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Self-Assemble and In-Situ Formation of Laponite RDS-Decorated d-Ti₃C₂T_x Hybrids for Application in Lithium-ion Battery

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Abstract

Two-dimensional transition metal carbide materials called MXenes show potential application for energy storage. However, the lower capacity of MXene anodes limits their further application in lithium-ion batteries. d-Ti₃C₂T_x with less layered structure by intercalation and delamination of acoustic degradation method in DMSO(dimethyl sulfoxide). This fabricated fewer sheets samples not only improve the electrical conductibility, specific area, but also reduce the ion diffusion resistance. Here we reported the facile synthesis of new laponite/d-Ti₃C₂T_x nanocomposites by the edge positive RDS nanosheets were assembled on negative MXene nanosheets through electrostatic interaction. Structure of laponite RDS/d-Ti₃C₂T_x nanocomposites was investigated by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The characterization results show that the RDS nanosheets were intimately assembled on the d-Ti₃C₂T_x nanosheets. The electrochemical properties of the developed nanocomposite as anode materials of lithium-ion batteries were characterized. Electrochemical tests indicate that the charge-discharge result of laponite RDS/d-Ti₃C₂T_x can deliver an initial specific discharge capacity of 458 mAh • g⁻¹ under a current density of 50 mA • g⁻¹. And a reversible discharge capacity of 160 mAh • g⁻¹ at a current density of 1000 mA • g⁻¹, which was significantly higher than that of pure Ti₃C₂T_x, laponite RDS. The exceptional electrochemical performance of laponite/d-Ti₃C₂T_x electrode could be attributed to the improvement of electronic conductivity by d-Ti₃C₂T_x and laponite in the laponite/d-Ti₃C₂T_x composite.

Keywords: laponite RDS; Ti₃C₂T_x MXene; Li-ion batteries (LIBs); Electrochemical property; Anode materials.

1. Introduction

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Demand for novel, low-cost, eco-friendly, high performance energy storage systems has been increasing, to meet the energy needs of modern society and respond to emerging ecological problems. A requirement for almost every form of alternative energy is energy storage. Electrochemical energy storage systems, such as rechargeable batteries [1] and electrochemical capacitors (ECs), are among the leading electrical energy storage systems today. It is well known that small size electroactive materials can provide high electroactive regions, shorten the diffusion and migration path of ions, and mitigate mechanical deformation, all of which are conducive to improving the utilization rate of active materials and improving the stability of electrodes [2]. As ideal electrode material should be able to deliver the electrical charges quickly and store the charges at high density. However, it is not easy to find materials with both requirements at the same. Some of carbon materials with active sites for redox reactions and high conductivity are the most widely used electrode materials [3]. It is a pity that carbon materials exhibit a low specific capacitance and limited voltage window. Thankfully, since the pioneering work on graphene [4], the amount of research on other 2D materials, including inorganic graphene analogues (IGAs), has increased rapidly. In 2011, researchers at Drexel University reported a selective etching method to prepare a new IGAs family, called MXenes, from bulk materials [5].

In this strategy, the block materials with $M_{n+1}AX_n$ structure are transformed, where M is an early transition metal, A is a group 13-16 element, X is carbon or nitrogen, and $n=1-3$, into MXene by selective etching process[6]. The etching process, the surfaces of MXene are terminated by -F, -O, and -OH groups, MXene can be made to express different properties by modifying these terminating groups with various addends. In order to distinguish surface terminated MXenes from ones with bare surfaces, we will refer to the former as $M_{n+1}X_nT_x$, where T refers to the terminating functional groups. MXene materials contain a variety of elements, providing additional compositional variables [7]. These additional variables, combined with their complex hierarchical structure, give MXenes many specific properties. For example, MXenes provide the potential for developing electrode materials in lithium (Li)-ion batteries [8] and supercapacitors [9] with performance that outperform most previously reported materials. However, compared to graphene, the capacitance of MXenes are still lower, the lower capacity of MXene anodes limits their further application in lithium-ion batteries. In order to improve the performance, MXene-based synergistic hybrid systems with various materials such as metal oxide/sulfides [10-13], graphene [14,15], and carbon nanotubes [16], were investigated. Strong interfacial interaction and electronic coupling between the two components can reduce the resistance and improve the ion and/or electron conduction. As far as we know, the use of electrostatic self-assembly to fabricate a layered Laponite RDS/MXene composite has not been reported before.

Laponite is a synthetic mineral made of uniform disk-shaped nanosheets, similar in structure and composition to natural hectorite. It is a layered hydrous magnesium silicate belonging to the family of (2:1) phyllosilicates made up of sheets of octahedrally coordinated magnesium oxide sandwiched between two parallel sheets of tetrahedrally coordinated silica. Laponite RDS, a peptized version of Laponite RD, has an aspect ratio of 20:306 and chemical formula $Na_{0.7}$

($\text{Si}_8\text{Mg}_{5.5}\text{Li}_{0.3}\text{O}_{20}(\text{OH})_4\text{Na}_4\text{P}_2\text{O}_7$) [17, 18]. Most importantly, the lithium algal soil has a negative charge on the surface and a positive charge on the edge. Since the edge charges of the Laponite RDs nanosheets and MXene nanosheets are opposite, the two types of nanosheets can attract each other through electrostatic interactions. Therefore, a novel layered RDS/MXene composite material was prepared by electrostatic self-assembled method for the first time in this study. The architecture of the composite we have synthesized enabled excellent contact and enhances interfacial electron transfer. In addition, the electrochemical properties of RDS/MXene electrodes were studied in detail, and excellent results such as higher capacitance and better stability were obtained.

2. Experimental section

2.1. Materials

Powder samples: TiH_2 (99.7%, -300 mesh, Tianjin Sea of Clouds Titanium Industry Co., Ltd. China), aluminum powder (Al, 99%, -200 mesh, Chinese Medicine Group Shanghai Chemical Reagent Co., Ltd.), graphite (C, 99%, -200 mesh, Henan Huaxiang Carbon Powder Technology Co., Ltd), dimethyl sulfoxide (DMSO, Tianjin Damao Chemical Reagent factory), ethyl alcohol (AR, 99%) were afforded by Hongyan Reagent Company of China and distilled water (DW, lab-synthesized). MAX phase Ti_3AlC_2 , the precursor of 2-D structure nanomaterial $\text{Ti}_3\text{C}_2\text{T}_x$, was synthesized by pressless sintering technology and passed 500 mesh sieves in the previous report [19]. The pristine $\text{Ti}_3\text{C}_2\text{T}_x$ utilized [13] in this study were synthesized by selectively exfoliated “A” atoms from Ti_3AlC_2 (MAX) phase in hydrochloric acid (HCl, AR) solution of lithium fluoride (NaF, 99%, uoyang chemical reagent factory, China).

2.2. Synthesis procedure of the delaminated $\text{Ti}_3\text{C}_2\text{MXene}$

$\text{Ti}_3\text{C}_2\text{T}_x$ powders (2g) were added to 40 mL of DMSO and under magnetically stirred at room temperature for 18 h. Then DI water was added and the mixture was centrifuged at 8000 rpm for 10 min to obtain the precipitate, which was dispersed in 500 mL deoxygenated DI water. The suspension was then ultrasonicated for 6 h under Ar flow, Ar gas was introduced to protect the as-delaminated nanosheets from oxidation. After that, the suspension was centrifuged for 1 h at 3500 rpm. The supernatant was collected to obtain the delaminated MXene suspension, stored in the glass vials and labelled as “d- $\text{Ti}_3\text{C}_2\text{T}_x$ ”. lastly measure the concentration of the delaminated MXene. Fig. 1(a) is XRD patterns of the resulting ‘paper’ clearly showed that the non-basal peaks at $2\theta=60^\circ$ vanished after delamination. The morphology of Ti_3AlC_2 , Ti_3C_2 and d- Ti_3C_2 were characterized by FESEM. In the Fig. 1(b)-(d) showed the tightly layered structure of Ti_3AlC_2 , the multi-layered structure of Ti_3C_2 and the flakes structure of d- Ti_3C_2 . This result provided compelling evidence for the loss of order along all, but [0001] and consequently, full delamination [8].

Fig .1 (a) XRD patterns of Ti_3AlC_2 , Ti_3C_2 and $\text{d-Ti}_3\text{C}_2$; (b)-(d) The morphology of Ti_3AlC_2 , Ti_3C_2 and $\text{d-Ti}_3\text{C}_2$.

2.3 Fabrication of $\text{d-Ti}_3\text{C}_2\text{T}_x$ / Laponite nanocomposite

The RDS/MXene composite was prepared by mixing two dispersion solutions of edge positive RDS nanosheets and negative MXene nanosheets. In details, in a typical batch Laponite RDS in a mass ratio of 20%, was dissolved in a 10 ml of water and sonicated for 2 h until complete dissolution. 100 mL $\text{d-Ti}_3\text{C}_2$ was then poured into the obtained solution, and sonicated for 30 min and then the mixture was kept standing for 24 h. The composite slowly transforms into a precipitate and settles to the bottom due to electrostatic selfassembly. Certain amount of $\text{d-Ti}_3\text{C}_2\text{T}_x$ and Laponite RDS/ $\text{d-Ti}_3\text{C}_2\text{T}_x$ dispersion were added to stainless steel dish, respectively. The resulting mixture precooled in liquid nitrogen, and then transferred to the freeze-drying apparatus with a temperature of -50°C . The system was continuously pumped (under 1 Pa) for 24 h to sublimate the frozen solvent. After that, the powder was collected and labelled as “freeze-dried $\text{d-Ti}_3\text{C}_2\text{T}_x$ and Laponite RDS/ $\text{d-Ti}_3\text{C}_2\text{T}_x$ ”. Here, for comparison, $\text{d-Ti}_3\text{C}_2\text{T}_x$ powder was synthesized but without laponite,

2.4 Materials characterization

The morphologies and microstructures of samples were observed by field emission scanning electron microscope (FESEM, Hitachi S4800) with integrated Energy-dispersive X-ray spectroscopy (EDS) for element analysis and a transmission electron microscopy (TEM, JEOL JEM-2010, Japan, acceleration voltage = 100 kV). The crystal structure of samples were determined by X-ray diffractometer (XRD, D8 Advance Bruker X-ray diffractometer equipment with Cu K α radiation using Ni-filtered) with a scanning rate of $15^\circ/\text{min}$ and a step size of 0.02° in the range of $5-80^\circ$. Thickness was characterized by the atomic force microscopy (AFM, FM-Nanoview6800, Jiangsu, China.).

2.5 Electrochemical measurements

To test the electrochemical performance of Laponite RDS, d-Ti₃C₂T_x and Laponite RDS/d-Ti₃C₂T_x made in this paper as anode materials for lithium-ion batteries. Cell measurements were performed using coin-type 2016 cells with pure lithium metal as both the counter electrode and reference electrode at room temperature. Sample electrodes, consisting of 80 wt.% the active material, 10 wt.% acetylene black and 10 wt.% polyvinylidene fluoride (PVDF) binder. above the materials were mixed in solution of N-methyl-2-pyrrolidinone (NMP) and stirred for 1.5 h. The slurry was then carefully and uniformly coated onto copper foil using a glass rod and dried at overnight 110°C in a vacuum oven. The electrolyte was 1M LiPF₆ in a mixture of ethylene carbonate (EC): dimethyl carbonate (DMC): ethylmethyl carbonate (EMC) in a 1:1:1 volume ratio. The separator was a Celgard polypropylene membrane. Stainless steel spacers were also inserted in the cell to ensure good electrical contact between the layers. Thereafter, the mass loading of the five electrode materials were about 0.02 mg/cm², the electrodes were assembled into lithium-ion batteries in an argon-filled glove box with concentrations of H₂O and O₂ (H₂O < 1 ppm, O₂ < 1 ppm) to avoid any moisture contamination, using lithium metal as the counter electrode. The tests of galvanostatic charge/discharge of the coin cells were carried out using XINWEI electrochemical work station, with a current density ranging from 50 to 1000 mA • g⁻¹ under the voltage between 0.01 and 3 V versus Li⁺/Li. And cyclic voltammetry (CV) were performed to examine the reduction and oxidation peaks by an EQCM440 workstation (Shanghai Chenhua, China) at a scan rate of 0.2 mVs⁻¹. Electrochemical impedance spectroscopy (EIS) was conducted on an electrochemical workstation (Parstat 2273, Princeton) with a frequency range from 50 mHz to 100 kHz. All of the electrochemical measurements were carried out at room temperature.

3. Results and Discussion

3.1 Structure and morphologies of RDS/d-Ti₃C₂T_x composite

Fig. 2 Illustration of the process for preparing the RDS/d-Ti₃C₂T_x composite

The fabrication process of the RDS/MXene composite, obtained by electrostatic self-assembly between edge positive charge of the RDS nanosheets and surface negative charge of MXene nanosheets, was schematically illustrated in Fig. 2. The RDS with surface negatively charge and edge positively charge forms a stable aqueous dispersion, and d-Ti₃C₂T_x synthesized by etching Ti₃AlC₂ and exfoliating the multilayered Ti₃C₂T_x, forms a well dispersible suspension. When the RDS nanosheets with edge positive charge were poured into the negative d-Ti₃C₂T_x nanosheet solution, the RDS nanosheets were adsorbed on the MXene nanosheets by electrostatic self-assembly, and an RDS/d-Ti₃C₂T_x composite is formed finally. These results indicated that the RDS nanosheets and MXene nanosheets completely self-assemble. According to the analysis above, we could conclude that electrostatic self-assembly was a mild and effective method to prepare RDS/d-Ti₃C₂T_x composite materials.

To investigate the dispersion of the Laponite RDS layers in the d-Ti₃C₂T_x matrix, XRD analyses were performed on the nanocomposites. Typical XRD patterns of several samples are presented in Figure 3, the several sharp of laponite RDS powder diffraction peaks due to Na₄P₂O₇ are also observed at $2\theta = 19.64^\circ$ (basal d-spacing (d) = 0.45 nm); $2\theta = 20.11^\circ$ (d = 0.44 nm); and $2\theta = 26.64^\circ$ (d = 0.34 nm) [20]. In all XRD patterns of the nanocomposites, no diffraction peaks between $2\theta = 5-12^\circ$ were observed (Figure 3b), indicating a good nano dispersion and exfoliation of the clay platelets, that is, separated platelets dispersed individually in the d-Ti₃C₂T_x matrix [18]. According to Delhom et al [21], the lack of a diffraction peak in a composite with clay as part of its structure was good indication that the composite is a true nanocomposite, with the polymer intercalated with the exfoliated clay.

Fig. 3. (a) X-Ray diffraction (XRD) patterns of the Laponite RDS, d-Ti₃C₂T_x and Laponite RDS/d-Ti₃C₂T_x nanocomposites and (b) XRD patterns expanded in the $2\theta = 5-12^\circ$ region showing the nano dispersion/exfoliation of the clay platelets.

The SEM was used to investigate the morphology of d-Ti₃C₂T_x and Laponite RDS/d-Ti₃C₂T_x. Fig. 4a shows the few-layer flakes that may result from restacking of the flakes during drying. The d-Ti₃C₂T_x flakes exhibited features from delamination of exfoliated MXene Ti₃C₂ domains, namely a crumpled and superposed morphology. The surfaces of the Laponite/d-Ti₃C₂T_x composites were shown in Figure 4b. These SEM images indicate that the Laponite is very well

dispersed in the MXene nanosheets. The formation of the as-prepared RDS/d-Ti₃C₂T_x composite was also verified by the elemental mapping using energy dispersive spectroscopy (EDS) analysis (Fig. 4c). The signals of Mg, Si and Ti were well distributed according to the sites of the RDS nanosheets and d-Ti₃C₂T_x nanosheets on the surface of the RDS/d-Ti₃C₂T_x composite, respectively. Besides, the EDS result verifies the elementary composition of the composite.

Fig. 4 (a-b) Scanning electron micrographs of the d-Ti₃C₂T_x and Laponite RDS/d-Ti₃C₂T_x nanocomposites; (c) EDS elemental mapping of Ti, C, O, F, Si and Mg of the area in the (b) inset.

The incorporation of exfoliated clay nanosheets on into d-Ti₃C₂T_x is further confirmed by Transmission electron microscopy (TEM) analysis. As shown in Figure. 5a, due to ultimately thin shapes, the d-Ti₃C₂ entirely transparent to an electron beam, TEM of d-Ti₃C₂T_x indicated that it exhibited a sheet morphology. Fig. 5c shown the TEM images of Laponite RDS/d-Ti₃C₂T_x nanocomposites. Black flakes of Laponite, marked by red circles, were found to be adhered to the d-Ti₃C₂T_x sheets, which was consistent with SEM results shown in Fig. 5b. This structure was due to an electrostatic self-assembly mechanism involving the surface charge of Laponite and the d-Ti₃C₂T_x. Normally, Laponite particles acquire a negative charge on their faces, and positive charge on the rims. From high resolution lattice images of Ti₃C₂T_x 2D nanosheets (Fig. 5a inset), we could estimate an interplanar distance of 0.228 nm, which was ascribed to the (104) planes of Ti₃C₂T_x [22, 23]. After removal of large particles by centrifugation, the resulting aqueous colloidal suspensions of d-MXene flakes were quite stable. The majority of flakes were small with a relatively narrow size distribution. Atomic Force Microscope (AFM) analysis (Fig. 5b) of the exfoliated flakes which remained in suspension indicates that most of the flakes have a typical thickness of about 1.5 nm (Fig. 5b inset), less than the 2 nm expected thickness of MXene layers. Laponite RDS in water forms a colloidal dispersion of charged disk-like particles with a diameter of ~25 nm and a thickness of ~1 nm [24]. Some Laponite have curled edges, rendering it possible to evaluate a sheet thickness during TEM. As shown in (Fig. 4c inset), TEM images displaying

Laponite with a thickness of around 1nm. From the image, it could be seen that Laponite RDS was adsorbed uniformly by electrostatic forces on the surface of d-Ti₃C₂T_x sheets. The positive charge on the edge of Laponite RDS, form static adsorption with the negative charge taken by d-Ti₃C₂T_x MXene. This would lead to the formation of layered framework structure (as shown in Fig. 5d), which would be favorable to improve the electric conductivity of Laponite RDS/d-Ti₃C₂T_x nanocomposites.

Fig. 5 (a, b) TEM and AFM images of d-Ti₃C₂T_x flakes; (c) TEM images of the Laponite RDS/ d-Ti₃C₂T_x nanocomposite; (d) the structure schematic of Laponite RDS/ d-Ti₃C₂T_x nanocomposite

3.2 Electrochemical results

The electrode activities of the d-Ti₃C₂T_x and Laponite RDS/d-Ti₃C₂T_x nanocomposites were examined by employing them as anode materials for lithium ion batteries (LIBs). Results of these experiments were shown in the top and middle panels of Fig. 6. The discharge capacity and cycling performance of the electrode materials at an elevated current density were significant parameters for an anode. In Fig. 6a, at current densities of 50 mA • g⁻¹, the Laponite RDS/d-Ti₃C₂T_x nanocomposite had a first-cycle capacity of roughly 457 mAh • g⁻¹ and a reversible capacity of roughly 214 mAh • g⁻¹. These results shown that the Laponite RDS/d-Ti₃C₂T_x composite had higher specific capacitance, Compared with the MXene and RDS nanosheets, The first-cycle irreversibility is probably caused by the formation of a solid electrolyte interphase (SEI)

layer, and possibly by an irreversible reaction between Li ions and the surface functional groups on the Laponite/d-Ti₃C₂T_x flakes [25].

In order to study the lithium storage performance and mechanism of electrode material, the LIBs with d-Ti₃C₂T_x and Laponite RDS/d-Ti₃C₂T_x nanocomposites as an anode material were tested. Typical cyclic voltammetry (CV) curves of LIBs made using d-Ti₃C₂T_x and the Laponite/d-Ti₃C₂T_x composites are shown in Fig. 6b. These sweeps used an electrochemical window of 3.0 to 0.01 V at a scan rate of 0.2 mV • s⁻¹. One sharp reduction peak at about 0.67 V was recorded, corresponding to formation of a solid electrolyte interphase (SEI) film from electrolyte decomposition and an irreversible reaction with the electrode material, which disappeared during subsequent cycling [26]. Another obvious lithiation peak at 0.01 V was related to the lithiation of the acetylene black, while a broad pair of oxidation/reduction peaks of around 2.4/1.59 V corresponded to the Li⁺ insertion/extraction from the electrodes [27,28]. The reactions were described in the following equations:

These three electrodes were then cycled at different current densities for 50 cycles, with the results shown in Fig. 6c. In the first 10 cycles at a current density of 50 mA • g⁻¹, the capacities of all of the electrodes were unstable. At this low current density, all of the electrodes had a relatively high specific capacity, but with an increase in current density, the specific capacity decreased. Results from longer term cycling stabilities of the as-prepared d-Ti₃C₂T_x, Laponite RDS/d-Ti₃C₂T_x composites were shown in Fig. 6d. Overall, the Laponite/d-Ti₃C₂T_x composites show superior electrochemical performance compared to d-Ti₃C₂T_x, while cycles proceed with a Coulombic efficiency close to 100% (fig. 6d). The addition of clay nanosheets into the nanocomposite contributes to a gradual increase of discharge capacity upon cycling, underscoring the beneficial role of clay nanosheets as an additive [29]. These results were further investigated using EIS, described below.

To further investigate the effect of the incorporation of clay nanosheets on the electrode activity of the Laponite/d-Ti₃C₂T_x electrodes, impedance spectra of the d-Ti₃C₂T_x, and the Laponite/d-Ti₃C₂T_x composites were measured. Fig. 5e compares the Nyquist plots of fresh cells made using the two materials. The frequency used for the measurements ranges from 100 kHz to 50 mHz. All three EIS curves consist of high-frequency and medium-frequency regions (depressed semicircle), as well as low-frequency regions (linear). The depressed semicircle represents the charge transfer resistance, while the linear portion at low frequency corresponds to the Lithium-ion diffusion coefficient in the anode materials[30]. The diameter of the semicircle corresponds to the charge transfer resistance (R_{ct}) originating from the electrochemical reaction between the electrode and electrolyte. The diameter of the semicircle for Laponite RDS/d-Ti₃C₂T_x was much smaller than that of d-Ti₃C₂T_x, indicating that the nanocomposites incorporating Laponite RDS had the best charge transfer performance among the two electrodes. This phenomenon may result from the synergic conductive network (as shown in Fig. 6d) of Laponite

RDS/d-Ti₃C₂T_x constructed by electrostatic self-assembly method, indicating a significant increase in the material conductivity of Laponite RDS/d-Ti₃C₂T_x.

Fig. 6 Characterization of Li-ion batteries made using d-Ti₃C₂T_x, Laponite RDS and Laponite/d-Ti₃C₂T_x composite anodes, including (a) galvanostatic charge/discharge curves at 50 mA.g⁻¹ for first cycle, (b) cyclic voltammetry curves (first three cycles); (c) Rate performance; (d) cycling performance and corresponding coulombic efficiency of d-Ti₃C₂T_x and Laponite/d-Ti₃C₂T_x composite at 1000 mA · g⁻¹, and (e) electrochemical impedance spectroscopy Nyquist plots.

Finally, to demonstrate the reasons for the increase in electrode capacity, we investigated the morphological changes of the d-Ti₃C₂T_x and Laponite/d-Ti₃C₂T_x composite anodes before and after all cycles using SEM (Fig. 7). Before assembling coin cells, all fresh electrodes exhibit a rough surface, as shown in Fig. 7a-b. After electrochemical cycling, however, the microstructure of the d-Ti₃C₂T_x electrode surface was hardly changed (Fig. 7c). This could be the result of partial loss of soluble lithium and the large volumetric expansion during discharge/charge process. In

comparison, the Laponite/d-Ti₃C₂T_x electrode microstructures became compact and smooth throughout the cycling test. The surface of the Laponite RDS/d-Ti₃C₂T_x is denser than d-Ti₃C₂T_x, as shown in Fig. 7d. These suggested that the presence of Laponite in electrode can alleviate the volumetric expansion of the layered microstructure by lithium, leading to enhanced electrochemical performance.

Fig. 7. SEM images of the following electrodes before and after all cycles: (a)-(c) d-Ti₃C₂T_x, (b)-(d) Laponite RDS/d-Ti₃C₂T_x.

4. Conclusions

In summary, we have put forward a suitable strategy for the synthesis of a novel RDS/d-Ti₃C₂T_x composite by simple electrostatic self-assembly between Laponite RDS clay nanosheets and MXene nanosheets. The structure and properties of the MXene material can be effectively modified by this approach at the nanoscale. Laponite RDS-coated d-Ti₃C₂T_x exhibits excellent electrochemical performances, including better capacity retention and rate capability than pure materials. Laponite RDS/d-Ti₃C₂T_x has a high reversible capacity of 160 mAh • g⁻¹ at a current density of 1000 mA • g⁻¹ for 500 cycles. The coating of Laponite might act as anode materials for lithium-ion batteries to enhance the initial rate capability and to give better cycle performance, because Laponite RDS has a positive edge charge that makes it easier to interact electrostatic with the surface charge of the d-Ti₃C₂T_x. We believe that this composite can be a promising electrode material for application in lithium (Li)-ion batteries.

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