Transformative Synthesis of Carbon-Based Materials - From Graphene to Nanotubes and MXenes

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The ability to synthesize new carbon-based materials has been foundational to technological progress over the last decades leading to advances in separation and energy technologies, catalysis, electronics, and medicine [1]. This lecture will provide fundamental insights and describe approaches to realizing non-equilibrium carbon materials via solid state transformations of carbides. Solid state transformations, where one crystalline phase is converted to another through, for example, reassembly of carbon atoms of SiC to form graphene, nanotube arrays or porous carbide-derived carbons (CDC); and removal of atomic planes of MAX phases to form 2D carbides (MXenes) offer opportunities to produce nanoscale and hierarchical structures with atomic precision [2]. CDC and MXene can be produced at room or slightly elevated temperature, while graphene and nanotubes require higher temperatures. The moderate temperature and far-from-equilibrium nature of many of these transformations allows for the realization of metastable structures by kinetically avoiding equilibrium phases (graphite). Solid state transformations or selective etching processes can lead to numerous carbon-based nanomaterials with outstanding properties [3]. 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. Dozens of porous carbide-derived carbons and more than 20 different 2D carbides have been synthesized [4]. The ability to tune the pore size, number of atomic layers and surface chemistry opens opportunities for fine tuning of properties. Examples of electrochemical energy storage applications will be presented, but applications in optoelectronics, electromagnetic interference shielding, plasmonics, sensors, water purification and desalination, electrocatalysis, medicine and other fields are equally exciting [3,4].

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