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Development of a Nanomanufacturing Process to Produce Atomically Thin Black Phosphorus

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ABSTRACT

Atomically thin black phosphorus (phosphorene) has both unique and desirable properties that differ from bulk black phosphorus. Unlike graphene, phosphorene has a bandgap, which makes it potentially useful for applications in the next generation of transistors. Large-scale applications of phosphorene, like other 2D materials, are limited by current production methods. The most common method of making phosphorene is mechanical exfoliation, which can only produce small and irregular quantities. In this work we investigate a top-down method of producing phosphorene by using a scanning ultrafast laser to thin black phosphorus flakes. Because the bandgap of phosphorene increases as layers are removed, it is anticipated that the last few layers will be harder to remove using the laser than the upper layers. Hopefully with properly tuned laser parameters, all but the last layer can be removed. Using a custom laser machining setup, the effects of laser power, wavelength, and scanning speed on ablation phenomena are investigated. After laser processing, flakes are characterized using Raman spectroscopy and atomic force microscopy in order to determine the nature and thickness of exposed regions. Tests done at 400 nm wavelength showed removal of material with comparatively weaker Raman peaks in the exposed areas, indicative of thinning. Removal of material was observed at 800 nm and 1500 nm wavelengths, but absence of Raman peaks indicated that thinned regions had melted and recrystallized, becoming amorphous. The present work sets the foundation for future experiments to refine this process and further explore the physics governing the thinning phenomenon.

KEYWORDS

Phosphorene, ultrafast laser, laser-induced thinning, atomically thin crystal, mechanical exfoliation

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