ABSTRACT

Two-Dimensional Xenes: Synthesis and Paths for Applications

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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, i.e. 2D single-element materials beyond graphene, are a representative case in this respect [1]. Here, we will describe how the Xenes can be produced by physical and chemical methods, and how they can be engineered and configured to address specific nanotechnology applications [2]. Silicene is taken as paradigmatic and versatile case either of epitaxial growth or chemical derivation from CaSi2. In the former case, epitaxial silicene is treated through atomistic Sn interface engineering and all-around encapsulation in order to achieve a large-scale, single-crystal and environmentally stable silicene [3,4]. So-stabilized silicene allows us to elucidate its inherent electrical, thermal, and optical properties with no interference from the substrate [5], and can be delaminated from the substrate as an atomically thin membrane that is readily transferable to a device platform. In this respect, we show silicene transfer to flexible substrates resulting in piezoresistor devices (see Figure 1a) [6], see Figure. On the other hand, we will show how silicene nanosheets can be effectively derived from vacuum nitrogen cycle assisted topotactical deintercalation from CaSi2 crystals at room temperature [7]. The so-produced silicene nanosheets are incorporated into silk fibroin nanofibers via electrospinning where they self-preserve their structural integrity with varying concentrations. Biocompatibility and biodegradability of silicene incorporated in silk fibroin makes it suitable for engineering biomedical applications. Finally, we focus on nanoscale tellurium growth as a path towards a tellurium-based memristor circuitry aiming a neuromorphic computation. Tellurium vapors transported by an inert carrier gas in a chemical vapor deposition reactor can be exploited to produce tellurium nanosheets down to the 2D level of tellurene. The low-temperature process of tellurene (below 400°C) is tailored to design diode cells (see Figure 1c) with memristive behavior where the substrate plays a critical role in determining the local resistive switching effect [8].
The reported cases are examples of how Xene can be synthesized in technology relevant platforms and then engineering towards prototypical electronic devices like piezoresistors and memristors.
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[1] “Xenes - 2D Synthetic Materials Beyond Graphene” A. Molle and C. Grazianetti, Eds., Woodhead Publishing, Elsevier Ltd. (2022), Kidlington; [2] A. Molle et al, Chem. Soc. Rev. (2025) 54, 1845; [3] S. Achilli, et al., Nanoscale (2023) 15, 11005; [4] D. S. Dhunghana, C. Massetti, et al., Nanoscale Horiz. (2023) 8, 1428; [5] E. Bonaventura et al., Adv. Opt. Mater. (2024) 12, 2401466; [6] C. Martella, et al., Adv. Mater. (2023) 35, 2211419; [7] E. Kozma, et al., Small (2024) 21, 2406088; [8] S. Ghomi et al., Adv. Sci. (2025) 12, 2406703.