Two-Dimensional Carbides and Nitrides Pave the Road to Future Technologies

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Discovery of new materials provides moments of inspiration and shifts in understanding, shaping the dynamic field of materials science. Following the graphene breakthrough, many other 2D materials emerged. Although many of them remain subjects of purely academic interest, others have jumped into the limelight due to their attractive properties, which have led to practical applications. Among the latter are 2D carbides and nitrides of early transition metals known as MXenes [1]. The family of MXenes has been expanding rapidly since the discovery of Ti_3C_2 in 2011. More than 30 different stoichiometric MXenes have been reported, and the structure and properties of numerous other MXenes have been predicted. Moreover, the availability of solid solutions on M and X sites, multi-element high-entropy MXenes, control of surface terminations, and the discovery of out-of-plane ordered double-M *o*-MXenes (e.g., Mo_2TiC_2), as well as in-plane ordered *i*-MAX phases and their *i*-MXenes offer a potential for producing dozens of new distinct structures. Chalcogen terminated carbides, which are crossover between carbides and chalcogenides, 2D borides, and Si-containing nitrides of transition metals further expanded the family of 2D non-oxide materials in the recent years. This presentation will describe the state of the art in the manufacturing of those new 2D compounds, their delamination into single-layer 2D flakes and assembly into films, fibers and 3D structures [2]. Synthesis-structure-properties relations of MXenes will be addressed on the example of Ti_3C_2. Many MXenes offer high electronic conductivity combined with hydrophilic surfaces. This allows environmentally friendly and scalable manufacturing and processing of MXenes from dispersions in water, with no surfactant of binder added. The versatile chemistry of the MXene family renders their properties tunable for a large variety of energy-related, electronic, optical, biomedical and other applications. In particular, the applications of MXenes in electrochemical energy storage and harvesting, electrocatalytic water splitting and water purification/desalination are promising. However, MXene antennas, sensors, actuators, films for electromagnetic interference shielding are equally attractive. Structural, tribological and high-temperature applications of MXenes are being explored as well.

1. A. VahidMohammadi, J. Rosen, Y. Gogotsi, The World of Two-Dimensional Carbides and Nitrides (MXenes), *Science*, **372**, eabf1581 (2021)
2. X. Li, Z. Huang, C. E. Shuck, G. Liang, Y. Gogotsi, C. Zhi, MXene chemistry, electrochemistry, and energy storage applications, *Nature Reviews Chemistry*, **6** (6), 389–404 (2022)