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N-type doping of black phosphorus by using benzyl viologen.
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COLLABORATION — Black phosphorus (BP) meets several critical material re-
quirements for the development of future nanoelectronic applications, but the real-
ization of n-type semiconductor behavior from it has remained elusive. Here, we re-
port the ambipolar characteristics of few-layer BP, induced using an novel technique:
chemical doping with benzyl viologen (BV), which serves as a surface charge transfer
donor for BP flakes. The n-doped BP devices exhibit excellent electron mobility up
to $\sim 83 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ from 2-terminal measurement at 300K, thereby demonstrating
n-type behavior. On the basis of ambipolar BP devices, we also comprehensively
analyzes temperature and BP thickness dependence of ambipolar devices, in which
we found the degenerate doping limit below around 150K and highest electron trans-
port performance in $\sim 10 \text{ nm}$ BP flakes at 300K. As a proof of concept, ultrafast BP
photodetectors were fabricated with a very high photoresponsivity of $\sim 10^4 \text{ mA/W}$
over the UV, visible, and IR spectral ranges. Furthermore, we fabricated a homoge-
neous BP based inverter through BV doping and h-BN capping that offers a feasible
approach to fabricating a key building block of future 2D logic semiconductors.

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