Supporting information

Patterning and doping of Transition Metals in Tungsten Dichalcogenides

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Figure S1. (a) STEM-ADF image of Cr:WSe$_{2-x}$ with Se flow to repair the Se vacancies through ORC reaction. The Cr substitutional dopants are highlighted by red circles. (b) Magnified STEM-ADF image of Cr:WSe$_2$. The atom-by-atom EELS line scan is performed along the green line. (c) EELS profile of Cr $L_2$, $L_3$ edges extracted from the EELS line scan.
Figure S2. (a) STEM and corresponding FFT image of pristine WSe$_2$. Se vacancies are marked with green circles. (b) STEM and corresponding FFT image of WSe$_2$ covered with graphene after the ORC process. The yellow circles in the FFT image are contributed from the graphene lattice covered on WSe$_2$. 
**Figure S3.** Optical images and corresponding Raman spectra of the single layer graphene mask after the ORC reaction.

**Figure S4.** Raman and PL mapping of the unmasked region where the WSe$_2$ was transformed into Cr:WS$_2$ completely after the ORC reaction. The Raman and PL mappings were plotted regarded to the integrated WS$_2$ $E_{2g}^1$ peak (325~275 cm$^{-1}$) and the
WS₂ exciton peak (1.9~2.1 eV).

**Figure S5.** AFM image of Cr:WS₂. The height of the Cr:WS₂ is about 1 nm and the surface is uniform without extra layer grown on the surface after the ORC reaction.

**Figure S6.** (a,b) STEM images of 0.4% Cr-doped WSe₂ at different magnifications. (c,d)
STEM images of 1% Cr-doped WSe$_2$ at different magnifications.

**Figure S7.** To make lateral heterostructures, graphene is used as the mask and transferred onto a monolayer WSe$_2$ film. The exposed WSe$_2$ areas allow for ORC reaction. After the ORC reaction with the supply of Mo and S precursors, the exposed WSe$_2$ stripes can be nearly converted into MoS$_2$.

**Figure S8.** Raman spectra before the ORC reactions with the supply of Mo and S precursors. (a) Raman spectrum acquired on the area of exposed WSe$_2$. (b) Raman spectra acquired on the area of Gr/WSe$_2$. The figure insets in (a) and (b) show the optical microscopy image of the patterned Gr mask on WSe$_2$. 
Figure S9. Raman spectra and optical microscopy images of the patterned Gr mask on WSe$_2$ after the ORC reactions with the supply of Mo and S precursors. (a) and (c) show the optical microscopy images of the area where Raman spectra were acquired. (b) and (d) show, respectively, the Raman spectrum acquired on the exposed and masked areas of Gr/WSe$_2$. On the exposed area, the Raman characteristic peaks of WSe$_2$ vanish and is replaced by those of MoS$_2$ after the ORC reaction. On the contrary, the Raman characteristic peaks of WSe$_2$ on the Gr-masked areas remain unchanged after the ORC reaction.