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Research team finds a way to produce black phosphorus in bulk

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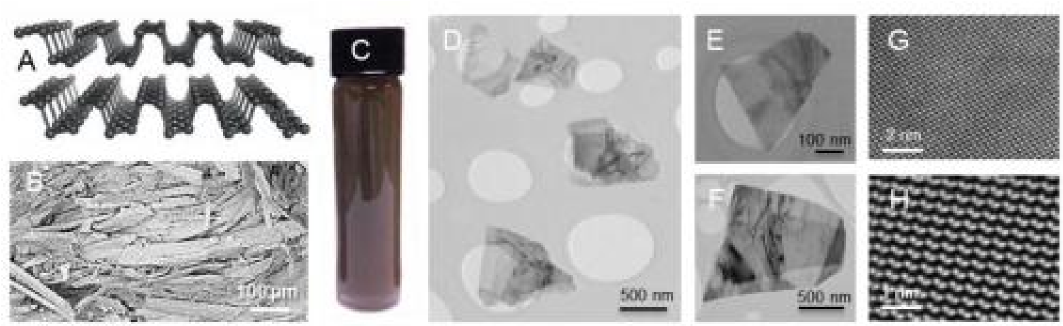

A) Structure of Black Phosphorus (BP). B) SEM image of a layered BP crystal. C) Photograph of a dispersion of exfoliated FL-BP in CHP. D-F) Representative low-resolution transmission electron microscopic (TEM) images of FL-BP exfoliated in N-cyclohexyl-2- pyrrolidone (CHP). G) Low-by-pass bright-field scanning transmission TEM (STEM) image and H) Butterworth filtered high-angle annular dark field (HAADF) STEM image of FL-BP (exfoliated in isopropanol) showing the intact lattice. Credit: arXiv:1501.01881 [cond-mat.mes-hall]

(Phys.org)—A team of researchers working at Trinity College in Ireland has found a way to produce black phosphorus in bulk, theoretically paving the way for its use in real applications. They have written a paper describing their technique and have uploaded it to the preprint server *arXiv*.

For several years, material scientists, chemists, physicists and others researchers have been excitedly working to find a way to create graphene in bulk and to force it to have a band gap. Thus far, that work has not led to a breakthrough that would allow the so-called miracle material to be used for much in the way of real world applications. In this new effort, the research team has moved their focus to black phosphorus (aka phosphorene) which has many of the same beneficial traits as graphene, but currently has, at least theoretically, a way to induce a band gap. Up till now, however, making black phosphorus was done the same way as making graphene, e.g. using sticky tape to pull layers off a bulk sample—that is obviously not a good way to produce material suitable for commercial applications. Now it appears the team in Ireland has found another way—one that is simple, inexpensive and allows for separating out different sized sheets.

To get sheets of black phosphorus the team created a block of it first, then, instead of trying to rip layers off with tape, they submerged it in a CHP liquid solvent and then piped in acoustic waves, which served to knock off layers of phosphorene (nanosheets) into the solution. The team then filtered the sheets using a centrifuge. Using this method the team reports that they have been able to produce nanosheets of black phosphorus in bulk, some of which are just a few layers thick.

The researchers have used the results of their efforts to test the usefulness of using black phosphorus in a variety of applications, ranging from increasing the strength of polyvinyl chloride, to an ammonia detector. They note the nanosheets do suffer from one serious drawback—they tend to disintegrate over a short period of time when exposed to water or oxygen, but the team is optimistic that solvents can be created to provide a protective shell around the sheets that will still allow it to perform its useful functions.

More information: Liquid exfoliation of solvent-stabilised black phosphorus: applications beyond electronics, arXiv:1501.01881 [cond-mat.mes-hall] arxiv.org/abs/1501.01881

Abstract
Few layer black phosphorus is a new two-dimensional material which is of great interest for applications, mainly in electronics. However, its lack of stability severely limits our ability to synthesise and process this material. Here we demonstrate that high-quality, few-layer black phosphorus nanosheets can be produced in large quantities by liquid phase exfoliation in the solvent N-cyclohexyl-2-pyrrolidone (CHP). We can control nanosheet dimensions and have developed metrics to estimate both nanosheet size and thickness spectroscopically. When exfoliated in CHP, the nanosheets are remarkably stable unless water is intentionally introduced. Computational studies show the degradation to occur by reaction with water molecules only at the nanosheet edge, leading to the removal of phosphorus atoms and the formation of phosphine and phosphorous acid. We demonstrate that liquid exfoliated black phosphorus nanosheets are potentially useful in a range of applications from optical switches to gas sensors to fillers for composite reinforcement.