Black Phosphorus: An electronic and optoelectronic elemental analog of graphene

Black-phosphorus (BP) has emerged as a material of interest owing to its high carrier mobility and the presence of an intrinsic direct bandgap. Its thickness-dependent energy gap and highly anisotropic properties make it an important material to investigate amongst the family of two-dimensional (2D) materials. Few-layer BP has been a focus of several studies and is promising for applications in electronics, optoelectronics, energy storage, gas sensing, catalysis and chemical/biosensing. However, the ambient instability of BP remains the biggest hurdle in its progress. The fact that the material has to be stored and handled in an inert environment renders it to be unfavourable for practical implementation. To date, the solution to avoid degradation has been capping BP to minimize its interaction with the ambient environment. Here, we present a systematic investigation of the origins of oxidative degradation in few-layer black phosphorus (BP). Subsequently, we also propose an ionic liquid based approach to prevent ambient degradation of BP.

First, we conducted an in-depth investigation into the origins of degradation revealing that oxidation due to light causes degradation whereas humidity on its own does not cause any material and acts merely as a facilitator of photo-oxidation [1].

Subsequently, we determine the influence of discrete wavelengths ranging from UV to infrared on the degradation of BP. It is shown that the UV component of the spectrum is primarily responsible for the deterioration of BP in ambient conditions [2]. Based on these results, new insights into the degradation mechanism have been generated which will enable the handling and operating of BP in standard laboratory environments.

Finally, we designed an approach that allows this sensitive material to remain stable without requiring its isolation from the ambient environment [3]. We employ imidazolium-based ionic liquids (ILs) as quenchers of damaging oxidative species on the BP surface. This chemical sequestration strategy allows BP to remain stable for over thirteen weeks, while retaining its key electronic characteristics.

Besides, fundamental studies on the degradation of BP, we have also explored plasma thinning and defect engineering of BP layers to reveal exciting optoelectronic properties governed by defects.

References:

[1] S. Walia, et al," 2D Materials, vol. 4, 2016, Article No. 015025.

[2] T. Ahmed, et al," npj: 2D Materials and Applications, vol. 1, 2017, pp. 18.

[3] S. Walia, et al," Advanced Materials, vol. 29, 2017, 1700152.