Two-Dimensional Xenes: Synthesis, Processing, and Engineering

Alessandro Molle*, Christian Martella, Carlo Grazianetti
*e-mail: alessandro.molle@cnr.it , https://alessandromolle.wixsite.com/xfab
CNR-IMM, Unit of Agrate Brianza, via C. Olivetti 2, 20864 Agrate Brianza (MB), Italy

Isolation of graphene paves the way to a new and unprecedentedly rich fashion of two-dimensional (2D) materials. While many of them are naturally available in the form of exfoliable single-crystal flakes, others can be artificially derived by synthetic approaches and their atomistic features tailored by design. Xenes, namely 2D single-element materials beyond graphene, are a representative case in this respect [1]. Xenes expand the graphene potential and constitute an emerging nanomaterials platform with potential for ultra-scaled electronics, topological science, photonics, energetics, and biomedicine [2].

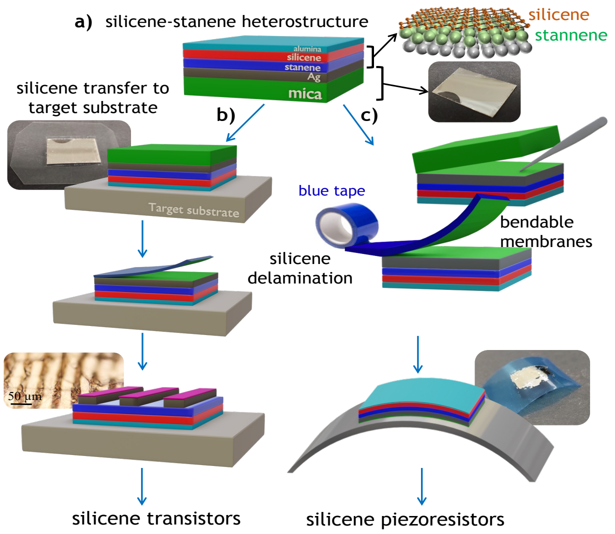

Fig. 1 Processing of silicene-stannene heterostructures (a) for the manufacture of silicene transistors (b) and piezo-resistors (c).

Here we will present a taxonomy of the Xenes with element X spanning from the IV column of the periodic table (e.g. silicene) to the adjacent columns (e.g. borophene, phosphorene, tellurene, etc.), and Xene configurations like functionalized Xenes, Xene hybirds, and Xene heterostructures. In parallel, with silicene stannene, and tellurene as representative examples, we will describe how the Xenes can be produced by epitaxial methods including the direct deposition, the top-to-bottom intercalation through an interface layer, the bottom-to-top segregation, and chemical methods like topotactic deintercalation. In particular, silicene stands out as a paradigmatic case for atomic structure engineering. In this respect, interface engineering through atomic Sn decoration and stannene buffering leads to the scalable epitaxy of phase-selected silicene [3] and to the formation of Xene heterostructures [4], respectively.

Xene heterostructures with a top face Al_2O_3 capping layer are the enabling layout for a durable stabilization of silicene against environmental degradation via an all-around encapsulation (Fig. 1a) [5]. This configuration allows us to elucidate the inherent electrical, thermal, and optical properties of silicene with no interference from the substrate. Stabilized silicene membranes can be thus delaminated off from the pristine substrates and transferred to second target substrate (Fig. 1b) aiming at electronic device applications [6]. We will describe methods leading us to fabricate silicene transistors on solid-state platforms and e silicene piezoresistor on bendable substrate (Fig. 1c) [7].

The development of silicene by means of epitaxial methods and atomic control at the surface level thus proves to be a viable path for Xene engineering towards the derivation of unique properties in carefully tailored configurations and the manufacture of prototypical devices. This approach can be universally extended to the whole class of the epitaxial Xenes towards a Xene-based science and technology.

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References

[1] “Xenes - 2D Synthetic Materials Beyond Graphene” A. Molle and C. Grazianetti, Eds., Woodhead Publishing, Elsevier Ltd. (2022), Kidlington.
[2] C. Grazianetti et al, PSS-RRL (2020) 14, 1900439.
[3] S. Achilli, et al., Nanoscale (2023) 15, 11005.
[4] D. S. Dhungana et al., Adv. Funct. Mater. (2021) 31, 2102797.
[5] D. S. Dhunghana, C. Massetti, et al., Nanoscale Horiz. (2023) 8, 1428.
[6] C. Martella, et al, Adv. Funct. Mater. (2020) 30, 2004546.
[7] C. Martella, et al., Adv. Mater. (2023) 35, 2211419.