From surface alloys to germanene: Ge/Ag(111) growth

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Two-dimensional (2D) honeycomb lattices beyond graphene, such as germanene, appear very promising due to their outstanding electronic properties, such as quantum spin hall effect. While there have been many claims of germanene growth, experimental evidence for a honeycomb structure has only been obtained indirectly, from STM observations or electronic properties measurements.

Among all the potential substrates for germanene growth, Ag(111) which is known to be well suited for the growth of silicene, is undoubtedly the most discussed one today. On this substrate, the structures observed have been either described as honeycomb germanene or surface alloys. Using scanning tunneling microscopy (STM), surface X-ray diffraction and density functional theory, we have studied the structure and energetics of germanium layers on Ag(111) in the 400K-450K temperature range [1-3]. We show that upon increasing coverage, a series of alloyed phases forms. Two of these phases correspond to highly ordered reconstructions for which we determined precisely the atomic structure. The first one is a c(31x$\sqrt{3}$) reconstruction corresponding to a Ag_2Ge surface alloy with an atomic density 6.45% higher than the Ag(111) atomic density. It is formed by stripes associated with a face-centered cubic top-layer alignment, alternating with stripes associated with a hexagonal close-packed top-layer alignment, in great analogy with the (22x$\sqrt{3}$) Au(111) reconstruction [2]. The second one is a ($\sqrt{109} \times \sqrt{109}$) reconstruction, composed of a periodic arrangement of Ge pentagons, hexagons and heptagons with a small concentration of Ag atoms [3]. Our result opens new perspectives related to the understanding of the complex structures observed after growth of Ge or Si on metal surfaces.

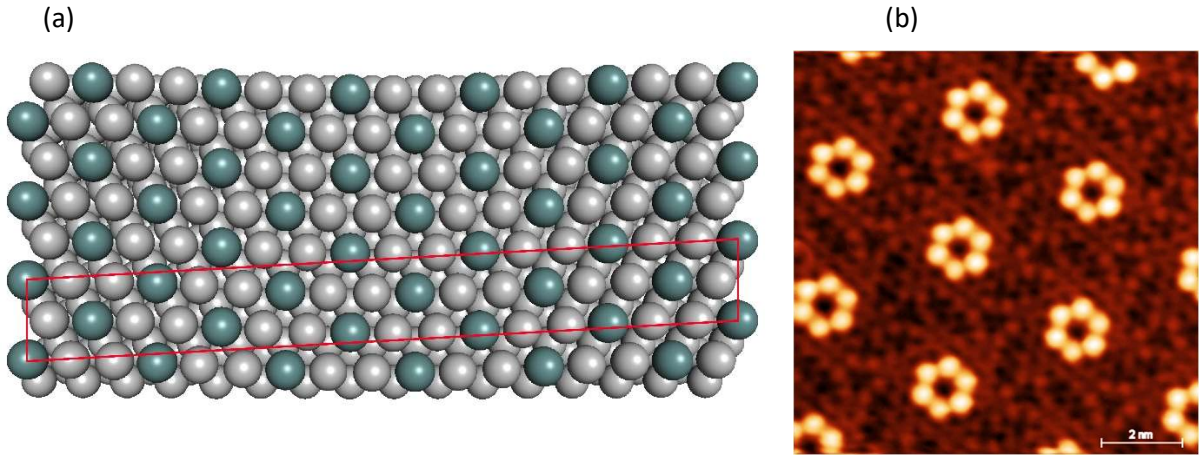

Fig. a) Top view of the atomic structure of the c(31x$\sqrt{3}$) reconstruction.
b) STM image (8.5x8.5 nm^2) of the ($\sqrt{109} \times \sqrt{109}$) reconstruction.

[1] K. Zhang, R. Bernard, Y. Borensztein, H. Cruguel, G. Prévot, Phys. Rev. B 102 (2020) 125418
[2] K. Zhang, et al., Phys. Rev. B 104 (2021) 155403
[3] K. Zhang, et al., to be published