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Controlled growth and doping of black phosphorus with tunable properties

Black phosphorus (BP) is a candidate 2D material in optoelectronics owing to its excellent electronic properties and a tunable bandgap in mid-far infrared region. Doping has been a reliable way to tune bandgap and improve the properties of BP. However, a uniform and large amount of doping into BP lattice remains a challenge. Here, a facile approach using CVT reaction furnace under uniform temperature gradient have been applied to synthesize centimeter-sized, high-quality BP crystals. Compared with tradition gradient temperature furnace, much larger crystal yield are obtained (more than 90%) using this new approach. Uniform and controllable doping of various elements are also achieved with the same method. It should be noted that some elements (such as Sb, Bi, Se and Te) that are normally difficult to doped into BP are successfully obtained here and the doping level is the highest reported so far. In addition, to understand the growth mechanism, control experiments have been carried out by tuning various synthesis conditions. Structural and optical characterization show that the synthesized pristine and doped BP crystals exhibit high crystalline quality. Furthermore, our synthetic approach enables uniform doping in the lattice of BP crystals, which is evidenced by the XRD, TEM and Raman spectroscopy. Furthermore, the atomic doping can significantly improve the stability of BP in air, which lays a foundation for the large-scale development of BP in the field of optoelectronic devices. High tunability of bandgap and work function via controlling doping type and concentration provides a large variety of choices in real applications.

References

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Figures

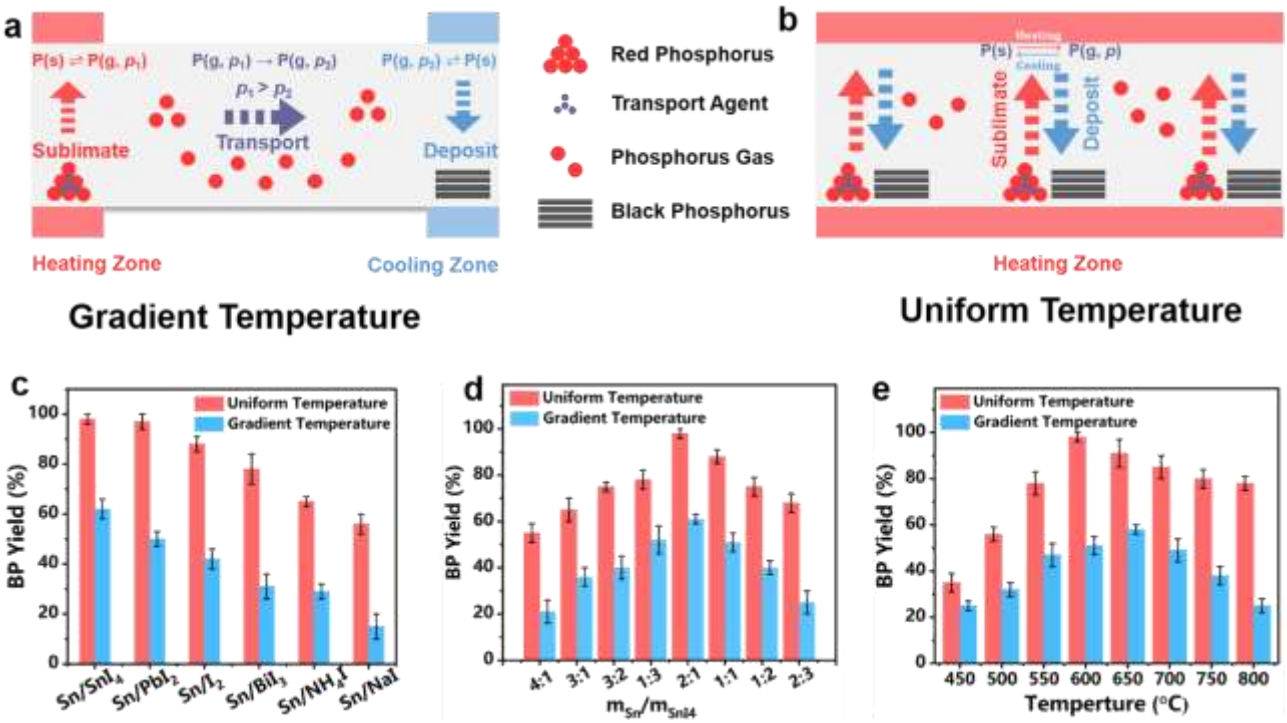

Figure 1. Experimental setup of BP crystal growth with both uniform and gradient temperature furnace and the comparison of BP yield with various growth conditions.