Position Control of a 3D Printed Soft Finger with Integrated Soft Pneumatic Sensing Chambers

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Position Control of a 3D Printed Soft Finger with Integrated Soft Pneumatic Sensing Chambers

Abstract
© 2020 IEEE. Soft robots require robust soft and flexible sensors that can undergo large deformations repeatedly. This work reports on soft robotic fingers with embedded soft pneumatic sensing chambers that are directly 3D printed without requiring postprocessing. A low-cost and open-source fused deposition modeling (FDM) 3D printer that employs an off-the-shelf soft thermoplastic poly(urethane) (TPU) was used to fabricate the monolithic fingers and sensing chambers. These pneumatic sensing chambers have multiple advantages including very fast response to any change in their internal volume, linearity, negligible hysteresis, repeatability, reliability, stability over time, long lifetime and very low power consumption. The performance of these chambers is accurately predicted, and their topologies are optimized using finite element modeling (FEM). Also, the flexion of the soft robotic finger is predicted using a geometric model for use in real-time position control. The position control of the soft robotic finger is achieved using feedback signals from the soft pneumatic sensing chambers embedded in the finger.

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Effects of Carbon Content on the Electrochemical Performances of MoS$_2$-C Nanocomposites for Li-Ion Batteries

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**KEYWORDS:** Li-ion batteries, MoS$_2$, anode, effect of carbon content, stability

**ABSTRACT:** Molybdenum disulfide is popular for rechargeable batteries, especially in Li-ion batteries, due to its layered structure and relatively high specific capacity. In this paper, we report MoS$_2$-C nanocomposites which are synthesized by a hydrothermal process, and their use as anode material for Li-ion batteries. Ascorbic acid is used as
the carbon source, and the carbon contents can be tuned from 2.5wt% to 16.2wt%. With increasing of carbon content, the morphology of MoS$_2$-C nanocomposites changes from nanoflowers to nanospheres, and the particle size is decreased from 200nm to 60nm. This change is caused by the chemical complex interaction of ascorbic acid. The MoS$_2$-C nanocomposite with 8.4 wt% C features a high capacity of 970 mAh·g$^{-1}$ and sustains a capacity retention ratio of nearly 100% after 100 cycles. When the current increases to 1000 mA·g$^{-1}$, the capacity still reaches 730 mAh·g$^{-1}$. The above manifests that the carbon coating layer does not only accelerates the charge transfer kinetics to supply quick discharging and charging, but also holds the integrity of the electrode materials as evidenced by the long cycling stability. Therefore, MoS$_2$-based nanocomposites could be used as commercial anode materials in Li-ion batteries.

1. INTRODUCTION

Among the different kinds of devices for energy storage and conversion, lithium ion batteries (LIBs) are considered to be important to people’s daily lives because of their characteristics of relative safety, portability, and long life.$^{1-4}$ Nevertheless, commercial graphite anode suffers from low specific capacity of 372 mAh g$^{-1}$. For purpose of increasing the capacity and maintain long runtime in portable devices, various kinds of anode materials having the predominance of high capacity are being researched.$^{7-10}$ Recently MoS$_2$, a transition metal dichalcogenide compound, has attracted intensive attention for energy storage,$^{11-14}$ owing to its high specific capacity and unique large interlayer spacing which provides two-dimensional diffusion channel for Li$^+$. MoS$_2$ as a conversion-type anode material features a high theoretical capacity of 670 mAh·g$^{-1}$. The process of Li$^+$ ion intercalation forming the intermediate Li$_x$MoS$_2$, and then converting to the Mo metal and Li$_2$S are basic for the electrochemical
reaction of Li-MoS$_2$ batteries.$^{15-17}$ The reaction brings large volume changes and introduces a serious problem of high irreversible capacity which is ascribed to the separation of the Mo metal and Li$_2$S matrix.$^{18}$ In addition, the conductivity of MoS$_2$ is not high, which limits its rate performance. Since Li-MoS$_2$ batteries were first reported by Haering et al.,$^{19}$ many forms of nanostructured MoS$_2$ have been investigated to solve the above problems.$^{16,20-23}$ Ultrasmall, single-layer MoS$_2$ nanoplates decorated with carbon nanofibers (38wt%) were made by electrospinning in Maier’s group.$^{20}$ Xu and co-workers synthesized MoS$_2$-C via a simple hydrothermal method, with carbon content approximately 10 wt%, and achieved a high capacity of 888.1 and 511 mAh·g$^{-1}$ at a current density of 100 and 1000 mA·g$^{-1}$, respectively.$^{23}$ Liu et al. synthesized expanded layers in MoS$_2$-graphene nanocomposites by using butyllithium,$^{24}$ and they demonstrated a stable capacity of $\sim$1300 mAh·g$^{-1}$ after 200 cycles at 100 mA g$^{-1}$. All such reports show that modification of nanostructured MoS$_2$ with carbon materials is a very efficient method to accelerate the speed of the ionic and electronic transport.$^{17,22,24-27}$ In summary, control of the MoS$_2$ particle size and the carbon content in the composite (as little as possible) is very necessary.

Although many carbon materials have been tried for loading MoS$_2$, studies on the effects of the carbon content on the electronic and ionic transport, as well as the electrochemical performance, are limited. Herein we have synthesized MoS$_2$-C nanocomposites with expanded interlayer spacing through an ascorbic acid assisted hydrothermal method. The carbon source is ascorbic acid, which as an additive for refining the particle size. The as-prepared MoS$_2$-C with a carbon content of 8.4wt% exhibits a considerable capacity of 970 mAh·g$^{-1}$ at 100 mA g$^{-1}$ and 730 mAh·g$^{-1}$ at 1000 mA g$^{-1}$. After 100 cycles at 100 mA g$^{-1}$, the discharge capacity is still as high as 970 mAh·g$^{-1}$, with capacity retention of 97.3%.

2. EXPERIMENTAL SECTION

The MoS$_2$ and MoS$_2$-C samples preparing by the hydrothermal method were shown in Fig. 1.$^{28}$ Briefly, 0.3 g Na$_2$MoO$_4$·2H$_2$O and 0.4 g CS(NH$_2$)$_2$ were
dissolved in 30 mL of distilled water. The designed amount of ascorbic acid was added, and by the addition of concentrated hydrochloric acid (HCl), the pH was adjusted to 1. After stirring for 30 min, the precursors were transferred into a 45 mL Teflon-lined stainless steel autoclave and maintained at 180 °C for 24 h. The resultant black precipitate was centrifuged and washed with distilled water and ethanol. After drying in a vacuum oven and annealing at 700°C for 3 h, the final products were obtained. The molar ratios of Na₂MoO₄·2H₂O to ascorbic acid for the different samples were 2:0, 2:1, 2:2, and 2:3.

Fig. 1 Schematic illustration of the preparation of MoS₂-C nanocomposites.

X-ray diffraction (XRD) was performed in Rigaku MiniFlex600 using a Cu Kα radiation in the range of 5 – 80° at a scanning rate of 4°min⁻¹. Raman spectra were taken in DXR Thermo-Fisher Scientific with a laser wavelength λ=532 nm. Field-emission scanning electron microscope (SEM) images were taken from JEOL JSM7500F. High resolution transmission electron microscopy (HRTEM) was Philips Tecnai-F20. The carbon content of the MoS₂-C samples was determined by a TG-DSC using NETZSCH, STA 449 F3 with a ramp speed of 5°C min⁻¹ in ambient air in a temperature range of 30 °C to 650 °C.

The electrochemical testing procedure was similar as the previous report. Herein only change is the active materials. The batteries were tested within a potential range of 0.01 - 3 V at various current densities.

3. RESULTS AND DISCUSSION

3.1 Material Characterization. Fig. 2a reveals the TG curves of the MoS₂-C nanocomposites. The mass loss can be attributed to the decomposition of C and MoS₂ in accordance with the following equations:
The decomposition of MoS$_2$ contributes to the mass loss (Equation (1)), and the carbon content is calculated by Equation (2). The carbon content of the composites are estimated to be 0.4wt%, 2.5wt%, 8.4wt%, and 16.2wt%, Therefore, these samples were labeled as 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$, respectively.

The X-ray diffraction patterns of the as-prepared 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ are shown in the Figure 2b. All the synthesized samples are in accordance with the 2H-MoS$_2$ (JCPDS card No. 37-1492), yet with weak and broadened peaks. When the content of carbon increases, the peak around 14°, corresponding to the (002) planes, becomes weaker, which is caused by the breaking of the weak van der Waals force bonds to form disordered layers. Moreover, the peak for the (002) planes shows a slight leftwards shift to a lower angle. Note also that the shift becomes larger as the amount of ascorbic acid rise. Because the (002) planes represent the interlayers of the MoS$_2$ material, there are inevitable changes to the layer morphology among the as-prepared samples, which could be due to the intercalation of small molecules between the interlayers of MoS$_2$ after large amounts of carbon coating are applied. As shown in Fig. 2c, Raman peaks around 375 cm$^{-1}$ and 405 cm$^{-1}$ correspond to the $E_{2g}$ and $A_{1g}$ vibration modes. According to previous reports, the broadened peaks represent nanoscale morphology, and the shorter peak distance between $E_{2g}$ and $A_{1g}$ also reflects the few-layer structure of the as-prepared samples, especially for the 16.2%C-MoS$_2$. The carbon coated samples are also characterized in the range from 1100 cm$^{-1}$ to 1800 cm$^{-1}$ (Fig. S1). Compared with 0.4%C-MoS$_2$ and 2.5%C-MoS$_2$, the 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ samples show clearer peaks around 1364 cm$^{-1}$ and 1587 cm$^{-1}$, which are distributed to the D (disordered) band and the G (graphite) band, respectively. The intensity ratio of the D peak to the G peak ($I_D/I_G$) can reflect the graphitization of each sample. The detailed value of $I_D/I_G$ is 1.05, 0.97, and 0.87
for 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$, respectively. It should be noted that, as the ascorbic acid content increases, the degree of graphitization becomes higher.

**Fig. 2** (a) Thermogravimetric analysis of 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ (b) XRD patterns of the as prepared 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ (JCPDS No. 37-1492 is served as comparison.) (c) Raman spectra of 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ within a range of 300 - 500 cm$^{-1}$.

Figure 3 presents SEM images of the MoS$_2$-C samples. With increasing carbon content, the morphology of MoS$_2$-C changes in three aspects. Firstly, the flower-like morphology partially changes to nanoparticles. The flower-like morphology can be clearly observed for 0.4%C-MoS$_2$ (Fig. 3a), while a distorted flower-like morphology with sub-microparticles is observed for 2.5%C-MoS$_2$.
(Fig. 3b). The 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ samples did not exhibit a flower-like morphology (Fig. 3c, 3d). Secondly, the size of the nanoparticles is reduced with the increasing carbon content. Compared with the 200 nm particle size of 0.4%C-MoS$_2$, the particle diameter of 16.2%C-MoS$_2$ shrinks to 60 nm. Furthermore, the surface area increases. The surface area was found to be 21.47, 47.94, 94.92 and 144.38 m$^2$g$^{-1}$ for the 0.4%, 2.5%, 8.4%, and 16.2% C samples by the BET method (Fig. S2). The carbon contents thus increase the surface area significantly, and this trend agrees with our previous work.$^{34}$

**Fig.3** SEM images of (a) 0.4%C-MoS$_2$, (b) 2.5%C-MoS$_2$, (c) 8.4%C-MoS$_2$ and (d) 16.2%C-MoS$_2$. (All the figures are taken at the same magnification)

Fig. 4 reveals the HRTEM images. From Fig. 4a, the graphene-like MoS$_2$ with few layers are detected, and no obvious amorphous carbon are found, which means layered construction forms during the hydrothermal process without adding ascorbic acid, and is preserved with less ascorbic acid in the precursors. However, compared to the 0.4%C-MoS$_2$, the interlayer of 2.5%C-MoS$_2$ (Fig. 4b) has an expansion from 0.63 nm to 0.66 nm. The carbon layer of 2.5%C-MoS$_2$ is thinner than that on 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$, and cannot be covered the surface completely. The 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ sample display a rather larger layer space of 0.67 nm and 0.70 nm. Furthermore, the surface of 8.4%C-
MoS$_2$ and 16.2%C-MoS$_2$ are coated with an amorphous carbon layer (Fig. 4c, 4d). From the HRTEM image of 16.2%C-MoS$_2$, the carbon layer is much thicker than for the other samples. With increasing carbon content, the MoS$_2$ layers become distorted, which should be a reasonable explanation for the broadened and weak XRD peak at ~14° for the MoS$_2$-C nanocomposites. Carbon coating could also help to prevent the restacking of MoS$_2$, with efficient separation for a few layers of MoS$_2$ sheets.

![HRTEM images of (a) 0.4%C-MoS$_2$, (b) 2.5%C-MoS$_2$, (c) 8.4%C-MoS$_2$ and (d) 16.2%C-MoS$_2$.](image)

3.2. Electrochemical Performance. Fig. 5 displays the electrochemical characterization of the as-prepared samples. The specific discharge capacities at the 1st cycle for 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$, and 16.2%C-MoS$_2$ are 887, 822, 1111, and 1297 mAh·g$^{-1}$, and the coulombic efficiencies are 86.1%, 85.2%, 78.9%, and 64.1% at the 1st cycle, respectively. At the 2nd cycle, the discharge capacities become 754, 709, 876, and 893 mAh·g$^{-1}$, respectively. The rate property is presented in Fig. 5a. 8.4%C-MoS$_2$ achieves a high rate capability, with 970 mAh·g$^{-1}$ at 100 mA·g$^{-1}$ and 710 mAh·g$^{-1}$ at 1000 mA·g$^{-1}$ (after activation). On the contrary, 0.4%C-MoS$_2$ suffers from rapid capacity fade as the current density increases. 2.5%C-MoS$_2$ shows improved rate capability.
compared to 0.4%C-MoS$_2$, but the capacity still undergoes a serious decline at high current density. 16.2%C-MoS$_2$ also features better rate performance, but the electrochemical performance at low current density is worse than that of 8.4%C-MoS$_2$, which should be ascribed to the carbon content. At a low current density, the Li$^+$ ion diffusion is hindered by the thicker carbon layers, leading to a low capacity for 16.2%C-MoS$_2$. 16.2%C-MoS$_2$ shows better tolerance of higher current densities, owing to the more conductive carbon associated with the higher degree of graphitization. The cycling performance is consistent with the rate performance (Fig. 5b). 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ show better cycling performance, compared to 0.4%C-MoS$_2$ and 2.5%C-MoS$_2$. 8.4%C-MoS$_2$ features capacity retention of 97.3% at 100 mA·g$^{-1}$. The charge and discharge curves of the first two cycles at 100 mA·g$^{-1}$ are displayed in Fig. 5c and Fig. S3. 0.4%C-MoS$_2$ (Fig. S3a) and 2.5%C-MoS$_2$ (Fig. S3b) show clear discharge platforms. 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$ (Fig. S3c), however, do not show any obvious platform, but have a slope instead, which may be owing to the amorphous carbon in the composite resulting in poor crystallinity. And the overlapped voltage range of MoS$_2$ and carbon also should be taken into account (Fig. S3d). The charge and discharge curves at the 2nd cycle exhibit large changes in the voltage platform, which is very common for the Li$_2$S/S couple in Li-S batteries.$^{35-37}$

Fig. 5d indicates obvious reduction peaks at 1.06 and 0.59V in the first cycle, corresponding to the formation of Li$_x$MoS$_2$ and the decomposition of MoS$_2$.\textsuperscript{18} In the reverse anodic scan, an oxidation peak at 1.57 V corresponds to the partial oxidation of Mo, and another pronounced peak at about 2.3 V is corresponding to S from the oxidation of Li$_2$S. During the following cycles, these peaks in CV less obvious and the two new reduction peaks at 1.86 V and 1.05 V appear, indicating the formation of Li$_2$S convert from the S with lithium-ion.\textsuperscript{38} Notably, the strength of cathodic peaks weakens rapidly, manifesting an irreversible conversion reaction during the lithium-ion insertion/extraction process. The other samples show the similar tendency with 8.4C%-MoS$_2$ while suggesting
inferior reversibility (Fig.S4). For the reference, the electrochemical performances of pure carbon are shown in Figure S5. It is declared that pure carbon contributes about 110 mAh g\(^{-1}\) at 100 mA g\(^{-1}\) after 50 cycles. And the reversible capacity is reduced to 45 mAh g\(^{-1}\) at the current density of 400 mA g\(^{-1}\). Considering the theoretical Li-storage capacity of MoS\(_2\) (670 mAh g\(^{-1}\)), the theoretical capacity of MoS\(_2\)-C at 100 mA g\(^{-1}\) is calculated as Equation (3):

\[
C_{8.4\%\text{-MoS}_2} = C_{\text{MoS}_2} \times \% \text{mass of MoS}_2 + C_{\text{pure carbon}} \times \% \text{mass of pure carbon} (3)
\]

\[
= 670 \times 91.6\% + 110 \times 8.4\% = 622.96 \text{ mAh g}^{-1}
\]

The high specific capacity of the MoS\(_2\)-C (our test result) is attributed not only to flower-like MoS\(_2\) nanosheets, but also to the synergistic effect between the MoS\(_2\) with expanded layers distances and the carbon. Although the reaction mechanism is partly equivalent to Li-S batteries after 1st cycling, the unique large interlayer spacing has still advantageous features as electrodes. MoS\(_2\) nanostructures with a larger spacing result in better material utilization and faster ionic diffusion for the initial lithiation kinetics.\(^{39}\) Furthermore, according to the galvanostatic charge and discharge profiles of MoS\(_2\)-C with the different interlayer space optimized, it shows that the large interlayer space can lower the discharge plateau in favour of applying to the full cells. Moreover, it is claimed that the first intercalation stage is important for optimizing the nanostructured electrode.\(^{40}\) After the first discharge, full charging–discharging for the Li–MoS\(_2\) system contains intermediate sulfur and the Mo nanoparticles have a multifunctional beneficial effect. First, the particles make for enhancing the electrical conductivity of the Li\(_2\)S matrix. Second, the nanoparticles Mo provide adsorption sites for soluble sulfur to prevent their dissolution. Therefore it can relieve the shuttling effect causing performance deterioration and guarantee the stability of cycling. Besides, carbon also works in the above role cooperating with Mo nanoparticles.\(^{41,42}\)
Fig. 5 Electrochemical tests on the MoS$_2$-C composites. (a) Rate and (b) cycling performances of 0.4%C-MoS$_2$, 2.5%C-MoS$_2$, 8.4%C-MoS$_2$ and 16.2%C-MoS$_2$. (c) Charge and discharge curves of 8.4%C-MoS$_2$ at 100mA g$^{-1}$ for the 1st and 2nd cycles, and (d) the initial three CV curves of 8.4%C-MoS$_2$.

Fig. 6a presents the electrochemical impedance spectra (EIS) of the samples. The signal was collected at 1.0 V in the 1st discharge. The EIS plots consist of a semicircle at high frequency (with the diameter of the semicircle related to the charge transfer resistance) and a line at low frequency (related to the Li$^+$ ion diffusion). By simulating the EIS data with the equivalent circuit in the inset of Fig. 6a, we have calculated the values of $R_{ct}$ for the samples, and these are shown in Table S1.$^{43}$ As the carbon content increases, the value of $R_{ct}$ decreases. The results indicate that 16.2%C-MoS$_2$ possesses the lowest $R_{ct}$. EIS characterizations of 2.5%C-MoS$_2$, 8.4%C-MoS$_2$, and 16.2%C-MoS$_2$ after 10, 20, 50 and 100 charge and discharge cycles are shown in Fig. S6. The $R_{ct}$ value of 2.5%C-MoS$_2$ obviously increases as the charge-discharge cycling proceeds. After 100 cycles, 2.5%C-MoS$_2$ shows the largest $R_{ct}$ among these three samples. Although the $R_{ct}$ of 16.2%C-MoS$_2$ after 10 cycles is lower than that of 8.4%C-MoS$_2$, their $R_{ct}$ values are almost the same after 100 cycles (Table S2).
particular, the value for 8.4\%C-MoS$_2$ is nearly unchanged after 20 cycles. To understand the in-depth mechanism behind the impedance, the samples were compared using galvanostatic intermittent titration technique (GITT) measured from 0.4 to 3V, based on Fig. S7 and Equation (4).\textsuperscript{44} The $L$ is the thickness of the electrode, $\tau$ is the titration time, $\Delta E$ is the difference between two consecutive stabilized open circuit voltage, and $D$ is the variable of Li$^+$ diffusion coefficients. The battery was discharged at a constant current 0.7 mA for an interval $\tau$ of 10 min followed by an open circuit stand for 40 min. The chemical diffusion coefficients of Li$^+$ are shown in Fig. 6b. It follows that the diffusion coefficients in the MoS$_2$ composite electrodes are in the range of $10^{-15}$-$10^{-9}$ cm$^2$ s$^{-1}$. Meanwhile, the diffusion coefficient of 8.4\%C-MoS$_2$ is higher than for the other three nanocomposites from 0.5 V to 1.6 V. This is a convincing clue to the better electrochemical performance of this sample. The above-mentioned electrochemical properties exactly represent the importance of the carbon framework, as in previous work.\textsuperscript{45}

$$D = \frac{4}{\pi} \left( \frac{IV}{Z_{AFS}} \right)^2 \left[ \frac{dE(x)}{dx} \right] \left[ \frac{dE(\tau)}{d\sqrt{\tau}} \right]^2$$

\begin{equation}
\text{for } \tau \ll \frac{L^2}{D}
\end{equation}

\textbf{Fig.6} (a) EIS characterization of 0.4\%C-MoS$_2$, 2.5\%C-MoS$_2$, 8.4\%C-MoS$_2$ and 16.2\%C-MoS$_2$ (at the discharge platform of the 1st cycle after activation). The inset is the equivalent circuit (Rs: solution resistance, $R_{ct}$: charge transfer resistance, $Z_w$: Warburg impedance, $CPE1$: double layer capacitance between
(a) The chemical diffusion coefficient of Li$^+$ as a parameter of voltage calculated by GITT.

The excellent electrochemical property of MoS$_2$-C is ascribed to the following merits. On the one hand, the carbon frame mainly can not only promote the electrons and Li$^+$ ions diffusion kinetics but also prevent their pulverization and remit the volume expansion of MoS$_2$. Moreover, the carbon also can serve as conductive material, which avoids the loss of electrochemical contact between the active materials and the current collector, and act as a binder between the Li$_2$S/S and the Mo nanoparticles.\textsuperscript{37} To further explain why 8.4%C-MoS$_2$ has better electrochemical performance, an ideal model of MoS$_2$-C nanoparticles with carbon coatings is illustrated in Fig 7. Although the carbon layer restricts the volume change during electrochemical reactions, it also leads to fewer interfaces between MoS$_2$ and the electrolyte, which means sluggish kinetics and lower specific capacity. For MoS$_2$ with very little carbon content (Fig. 7a), the MoS$_2$ surface can’t be coated with carbon completely. When the MoS$_2$ particle is covered by an appropriate carbon content (Fig. 7b), the layer contains randomly distributed defects and vacancies, which promote Li$^+$ and electron transport.\textsuperscript{46} A thick carbon layer on the MoS$_2$ particle prolongs the distance for Li$^+$ transport (Fig. 7c). That is the reason why a proper amount of carbon (8.4 wt%) is required in the MoS$_2$-C composite to give it both high capacity and high rate capability.
Fig. 7 Proposed models of (a) 2.5%C-MoS₂, (b) 8.4%C-MoS₂, and (c) 16.2%C-MoS₂, showing the effects of the carbon coating layer on the electron conduction and Li⁺ transport within the MoS₂-based particles.

4. CONCLUSION

MoS₂-C nanocomposites have been synthesized through an ascorbic-acid-assisted hydrothermal process. Ascorbic acid as a carbon source plays a decisive role in refining the MoS₂ particle size, and enhancing the total electronic conductivity by forming three-dimensional carbon frameworks which not only accelerates the charge transfer kinetics but also guarantees the integrity of the electrode materials. 8.4%C-MoS₂ features the excellent electrochemical performance, due to its optimal carbon content and stable carbon frameworks, and in particular, it is large surface area and many active reactive sites. MoS₂ nanoparticles coated with carbon have great potential for application in rechargeable lithium ion batteries.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information about the detailed description of the experiments is available free of charge on the ACS Publications website

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