Two-Dimensional Carbides (MXenes): Synthesis, Properties and Applications

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Two-dimensional (2D) solids – the thinnest materials available to us – offer unique properties and a potential path to device miniaturization. The most famous example is graphene, which is an atomically thin layer of carbon atoms bonded together in-plane with sp^2 bonds. In 2011, an entirely new family of 2D solids – transition metal carbides (V_2C, Ti_3C_2, Nb_4C_3, etc.) and nitrides – were discovered by Drexel University scientists [1]. Selective etching of the A-group element from a MAX phase results in formation of 2D $M_{n+1}X_n$ solids, labeled "MXenes". 17 different 2D carbides and carbonitrides have been reported to date [2-5]. A new sub-family of multi-element ordered MXenes was discovered recently [2]. Structure and properties of numerous MXenes have been predicted by the density functional theory, showing that MXenes can be metallic or semiconducting, depending on their composition, structure and surface termination. Their elastic constants along the basal plane are expected to be higher than that of the binary carbides. Oxygen or OH terminated MXenes, are hydrophilic, but electrically conductive (up to 6000 S/cm). Hydrazine, urea, amines and other polar organic molecules can intercalate MXenes leading to an increase of their *c* lattice parameter [3]. Colloidal solutions of single- and few-layer MXene flakes can be used to manufacture MXene films with controllable optical and electronic properties. One of the many potential applications for 2D Ti_3C_2 is in electrical energy storage devices such as batteries, Li-ion capacitors and supercapacitors [3-6]. Cations ranging from Na^+ to Mg^{2+} and Al^{3+} intercalate MXenes. Ti_3C_2 paper electrodes, produced by vacuum assisted filtration of an aqueous dispersion of delaminated Ti_3C_2, show a higher capacity than graphite anodes and also can be charged/discharged at significantly higher rates. They also demonstrate very high intercalation capacitance (up to 1000 F/cm^3) [5].

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