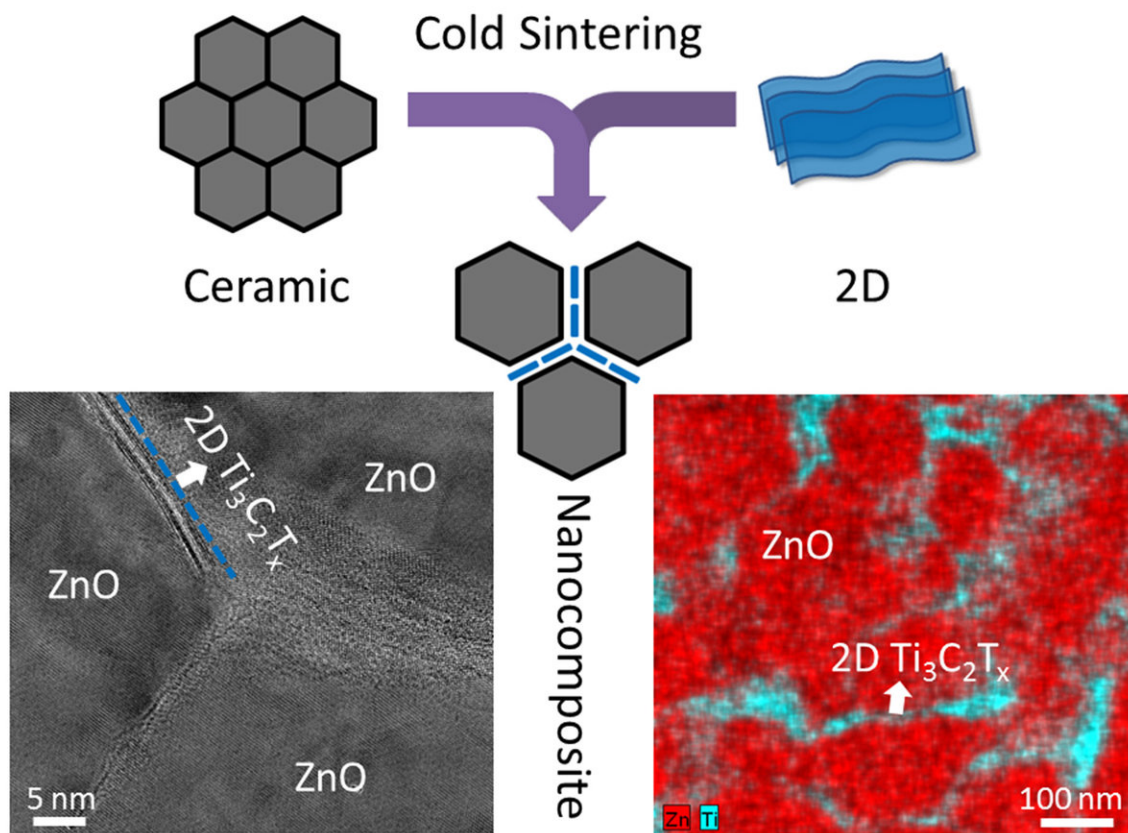


Sintering atomically thin materials with ceramics now possible

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The schematic illustration showing the co-sintering of ceramics and 2-D materials using cold sintering processing, and TEM image and energy dispersive spectroscopy (EDS) map of cold sintered 99ZnO-1Ti₃C₂T_x nanocomposite. The MXene nanosheets are distributed homogeneously along the ZnO grain boundaries, as seen in the TEM image and EDS map. Credit: MRI/Penn State

For the first time, researchers have created a nanocomposite of ceramics and a two-dimensional material, opening the door for new designs of nanocomposites with such applications as solid-state batteries, thermoelectrics, varistors, catalysts, chemical sensors and much more.

Sintering uses high heat to compact powder materials into a solid form. Widely used in industry, ceramic powders are typically compacted at temperatures of 1472 degrees Fahrenheit or higher. Many low-dimensional materials cannot survive at those temperatures.

But a sintering process developed by a team of researchers at Penn State, called the cold sintering process (CSP), can sinter ceramics at much lower temperatures, less than 572 degrees F, saving energy and enabling a new form of material with high commercial potential.

"We have industry people who are already very interested in this work," said Jing Guo, a post-doctoral scholar working in the group of Clive Randall, professor of materials science and engineering, Penn State. "They are interested in developing some new material applications with this system and, in general, using CSP to sinter nanocomposites." Guo is first coauthor on the paper appearing online in *Advanced Materials*.

The idea of trying to develop a ceramic-2-D composite system was the result of a National Science Foundation workshop on the future of ceramics, organized by Lynnette Madsen, that drew 50 of the top ceramic scientists in the U.S. Yury Gogotsi, a Charles T. and Ruth M. Bach Distinguished University Professor and director of the A.J. Drexel Nanomaterials Institute, at Drexel University, heard Randall's presentation on cold sintering and proposed a collaboration to develop a ceramic composite using a new class of two-dimensional materials, called MXenes, discovered by Gogotsi and his collaborators at Drexel. MXenes are carbide and nitride sheets a few atoms thin that possess extreme strength. Many of them are excellent metallic conductors.

While it has been known that mixing even a very small amount of 2-D materials, such as graphene, into a ceramic can dramatically change its properties, MXene has never been used in ceramic composites. In this work, Guo and Benjamin Legum, Gogotsi's doctoral student, mixed 0.5 to 5.0 percent MXene into a well-known ceramic system called [zinc oxide](#). The metallic MXene coated the ceramic powder and formed continuous two-dimensional grain boundaries, which prevented grain growth, increased the conductivity by two orders of magnitude, transforming semiconducting zinc oxide into a metallic ceramic, and doubled hardness of the final product. The addition of MXene also improved the ability of zinc oxide to transform heat to electricity.

"Ben came here quite frequently to work with Jing, and over time they overcame all of the problems involved with dispersing the 2-D MXenes into the zinc oxide and then sintering it," said Randall. "This opens a whole new world incorporating 2-D [materials](#) into ceramics."

Gogotsi added, "This is the first ceramic composite containing MXene. Taking into account that about thirty MXenes with diverse properties are already available, we are opening a new chapter in research on ceramic matrix composites, with potential applications ranging from electronics to batteries and thermoelectrics."

Guo and Legum are co-first authors on the paper "Cold Sintered Ceramic Nanocomposites of 2D MXene and Zinc Oxide."

More information: Jing Guo et al. Cold Sintered Ceramic Nanocomposites of 2D MXene and Zinc Oxide, *Advanced Materials* (2018). [DOI: 10.1002/adma.201801846](https://doi.org/10.1002/adma.201801846)

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