Germanene: A new 2D-material with high potential for nano-electronics

M.E. Dávila [1], L. Xian[2], S. Cahangirov[2], A. Rubio[2], G. Le Lay[3]

[1]Instituto de Ciencia de Materiales de Madrid-ICMM-CSIC, C/Sor Juana Inés de la Cruz, 3 Cantoblanco 28049-Madrid Spain
[2]Nano-Bio Spectroscopy group, Universidad del País Vasco and European Theoretical Spectroscopy Facility (ETSF), CFM CSIC-UPV/EHU-MPC and DIPC, Av. Tolosa 72. E-20018 San Sebastián, Spain.
[3]Aix-Marseille Université, CNRS, PIIM UMR 7345, 13397 Marseille Cedex, France.

Presently, two-dimensional materials are one of the most active areas of nanomaterials research. Here we report the structural stability, and electronic properties of monolayer configurations of a novel synthetic germanium allotrope that does not exist in nature i.e., germanene [1].

The discovery of graphene, a one-atom-thick honeycomb carbon sheet, can be considered as a defining point in the research and development of stable, truly 2D material systems [2]. This new materials exhibit unusual electrical and mechanical properties, that have been the subject of much research and have inspired the study of other 2D materials such as silicene [3], germanene [1], phosphorene [4], stanene...

Nowadays, silicene is a fact and has already formed the gate of transistor devices [5], while single layer germanene has been synthesized recently on different substrates, namely Pt(111), Au(111) and also Al(111) [6,1,7].

In our particular case, we have grown *in situ* an atom-thin, ordered, two-dimensional multi-phase film through germanium molecular beam epitaxy using a gold (111) surface as a substrate. Its growth is similar to the formation of silicene layers on silver (111) templates. One of the phases, forming large domains, as observed in scanning tunneling microscopy, shows a clear, nearly flat, honeycomb structure. Thanks to thorough synchrotron radiation core-level spectroscopy measurements and advanced density functional theory calculations we can identify it as a $\sqrt{3} \times \sqrt{3}$ $R(30°)$ germanene layer in conjunction with a $\sqrt{7} \times \sqrt{7}$ $R(19.1°)$ Au(111) supercell. Hence, compelling evidence of the synthesis of the germanium-based cousin of graphene on gold has been presented [1]. We have performed further studies on the formation of multilayer germanene trying to understand the initial interaction with the substrate and then the multilayer structure.

One can anticipate a strong impact of both single and multi layer germanene because of the expected very high mobilities of the carriers, the potential optical applications, the predicted robust two-dimensional topological insulator character, nearly up to room temperature, resulting from the large effective spin-orbit coupling opening the way to the Quantum Spin Hall Effect, the possibility of very high Tc superconductivity, and, last but not least, the practicability of direct integration in the current electronic industry.

[1] M.E. Dávila, L. Xian, S. Cahangirov, A. Rubio and G. Le Lay, New J. Phys., 16, 095002 (2014).
[2] K. Geim, K. S. Novoselov, Nature Materials 6, 183 (2007).
[3] P. Vogt, P. De Padova, C. Quaresima, J. Avila, E. Frantzeskakis, M.C. Asensio, A. Resta, B. Ealet, G. Le Lay, Physical Review Letters 108, 155501 (2012).
[4] A. Castellanos-Gomez, L. Vicarelli, E. Prada, J. O. Island, K. L. Narasimha-Acharya, S. I Blanter, D. J. Groenendijk, M. Buscema, G. A. Steele, J. V. Alvarez, H. W. Zandbergen, J. J. Palacios and H. S. J. van der Zant, 2D Materials 1, 025001 (2014)
[5] L. Tao, E. Cinquanta, D. Chiappe, C. Grazianetti, M. Fanciulli, M. Dubey, A. Molle and D. Akinwande, Nature Nanotechnol. 10, 227 (2015).
[6] L. Li, S.-Z Lu, J. Pan , Z. Qin, Y.-Q. Wang, Y. Wang, G.-Y. Cao, S. Du, H.-J. Gao, Adv. Mater., 26, 4820 (2014).
[7] M. Derivaz et al., To be published.