Electronic Supporting Information

Direct Growth of Doping Controlled Monolayer WSe_2 by Selenium-Phosphorus Substitution

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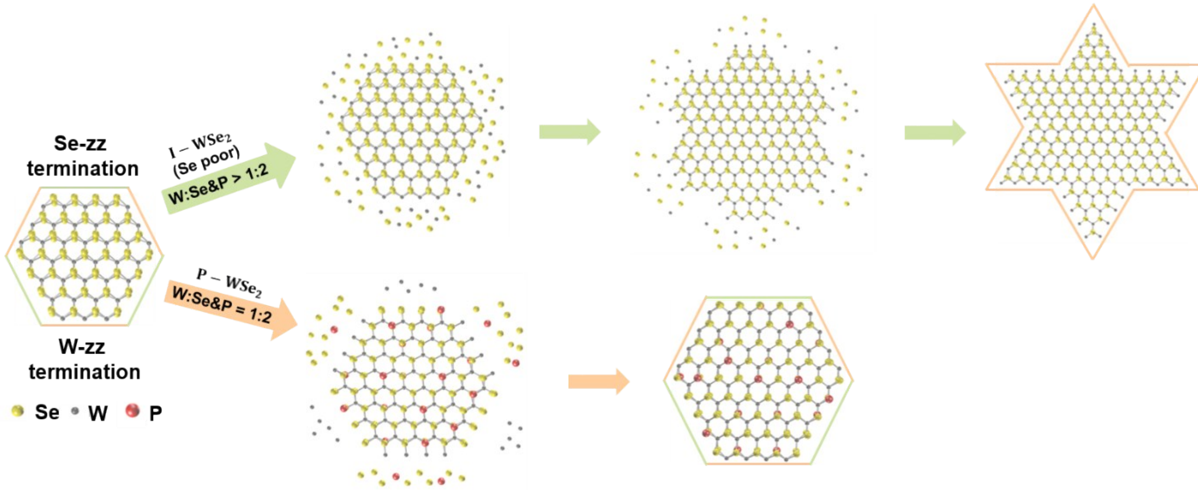

Figure S1. Schematic illustration of the domain shape changes and their comparison between intrinsic and P-doped WSe_2. Schematic ball-and-stick models for the different shapes of the monolayer WSe_2 structure. The initial crystal structure on the left shows two types (W or Se) of WSe_2 terminations. The schematic diagram on the right illustrates the domain shape changing procedure depending on the W:Se&P rates of the two different terminations.

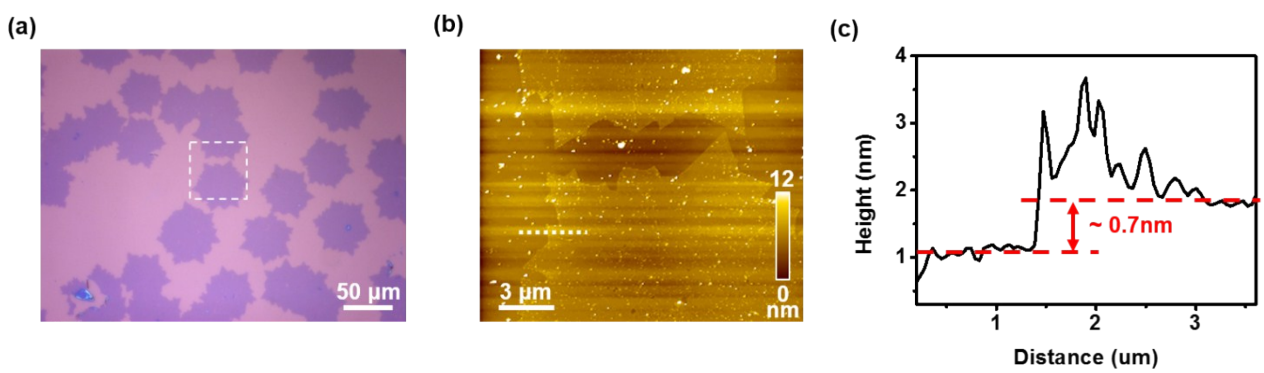

Figure S2. AFM images of P-doped WSe_2 layers. (a) Optical image of CVD grown P-doped WSe_2 layers. (b) AFM image of the dotted area in (a). Height profile of a WSe_2 layer taken across the dotted line in (b), which indicates the monolayer thickness.

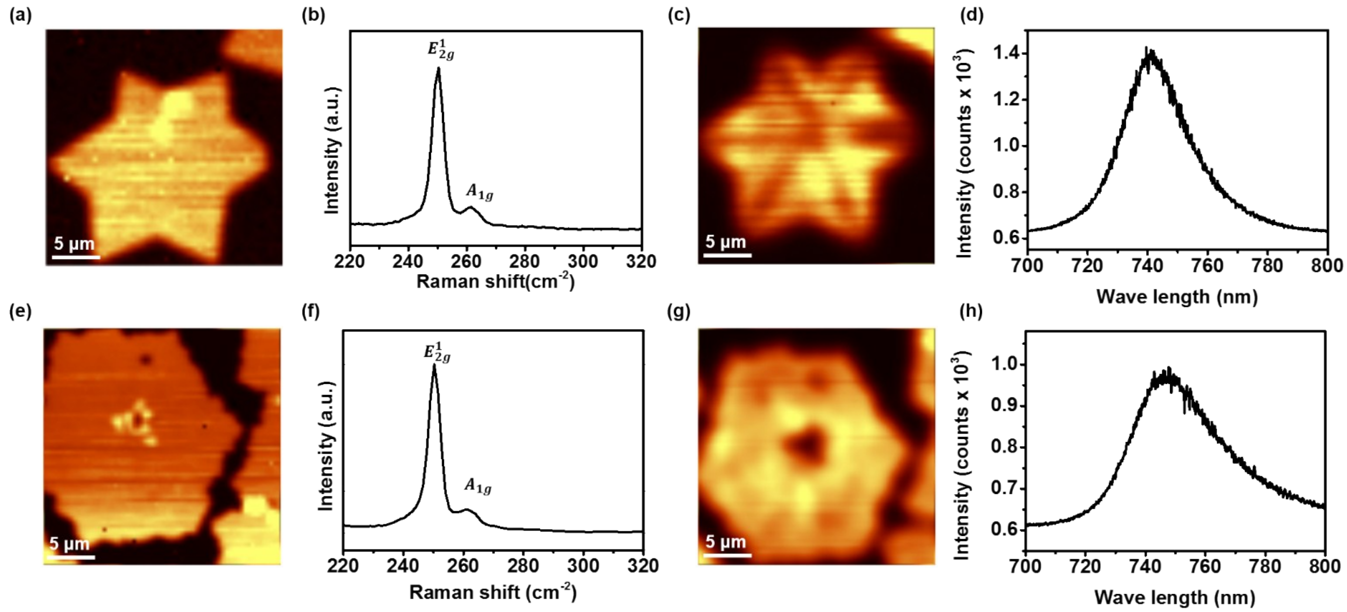

Figure S3. Raman and photoluminescence spectra of other intrinsic and p-doped WSe_2 flakes. (a) Scanning Raman intensity at the E^1_{2g} peak of intrinsic WSe_2. (b) Raman spectrum of intrinsic WSe_2. (c) Scanning photoluminescence of intrinsic WSe_2. (d) Photoluminescence spectrum of intrinsic WSe_2. (e) Scanning Raman intensity at the E^1_{2g} peak of P-doped WSe_2. (f) Raman spectrum of P-doped WSe_2. (g) Scanning photoluminescence of P-doped WSe_2. (h) Photoluminescence spectrum of P-doped WSe_2. Scale bars are 5µm.

Supporting information 1: 2D carrier concentration calculation

The 2D carrier concentration in an p-type semiconductor is derived from the drift current density (J)[1,2] equation:

$$J = qn\mu_n E + qp\mu_p E = \sigma E \qquad \text{(Equation 1)}$$

Where, q is the electron charge, E is the electron field, n is electron concentration, p is hole concentration, μ_n is electron mobility, μ_p is hole mobility, and σ is conductivity respectively.

P-doped WSe_2 is p-type semiconductor materials with hole majority carrier (equal to 2D carrier concentration, n_{2d}), electron minority carrier can be neglected and the supplementary equation 1 becomes:

$$J = qn_{2d}\mu_p E \qquad \text{(Equation 2)}$$

Carrier concentration can be calculated by:

$$n_{2d} = \frac{J}{q\mu_p E} = \frac{\sigma}{q\mu_p} \qquad \text{(Equation 3)}$$

To calculate the conductivity, we use the following equation:

$$\sigma = \frac{I_{ds}\ L}{V_{ds} W} \qquad \text{(Equation 4)}$$

Where, I_{ds} is the drain current, V_{ds} is the drain voltage, L, and W are the channel length and channel width, respectively.

To calculate the hole mobility, we use the following equation:

$$\mu_p = \frac{G_m\ \ L}{C_i V_{ds} W} \qquad \text{(Equation 5)}$$

Where, G_m and C_i are transconductance and capacitance per unit area, respectively.

Using above conductivity and hole mobility equation, the equation 3 becomes:

$$n_{2d} = \frac{I_{ds}\ \ L}{q\mu_p V_{ds} W} = \frac{I_{ds} C_i}{q G_m} \qquad \text{(Equation 6)}$$

Based on the conductivity-voltage characteristic in Figure 7b, we extract the doping concentrations.

References

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