Seamless Textile Integration of MXene Yarn Asymmetric Supercapacitors for Powering Future Wearable Technology

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The ever-growing interest for close human interaction with electronic devices for health and activity monitoring, sports, communication, and entertainment has driven rapid advancements in wearable technology. As wearable technology evolves, there is a paradigm shift from rigid, heavy, and bulky accessories to soft, lightweight, and textile-integrated platforms. A new generation of wearable technology is emerging that uses soft electronic textiles (E-textiles) [1] to seamlessly integrate a wide range of functionalities while retaining the original properties of conventional textiles. As E-textiles continues to advance, there is a growing need for energy storage solutions that match the inherent textile's flexible form factor while being seamlessly integrable into garments to power the embedded electronic devices. However, a significant challenge remains in developing high-performance yarn-based energy storage systems that can be seamlessly integrated into everyday textiles for unobstructive application as embedded power supply units. Two-dimensional (2D) nanosheets of transition metal carbides and nitrides, known as MXene ($M_{n+1}X_nT_x$ – M: transition metal, X: carbon and/or nitrogen, n: 1-4, and T_x: surface functional groups) [2], offer an outstanding electrical conductivity of up to ~15,000 S cm^{-1} (on a par with metals) [3] and a high specific capacitance of up to ~1,500 F cm^{-3} (>10 times higher than activated carbon used in commercial supercapacitors) [4]. $Ti_3C_2T_x$ MXene has been processed into fiber electrodes for symmetric supercapacitors [5]. This presentation addresses the need for a fully integrated soft energy storage system by reporting novel yarn asymmetric supercapacitors (YSCs) that are seamlessly integrated into textiles through a customizable riveted interconnection strategy [6]. $Ti_3C_2T_x$ MXene-coated cotton yarns (negative electrode) are developed that achieve a remarkable specific capacitance of ≈7,360 mF cm^{-2} (≈536 F g^{-1}). To complement the negative electrode, positive yarn electrodes based on reduced graphene oxide (rGO) and MoS_2 composite are then achieved through a tailored synthesis process. A YSC fabrication strategy based on matching the capacitance of the yarn electrodes results in an impressive specific capacitance of ≈658 mF cm^{-2} (≈53 F g^{-1}), energy density of ≈154.5 μWh cm^{-2} (≈12.3 Wh kg^{-1}), and power density of ≈8,147 μW cm^{-2} (≈650 W kg^{-1}). The practical applicability of the YSCs is demonstrated via a novel yet simple integration design, whereby YSCs are connected to conductive rivets which serve as buttons capable of toggling charge/discharge and easy removal from clothes for washing. This innovative textile integration strategy is facile, cost-effective, and compatible with the existing textile manufacturing technology, allowing for the seamless integration of a wide range of YSCs into everyday textiles with minimal infrastructure adjustments, opening new avenues for the widespread adoption of YSCs for wearable electronics. These advancements enable on-the-go powering of a diverse range of wearable systems such as health monitoring systems, sensors, display devices, and the Internet of things.

References

[1] R.F. Service, Science 301 (2003) 909–911.
[2] B. Anasori, M.R. Lukatskaya, Y. Gogotsi, Nat. Rev. Mater. 2 (2017) 16098.
[3] J. Zhang, N. Kong, S. Uzun, A. Levitt, S. Seyedin, P.A. Lynch, S. Qin, M. Han, W. Yang, J. Liu, X. Wang, Y. Gogotsi, J.M. Razal, Adv. Mater. 32 (2020) 2001093.
[4] M.R. Lukatskaya, S. Kota, Z. Lin, M. Zhao, N. Shpigel, M.D. Levi, J. Halim, P. Taberna, M.W. Barsoum, P. Simon, Y. Gogotsi, Nat. Energy 2 (2017) 17105.
[5] J. Zhang, S. Uzun, S. Seyedin, P.A. Lynch, B. Akuzum, Z. Wang, S. Qin, M. Alhabeb, C.E. Shuck, W. Lei, E.C. Kumbur, W. Yang, X. Wang, G. Dion, J.M. Razal, Y. Gogotsi, ACS Cent. Sci. 6 (2020) 254–265.
[6] N. Kumar, P. Wojciak, S. Seyedin, Small Sci. 5 (2025) 2500229.