Metallically Conducting Carbides and Nitrides (MXenes) for Energy Storage Technologies

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Two-dimensional (2D) materials with a thickness of a few nanometers or less can be used as single sheets, or as building blocks, due to their unique properties and ability to assemble into a variety of structures. Graphene is the best-known example, but several other elemental 2D materials (silicene, borophene, etc.) have been discovered. Numerous compounds, ranging from clays to boron nitride (BN) and transition metal dichalcogenides, have been produced as 2D sheets. By combining various 2D materials, unique combinations of properties can be achieved which are not available in any bulk material. The family of 2D transition metal carbides and nitrides (MXenes) has been expanding rapidly since the discovery of Ti_3C_2 in 2011 [1]. Approximately 30 different MXenes have been synthesized, and the structure and properties of numerous other MXenes have been predicted using density functional theory (DFT) calculations. Moreover, the availability of solid solutions on M and X sites, control of surface terminations, and the discovery of ordered double-M MXenes (e.g., Mo_2TiC_2) offer the potential for synthesis of dozens of new distinct structures.

This seminar will describe the synthesis of MXenes and their delamination into single-layer 2D flakes and assembly into films and 3D structures. Synthesis-structure-properties relations of MXenes will be addressed on the example of Ti_3C_2. The versatile chemistry of the MXene family renders their properties tunable for a large variety of applications. Oxygen or hydroxyl- terminated MXenes, such as $Ti_3C_2O_2$, have been shown to have redox capable transition metal layers on the surface and offer a combination of high electronic conductivity with hydrophilicity, as well as fast ionic transport. This, among many other advantageous properties, makes the material family promising candidates for energy storage and related electrochemical applications [3], but applications in optoelectronics, plasmonics, electromagnetic interference shielding, antennas, electrocatalysis, medicine (photothermal therapy and drug delivery), sensors, water purification/ desalination and other fields are equally exciting.

The most commonly researched MXene, titanium carbide ($Ti_3C_2T_x$), has already shown great potential as a supercapacitor and battery material owing to the high specific capacitance due to redox active transition metals at their surfaces and their high conductivities (>5000 S/cm) when they are fabricated into free-standing, flexible films. Strong binding of polysulfides makes it attractive for Li-S battery applications. The high conductivity and flexibility make MXenes great candidate materials for microscale on-chip and flexible energy storage devices and electronics. It can also be used as a conducting binder or current collector to replace the currently used materials. The ease with which MXenes can be dispersed in aqueous and organic solvents to make colloidal, functional inks allows for printing, spray coating, drop casting, and spin coating of MXenes, facilitating device manufacturing.

Reference
1. B. Anasori, M. Lukatskaya, Y. Gogotsi, 2D Metal Carbides and Nitrides (MXenes) for Energy Storage, *Nature Reviews Materials*, **2**, 16098 (2017)

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He has received numerous awards for his research including several honorary doctorates, the European Carbon Association Award, S. Somiya Award from the International Union of Materials Research Societies, Nano Energy award from Elsevier, International Nanotechnology Prize (RUSNANOPrize), R&D 100 Award from R&D Magazine (twice) and two Nano 50 Awards from NASA Nanotech Briefs. He has been elected a Fellow of the American Association for Advancement of Science (AAAS), Materials Research Society, American Ceramic Society, the Electrochemical Society, Royal Society of Chemistry, NanoSMAT Society, as well as Academician of the World Academy of Ceramics and Full Member of the International Institute for the Science of Sintering. He also serves on the MRS Board of Directors and acts as Associate Editor of ACS Nano.