The application of functionalized 2D materials in solid-state electrolyte for flexible supercapacitors

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Solid-state flexible supercapacitors (SSFSs) have drawn an increasingly attention due to their high-power density (i.e., fast charge-discharge rate) and special mechanical properties (e.g., foldability) [1]. Owing these properties, SSFSs represent appropriate candidates for powering portable electronic devices, including wearable power-supply units [2]. In addition, SSFSs eliminate some negative features concerning traditional supercapacitors such as electrolyte leakage, safety and environmental issues and the requirement of rigid and robust packaging [3]. However, solid-state electrolytes still suffer of poor ion mobility and reactivity that undermine the distinctive high-power density of supercapacitors [4]. To overcome these issues, the incorporation of transition metal dichalcogenides (TMDCs), i.e., sulfonated 2D niobium disulphide (S-NbS_2), in proton-conducting sulfonated poly(ether ether ketone) (SPEEK) was investigated as solid-state electrolyte for high-power SSFSs. Ultrasonication-assisted liquid-phase exfoliation was applied to produce single-/few-layer NbS_2 flakes starting from their bulk counterpart [5]. The 2D NbS_2 flakes have been functionalized with sodium 3-mercapto-1-propane sulfonate [6]. The incorporation of S-NbS_2 into the SPEEK matrix increases the proton conductivity and dimensional stability of the pristine polymer due to the interaction between functionalized groups of S-NbS_2 and sulfonated groups of SPEEK. In this regard, a maximum proton conductivity of 94.35 mS cm^{-2} was achieved at room temperature by optimizing the S-NbS_2 loading into the nanocomposite electrolytes. In addition, the mechanical strength of the composite membrane (up to 38.3 MPa) improved of 18% compared to pristine SPEEK. To design advanced SSFSs, either SPEEK or polyvinylidene fluoride was used as different binders for the electrodes. The aim is to elucidate the importance of the compatibility of the current collector, solid electrolyte, and the binder to maximize the electrostatic charging of the electrode active material. The use of optimized solid-state electrolyte in SSFSs, based on proton-conducting SPEEK binder, allowed us to achieve a specific capacitance of 115.724 F g^{-1} at 0.02 A g^{-1}, showing optimal rate capability (75.94 F g^{-1} at 10 A g^{-1}) and electrochemical stability over galvanostatic charge/discharge cycling tests. Overall, our results rationalize the use of S-NbS_2 as additive for solid-state electrolytes, promoting the development of high power SSFSs.

References

[1] X. Hou, Q. Zhang, L. Wang, G. Gao, W. Lü, ACS Appl. Mater. Interfaces. 13 (2021) 12432–12441.
[2] Y.R. Jeong, G. Lee, H. Park, J.S. Ha, Acc. Chem. Res. 52 (2019) 91–99.
[3] C. Zhong, Y. Deng, W. Hu, J. Qiao, L. Zhang, J. Zhang , Chem. Soc. Rev. 44 (2015) 7484–7539.
[4] H. Beydaghi, L. Najafi, S. Bellani, A. Bagheri, B. Martín-García, P. Salarizadeh, K. Hooshyari, S. Naderizadeh, M. Serri, L. Pasquale, B. Wu, R. Oropesa-Nuñez, Z. Sofer, V. Pellegrini, F. Bonaccorso, J. Mater. Chem. A. 9 (2021) 6368–6381.
[5] L. Najafi, S. Bellani, R. Oropesa-Nuñez, B. Martín-García, M. Prato, V. Mazánek, D. Debellis, S. Lauciello, R. Brescia, Z. Sofer, F. Bonaccorso, J. Mater. Chem. A. 7 (2019) 25593–25608.
[6] L. Najafi, S. Bellani, R. Oropesa-Nuñez, B. Martín-García, M. Prato, L. Pasquale, J.K. Panda, P. Marvan, Z. Sofer, F. Bonaccorso, ACS Catal. 10 (2020) 3313–3325.