Energy Applications of 2D Nanomaterials

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MXene-Based 2D Nanomaterials for Solar Cells

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10.1 INTRODUCTION

The MXenes-based 2D nanomaterials are a novel material, which has been created in 2011 by Gogotsi research group. This titanium-carbide MXenes, Ti$_3$C$_2$Tx, (T signifies some surface-terminating functional groups (−O, −OH and −F)), have triggered wide attention and have been explored in different research fields including sensors devices [1–7], catalysis [8–12], water purification [13–15], biomedical application [16–18], electromagnetic fields [19–23], batteries application [24–28], and supercapacitor [29–30]. This is due to the distinctive advantages shown by MXene-based 2D nanomaterials such as good electrical conductivity, high charge carrier transport, outstanding transparency in visible range, and tunable work function (WF) [31].

In the study of solar cell performance, the important parameters that are used to characterize the photovoltaic are including the open-circuit voltage $V_{oc}$, $J_{sc}$, fill factor (ff), and solar cell efficiency ($\eta$). At the maximum point for $J$-$V$ curves shows the current density ($J_{max}$) and voltage ($V_{max}$). From this study, we can learn and investigate how good the MXene-based 2D nanomaterials influence or impact the solar cell performance.

This book chapter presents the utilization of MXene-based 2D nanomaterials for solar cells application such as perovskite solar cells (PSCs), silicon solar cells,
organic solar cells (OSCs), quantum dot-sensitized solar cells (QDSCs), and dye-sensitized solar cells (DSSCs). In this book chapter also provide the information about the role of MXene-based 2D nanomaterials in the solar cells application such as additive in the electrolyte or electrode, hole transport layer (HTL) or electron transport layer (ETL), and additive in HTL/ETL.

10.2 MXene-BASED 2D NANO MATERIALS FOR PEROVSKITE SOLAR CELLS

The exclusive and attractive properties of 2D MXenes-based nanomaterials that occur from terminating functional groups and oxidation of 2D MXenes-based nanomaterials, show good sign to use in solar cell fabrication such as PSCs. Saranin et al. [32] have proposed the usage of MXenes which has an advantageous role as perovskite absorber and ETL by doping these MXene nanomaterials in the nickel oxide-based inverted PSCs. In this research, the planned method opens uncountable ways for engineering inverted PSC mechanism by owing to the opportunity to excellently adjust the Ti$_3$C$_2$T$_x$ WF, which display a high PSC efficiency of ~20%. Another example is Ti$_3$C$_2$T$_x$ MXene hydrocolloid, which has got through the oxidation process has been used in the PSC, which is resulting the best PSCs efficiency of ~18% as reported by Yang et al. [33].

According to Wang et al. [34], the 2D MXene materials are expected to boost the charge transport in PSCs. Interface engineering is important to enhance the efficiency of PSCs. The authors offer a vowing method by introducing a 2D carbide (MXene) nanomaterials with great interface contact, which has improved the electron transportation and charge transfer ability of tin oxide (SnO$_2$) ETL. The 2D MXene nanomaterials-modified tin oxide ETL also proposes a better growth platform for the perovskite layer including decreased trap density. By using a spatially resolved imaging method, profoundly decreased non-radiative recombination and charge transport losses in PSCs based on 2D MXene nanomaterials-modified tin oxide are also recorded. As solar cells performance result, the PSC (Figure 10.1) with minor hysteresis displays an improved solar cell efficiency of ~20.7% (which is including ultralow saturated current density, J). In this research, the authors are offering in-depth systematic knowledge of the 2D MXene nanomaterials interface engineering, proposing an alternate method to achieve efficient PSCs.

Yang et al. [35] have proposed MXenes nanomaterials (a type of 2D Ti$_3$C$_2$) that can be employed in the PSCs application due to some advantages such as their exclusive electronic properties, optical character, and plasmonic properties. The authors investigate the usage of the MXene 2D nanomaterials in organic–inorganic lead halide (gaining from reacting halides of lead and organic ammonium with dopants) PSCs. In the methodology section, the composite of tin (IV) oxide (SnO$_2$) and Ti$_3$C$_2$ MXene nanomaterials have been prepared where the amounts of MXene nanomaterials was varied from 0, 0.5, 1.0, 2.0, and 2.5 (in weight percentage). In this study, the MXene has been applied as surface for electron mobility in the PSCs. In the solar cells result, by blending SnO$_2$ with 1.0 weight percentage of MXene nanomaterials showing improvement of the PSC efficiency, which started from ~17.2% to ~18.3%. However, PSCs utilizing with pure MXene as the ETL achieved a PSC efficiency
of ~5.3%. In the photoluminescence spectroscopy and electrochemical impedance spectroscopy (EIS) study, the results expose that MXene nanosheets offer higher charge transfer pathways. From this analysis, the presence of MXene nanomaterials shows improving the electron behavior at the ETL/PSC intercontact. This phenomenon is heading to greater photocurrents. Overall, this research highlights the usage of MXene nanomaterial and a favorable technique to improve the solar cells’ conversion efficiency.

Some researchers have been utilizing the MXene nanosheets with the titanium dioxide doped for PSCs [36]. The inorganic lead-free Cs₂AgBiBr₆ double perovskite structure is the promising development path in PSCs device to work out the difficulty of the instability of the APbX₃ (A = MA, FA, and Cs; X = Cl, Br, and I) perovskite nanocrystals structure and lead toxicity. Though, the small short-circuit current (I) and power conversion efficiency affected by Cs₂AgBiBr₆ (with low crystallization) significantly reduce the optoelectronic research field. Here, the researcher approves an easy method to dope single-layered MXene nanosheets into titanium dioxide (titanium carbide MXene-TiO₂). This will perform as a multifunctional ETL for stability and effective Cs₂AgBiBr₆ double PSCs. The single-layered MXene nanosheets suggestively increased the electrical conductivity and electron extraction rate of titanium dioxide. At the same time, the single-layered MXene nanosheets shift the surface wettability of the ETL and boost the crystallization of the Cs₂AgBiBr₆ double PSCs assembly. Hence, the PSC (Figure 10.2) increased (hysteresis was eliminated) by approximately >40% to 2.81% (Vₜₜc of 0.96 V, Jₜsc of 4.14 mA cm⁻², and ff of 0.70) compared to that of a titanium dioxide-based device (Vₜₜc of 0.93 V, Jₜsc of 2.84 mA cm⁻², ff of 0.62, and η of 1.64%). Additionally, the PSCs based on titanium carbide MXene-titanium dioxide proved the long-term operational stability after keeping this PCS for 15 days with normal air conditions. This is resulting the PSCs efficiency still same showing a retention rate of ~90% of the primary one. This work showed the capability of titanium carbide MXene-titanium dioxide in ETL material for high-performance double PSCs.

FIGURE 10.1 Configuration of 2D MXenes-based perovskite solar cell. (Adapted with permission from Ref. [34]. Copyright (2020) American Chemical Society.)
In the silicon-type solar cells research, which is owing to their high-power conversion efficiency as attraction of global interest, a heterostructure solar cells (HSCs) utilizing donor and acceptor semiconductors can be constructed. According to Zhang et al. [37], a complete evaluation of 64 2D transition metal carbides (MXenes) was performed. The results emphasize that zirconium carbide (Zr$_2$CO$_2$) and transition metal carbides MXene are encouraging donor and acceptor materials, individually. Excitingly, the HSCs have a suitable bandgap (1,220 meV) and display a clear absorbance coefficient. Furthermore, the heterostructures (type-II nature) might generate valuable electron–hole separation. Moreover, the photocurrents of transition metal carbides/zirconium carbide and transition metal carbides/Hf$_2$CO$_2$ HSCs fabrication are competitive with the standard silicon devices. In detail, transition metal carbides/zirconium carbide and transition metal carbides/Hf$_2$CO$_2$ HSCs provide a high efficiency of ~23% and ~20%, individually. This study also exposes the method for enabling the potential application of 2D MXenes as solar cell materials.

10.4 MXene-BASED 2D NANOMATERIALS FOR ORGANIC SOLAR CELLS

As reported by Tang et al. [38], which is employing the MXene nanomaterials in the OSCs due to the excellent properties such as good metallic conductivity and hydrophilicity. In this research, the manufacture of visible, highly conductance,
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and suitable MXene and silver nanowire (AgNW) hybrid films has been reported. This results in the maximum figure of merit (a quantity used to characterize the performance of device) of ~162.50 in reported literature to date concerning the 2D MXene nanomaterial-based transparent electrode. The preparation of the hybrid films has been carried out through a straightforward and scalable solution-processed technique. By using this technique, the prepared hybrid films display high electrical conductivity, maximum transmittance, low toughness, suitable for WF, and strong mechanical properties. In the OSC assembly, the hybrid electrodes should exhibit to work as transparent electrodes in fullerene molecule (an allotrope of carbon) PTB7-Th:PC71BM and nonfullerene molecule PBDB-T:ITIC OSCs. In additional research to develop the performance of flexible OSCs, the PBDB-T:ITIC:PC71BM assembly has shown an efficiency of ~8%. The mechanical properties of this OCS have been studied. The flexible ternary OSCs can retain 84.6% of the original OSC efficiency after 1,000 bending and unbending cycles to a 5-mm bending radius. These OSCs and mechanical performance metrics describe a discovery in flexible OSC field.

According to Yu et al. [39], MXenes two-dimensional nanomaterials have fascinated good interest and potentially use in the OSCs. In this research, the utilization of MXene nanomaterials for the electron–hole collections of OSCs has been studied and shows the OSC of ~9.1%. This OSC efficiency is similar to that using standard charge-collection buffer layer materials.

10.5 MXene-BASED 2D NANOMATERIALS FOR QUANTUM DOT-SENSITIZED SOLAR CELLS

There are solar cells studies that are employing the MXene nanomaterials in the QDSCs as reported by Chen et al. [40]. This research shows that the copper selenide (CuSe) nanoparticles have been in situ growing on the MXene nanomaterials using one-step hydrothermal method to form the copper selenide–MXene composite. The copper selenide–MXene slurry was produced using a solvothermal method where the 20 mg of copper selenide–MXene and polyvinylidene fluoride (PVDF) (6 mg) has been mixed in N methyl-2-pyrrolidone (NMP) (300 μL). In the QDSCs, the counter electrode has been created using copper selenide–MXene slurry, which has been screen-printed (one layer) on a graphite sheet. The QDSCs have been configured with the copper selenide–MXene-based electrode, parafilm spacer (80 μm), and photoanodes (Cds/CdSe co-sensitized TiO2). Then, the QDSC has been inserted with the polysulfide aqueous liquid electrolyte via the hole in the spacer. This electrolyte is containing sodium sulfide, sulfur, and potassium hydroxide. In the solar cell study, current density, J – voltage, V of QDSC utilizing copper selenide, copper selenide-MXene, and MXene counter electrode have been measured. The QDSC was done under illumination of 100 × 10−3 cm2 (AM 1.5) with QDSC active area fixed at 1 × 10−1 cm². The authors reported that the QDSCs employing copper selenide-based counter electrode show solar cell parameter such as short-circuit current density (Jsc) of ~17 × 10−3 A cm−2, Voc of 547 mV, ff of 37%, and resulting QDSC efficiency of ~3.5%). Another test, when the QDSC using the copper selenide-0.3 mg of MXene counter electrode, it is resulting in an increment for the QDSC parameter such as Jsc of ~19 × 10−3 A cm−2, Voc of 565 mV, ff of 48%, and QDSC efficiency of 5.12%. This
QDSC improvement could be attributed to a 3D structure of copper selenide-MXene, which is leading to a large specific surface area (SSA) of the counter electrode. Another explanation from the author also described that the catalytic activity of counter electrode toward polysulfide electrolytes is increased, which is at the counter electrode-polysulfide the charge transport struggle is decreased. However, when the QDSC is utilizing the MXene counter electrode, the QDSC performance displays a decreasing trend where the short-circuit current density of \( \sim 10 \times 10^{-3} \) A cm\(^{-2}\), open-circuit voltage of 530 mV, fill factor of 39\%, and QDSC efficiency achieved at \( \sim 2\% \). The incident photon to current efficiency patterns of the QDSC using various types of counter electrodes has been measured. The QDSC utilizing of copper selenide-MXene counter electrode shows an increment trend compared with QDSC using MXene counter electrode or copper selenide counter electrode, which is in good statement to support the increasing of QDSC’s short-circuit current density, \( J_{sc} \). The intercontact resistance and charge transfer at the interfaces in QDSC have been studied by carrying out the EIS analysis. From this EIS study, the Nyquist plot for all QDSC has been obtained, which has been fitted by an equivalent circuit resulting in charge transfer resistance at the counter electrode/electrolyte intercontact, \( R_{ct1} \) and the second charge transfer resistance at the photoanode/electrolyte intercontact, \( R_{ct2} \) [41]. The \( R_{ct1} \) and \( R_{ct2} \) shown by copper selenide-30 mg MXene counter electrode have the lowest value than both counter electrodes (copper selenide and MXene). This is because the combination of copper selenide and MXene resulting 3D structure, which provides more diffusion pathways and improves the maximum electrocatalytic area for redox reaction in the electrolyte.

According to Sharbirin et al. [42], the utilizing of metal carbides and nitrides or known as MXene nanomaterials is an evolving level of 2D nanolayer structures. Ti\(_3\)C\(_2\)T\(_x\) nanomaterials were discovered by worldwide applications in sensor, batteries, supercapacitor, catalysis, and others. This is because the Ti\(_3\)C\(_2\)T\(_x\) MXene nanomaterials display good electronic conductivity and very broad range in optic properties. Though, the presence of Ti\(_3\)C\(_2\)T\(_x\) nanomaterials has restricted their ability to correlate to light characterization. In this work, Ti\(_3\)C\(_2\)T\(_x\) nanomaterials were potentially used in the light-emitting (LE)-MXene quantum dots (MQDs), which exhibited excellent advancement, and MQDs displayed multi-color photoluminescence emission along with maximum quantum yield. The synthesis techniques also act an important role in controlling the light emission properties of these MQDs. In this paper, a summary of LE-MQDs and their synthesis processes, optical characteristic, and applications in different optical fields, sensor devices, and imaging devices have been discussed. The next project of LE-MQDs is also reviewed to give an understanding that helps to further advance the development on MQDs.

According to Xue et al. [43], the Ti\(_3\)C\(_2\) MXene nanomaterials can be utilized in the quantum dot. In this work, by using a facile hydrothermal method for the construction of photoluminescent Ti\(_3\)C\(_2\) MQDs are described. This is considerably expanding the functions of MXene-based nanomaterials, which is potentially used in QDSCs fabrication. Excitingly, the as-prepared MQDs display excitation-dependent photoluminescence region with \( \sim 10\% \) quantum yields due to powerful quantum confinement. This research is also demonstrating the applications of Ti\(_3\)C\(_2\) MQD as biocompatible multicolar cellular imaging probes and zinc ion sensors.
10.6 MXene-BASED 2D NANOMATERIALS FOR DYE-SENSITIZED SOLAR CELLS

In the dye-sensitized solar cells (DSSCs) application, some research that is utilizing the MXene-based 2D nanomaterials as a shield layer of the counter electrode which is acting as conducting layer and catalyst as well [44]. Usually in the DSSC fabrication, the counter electrode is consisting of the transparent conducting oxide (TCO) layer and platinum (Pt)-based catalyst. The TCO layer of the counter electrode is responsible to assist the electron transport from the outer circuit to enter the DSSC. At the same time, the electrolyte will be oxidized by accepting the electron, which has been arrived through the counter electrode. The Pt-based catalyst will boost the efficient regeneration process in the electrolytes. From this research, both materials (TCO and Pt solution) have been replaced with the MXene-based 2D nanomaterials. The employing of MXene-based 2D nanomaterials in the counter electrode (substitute TCO-Pt) has been carried out by optimizing the layer thickness of MXene to offer a high DSSC efficiency. In this research, five samples counter electrode has been prepared with different thickness of MXene (2, 4, 6, 8, and 10 μm) and the standard counter electrode (TCO-Pt-based) as comparison reasons and to reach the highest possible implementation. Scanning electron microscope (SEM) and X-ray diffraction (XRD) have been performed to examine the MXene layer morphology and composition, respectively. From the SEM result, the MXene layer is in a micro-scale structure. XRD patterns of MXene show that the peaks appear in the right position approaching 2θ values (with related indices) of 10 (002), 20 (006), 40 (002), and 60 (110) represent of MXene.

The cyclic voltammetry has been done with the configuration of working electrode, counter electrode (Pt wire), reference electrode (Ag/AgCl), and electrolyte to test the catalytic process and stability purpose. By this CV analysis, no change in the shape of the curves for each variation thickness MXene-based electrode sample indicates the catalyst is more stable in the electrolyte. Fabrication of DSSC has been done by arranging the polymer sealing layer fill with the electrolyte in between of titanium dioxide (TiO₂)-dye photoanode and MXene-based counter electrode. EIS of the DSSC fabrication has been done to analyze the equivalent circuit. It shows that the Rs (serial resistance) and Rct decrease as increasing is the thickness of MXene-based electrode, which has improved the surface area. The increasing of the MXene layer also advances the reduction rate of I₃⁻ ions and decreases the value of Rct. The lowest Rct value of ~1.8 Ω cm⁻² was observed for counter electrode with MXene nanomaterials (8 μm thickness). This is because that the ideal contact surface area between electrolytes and catalytic sites of electrode affords for the good electronic path. The Zw (Warburg diffusion resistance of I⁻/I₃⁻ redox electrolytes) was obtained in the range between 1 and ~3 Ω cm². This shows that the contact surface for all MXene-based electrodes with electrolytes is in a good condition. The highest DSSC efficiency of ~8.7% was obtained by the electrode with the MXene nanomaterials (8 μm thickness). This is because the Jsc is increasing as the MXene thickness is increasing, which improves the ion transport between counter electrode and electrolytes. As comparison, the DSSC utilizing standard TCO-Pt counter electrode only shows the efficiency of ~8.3%. This proved that the replacement of TCO-Pt with the MXene-based 2D nanomaterials offers high
conductivity, good catalytic process of MXene toward I$^−$/I$_3^−$ electrolyte. The author concludes that the MXene nanomaterials have potential to replace the standard TCO and Pt in the counter electrode of DSSCs.

In Ref. [45], the researcher prepared the photoanode by using oxidizing process of 2D-MXene nanosheets (Ti$_3$C$_2$ MXene) with the nanoporous of TiO$_2$ for DSSCs fabrication. The electrodes preparation was started by using doctor-blade technique, the MXene slurry or TiO$_2$ paste was coated onto fluorein tin oxide (FTO) glass, which has been cleaned earlier. Then, FTO glass with coated MXene or TiO$_2$ was placed in the furnace with a temperature of 450°C for ~30 minutes. For the MXene-FTO glass electrode, this electrode has been cooled down to 100°C and then exposed to the outside air at various temperatures of 150°C–500°C for the oxidation process. Both MXene-FTO and TiO$_2$-fluorine tin oxide electrode have been soaked in the N719 (Ru-based complex dye sensitizer) for 18 hours at a temperature of 25°C under dark condition place. Then, MXene-FTO and TiO$_2$-FTO glass electrode were cleaned using ethanol solvent to remove the unbound dyes particles. All the electrodes prepared were tested in DSSCs. For the preparation of DSSCs fabrication, the MXene-FTO or TiO$_2$-FTO glass was located with the platinum electrode and sealed together using a thermal adhesive layer by supplying the heat at ~110°C on a hot surface. After the sealing process, the electrolyte was then inserted via a tiny gap in between both electrodes. DSSC characteristics were measured under illumination of 100 $\times$ 10$^{-3}$ W cm$^{-2}$ (AM1.5). In this work, the impacts of oxidation temperature and period time together with different thicknesses on the DSSC performance were explored. The best result has been obtained, which shows the DSSC efficiency of ~2.7%.

As reported by Adibah et al. [46], the new types of 2D transition metal carbides, carbonitrides, nitrides (known as MXene nanomaterials) have been found in the year of 2011. In this report, the synthesis MXene has been used for electrolyte filler for DSSCs fabrication. This is the MXene nanomaterials that have exclusive characteristic, which have made it fascinating for transparent conducting films, photocatalysts, charge-discharge batteries, electric double layer capacitor, catalysts, and flexible high-strength composites applications. The methodology section shows that the MXene nanomaterial has been synthesized via a discerning etching process by using either in situ or direct hydrofluoric acid (HF) techniques. This research details the influence of the in situ hydrofluoric acid and direct hydrofluoric acid etching processes on the morphology of the synthesis 2D MXene nanomaterials employing titanium aluminum carbide (Ti$_2$AlC$_3$) as a precursor. Finally, the results display that the Ti$_2$AlC$_3$ nanomaterial produced via the directly hydrofluoric acid process was effectively delaminated, which is in contrast with in situ hydrofluoric acid methods.

## 10.7 CONCLUSION

As conclusion, the employing of MXene-based 2D nanomaterials for solar cells application such as PSCs, silicon solar cells, OSCs, QDSCs, and DSSCs has been discussed in this book chapter. In the PSC, the researcher has presented the method of opens uncountable ways for engineering inverted PSC mechanism by owing to the opportunity to excellently adjust the Ti$_3$C$_2$T$_x$ WF, which display a high PSC
efficiency of ~20%. Then the other example, Ti,C,T MXene hydrocolloid, which has got through the oxidation process has been used in the PSC, which is resulting in the best PSCs efficiency of ~18%. Another research, the PSC based on 2D MXene nanomaterials-modified tin oxide and with minor hysteresis display an improved solar cell efficiency of ~20.7%. MXene has been applied as surface for electron mobility in the PSCs by blending SnO2 with 1.0 weight percentage of MXene nanomaterials showing improvement of the PSC efficiency, which started from ~17.2% to ~18.3%. Another PSC analysis, the single-layered MXene nanosheets shift the surface wettability of the ETL and boost the crystallization of the Cs2AgBiBr6 double PSCs assembly. Hence, the PSC increased (hysteresis was eliminated) by approximately >40% to 2.81% (Voc of 0.96V, Jsc of 4.14 mA cm−2, and ff of 0.70).

In the silicon-type solar cells research, which is owing to their high-power conversion efficiency as attraction of global interest, HSCs utilizing donor and acceptor semiconductors can be constructed. By completing the evaluation of 64 2D transition metal carbides (MXenes), it emphasizes the zirconium carbide and transition metal carbides MXene are encouraging donor and acceptor materials, individually. In detail, transition metal carbides/zirconium carbide and transition metal carbides/Hf2CO2 HSCs provide a high efficiency of ~23% and ~20%, individually. This study also exposes that the method for enabling the potential application of 2D MXenes as solar cell materials.

In the OSC assembly, the hybrid electrodes should exhibit to work as transparent electrodes in fullerene molecule (an allotrope of carbon) PTB7-Th:PC71BM and nonfullerene molecule PBDB-T-ITIC OSCs. In additional research to develop the performance of flexible OSCs, the PBDB-T:ITIC:PC71BM assembly has shown an efficiency of ~8%. The mechanical properties of this OCS have been studied. The flexible ternary OSCs can retain 84.6% of the original OSC efficiency after 1,000 bending and unbending cycles to a 5-mm bending radius. Another example of OSCs, the application of MXene nanomaterials for the electron–hole collections in OSCs displays the efficiency ~9.1%. This OSC efficiency is similar to that using standard charge-collection buffer layer materials.

In the QDSCs section, some researcher has prepared the copper selenide (CuSe) nanoparticles with in situ growing on the MXene nanomaterials using one-step hydrothermal method to form the copper selenide – MXene composite. This QDSC using the copper selenide-0.3 mg of MXene counter electrode is resulting in an increment for the QDSC parameter such as Jsc of ~19 × 10−3 A cm−2, Voc of 565 mV, ff of 48%, and QDSC efficiency of 5.12%. This QDSC improvement could be attributed to a 3D structure of copper selenide-MXene, which is leading to large SSA of the counter electrode. In addition, the catalytic activity of counter electrode toward polysulfide electrolytes is increasing, which is at the counter electrode-polysulfide the charge transport struggle is decreased. Some researcher has proposed a review paper describing the employing of MXene in QDSC. Ti,C,T nanomaterials has potentially used in the light emitting (LE)-MQDs which has exhibited excellent advancement, and MQDs displaying multi-color photoluminescence emission along with maximum quantum yield have been assembled. The synthesis techniques also act an important role in controlling the light emission properties of these MQDs. In this review paper, a summary of LE-MQDs and their synthesis processes, optical characteristic,
and applications in different optical fields, sensor devices, and imaging devices has been discussed. The next project of LE-MQDs is also reviewed to give an understanding that helps to further advance the development on MQDs. Some researcher has utilized the facile hydrothermal method for the construction of photoluminescent Ti$_3$C$_2$ MQDs. This is considerably expanding the functions of MXene-based nanomaterials, which is potentially used in QDSCs fabrication. Excitingly, the as-prepared MQDs display excitation-dependent photoluminescence region with $\sim$10% quantum yields due to powerful quantum confinement. This research is also showing the applications of Ti$_3$C$_2$ MQDs as biocompatible multicolor cellular imaging probes and zinc ion sensors.

In the DSSCs application, some research that is utilizing the MXene-based 2D nanomaterials as a shield layer of the counter electrode, which acts as conducting layer and catalyst as well. The employing of MXene-based 2D nanomaterials in the counter electrode (substitute TCO-Pt) has been carried out by optimizing the layer thickness of MXene to offer a high DSSC efficiency. The highest DSSC efficiency of $\sim$8.7% was obtained by the electrode with the MXene nanomaterials (8 μm thickness). This is because the $J_{sc}$ is increasing as there is an increase of MXene thickness, which is improving the ion transport between counter electrode and electrolytes. This proved that the replacement of TCO-Pt with the MXene-based 2D nanomaterials offers high conductivity, good catalytic process of MXene toward I$^-$/I$_3$ electrolyte and completes that the MXene nanomaterials have the potential to replace the standard TCO and Pt in the counter electrode of DSSCs. In another example, the photoanode has been prepared by using oxidizing process of 2D-MXene nanosheets (Ti$_3$C$_2$ MXene) with the nanoporous of TiO$_2$ for DSSCs. In this study, the impacts of oxidation temperature and period time together with different thicknesses on the DSSC performance were explored. The best result has been obtained, which shows the DSSC efficiency of $\sim$2.7%. Another DSSC report, the synthesis MXene has been used for electrolyte filler for DSSCs fabrication. This research details the influence of the in situ hydrofluoric acid and direct hydrofluoric acid etching processes on the morphology of the synthesis 2D MXene nanomaterials are employing titanium aluminum carbide (Ti$_2$AlC$_3$) as a precursor. Finally, the results display that the Ti$_2$AlC$_3$ nanomaterial produced via the directly hydrofluoric acid process was effectively delaminated, which is in contrast with in situ hydrofluoric acid methods.

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