Ultrahigh Rate Pseudocapacitive Energy Storage in Two-dimensional Transition Metal Carbides (MXenes)

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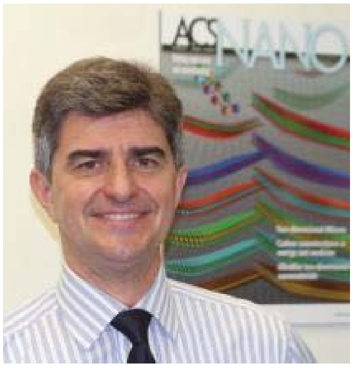
The use of surface redox storage (pseudocapacitive) mechanisms can enable devices that will store much more energy than electrical double layer capacitors and won't require prolonged charging, unlike batteries.[1] To deliver high energy densities at relatively high charge/discharge rates over thousands of cycles, pseudocapacitive materials must have a highly accessible surface, experience no phase transformations during operation, and have high electronic and ionic conductivity. Yet, few pseudocapacitive transition metal oxides can provide a high power capability due to their low intrinsic electronic and ionic conductivity. Therefore, pseudocapacitors usually operate at rates that are between that of batteries and double-layer capacitors. Herein we demonstrate that two-dimensional transition metal carbides (MXenes),[2,3] can operate at the rates exceeding that of conventional double-layer supercapacitors, but still provide higher volumetric and areal capacitance compared to carbons, conducting polymers or pseudocapacitive transition metal oxides. To benefit from their high electrical conductivity and transition metal oxide-like surfaces, which are readily accessible to ions, we designed electrode architectures that pushed performance of $Ti_3C_2T_x$ and Mo_2CT_x to the new heights. A macroporous $Ti_3C_2T_x$ MXene film delivered 210 Fg^{-1} at scan rates of 10 Vs^{-1} and 100 Fg^{-1} at 40 Vs^{-1}, surpassing the best carbon supercapacitors. Moreover, we show that MXene hydrogels are capable to deliver volumetric capacitance of ~1500 Fcm^{-3} - almost doubling the previously reported values and reaching the previously unmatched volumetric performance of RuO_2.

1. M. R. Lukatskaya, B. Dunn, Y. Gogotsi, *Nature Commun.* **7**, 12647, (2016).
2. M. Naguib, Y. Gogotsi, *Accounts of Chemical Research*, **48**, 128-135 (2015)
3. B. Anasori, M. R. Lukatskaya, Y. Gogotsi, *Nature Reviews Materials*, **2**, 16098 (2017)



Yury Gogotsi is Distinguished University Professor and Trustee Chair of Materials Science and Engineering at Drexel University. He is the founding Director of the A.J. Drexel Nanomaterials Institute and Associate Editor of *ACS Nano*. He works on nanostructured carbons and two-dimensional carbides for energy related and biomedical applications. His work on selective extraction synthesis of carbon and carbide nanomaterials with tunable structure and porosity had a strong impact on the field of capacitive energy storage. He has co-authored 2 books, more than 450 journal papers and obtained more than 60 patents. He has received numerous national and international awards for his research, the 2015 Nanotechnology International Prize (RUSNANO), Kavli Lecturer (MRS), Somiya Award (IUMRS), etc. He was recognized as Highly Cited Researcher by Thomson-Reuters in 2014-2016, and elected a Fellow of AAAS, MRS, ECS, RSC, ACerS and the World Academy of Ceramics.