Discovery of New Two-Dimensional Materials (MXenes) and Their Role in Advancing Technology

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The ability to synthesize new inorganic nanomaterials has been foundational to technological progress over the last decades leading to advances in energy technologies, catalysis, electronics, and medicine. This lecture will provide fundamental insights and describe approaches to realizing non-equilibrium two-dimensional (2D) nanomaterials via solid state transformations of ceramics. Solid state transformations, where one crystalline phase is converted to another through, for example, reassembly of carbon atoms of silicon carbide to form graphene, nanotube arrays or porous carbide-derived carbon; and removal of atomic planes of layered carbides and nitrides known as MAX phases to form 2D carbides and nitrides (MXenes), such as Mo_2C, Ti_3C_2, Nb_4C_3, Ti_4N_3, Mo_2Ti_2C, and other, offer opportunities to produce nanoscale structures with atomic precision.

More than 30 different MXenes with 7 different types of structures have been synthesized since 2011, not counting solid solutions, but the total number of compositions is virtually unlimited. MXene can be produced by solution processing at room temperature, while graphene and nanotubes require higher temperatures. Solid state transformations or selective etching processes can lead to numerous nanomaterials with outstanding physical properties, such as high strength and metallic conductivity. Additionally, the relatively low energy input needed to carry out the synthesis reduces the barriers to translating new material breakthroughs from the lab to industry. The versatile chemistry of the MXene family renders their properties tunable for a large variety of applications. Oxygen or hydroxyl-terminated Menes, such as $Ti_3C_2O_2$, have been shown to have redox capable transition metals 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, but applications in optoelectronics, plasmonics, electromagnetic interference shielding, antennas, electrocatalysis, medicine (photothermal therapy and drug delivery), brain electrodes, biosensors, water purification/desalination and other fields are equally exciting.