Supplementary information:

High Performance *p*-Type Black Phosphorus Transistor with Scandium Contact

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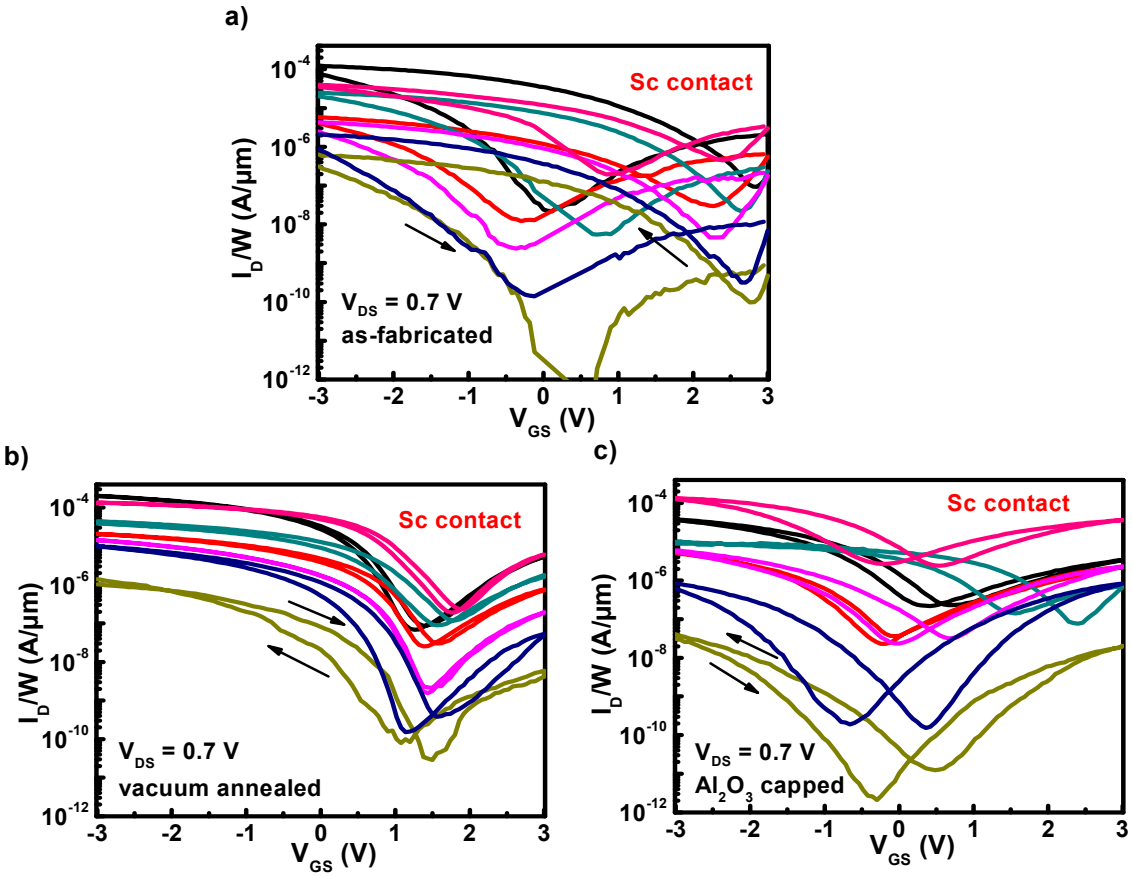

Figure S1. The transfer characteristics the BP transistors with Sc contact on 3-20 nm thick flakes at V_{DS} = 0.7 V measured a) as fabricated, b) after vacuum anneal and c) after Al_2O_3 capping.

As shown in Figure S1, all the 3-20 nm thick BP transistors of both the as-fabricated and the vacuum annealed ones exhibit strong *p*-type behavior which suggests that the moisture is not the *p*-type dopant for BP with Sc contacts. This is different from what was found in BP transistor with Ti/Au contact.[1] Moreover, they all show predominantly unipolar properties regardless of the BP thickness, different from the BP transistor with Al contact.**Error! Reference source not found.** In addition, the BP transistors become more ambipolar after capped with Al_2O_3 which has been discussed in 2. Thus it is better to analyze the polarity of BP transistors without dielectric capping layer.

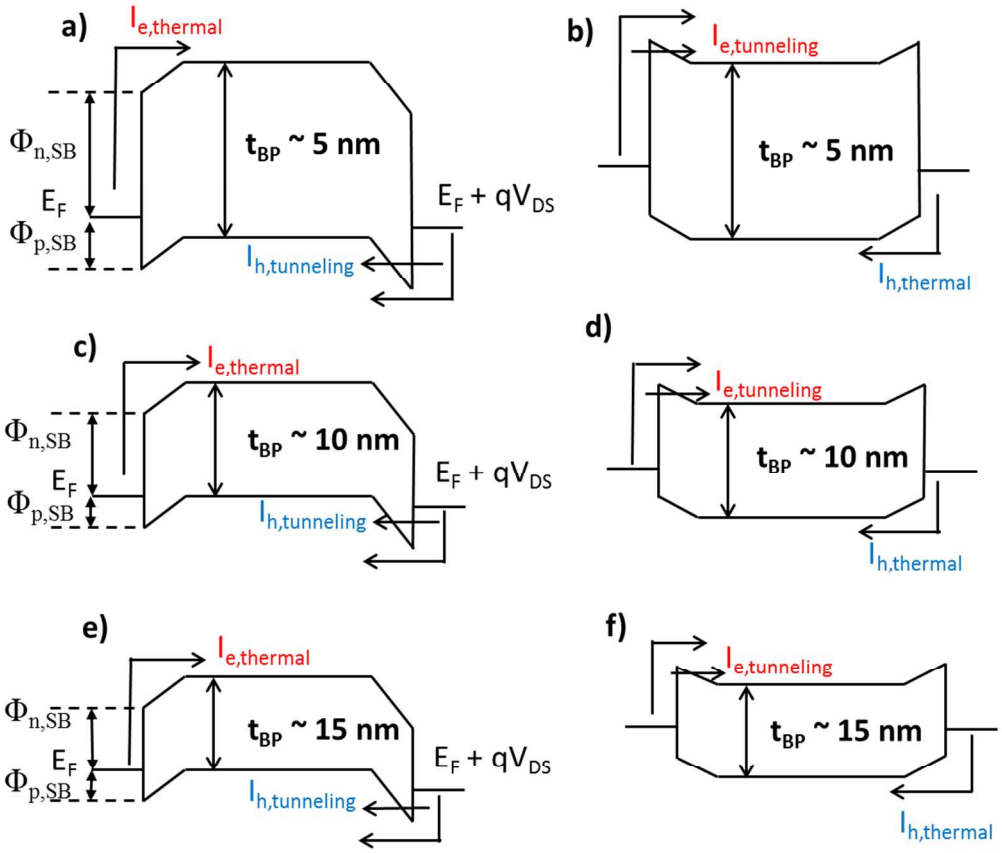

Figure S2. The schematic energy band diagrams of BP transistors with body thicknesses of ~5 nm, ~10 nm, and ~15 nm at a positive drain bias. a), c), and e) show the energy band diagrams with large negative gate voltage; b), d), and f) show the energy band diagram with large positive gate voltage. The band diagram is based on the Schottky barrier model from reference 4.

The thinner BP thickness has larger band gap.[4] For a qualitative discussion, the Schottky barriers for both electrons and holes ($\Phi_{n,SB}$ and $\Phi_{p,SB}$) are larger for a thinner BP. Thus the electron current and hole current are much smaller for a thinner BP transistor. As the current of a BP transistor is the sum of both the hole-current (I_{hole}) and electron-current ($I_{electron}$) based on the

Schottky barrier transistor model from reference 4, the total current of a thinner BP transistor is smaller than a thicker one.

For the ~10 nm and ~15 nm thick BP transistors in Figure 4 and Figure 5, the $I_{electron}$ is the same when V_{GS} is larger than 2 V. This indicates that the $\Phi_{n,SB}$ is almost the same for both thicknesses. As a result, the $\Phi_{p,SB}$ has to be larger for thinner transistor (~10 nm thick), which leads to a smaller I_{hole} with V_{GS} in -1 to 1 V range. This also explains the V_t shift between two thicknesses. At higher V_{GS} (-1 to -3 V), the interlayer resistance from the channel to the contact is the dominate factor so that the thinner flake shows higher $I_{electron}$.

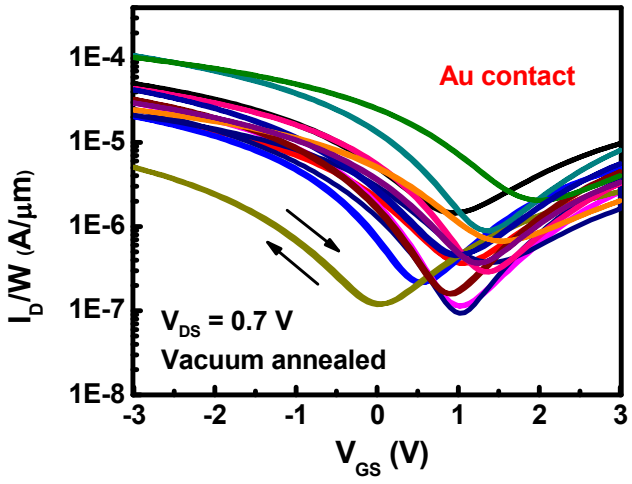

Figure S3. The transfer characteristics the BP transistors with Au contacts on 3-20 nm thick flakes at V_{DS} = 0.7 V measured after vacuum annealed.

The BP transistors with Au contact show *p*-type behavior regardless of the BP thickness, similar to the Sc contacted ones. Note that all the devices after vacuum annealing show almost 0 V hysteresis within a measurement resolution of 0.06 V.

REFERENCE

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