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IMPORTANCE OF MXENE NANOCOMPOSITES IN THE DETECTION OF HEAVY METALS

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One of the strongest and most common chemical pollution is its environmental pollution with heavy metals. Heavy metals are actively involved in biological processes, which are part of many enzymes. The toxicity of heavy metal ions causes a number of harm to environmental components and human health. That is why the detection of heavy metals is so important. The creation of a reliable and effective system for detecting heavy metals is crucial. And traditional detection methods are often not enough to meet the current needs. Therefore, the use of electrochemical sensors in the detection of heavy metals is currently taking an important place. Electrochemical sensors have become a promising area of research due to their unique capabilities. Improving the detection efficiency of electrochemical sensors is the main area of research. The leading strategy for significantly improving detection performance involves adding nanomaterials to electrochemical sensors. This review compares MXene nanocompasites with the achievements of nanomaterials in the field of electrochemical sensors in recent years. This makes it possible to obtain new ideas for the manufacture of electrochemical sensors with high sensitivity and low detection threshold. We believe that knowing and combining the benefits of different nanomaterials to produce innovative electrode modification materials can eliminate the risk of heavy metal ions in many food, environmental and other industries.

Keywords: heavy metals, electrochemical sensors, nanomaterials, modification, MXene nanocomposites.

АУЫР МЕТАЛДАРДЫ АНЫҚТАУДА MXENE НАНОКОМПОЗИТТЕРДІҢ МАҢЫЗЫ

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Ең күшті және ең көп таралған химиялық ластанудың бірі - ол қоршаған ортаның ауыр металдармен ластануы. Ауыр металдар көптеген ферменттердің құрамына кіретін биологиялық процестерге белсенді қатысады. Ауыр металл иондарының уыттылығы қоршаған орта компоненттеріне және адам денсаулығына бірқатар зиянын келтіреді. Сондықтан да ауыр металдарды анықтау өте маңызды болып табылады. Ауыр металдарды анықтау үшін сенімді және тиімді жүйені құру қажет. Ал дәстүрлі анықтау әдістері көбінесе қазіргі қажеттіліктерді қанағаттандыру үшін жеткіліксіз. Сондықтанда қазіргі кезде ауыр металдарды анықтауда электрохимиялық сенсорларды қолдану маңызды орын алып отыр. Электрохимиялық сенсорлар өзінің ерекше мүмкіндіктерінің арқасында зерттеудің перспективалық бағытына айналды. Электрохимиялық сенсорларды анықтау тиімділігін арттыру зерттеудің негізгі бағыты болып табылады. Анықтау өнімділігін айтарлықтай жақсартудың жетекші стратегиясы наноматериалдарды электрохимиялық сенсорларға қосуды қамтиды. Бұл шолу MXene нанокомпазиттерін соңғы жылдардағы электрохимиялық сенсорлар саласындағы наноматериалдардың жетістіктерін салыстырады. Бұл жоғары сезімталдығы бар және анықтау шегі төмен электрохимиялық сенсорларды дайындау үшін жаңа идеялар алуға мүмкіндік береді. Электродтарды модификациялау үшін инновациялық материалдар алу үшін әртүрлі наноматериалдардың артықшылықтарын білу және біріктіру көптеген азық-түлік, экологиялық және де басқа салалардағы ауыр металл иондарының қаупін жоя алады деген ойдамыз.

Түйін сөздер: Ауыр металдар, электрохимиялық сенсорлар, наноматериалдар, модификация, MXene нанокомпозиттері.

ВАЖНОСТЬ НАНОКОМПОЗИТОВ MXENE ДЛЯ ОПРЕДЕЛЕНИЯ ТЯЖЕЛЫХ МЕТАЛЛОВ

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Одним из самых сильных и распространенных химических загрязнений является загрязнение окружающей среды тяжелыми металлами. Тяжелые металлы активно участвуют в биологических процессах, входя в состав многих ферментов. Токсичность ионов тяжелых металлов наносит ряд повреждений компонентам окружающей среды и здоровью человека. Именно поэтому обнаружение тяжелых металлов так важно. Необходимо создать надежную и эффективную систему для обнаружения тяжелых металлов. А традиционных методов обнаружения зачастую недостаточно для удовлетворения современных потребностей. Поэтому использование электрохимических сенсоров для обнаружения тяжелых металлов в настоящее время занимает важное место. Электрохимические сенсоры стали перспективным направлением исследований благодаря своим уникальным возможностям. Повышение эффективности обнаружения электрохимических сенсоров является основным направлением исследований. Ведущей стратегией для значительного повышения эффективности обнаружения является добавление наноматериалов в электрохимические сенсоры. В данном обзоре сравниваются нанокомпозиты MXene с достижениями наноматериалв в области электрохимических сенсоров за последние годы. Это позволяет получить новые идеи для изготовления электрохимических сенсоров с выской чувствительностью и низким порогом обнаружения. Мы считаем, что знание и комбинирование преимуществ различных наноматериалов для создания инновационных материалов для модификации электродов может устранить опасность ионов тяжелых металлов во многих пищевых, экологических и других отраслях промышленности.

Ключевые слова: тяжелые металлы, электрохимические сенсоры, наноматериалы, модификация, нанокомпозиты MXene.

Introduction. Heavy metals are particularly biodegradable pollutants. They enter aquatic ecosystems, enter water and sediment phases, accumulate in organisms, and even at low levels cause a number of serious diseases and disorders [1-4]. For example, neurological, cardiovascular, respiratory and reproductive diseases [5]. Heavy metals in the environment pose a serious threat to wildlife and human health because they are bioavailable and can be absorbed and enriched in food [6]. Toxic metals are largely distributed into the environment. The distribution of heavy metals by wind in the form of particles or vapor depends on their physical state. The meta-components move from the atmosphere to the soil or water surface, resulting in environmental pollution. Industrial wastewater is a major source of metal pollution in the hydrosphere. Wastewater containing toxic heavy metals like nickel, lead, copper, chromium, cadmium, and arsenic poses environmental and health hazards [7]. Heavy metals affecting human health include elements such as mercury, nickel, lead, chromium, cadmium, aluminum and copper [8]. Heavy metals in water, air and soil can be transferred to plants, aquatic organisms and organisms and then enter the food chain and pose a threat to human health [9].

Year after year, the population around the world is growing. As the world' s population grows, the demand for food, drinking water and many other industries increases. Due to the increased demand, the quality requirements for food and drinking water are increasing. To ensure consumer safety, we must detect harmful substances present in very low concentrations. One of the most commonly used

methods today is the use of electrochemical sensors.

Electrochemical sensors are tools for detecting and counting heavy metals because they tend to be highly specific, sensitive, inexpensive and portable. This makes them valuable for small and mobile remote applications. Since complete elimination of food and drinking water contamination may not seem possible in the near future, assessment of legal limits should always be considered in the context of general nutrition, especially in the case of children. Ongoing research continues to improve sensor performance, enhance detection capabilities, and address calibration, interference, and sample preparation issues, further advancing the development of electrochemical sensors in food safety applications [10].

The world of sensors is diverse and due to this, it is developing at a rapid pace. Due to continuous technological improvement it is becoming more and more in demand. Electrochemical sensors are a convenient solution for variable analyzer detection due to their low cost and availability and are widely used in agriculture, food and oil industry as well as in environmental and biomedical fields. Electrochemical sensors have long been required for the study of biological substances. The sensors are characterized not only by their durability, high sensitivity and accuracy, but also by their low cost, speed and simplicity. Many nanomaterials have been obtained in more than two decades. Specific metals, conducting polymers, metal oxides and organometallic and carbon-based nanomaterial structures. Nanomaterials contribute to the analytical performance included in electrochemical analysis. This modification increases the payload capacity by utilizing recognition molecules such as enzymes, antibodies and aptamers as well as bioinspired receptors that can accurately and efficiently capture the target, thereby increasing the specificity of electrochemical sensors [11].

Table 1 - Lists many MXene-based sensors and their corresponding applications [19]

Nanocomposite components	Application
Ti_3C_2 / reduced graphene oxide	Pressure sensor
Ti_3C_2/ Ag nanowire	Strain sensor
Ti_3C_2 / chitosan	Biosensor for detecting pesticides
Ti_3C_2 / Nafion	Detecting nitrile ions
Ti_3C_2 / PANI	Ethanol, methanol, ammonia, and acetone detection
Ti_3C_2 / polyurethane	Stretchable strain sensing fabric
Ti_3C_2/ poly(vinylidene fluoride-trifluoroethylene)	Capacitive pressure sensor
Ti_3C_2 / natural microcapsules	Epidermal flexible pressure sensors
Ti_3C_2 / poly(dimethylsiloxane)	Skin conformal sensors for health monitoring
Ti_3C_2 / gold nanoparticles	Glucose detection biosensor
Ti_3C_2 and TiO_2	H_2O_2 detection
hollow MXene spheres/ reduced graphene	Piezoresistive pressure sensor
Ti_3C_2 / ink	Strain sensor for health monitoring

Electrochemistry-an important quantitative analysis strategy for testing various biochemical entities such as proteins, metabolites, neurotransmitters, electrolytes, heavy metals, etc. Further,

demonstrating wide applications in the fields of private health care, public health, clinical diagnostics, food safety and environmental analysis [12-14]. Generally, a complete electrochemical conversion system usually consists of two parts: sensing electrodes and electrochemically sensitive circuits. The former is used to convert biochemical signals into electrical signals. The latter uses various electrochemical test methods to excite the electrodes with voltage, collect, process, analyze the data and transmit them as electrical signals [15,16].

MXenes' electrical conductivity, rich surface chemistry and high aspect ratio are attractive characteristics for sensor processing . The ideal sensor has high performance, low detection , low production cost, low hysteresis, fast and efficient processing reaction, as well as fast recovery properties during reuse . Pressure and deformation sensors are production responsible in a wide pressure range and require high performance in thousands of deformation cycles. The cycles require high resistance in thousands of deformation cycles. The sensors demonstrated this product when made from MXenes, mxen/polymer nanocomposites, and mixed two-dimensional (2D) mxen-based heterostructures. Examples: silver nanoparticles, carbon nanotubes, and graphene oxide nanoparticles are 0D, 1D, and 2D nanoparticles that were combined with MXene and used to create Mxene-based 2D heterostructures [17].The latter includes mxen and heterostructure of 0D, 1D or 2D nanomaterials. These are heterostructures, as well as the detection of pure MXene and MXene /polymer nanocomposites and toxic compounds in food, monitoring of human movements and health status, gas and condition measurement, voice recognition and other input in sensory systems. appropriateness, voice recognition and other aspects [18].

MXene performance in sensor systems depends on the type and concentration of surface functional groups (hydroxyl, oxygen, fluorine, chlorine). For example, the simulation results showed that oxygen-ending MXene has excellent performance for ammonia detection, while hydroxyl-ending MXene has better performance for ethanol detection.To further improve the electrochemical performance of electrochemical sensors, sensitive Nanomaterials and 2D materials have been introduced due to high electrocatalytic effect and high electrical conductivity [20].

Mxene is a novel 2D material with a rare combination of properties such as electrical and metallic conductivity, hydrophilicity, biocompatibility and large surface area , convenient size customization, rich surface chemistry, flexibility, and layered structure. Due to its versatile properties, MXene is considered as a building material for future materials and devices [21].

As an electrode material, MXene is a potential candidate for synthesis for various energy storage devices such as supercapacitors and batteries. Composites based on metal oxides and metal sulfides are the most effective electrode materials for supercapacitor electrodes. Research was carried out to improve the properties of MXene-based composites [22].

Table 2 - Advantages and disadvantages of MXepe materials

	Advantages	Disadvantages
MXene	- Stability - Optical properties - Good hydrophilicity - Conductivity - Outstanding mechanical properties - Thermal effect - Excellent biocompatibility - High electrical conductivity	- The preparation process of MXene sensitive materials must be further developed - The abundant functional groups on the surface of MXene materials endow them with customizable optical and electrical properties, but also bring new challenge

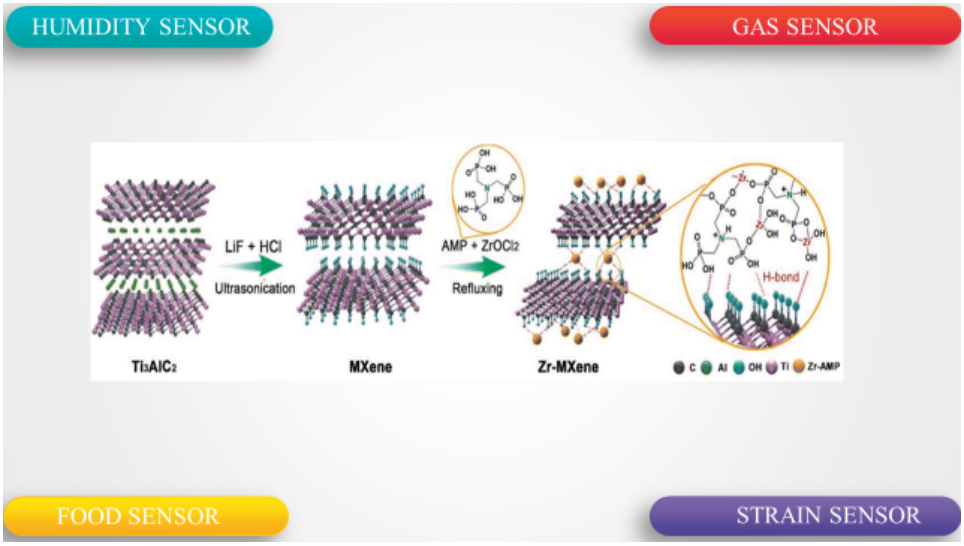

Figure 1 - Types of Mxene-based sensors [19]

Materials and methods. *Nanocomposite WO_3/Mxene*

Al-Zoha Wapsi and others [23] used a hydrothermal method for the synthesis of tungsten oxide nanorods. The synthesis of WO_3/MXene by a simple ultrasound method was carried out. The samples obtained were characterized by structural, spectral, morphological and elemental analysis. The photocatalytic and antibacterial activity of synthesized samples, these aspects are discussed in detail. Max (Ti_3AlC_2) powder was used in a 50 ml Teflon container to synthesize MXene with the formula Ti_3C_2Tx used. To synthesize MXene with the formula Ti_3C_2Tx in a 50 ml Teflon container. For MXene synthesis, 10 ml of HF is poured into a Teflon container and then released into a suction cup . Then, instead of low HF, MAX 0.5 g powder and a pinch were added. The mixture was equipped with magnetic instruments for an hour at room temperature.

The combustion optimization of the mixture was carried out at the installation temperature for 24 hours with magnetic power. Deionized (DI) water was added to dilute the product, and MXene was obtained by centrifugation at more than 5000 rpm. The washing of these deposits was performed until the PH reached 6. The Aqueous Dispersion was carried out using a PTFE membrane by vaum filtration. Filtrate is here.

For FESEM analysis, samples were sprayed with gold for 120 seconds at a current of 15 ma. Figure-2 A, B WO_3 and WO_3/MXene nanocomposite

morphology control. Figure-2 - (a) illustrates the block/stick pattern morphology of WO_3. Figure-2 (b) MXene WO_3 is defined as impregnated with nano wires. MXene Nano sample structure formation in Figure 2 - (c). The size of the WO_3 was about 13 nm, after the reduction of FESEM. The MXene layer was estimated at ~175 nm on an additional micro-image. For FESEM analysis, the samples were subjected to gold spraying for 120 seconds at a current of 15 ma. Figure-2 A,B WO_3 and WO_3/MXene nanocomposite morphology control. Figure 1 shows the morphology of WO_3 with a block or stick inscription. Figure - 2 (b) MXene WO_3 is detected in an impregnated manner with nano wires. Figure 2 (c) shows the MXene formation of the nanoscale structure. The size of the WO_3 volume was about 13 nm, which is after the reduction of FESEM. In the micrograph, the size of the mxen layer was 175 nm.

In this paper, A.Z. Warsi, Aziz, F. Zulfiqar et al. prepared WO_3, MXene and WO_3/MXene nanocomposite which showed potential applications in biological and environmental remediation. WO_3, MXene and WO/Mxene nanocomposite were synthesized by hydrothermal method, wet chemical etching and sonication, respectively. XRD, XRD, FTIR, EDX and FESEM were used to determine the structural, spectral, elemental and morphological characteristics of the synthesized samples, respectively. BET analysis was performed to determine the surface area. The photocatalytic degradation of methylene blue using WO_3, MXene and WO_3/MXene nanocomposites was 99%, 54% and 89%, respectively. The photocatalytic activity of WO_3 was significant. MXene is a two-dimensional material with very low photocatalytic activity, which acts only as an auxiliary material to enhance the photocatalytic ability of the composite with WO_3.

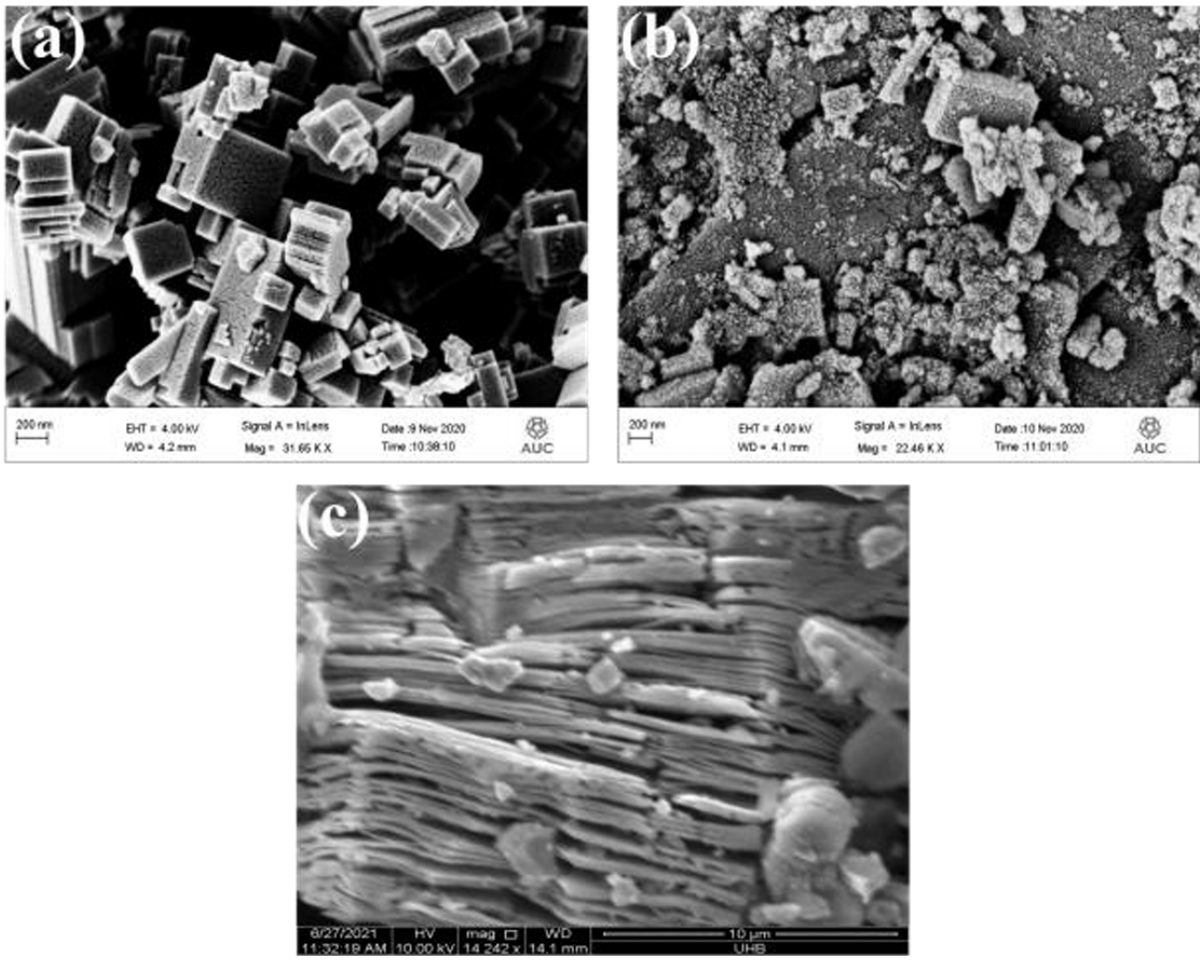

Figure 2 - FESEM images (A) WO_3, (b) WO_3/MXene nanocomposite and (c) MXene [23]

The prepared samples also showed good antibacterial activity against bacteria of positive strain; in case of negative strains, WO_3, MXene and WO_3/MXene nanocomposite showed antibacterial activity at high concentrations [23].

Bi_2S_3/MXene nanocomposite

In a study [24] by S. Sinha, A. Raucci et al. developed a novel electrochemical sensing platform using Bi_2S_3/MXene nanocomposite. The modified shape, composition and electrical characteristics of the prepared composites and their electrodes were studied by various electrochemical methods SEM, XRD, XPS and others. A 1 mg/ml solution of Bi_2S_3/Mxene nanocomposite was prepared by dispersing DI (deionized) in water. This standard solution was the base of the electrode modification process. This initial solution base served as the electrode modification process. An 8 μL dispersion of Bi_2S_3/Mxene nanocomposites was carefully placed on the surface of SPE to modify the electrode. Bi_2S_3/Mxene nanocomposites were synthesized directly by microwave-assisted hydrothermal method. The figure below shows the accumulation of 3 - (A) [24] Bi_2S_3 nanoparticles. These are granular nanoparticles with diameters ranging from 70 to 100 nm. And figure 3 - (B) shows the MXene SPE image. This figure shows the complex layered lamellar structure of MXene after removing the Al layers from the MAX phase. SEM image of Bi_2S_3-MXene nanocomposites are shown in Fig.3C and 3D (small and large scale).

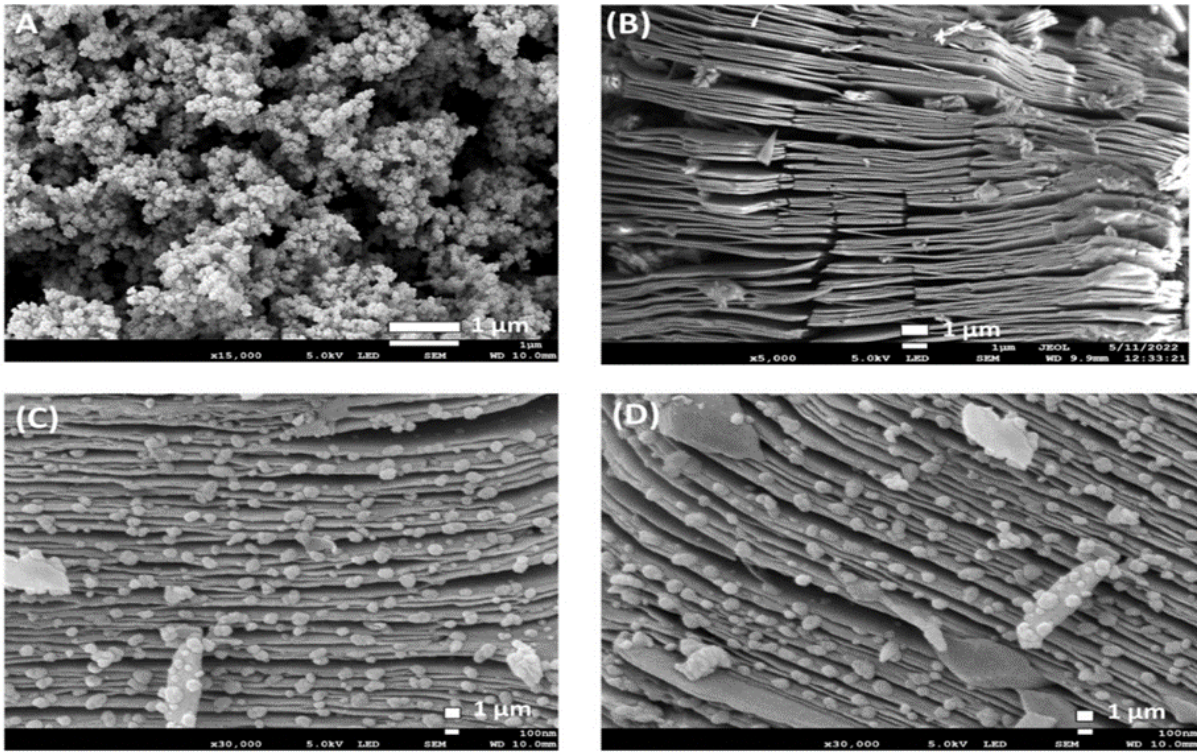

Figure 3 - Structural characteristics of (A) Bi_2S_3; (B) MXene; (C) Bi_2S_3-MXene nanocomposite at low magnification; (D) Bi_2S_3-MXene nanocomposite at high magnification [24]

The uniform growth of Bi_2S_3 nanoparticles in MXene layers growth of Bi_2S_3 nanoparticles (F and OH) was due to the presence of electronegative functional groups. The synergistic effect of Bi_2S_3 nanoparticles and MXene can improve the electrochemical performance. First, MXene provides a highly conductive platform for the uniform growth of Bi_2S_3 nanoparticles. This leads to reduced agglomeration of Bi_2S_3 nanoparticles and increased number of detection sites for the target analyte [25]. Secondly, MXene is highly conductive, which leads to an increase in charge between Bi_2S_3 nanoparticles and the electrolyte [26]. In addition, the oxidation resistance property demonstrated by MXene plays an important role in protecting Bi_2S_3 nanoparticles from corrosion [27]. The binding of MXene and Bi_2S_3 nanoparticles can lead to improved performance in Zn(II) detection.

The study focuses on the synthesis of a composite made of MoO_2@Mo_2C-MXene.

This article discusses the new CdS/MoO_2 photocatalyst @Mo_2C-MXene developed by You Jin, Huizhuan Jing, Libo Wang, Qianku Hu and Aigo Zhou. 0.2 g of NaBF4 (99.9%, McLean, China) was used as a guiding reagent, dissolved in 15 ml of 1.0 m HCl solution (36-38% C/a , Yantai Shuangshuang Chemical, China) and stirred for 30 minutes. The temperature of the hydraulic system is maintained at 180 ℃ for 24 hours every day. The temperature of the hydraulic system is kept at 180 ℃ for 24 hours every day. Subsequently, MoO_2@Mo_2C-MXene Composite powders were collected, subjected to washing with deionized water and ethanol to achieve a neutral reaction, and then dried for 12 hours at 60 ℃ for 12 hours under vacuum conditions.

CdS / MoO_2@ Mo_2C photocatalysts were effectively synthesized by a two-stage hydrothermal method . In this system, a sediment formed on the surface of the CdS MoO_2@Mo_2C-MXene Composite, forming an acanthospheric structure. CdS / MoO_2@Mo_2C(CMM5) showed an exceptional H_2 generation rate of 22,672 μmol/(g-h) in visible light under optimal conditions, which is 11.8 times higher than CdS. full row, Moo_2@Mo_2C-MXene binary co-catalyst using CdS using high photocatalytic activity of productive

H_2 generation with Mo_2C MXene as the only co-catalyst. Experimental effects the CdS/Mo_2C system effects work with CdS /Mo_2C with high photophysical and photoelectrochemical properties to serve as an electronic bridge between CdS and Mo_2C MXene with improved electrical conductivity . ”no,” he said. In addition to the CdS/Mo_2C script, the CdS conduction band (CB) is a place to charge when $MoO_2@Mo_2C$ is MXene bound. This effectively limits the re - diffusion of Altered electrons into CdS , thus facilitating the operation of recombination. The band forbidden to control over $CdS/MoO_2@ Mo_2C$ makes it easy to absorb visible light. This CdS/Mo_2C [28] element restored a new photocatalytic system with the formation of a binary H_2 co-catalyst.

The process of preparing Ti3C2 involves the use of various chemical and physical methods to create a highly durable and efficient material: The crude powder (50 g) was weighed in the following ratio TiC:Ti:Al = 3.6:1.4:1 and then placed in a Teflon ball mill. Anhydrous ethanol was then added to the ball mill tank as a ball grinding aid and zirconium dioxide (5 nm diameter) as a grinding medium. The mass ratio of raw material powder, anhydrous ethanol and pellets should be 1:1:3. The ball was placed in a grinding vessel and the powder mixture was pulverized at 300 rpm for 4 hours. Next, a ball mill was used to obtain a homogeneous mixture and then it was transferred into a petri dish. The mixture was dried in an oven at 40°C for 24 hours, then sintered in a corundum crucible without pressure.

After the reaction was completely completed, the sintering furnace was allowed to cool down naturally to room temperature and a Ti_3AlC_2 ceramic block was obtained by pressureless sintering. A high-energy ball mill was used to completely pulverize the Ti_3AlC_2 ceramic block obtained by pressureless sintering i+n the previous step; finally, the desired Ti_3AlC_2 powder was successfully obtained. At room temperature, 5 g of Ti_3AlC_2 powder was slowly added to 80 mL of 40 wt% HF and left to react for 24 h under magnetic stirring at 1200 rpm. The above corrosion products were purified with deionized water until the pH of the supernatant became > 6 after centrifugation. The substrate was lyophilized to obtain Ti_3C_2 powder.

Preparation of the PANI-Ti_3C_2 composite: first, 0.2 g of Ti_3C_2 powder was dispersed in 30 mL of 1M hydrochloric acid solution, then ultrasonic dispersion was carried out for 1 h until a homogeneous suspension was obtained. Second, 100 μL of pure aniline (ANI) obtained by distillation was added to the suspension and dispersed by ultrasonic dispersion for 1h. Then, 0.335 g of ammonium persulfate (APS) was dissolved in 30 mL of 1 M hydrochloric acid solution and added dropwise to the above solution. Finally, the solution was placed in an ice bath and stirred at 0°C for 6 hours. After reaction, the reaction product was washed with ultrapure water 5 times. After purification, the reaction product was lyophilized to obtain PANI-Ti_3C_2 nanocomposite [29].

Figure 1A shows the X-ray diffraction patterns of the obtained PANI, Ti_3C_2 and PANI-Ti_3C_2. The figure shows that the X-ray diffraction peak of PANI at 2 theta=20.5° corresponds to the surface (020) of the PANI crystal. The diffraction peak of Ti_3C_2 on the crystal plane (002) is shifted to the left along the x-axis from that of the original phase Ti_3AlC_2, which makes the characteristic peak of Ti_3C_2 weaker and wider.

This X-ray diffraction pattern can show that the degree of crystallinity and the degree of structural order of Ti_3C_2 are greatly reduced. In the X-ray radiograph of Ti_3C_2, the diffraction peaks at 2 theta =7.1°, 17°, 28°, 35°, 41° and 61° correspond to the crystal planes (002), (006), (008), (0010), (0012) and (110), respectively. Compared with the Ti_3C_2 XRD, the PANI-Ti_3C_2 XRD shows a new diffraction peak at 2 theta =20.7° corresponding to (020) crystal surface of PANI. The XRD peak of PANI-Ti_3C_2 at 2 theta =26° corresponds to TiO_2. This value is due to the fact that a small amount of Ti_3C_2 is oxidized by the addition of ammonium persulfate, an oxidizing agent, during the preparation of the PANI-Ti_3C_2 composite material. Thus, the phase analysis shows the successful preparation of PANI-Ti_3C_2 nanocomposite. Ti_3C_2 can easily immobilize enzymes/proteins on its surface, thus acting as a promising support to achieve DET with accelerated electrode kinetics, low detection limits, and high sensitivity and selectivity [30].

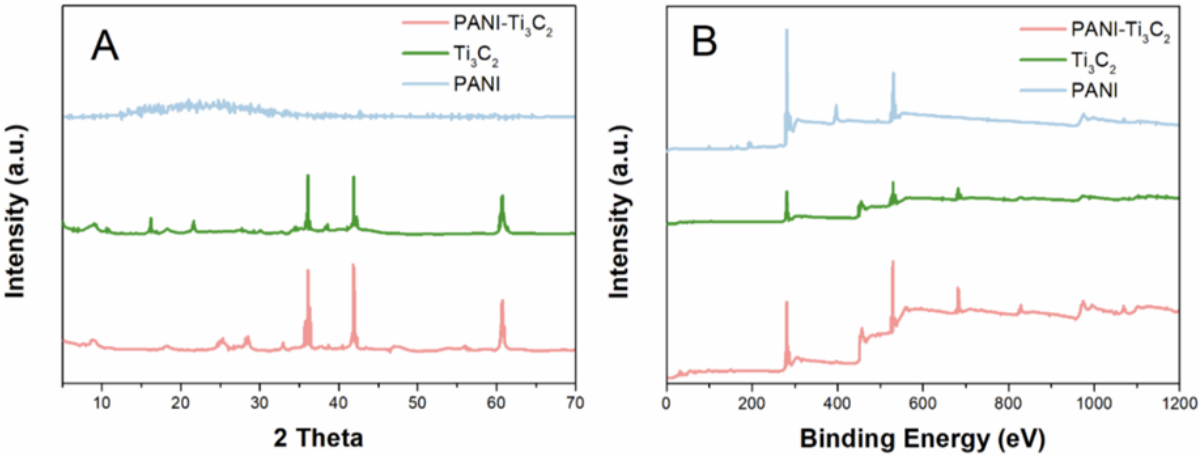

Figure 4 - (A) XRD patterns of PANI, Ti_3C_2 and PANI-Ti_3C_2. (B) XPS spectras of PANI, Ti_3C_2 and PANI-Ti_3C_2 [30]

Figure 1B shows the XRD spectra of the obtained PANI, Ti_3C_2 and PANI-Ti_3C_2. As can be seen from the figure, characteristic peaks C1s, O1s, F1s and Ti_2p appear, proving the existence of Ti_3C_2. At the same time, the appearance of characteristic peaks O1s and F1s proves the existence of functional groups -O, -OH and -F on the laminates of Ti_3C_2. The appearance of C1s and N1s peaks indicates the successful obtaining of PANI. Compared with Ti_3C_2 , the broad XPS spectrum of PANI-Ti_3C_2 shows N1s peak, which further proves the successful preparation of PANI-Ti_3C_2 nanocomposites under low temperature stirring conditions. The above results are in agreement with the results of X-ray diffraction analysis. By the integral approximation method, N1s -analysis of the RFES spectra of the PANI-Ti_3C_2 nanocomposite showed four characteristic peaks at 397.1 eV, 398.2 eV, 400.1 eV and 400.5 eV corresponding to the imine structure (=NH-), amino group (-NH-). -), N atom (N-+) with positron and protonated amino group, respectively. The results show that the PANI-Ti_3C_2 nanocomposite was successfully obtained by low-temperature oxidation reaction between Ti_3C_2 and aniline.

Ti_3C_2/TiO_2/CuO nanocomposites

In experiments, researchers Li, Wang, and Sun dissolved copper nitrate in deionized water and added Ti_3C_2 powder. The mixture was incubated for 24 hours, dried, and then synthesized into Ti_3C_2/TiO_2/CuO nanocomposites by annealing in an argon atmosphere at 500C for 30 minutes at a heating rate of 100C/min [31].

The fabrication of Ti_3C_2/TiO_2/CuO ternary nanocomposites, consisting of Ti_3C_2 nanosheets, TiO_2, and CuO nanoparticles, was enhanced by higher electron and hole separation efficiency compared to TiO_2, thereby improving their photocatalytic activity [32].

Discussion and results. In this research, a series of MXene-based nanocomposites including WO_3/MXene, Bi_2S_3/MXene, and Ti_3C_2/TiO_2/CuO were synthesized and characterized. The obtained materials showed high efficiency in various applications including photocatalytic decomposition of organic pollutants and electrochemical detection of heavy metals.

WO_3/MXene:

- The morphology of the nanocomposite determined by FESEM revealed the presence of nanowires and layered structure.

- The photocatalytic activity for methylene blue degradation reach-ed 89%, which is higher than that of pure WO_3 (99%) and significantly superior to that of MXene (54%).

- The nanocomposite demonstrated antibacterial activity against both positive and negative bacterial strains at high concentrations.

Bi_2S_3/MXene:

- The synergistic effect of Bi_2S_3 and MXene

was found to improve electrochemical performance, increase the number of active sites for analytical detection, and improve corrosion resistance.

- The nanocomposite was successfully used for Zn(II) detection with high sensitivity.

$Ti_3C_2/TiO_2/CuO$:

- The ternary nanocomposite showed enhanced photocatalytic activity due to the improved electron-hole separation ability.

- The enhanced photocatalytic efficiency was attributed to the presence of TiO_2 and CuO, which enhanced the interaction with Ti_3C_2.

These results confirm the potential of MXene-based nanomaterials in applications related to ecological remediation, biosensing and environmental monitoring.

The results confirm the significant contribution of MXene-based nanocomposites in improving the properties of sensors and catalysts.

Photocatalytic activity:

The high efficiency of WO_3/MXene in the photocatalytic decomposition of methylene blue can be explained by the combination of MXene (high conductivity) and WO_3 (active catalytic ability) properties. This supports the hypothesis of a synergistic effect in the creation of hybrid nanomaterials. Similarly, $Ti_3C_2/TiO_2/CuO$ nanocomposite demonstrates that the addition of CuO enhances the charge separation ability, which is critical for photocatalysis.

Electrochemical detection:

Bi_2S_3/MXene showed high sensitivity to Zn(II), which is attributed to the increase of active centers on the surface of MXene and its interaction with Bi_2S_3. This result is in line with current research in electrochemistry, where MXene is used as a basic structure to improve the sensor response.

Limitations and prospects:

Despite significant advances, difficulties in scaling up the production of MXene nanocomposites should be considered. Additional research is required to optimize synthesis methods and material stability. Prospects for the use of these materials include expanding their applications in environmental monitoring, biomedicine, and water quality control.

Thus, the results of this study confirm the relevance and promise of MXene-based nanocomposites for the development of high-performance sensors and catalysts. Future research should focus on improving the stability and fabrication processes of these materials.

Conclusion. This literature review is devoted to the detection of heavy metals. Heavy metals are found in many substances. There are many methods for detecting heavy metals. Despite the large number of methods, we must use the most effective of them. The article is written about the detection of heavy metals using a sensor. In order to improve the sensor, various nanomaterials are used. As a material, Mxene-based nanocompasites were considered. Focused on MXene-based nanocomposites and sensor research methods developed on their basis. MXene materials are a stable single-phase structure consisting of five or more atoms, and its elemental ratio can be adjusted. MXene contains more transition metals, which greatly optimizes material properties such as conductivity, hardness, chemical stability, and bulk capacity.

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