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The Emergence of Borophene: "Lightest Elemental Dirac Material"

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Research Snippets

Unraveling non-van der Waal material always leads to unique layered materials having unprecedented properties. Among the family of the non-van der Waal materials, borophene (the single atomic thick layer of boron) emerges as the only lightest elemental Dirac material and thus, has fueled the research on layered materials [1-6]. Boron, the only material in the periodic table with a complex yet unique structure called icosahedral, canent two-center-two-electron bonds as well as stable electron-deficient three-center-two-electron bonds [1-3]. Due to the presence of such peculiar bonding in the bulk, theoretical calculation predicts two planar polymorphs phases namely anisotropic β12 having parallel ridges and isotropic hexagonally bonded X3 phases respectively. β12 having parallel ridges has been conjectured to have protrusions while X3 phase is deemed to have holes for structural stability [4-5].

Contrary to X3 phase, a recent, theoretical investigation of borophene (β12 phase) reveals enhanced thermal stability compared to graphene and its cousins. In addition, the β12 phase is found to be metallic in comparison to its bulk counterpart, while X3 is semiconducting and thus is considered to be the rare phase in 2D family. Unlike graphene, silicene, and boron nitride which are isotropic in nature, β12 phase of borophene is considered to be anisotropic and with ridges is expected to have higher carrier density in one direction and enhanced mechanical stiffness [6-7]. The first experimental realization of borophene was demonstrated via atomic layer deposition by Mannix et al. and later was followed by the deposition through molecular beam epitaxy on Ag [111] substrate respectively [1,3]. It was hypothesized that lattice matching of the silver and boron atoms is the primary reason behind the formation of borophene films [3]. However, it was observed through computational results that boron is not a naturally layered material but its polymorphs such as β12 and X3 are layered and are also metastable (higher energy than its bulk) [3,5]. In this context, therefore, synthesis of free-standing borophene and exploration of its physical and chemical properties has not even been thought of until we demonstrated the synthesis through blended sonochemical and micromechanical exfoliation for the first time and overcame the hypothesis of substrate-mediated growth (see Fig. 1) [8-9]. In addition, a few of the properties and application of the free-standing borophene is explored by us. However, the material is destined to open new opportunities for the next generation of devices (see Fig. 2).

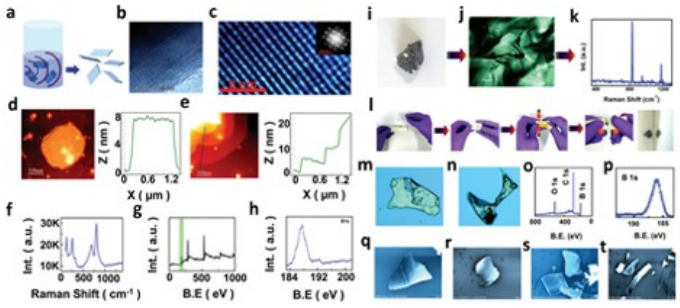

Figure 1. a) Schematic diagram depicting typical sonochemical exfoliation, b) Transmission Electron Microscopy, and c) High Resolution TEM images (inset contains electron diffraction pattern), d,e) Atomic Force Microscopy images and height profiles of the borophene seheets, f) Raman spectrum, g) XPS spectrum (survey) for borophene, and h) short scan XPS B 1s. Scotch tape exfoliation of free standing borophene i) Image of the borophene crystal, j) Optical image of the crystal, k) Raman spectrum, l) Camera images of the exfoliation process, m,n) Optical image of the transferred B onto SiO2/Si substrate, o,p) XPS/Long range scan of the B 1s spectra, q-t) FESEM images of exfoliated borophene.[8-9]

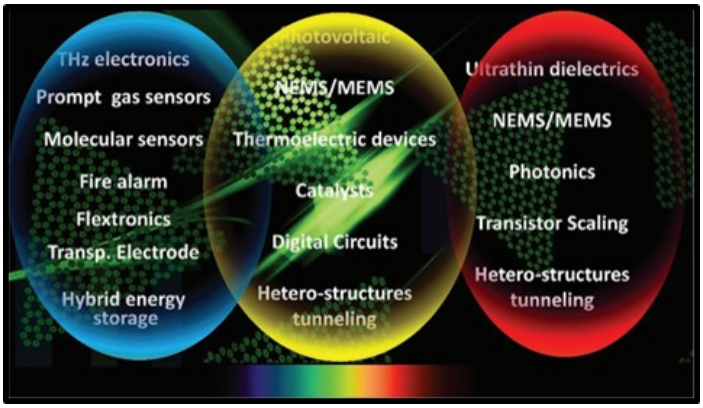

Figure 2. Pictorial representation of the upcoming applications of Borophene in different spectroscopic ranges.[10]

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