: Not applicable.

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Figures

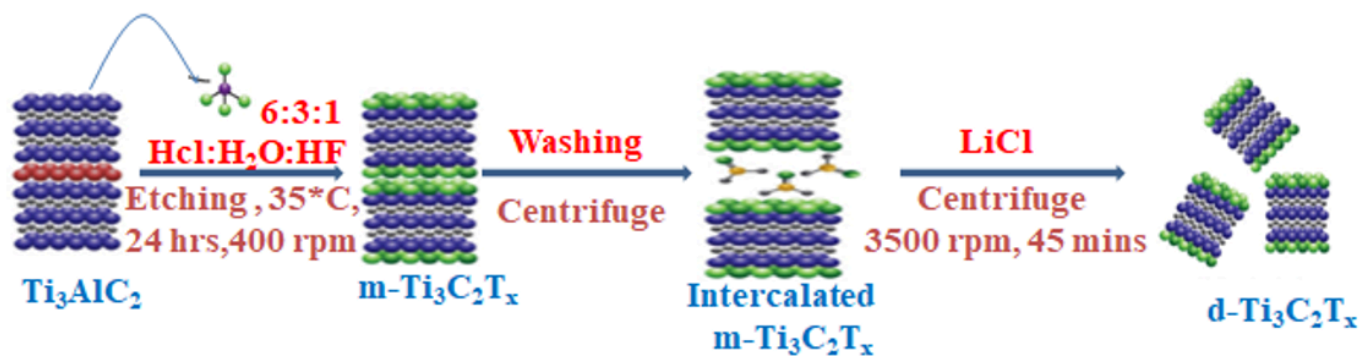


Figure 1

Schematic illustration of the synthesis of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene nanosheets. The process involves the selective etching of aluminum from Ti_3AlC_2 MAX phase using a HCl/HF solution, followed by LiCl intercalation and delamination to produce few-layer $\text{d-Ti}_3\text{C}_2\text{T}_x$.

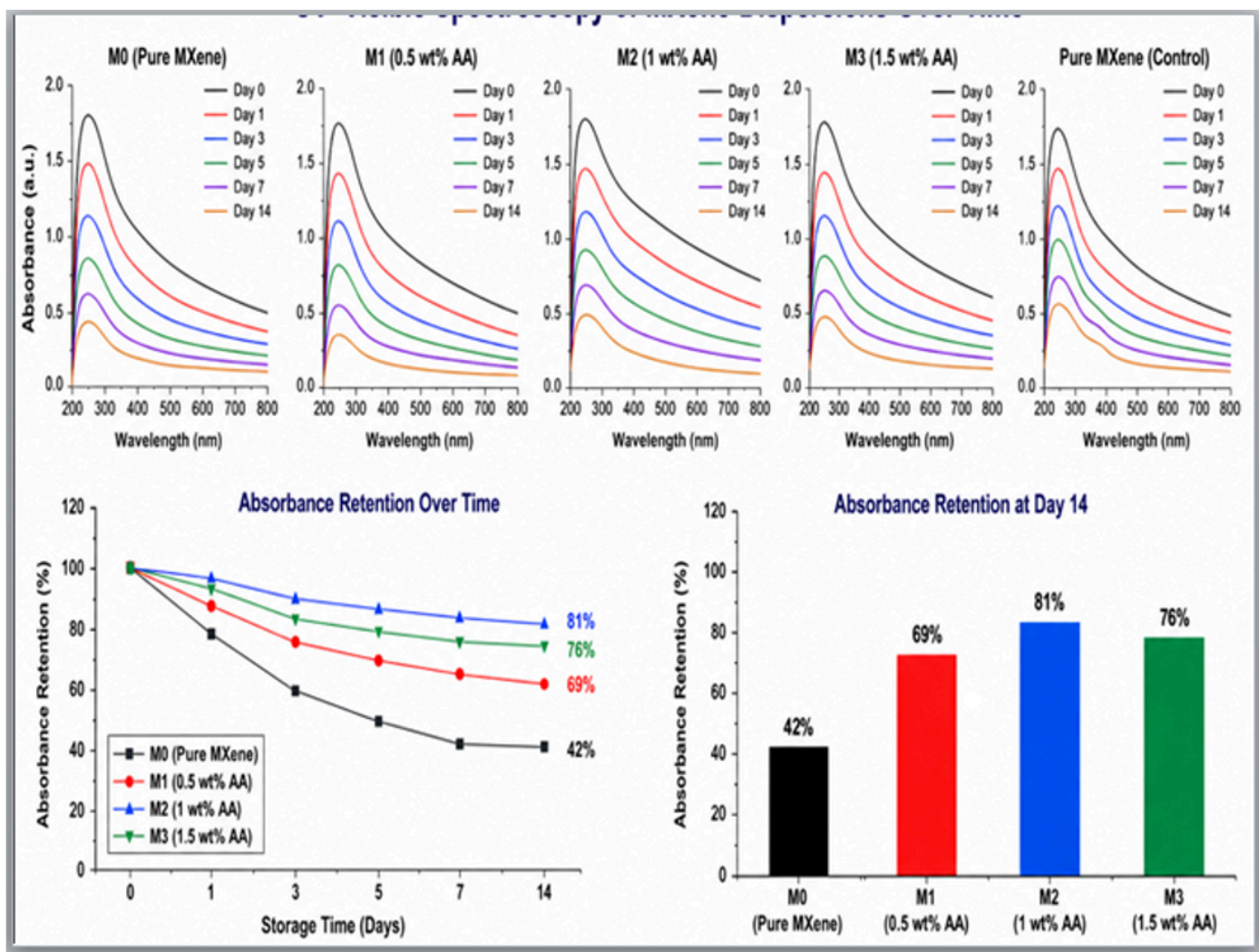


Figure 2

UV-VISIBLE Spectroscopy analysis of Ti_3C_2Tx MXene dispersions with varying ascorbic acid concentrations showing oxidation suppression, And Absorbance Retention .

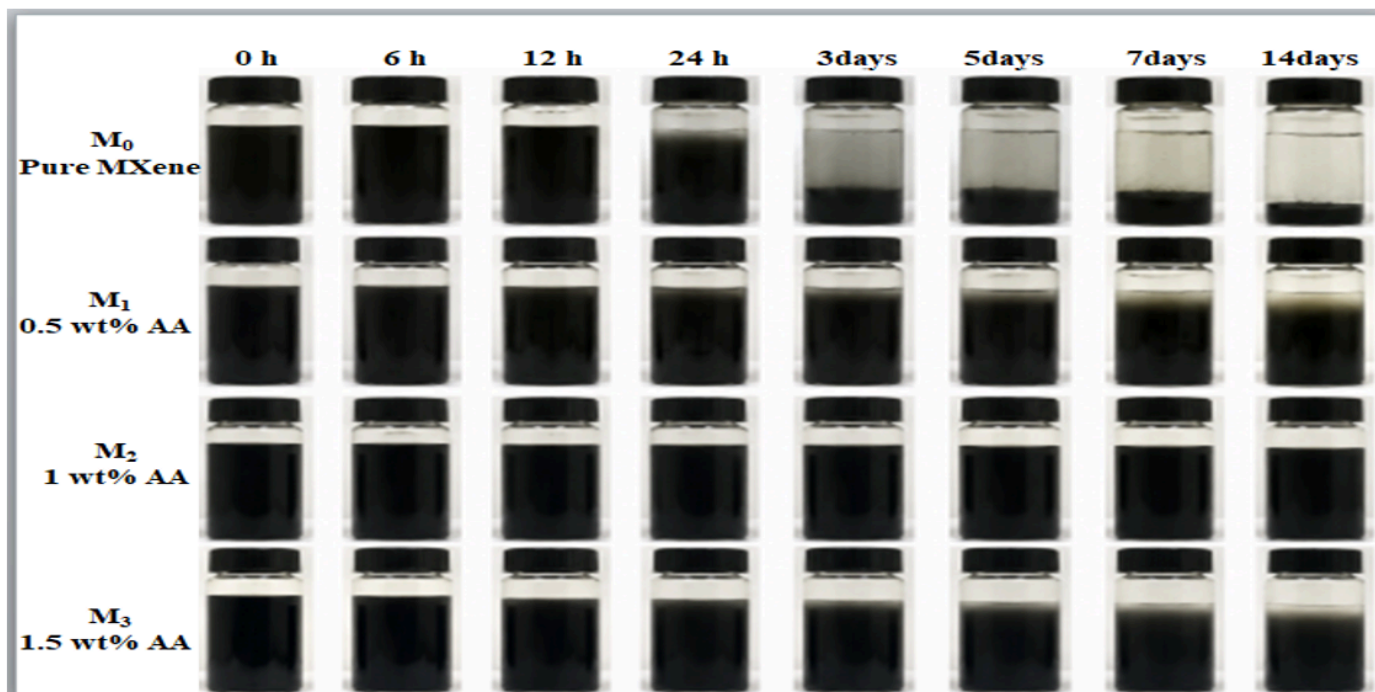


Figure 3

Sedimentation behaviour of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions with different ascorbic acid concentrations during 14 days of storage, showing improved colloidal stability and reduced aggregation in antioxidant-treated samples.

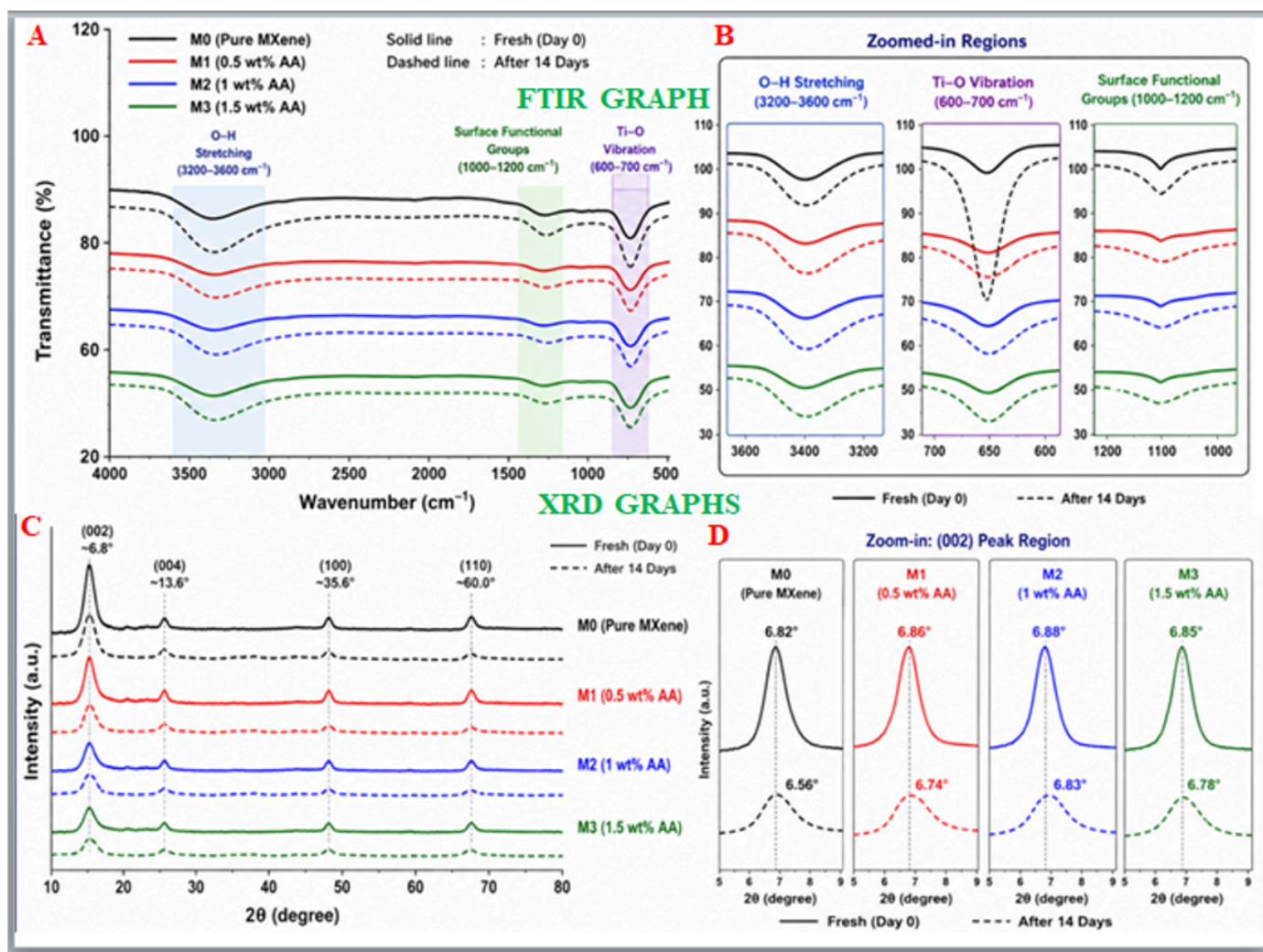


Figure 4

FTIR and XRD characterization of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene dispersions stabilized with different amounts of ascorbic acid after 14 days of storage. (A) FTIR spectra of fresh (solid line) and aged (dashed line) MXene samples which reveals the changes in the surface functional groups and oxide-related vibrations. Severe oxidation of pristine MXene (M0) can be witnessed from the raised O-H stretching (3200–3600 cm^{-1}) and Ti-O vibration peaks (600–700 cm^{-1}). The enhanced oxide formation is reduced in the antioxidant-treated samples. Especially, M₂ (1 wt% AA) can maintain the surface terminations and suppressed the oxide formation effectively. (B) Enlarge views of FTIR spectra (in different regions) that illustrate the change of the O-H stretching, Ti-O bonding, and surface functional groups for before and after storage. (C) XRD patterns of fresh and aged MXene dispersions displaying the (002), (004), (100) and (110) diffraction peaks. An obvious drop of the intensity of the (002) peak occurred on M₀ during the storage period, signifying structure degradation. (D) Enlarge view of the (002) peak, indicating that both of antioxidant-treated samples retain more structure, especially M₂, with the higher and less shifted intensity.