2D Carbides and Nitrides of Transition Metals (MXenes): Synthesis, Structure and Energy Storage 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. Recently, an entirely new family of 2D solids – transition metal carbides (Ti_2C, Ti_3C_2, Nb_4C_3, etc.) and carbonitrides – was discovered by Drexel University scientists [1,2]. Selective etching of the A-group element from a MAX phase results in formation of 2D $M_{n+1}X_n$ solids, labeled "MXene". 18 different carbides and carbonitrides have been reported to date [2-5]. 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 surface termination. Their elastic constants along the basal plane are predicted to be higher than that of the binary carbides. Oxygen or OH terminated MXenes are hydrophilic, but electrically conductive. Hydrazine, urea and other polar organic molecules can intercalate MXenes leading to an increase of the *c* lattice parameter of MXenes [3]. When dimethyl sulfoxide was intercalated into Ti_3C_2, followed by sonication in water, a stable colloidal solution of single- and few-layer flakes was produced. 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 [3-5]. 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 900 F/cm^3) in aqueous electrolytes [4].

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