Supermaterials out of the microwave

October 10 2018

Credit: CC0 Public Domain

Using non-conventional methods, Christina Birkel and her colleagues in the Department of Chemistry of the TU Darmstadt produce metallic ceramics and new materials for the energy supply of the future.

The microwave oven in the laboratory of Christina Birkel, junior research group leader at the TU Darmstadt, is not only larger and significantly more expensive than the usual household device, but also more powerful and fire and explosion-proof. Birkel had the turntable and its plastic support removed. "That would have melted anyway," she says. The chemist uses the oven for the synthesis of substances that experts call MAX phases. M stands for a transition metal, for example for titanium or vanadium, A for a main group element – usually aluminium – and X for carbon, and more rarely also nitrogen. Thus far, approximately 70 members of this family are known.

"Around the turn of the millennium, research efforts in the field of MAX phases have increased significantly," explains Birkel. No wonder, because the materials are scratch-resistant, high-temperature stable and in many cases oxidation-resistant like a ceramic, but they also conduct electricity and sometimes have extraordinary magnetic proper ties. They are therefore also referred to as metallic ceramics. Similarly to clay minerals, MAX phases have a lamellar structure of alternating A and M-X-M layers.

Synthesis in a microwave oven

While researchers worldwide, especially in the US, investigate the properties and potential applications of MAX phases, Birkel is involved in their synthesis. She has optimized a particularly simple method using microwave heating: The metal and graphite powders are pressed into a dense pellet that is subsequently sealed into an evacuated quartz ampoule. This is then surrounded by granular graphite and placed into the microwave oven. Graphite absorbs the energy of microwave radiation particularly well and ensures that the pellet heats to over 1300 degrees-at such high temperatures, MAX phases form.

But this is not the end of the road for Birkel. Because the MXenes, obtained from MAX phases for the first time in 2011, have an even more promising future than the latter. The name indicates the chemistry in this case: The MXene is a MAX phase without the A layers. These were removed with hydrofluoric acid. Although the procedure requires the utmost caution – hydrofluoric acid is highly corrosive – it does fulfil its purpose perfectly, as shown by the electron microscope: "The layered structure of MAX phases widens and then looks like a fanned-out book." The individual layers separate partially.

The term MXene with the ending "ene" indicates a certain similarity to graphene, the miracle material consisting of pure carbon layers. Regarding the MXene, a variety of applications from battery materials to water purification are also discussed. Recently, Birkel and her colleagues produced a new MXene. It consists of vanadium-carbon layers and is suitable as a catalyst for the hydrogen evolution reaction in the electrolysis of water, as demonstrated by the group of Ulrike Kramm, assistant professor at TU Darmstadt. Water electrolysis is becoming more and more important because it allows to store excessively generated solar or wind energy in the form of hydrogen.

Hydroxyl groups (oxygen and hydrogen), oxygen and fluorine atoms, which bind to the the surface of the layers during hydrofluoric acid treatment, play an important role in the catalytic activity of the MXene. The Birkel group researchers are currently investigating the exact mechanisms with the aim of optimizing the properties of the MXene. For example, organic molecules could be coupled to the layers via the hydroxyl groups. "Thus, according to the Lego principle, numerous new MXenes are imaginable," explains Birkel. So far, only around 20 MXenes are known. The prospective chemistry professor could not have identified a more expandable area of research.

More information: Minh H. Tran et al. Adding a New Member to the MXene Family: Synthesis, Structure, and Electrocatalytic Activity for the Hydrogen Evolution Reaction of V4C3Tx, *ACS Applied Energy*

Materials (2018). DOI: 10.1021/acsaem.8b00652

Structural, magnetic and electrical transport properties of non-conventionally prepared MAX phases V2AlC and (V/Mn)2AlC, *Mater. Chem. Front*. 2018, 483-490, DOI: 10.1039/C7QM00488

Provided by Technische Universitat Darmstadt