Graphene aerogels: a 3D approach to ultralow thermal conductivity, high electrical conductivity, superelasticity, and flame resistance

Jiří Červenka
FZU – Institute of Physics of the Czech Academy of Sciences, Prague, Czechia
cervenka@fzu.cz

Abstract

Graphene, a two-dimensional (2D) carbon variant, has emerged as one of the most researched materials due to its remarkable electronic, thermal, mechanical, and chemical properties. These intriguing properties give it significant potential as a novel molecular building block for creating large-scale three-dimensional monoliths. In this work, it is shown that free-standing 3D graphene aerogels made of covalently cross-linked graphene sheets can demonstrate very different properties compared to 2D graphene. Graphene aerogels have ultra-low density, large specific surface area, and adjustable pore size. While 2D graphene is the best thermal conductor, 3D graphene aerogel exhibits the lowest thermal conductivity but very high electrical conductivity. Moreover, 3D graphene exhibits exceptional elasticity, fire-retardant, and self-extinguishing properties [1,2]. Free-standing graphene layers assembled into a 3D cellular structure have 1000 °C higher flame resistance than 2D graphene on a substrate [1]. The cellular graphene aerogels resist flames at a temperature of 1500 °C for a minute without degrading their structure or properties. 3D graphene aerogels also feature innovative functions in tactile sensors [3] and terahertz (THz) applications [4]. 3D graphene aerogels, unlike 2D graphene, exhibit high absorption over a broad range of THz frequencies, which can be modulated by strain, enabling dynamic THz modulation [4]. The graphene aerogel modulator can be tuned to exhibit either shielding capability or stealth characteristics. These findings open new avenues for leveraging 2D materials in their 3D porous form, where strain-induced changes in interlayer interactions enable unique control over the properties of these materials.

References

[1] M. Šilhavík, P. Kumar, Z. A. Zafar, R. Král, P. Zemenová, A. Falvey, P. Jiříček, J. Houdková, J. Červenka, ACS Nano 16, 11 (2022) 19403-19411.
[2] M. Šilhavík, P. Kumar, Z. A. Zafar, M. Míšek, M. Čičala, M. Piliarik, J. Červenka, Communications Physics 5 (2022) 27.
[3] P. Kumar, M. Šilhavík, Z. A. Zafar, J. Červenka, Nanoscale 14 (2022) 1440-1451.
[4] P. Kumar, M. Šilhavík, M. R. Parida, Petr Kužel, J. Červenka, Advanced Electronic Materials, (2024) DOI: 10.1002/aelm.202300853.