

Supplementary information for **Precise p -type and n -type doping of two-dimensional semiconductors for monolithic integrated circuits**

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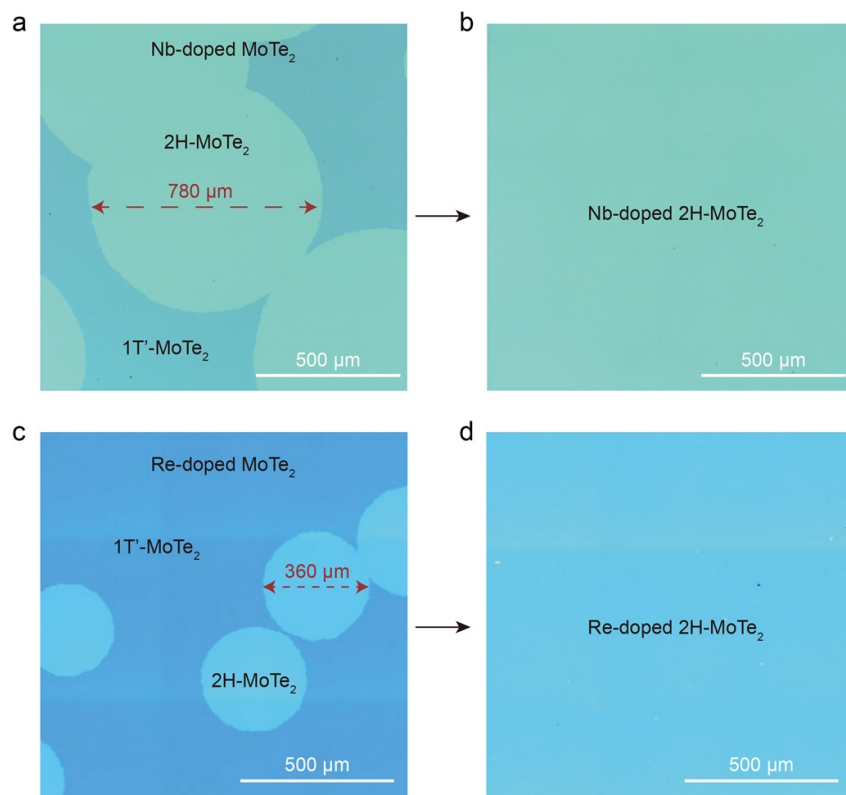
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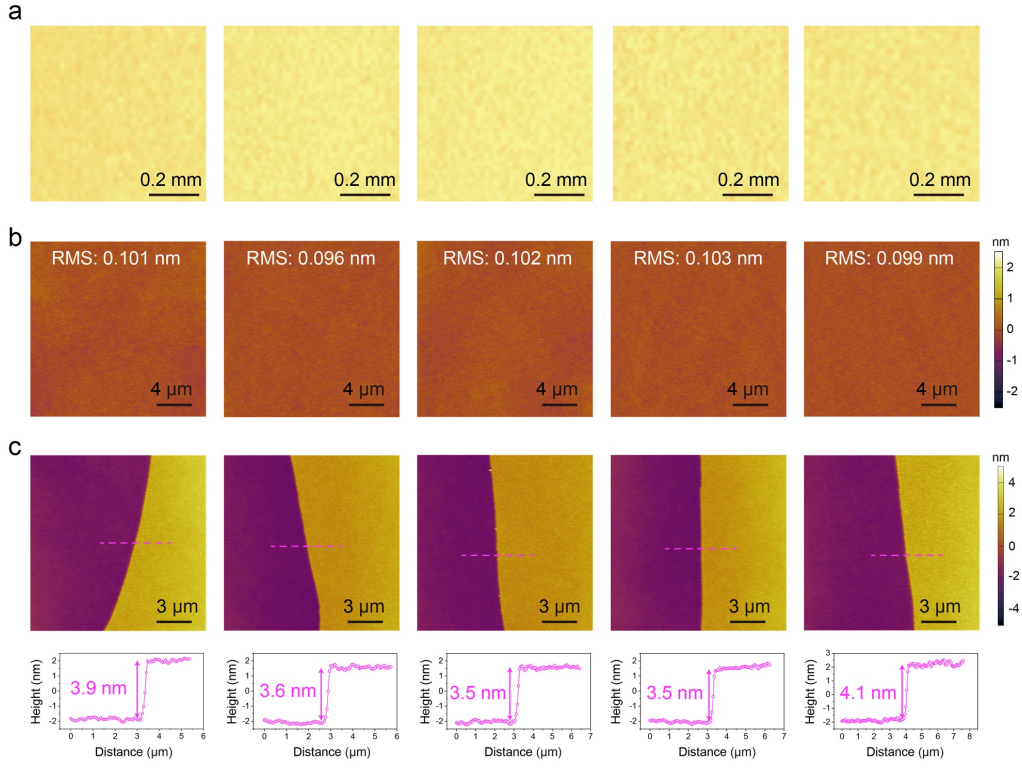
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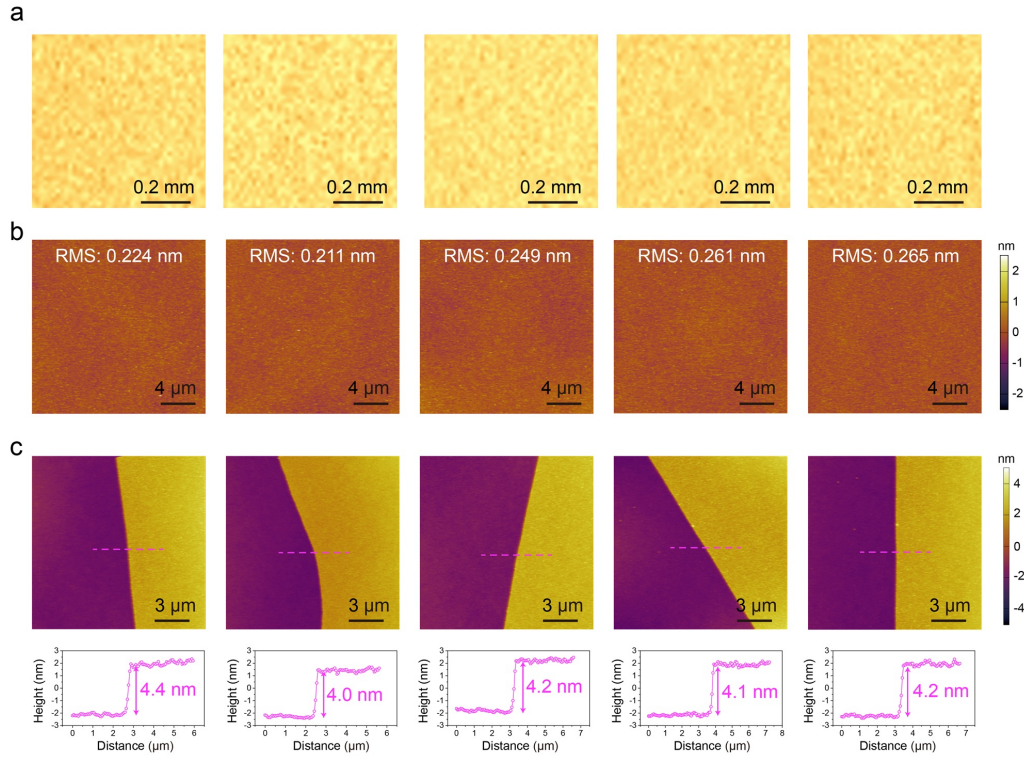
Supplementary Fig. 1 Preparation of the doped 2H-MoTe₂ films. **a, c,** MoTe₂ films doped with Nb or Re grown on Si/SiO₂ substrates for a short period of time. 2H-MoTe₂ circles with a domain size of a few hundred micrometers can be seen. **b, d,** As growth time prolongs, these 2H domains grow gradually and merge together to form a uniform 2H-MoTe₂ film with Nb doping or Re doping.

The kinetic process and driving forces of the phase transition from 1T'- to 2H-MoTe₂ have been extensively studied in our previous research (Journal of the American Chemical Society 141.5 (2019): 2128-2134). In brief, within a very short initial growth period, the Mo film is first converted to 1T'-phase MoTe₂ through tellurization, as the deficiency of Te reduces the free energy of 1T'-MoTe₂, leading to the formation of this metastable phase. Density functional theory (DFT) calculations have also confirmed that when Te deficiency exceeds 2%, 1T' phase is more stable compared to 2H phase (Journal of the American Chemical Society 141.5 (2019): 2128-2134). The early-formed 1T' phase is a defect-related polycrystalline film with grain sizes only in the tens of nanometers. With the supply of Te, nucleation and growth towards 2H-MoTe₂ are promoted, as in stoichiometric MoTe₂, the 2H phase is more stable. As the growth time extends, randomly distributed bright-colored 2H-MoTe₂ circular domains appear on the background of 1T'-MoTe₂ films, with each circle confirmed to be a single crystal 2H-MoTe₂ domain. Given the different lattice structures of 2H-MoTe₂ and 1T'-MoTe₂, along with the significantly larger domain size of single crystal 2H-MoTe₂ compared to 1T'-MoTe₂, we can infer atomic rearrangements during the phase transformation from 1T' to 2H. With prolonged growth time, the 2H-MoTe₂ circles gradually enlarge and merge, and with a sufficiently long growth period, all circles coalesce into a continuous 2H-MoTe₂ film.

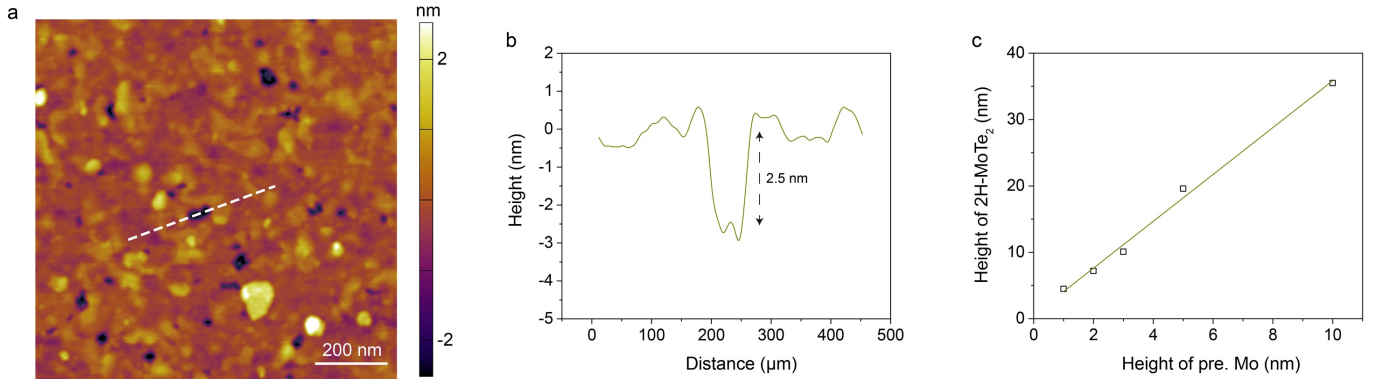
In order to evaluate the grain size of doped 2H-MoTe₂ films, the growth time was shortened so that the film did not fully transform into a continuous 2H-MoTe₂ film, allowing us to directly observe 2H-MoTe₂ single-crystal domains. Optical images reveal randomly distributed bright-colored 2H-MoTe₂ circular domains on the background of 1T'-MoTe₂ films. Previous work has indicated that due to two-dimensional in-plane epitaxial growth, 2H-MoTe₂ forms circular domains, with each circular domain representing a single crystal of 2H-MoTe₂. Consequently, optical images show that the diameter of Nb-doped single-crystalline 2H-MoTe₂ circle can reach 780 μm (360 μm for Re-doped 2H-MoTe₂ single-crystal circle). As the growth time is prolonged, the circular domains of 2H-MoTe₂ gradually enlarge and merge together, forming uniform continuous Nb-doped or Re-doped 2H-MoTe₂ films.



Supplementary Fig. 2 Large-scale uniformity of the as-synthesized Nb-doped 2H-MoTe₂ films. Raman mappings and AFM height images were measured at random 5 different positions across the wafer. **a**, Raman mappings of the representative 2H-MoTe₂ Raman peak intensity (E_{2g}^1 , 234 cm⁻¹), showing the high uniformity of the Nb-doped 2H-MoTe₂ film. The areas of the Raman mappings are 0.7 mm × 0.7 mm. **b-c**, AFM height images of Nb-doped 2H-MoTe₂ films measured at 5 different positions. The surface roughness (RMS) was in the range of 0.096-0.103 nm, and no holes were observed on the film surface, indicating that the film was continuous and very smooth. Meanwhile, the thickness of the Nb-doped 2H-MoTe₂ films is about 3.5-4.1 nm, corresponding to 5-6 layers of MoTe₂.

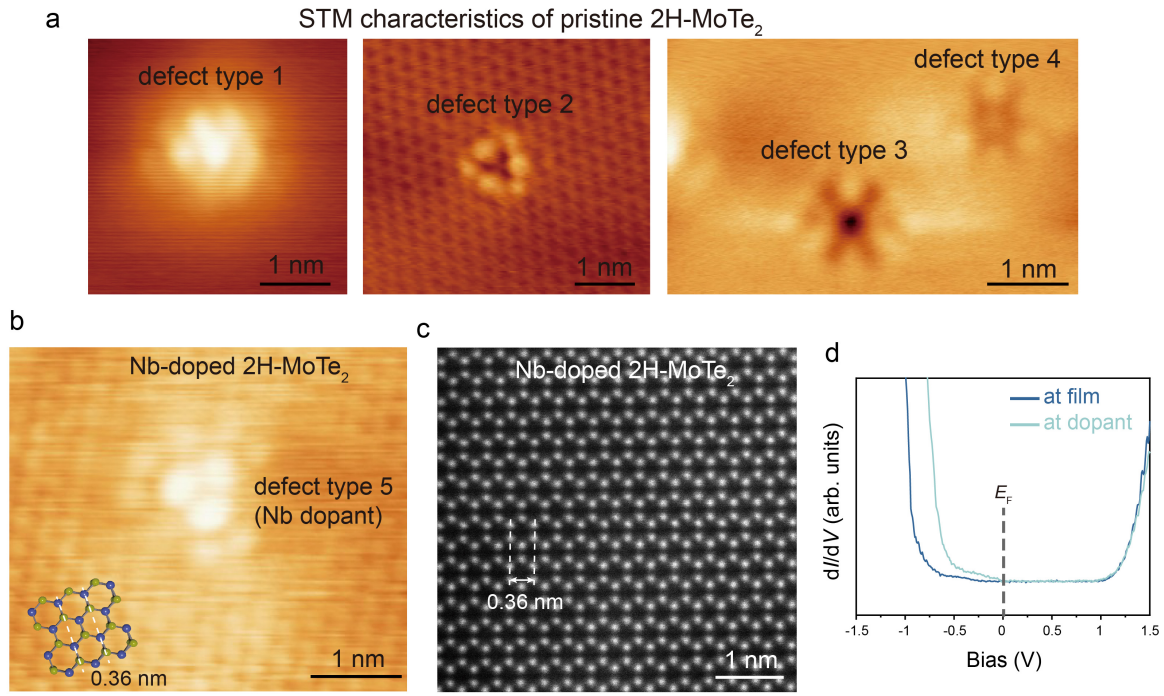


Supplementary Fig. 3 Large-scale uniformity of the as-synthesized Re-doped 2H-MoTe₂ films. Raman mappings and AFM height images were measured at random 5 different positions across the wafer. **a**, Raman mappings of the representative 2H-MoTe₂ Raman peak intensity (E_{2g}^1 234 cm⁻¹), showing the high uniformity of the Re-doped 2H-MoTe₂ film. The areas of the Raman mappings are 0.7 mm × 0.7 mm. **b-c**, AFM height images of Re-doped 2H-MoTe₂ films measured at 5 different positions. The surface roughness (RMS) was in the range of 0.211-0.265 nm, and no holes were observed on the film surface, indicating that the film was continuous and very smooth. Meanwhile, the thickness of the Re-doped 2H-MoTe₂ films is about 4.0-4.4 nm, corresponding to 6-7 layers of MoTe₂.

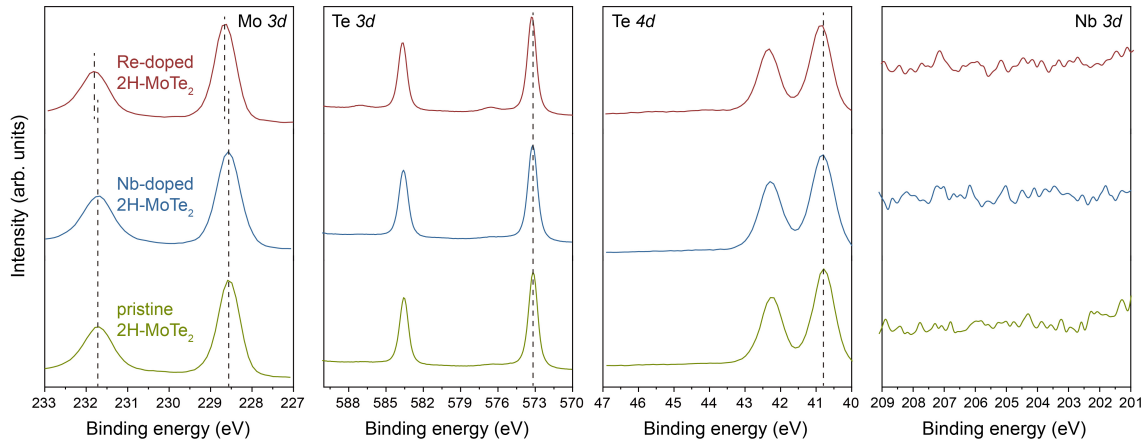


Supplementary Fig. 4 **a-b**, AFM topography image (a), and corresponding height profile (b) of a MoTe₂ (Nb) film with a thickness of 2.5 nm. **c**, Summary of the thickness of doped MoTe₂ films, depending on the thickness of the pre-deposited Mo precursor with dopant.

Our method for synthesizing 2H-MoTe₂ involves tellurization of a Mo film, requiring a continuous Mo film for in-plane epitaxy techniques. After the Mo film ultimately transforms into 2H-MoTe₂, the film thickness increases by approximately threefold. To explore the thinnest doped 2H-MoTe₂ films obtainable, we utilized initially Nb-incorporated Mo films and precisely controlled various thicknesses through magnetron sputtering. For the thinnest nucleation-capable Mo (Nb) films, we observed a remarkably slow growth rate of 2H-MoTe₂ films, resulting in rough films. Atomic force microscopy results indicate a 2H-MoTe₂ thickness of around 2.5 nm with non-continuous voids, high roughness. This discontinuity and roughness may stem from the initial ultra-thin Mo (Nb) film, hindering the outward expansion of the phase transition, thus leading to poor quality doped 2H-MoTe₂ films under these conditions. When a slight increase in the precursor Mo film thickness, we obtained a series of correspondingly thick 2H-MoTe₂ films. Therefore, the minimum thickness achievable for continuous doped 2H-MoTe₂ currently is approximately 3-4 nm.

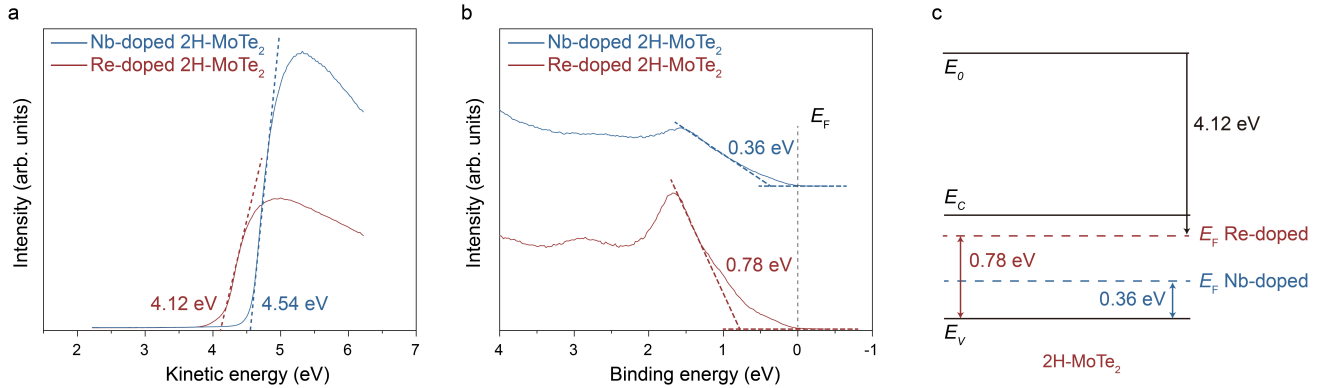


Supplementary Fig. 5 Scanning tunnel microscope (STM) characterizations of pristine and doped 2H-MoTe₂ films. **a** and **b**, STM topography images of the unintentionally doped 2H-MoTe₂ and Nb-doped films grown directly on HOPG substrates. Zoomed-in STM topography of Nb-doped 2H-MoTe₂, with structural model superimposed on top, showing a clear hexagonal 2H-MoTe₂ lattice with a lattice constant of 0.36 nm. The measured lattice constant is consistent with the result from the HAADF-STEM image shown in **c**. **c**, HAADF-STEM image of Nb-doped 2H-MoTe₂, showing a lattice constant of 0.36 nm. **d**, Corresponding dI/dV spectra on the Nb-doped 2H-MoTe₂ film and at the Nb dopant sites.

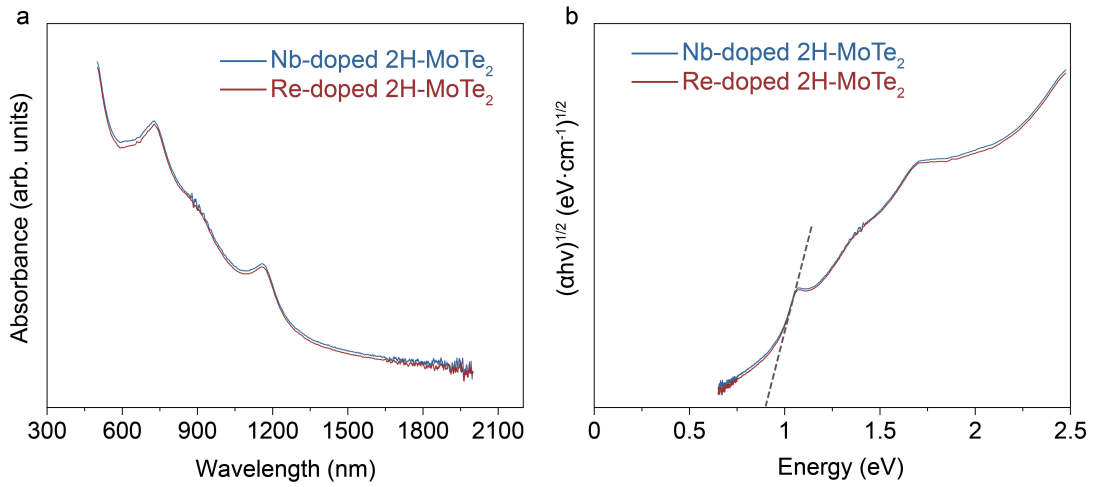


Supplementary Fig. 6 X-ray photoelectron spectroscopy (XPS) results of Mo 3d, Te 3d, Te 4d and Nb 3d regions of pristine, Nb-doped and Re-doped 2H-MoTe₂ thin films.

XPS findings revealed no substantial disparities between pristine MoTe₂ and Nb-doped MoTe₂. Notably, the absence of the Nb 3d characteristic peak within the binding energy range of 202-208 eV was observed. Moreover, in the Re-doped MoTe₂ samples, the prominence of the Te 4d peaks hindered the clear detection of weak Re characteristic peaks, as the latter were situated at 42 eV and 45 eV. Nevertheless, the introduction of Re dopants elicited a notable +0.13 eV displacement in the Mo 3d peaks at 228.6 eV and 231.8 eV, indicating an upward shift of the Fermi level attributable to *n*-type doping.

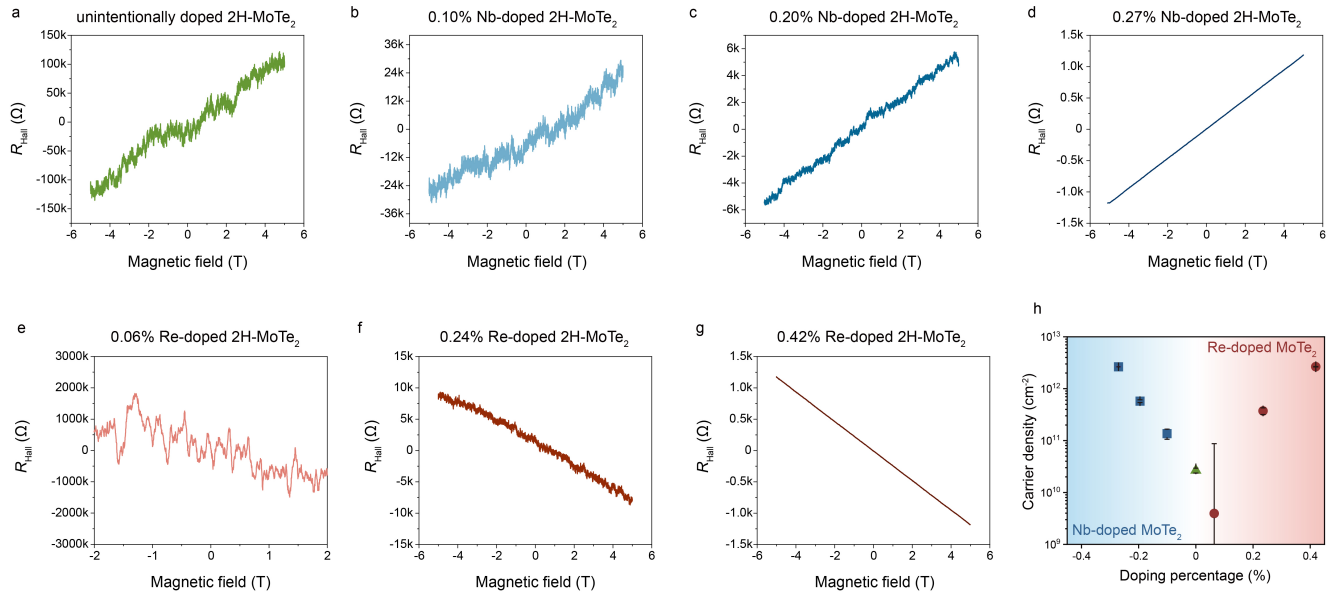


Supplementary Fig. 7 Ultraviolet photoelectron spectroscopy (UPS) spectra of Nb-doped and Re-doped 2H-MoTe₂. **a** Secondary electron cutoff region of the UPS spectra. Values indicate the work function for each sample. **b** Valence region relative to the Fermi level (E_F) in the UPS spectra. **c** Energy band diagrams of Nb-doped and Re-doped 2H MoTe₂. Values of the work function and valence band edges are obtained from UPS spectra.

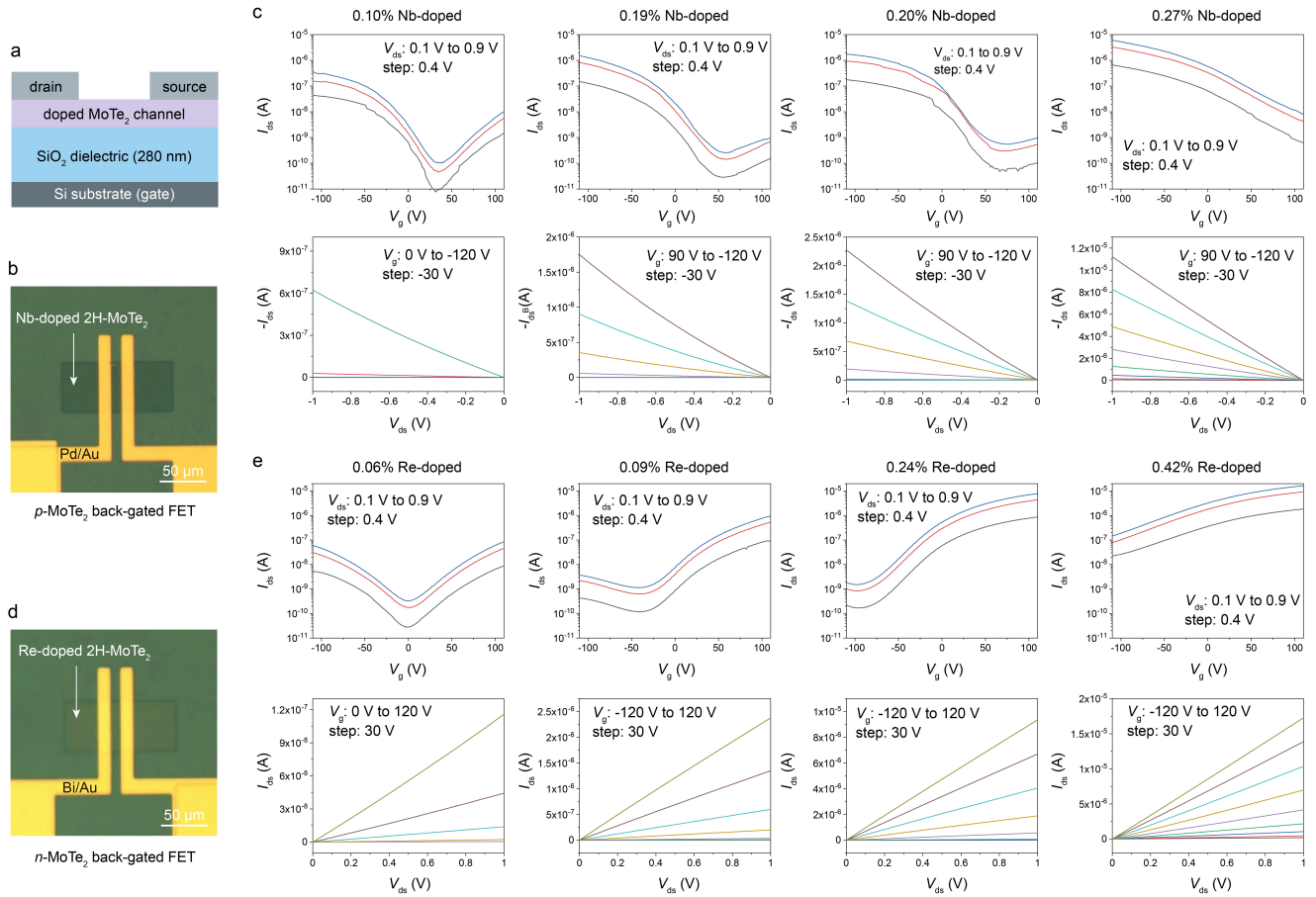


Supplementary Fig. 8 Tauc plot absorption spectra used to calculate the band gap of doped MoTe₂. **a** Optical absorption spectra of Nb-doped and Re-doped 2H-MoTe₂ thin films. **b** Tauc plot of $(\alpha h\nu)^{1/2}$ versus energy for Nb-doped and Re-doped 2H-MoTe₂ thin films.

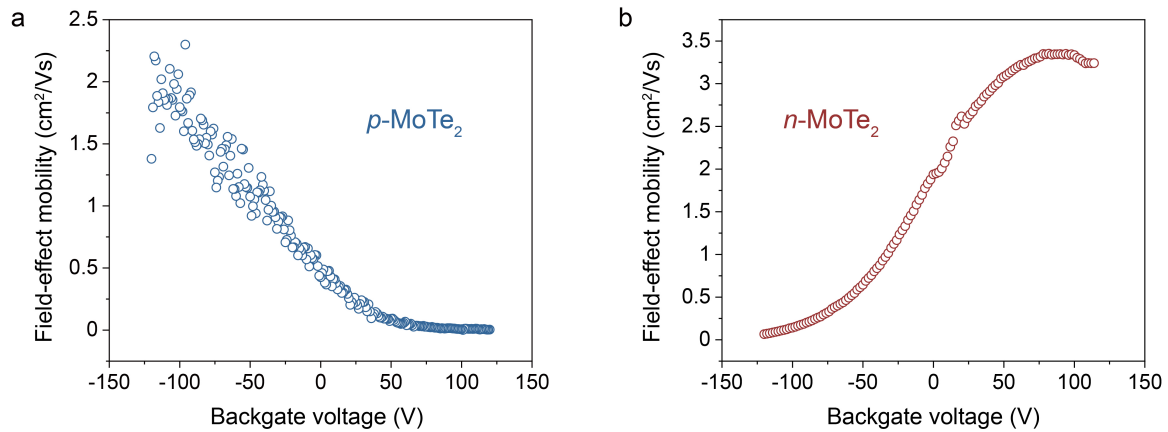
Further examination of the semiconductor state of doped 2H-MoTe₂ involved UV-Vis-NIR spectroscopy to calculate the bandgap using Tauc plot absorption spectroscopy. Due to the small doping concentrations, optical absorption spectra analysis showed no significant discrepancy between Nb- and Re-doped 2H-MoTe₂ films. Moreover, as indicated by Tauc plot, both Nb- and Re-doped 2H-MoTe₂ exhibited similar band gaps (0.9 eV).



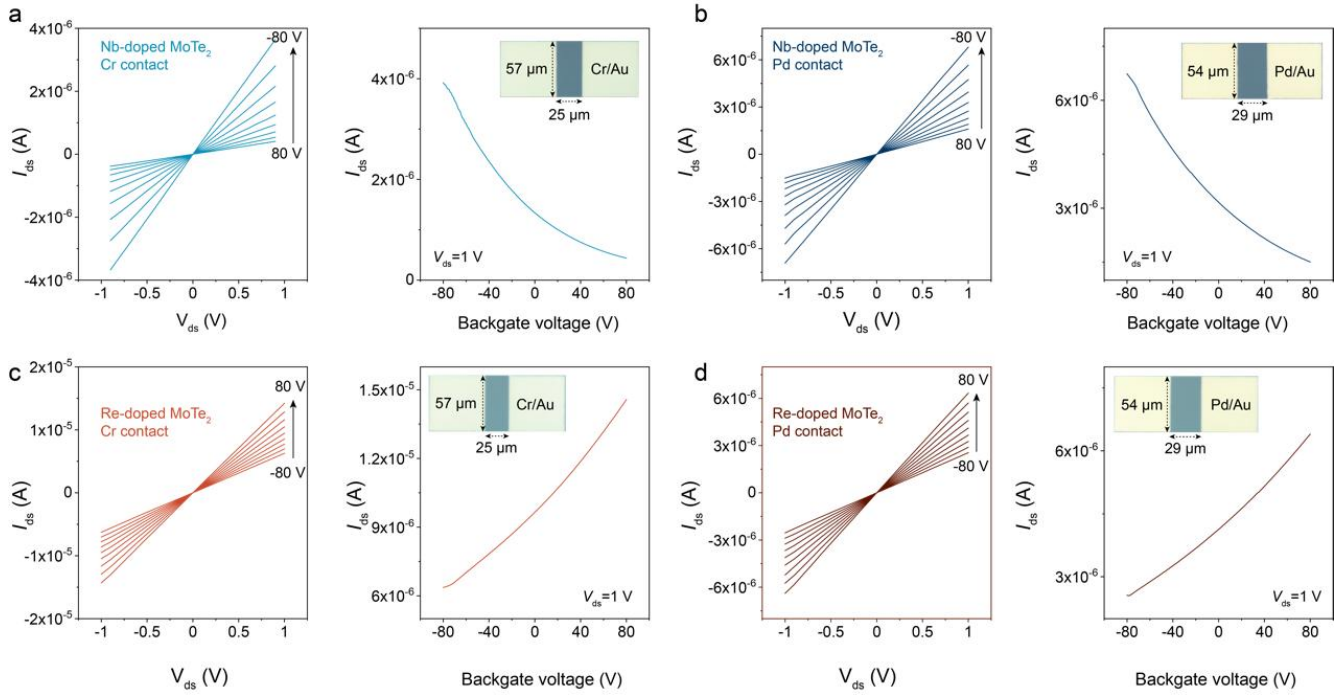
Supplementary Fig. 9 The magnetic field-dependent Hall resistance of the doped 2H-MoTe₂ thin films. **a**, The unintentionally doped case, showing a *p*-type behavior with a low background hole concentration. **b-d**, Nb-doped 2H-MoTe₂ cases with Nb incorporation ratio from 0.10% to 0.27%, showing the conduction hole-conducting *p*-type. **e-g**, Re-doped 2H-MoTe₂ cases with Re incorporation ratio from 0.06% to 0.42%, showing the conduction electron-conducting *p*-type. The inverse of the slope of the R_{Hall} versus B curve determines the carrier concentration. **h**, Hole or electron carrier densities of 2H-MoTe₂ semiconductor films with various Nb or Re incorporation ratios through logarithmic transformation. The error bars are standard deviation.



Supplementary Fig. 10 FET characteristics of 2H-MoTe₂ channels with different Nb or Re incorporation ratios. **a**, Schematic diagram of the structure of a doped 2H-MoTe₂ back-gate FET. To minimize process-induced doping effects, we fabricated back-gate FETs on 2H-MoTe₂ thin films with different doping types and carrier concentrations directly grown on commercial Si/SiO₂ substrates. The Pd/Au was used for *p*-MoTe₂ and Bi/Au for *n*-MoTe₂. **b**, **d**, Optical images of Nb-doped and Re-doped 2H-MoTe₂ back-gated FETs. These FETs have channels of the same size, with a length of 10 μm, a width of 40 μm, and a thickness of 5 nm. **c**, **e**, Transfer and output characteristics of the back-gated FETs with different incorporation ratios of Nb (**b**) and Re (**d**). The Nb-doped (Re-doped) 2H-MoTe₂ channel exhibits *p*-type (*n*-type) semiconductor transfer characteristic, and its on-current increases with the increase of doping concentration, while the transistor threshold voltage increases towards the positive (negative) voltage direction. The adjustment of transistor threshold voltage with doping concentration is summarized in Supplementary Fig. 13.

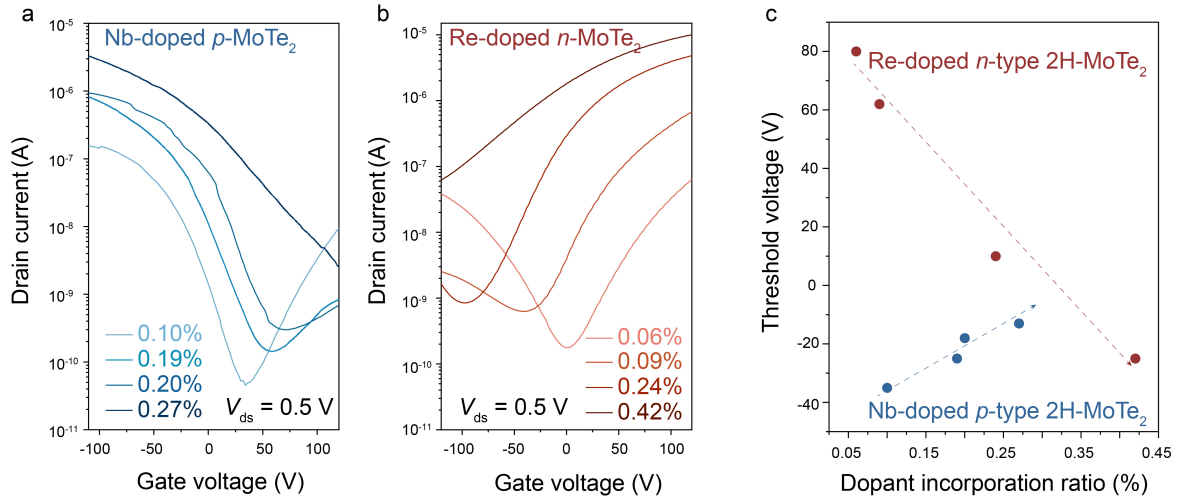


Supplementary Fig. 11 Nb-doped (a) and Re-doped (b) 2H-MoTe₂ back-gate-dependent field-effect mobilities. The device was fabricated from the Re- (0.42%) and Nb-MoTe₂ (0.27%) films as shown in Supplementary Fig. 10.

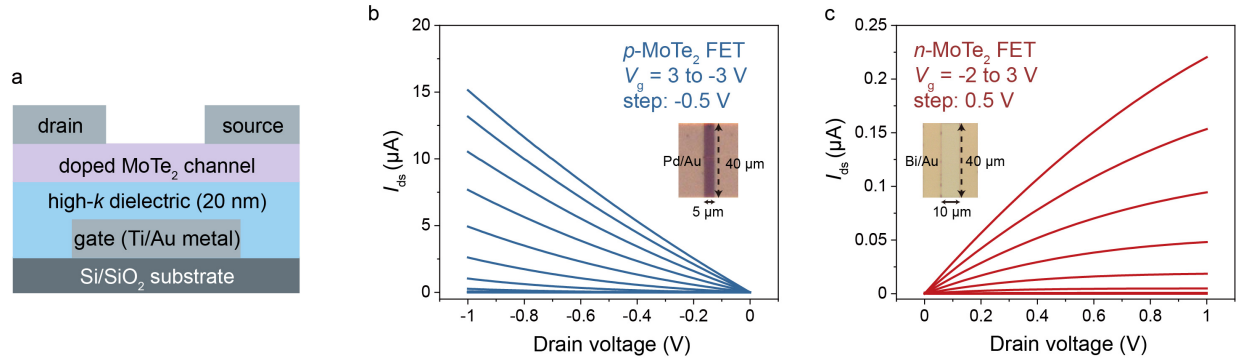


Supplementary Fig. 12 Electrical characterization of Cr- and Pd-contacted doped MoTe₂ transistors. **a-b** I_{ds} - V_{ds} and I_{ds} - V_g curves for Cr- and Pd-contacted Nb-doped 2H-MoTe₂ transistors, respectively. **c-d** I_{ds} - V_{ds} and I_{ds} - V_g curves for Cr- and Pd-contacted Re-doped 2H-MoTe₂ transistors, respectively. In the electrical characteristics of all devices, the range of V_g in the output curves is from -80 V to 80 V and the step is 20 V, the I_{ds} of the transfer curves is 1 V.

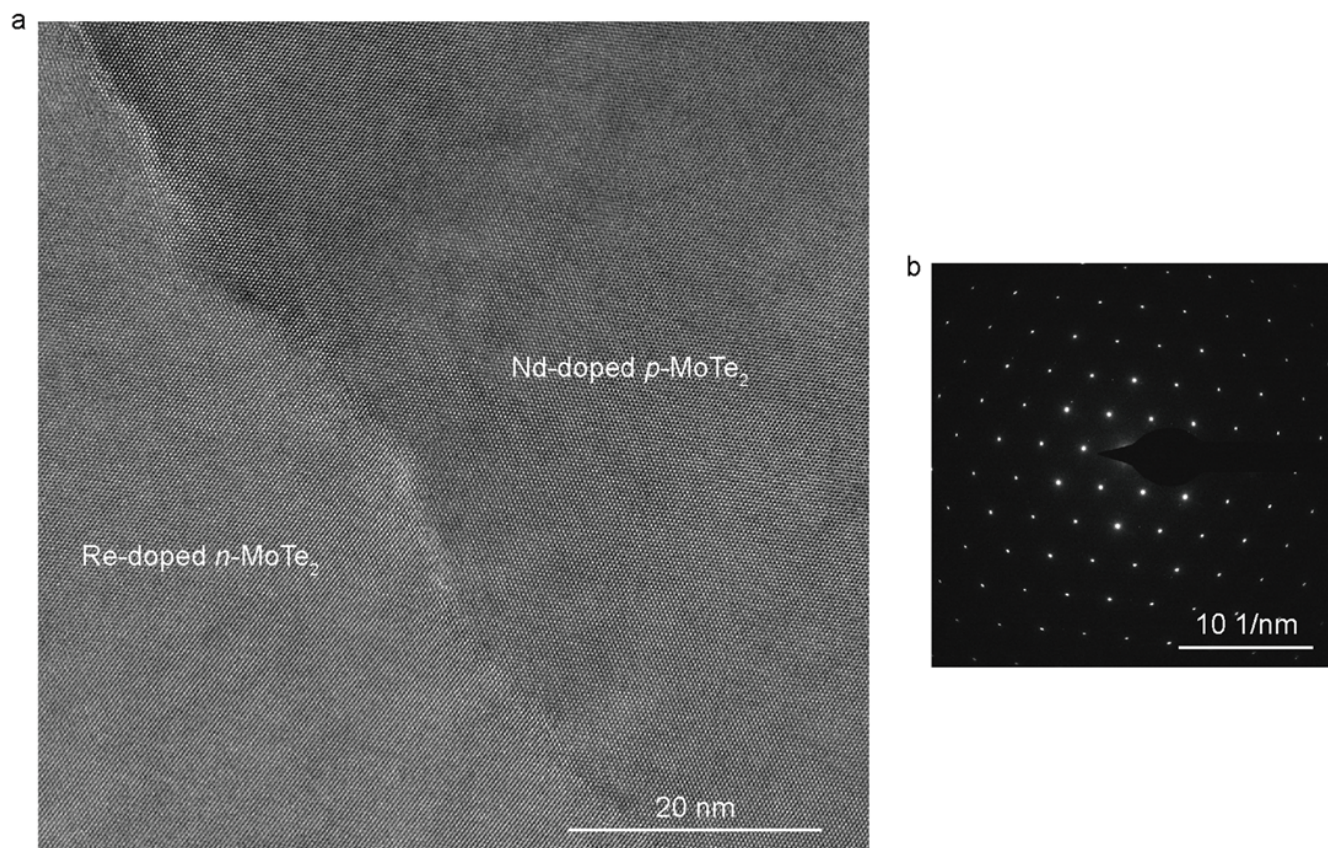
The higher doping concentrations of Re- (0.5 %) and Nb-MoTe₂ (0.4 %) FET devices of uniform thickness (about 15 nm) were fabricated in the same batch, with different metal contacts (Cr and Pd) to minimize environmental and process impacts. The electrical characterization of doped MoTe₂ transistors using the same contact metals further confirmed the change in semiconductor type induced by dopant, rather than being influenced by the contact metals. However, the Nb-MoTe₂ (Re-MoTe₂) devices with low work function Cr (high work function Pd) contacts exhibit lower output currents due to the work function mismatch compared to Nb-MoTe₂ (Re-MoTe₂) devices with high work function Pd (low work function Cr) contacts. Electrical measurements of differently doped 2H-MoTe₂ transistors with the same metal contact show that the Schottky barrier height in doped MoTe₂/metal structures is determined by the work function of the contact metal and the doping level in MoTe₂, where the doping level in MoTe₂ is solely determined by the incorporation of the dopants.



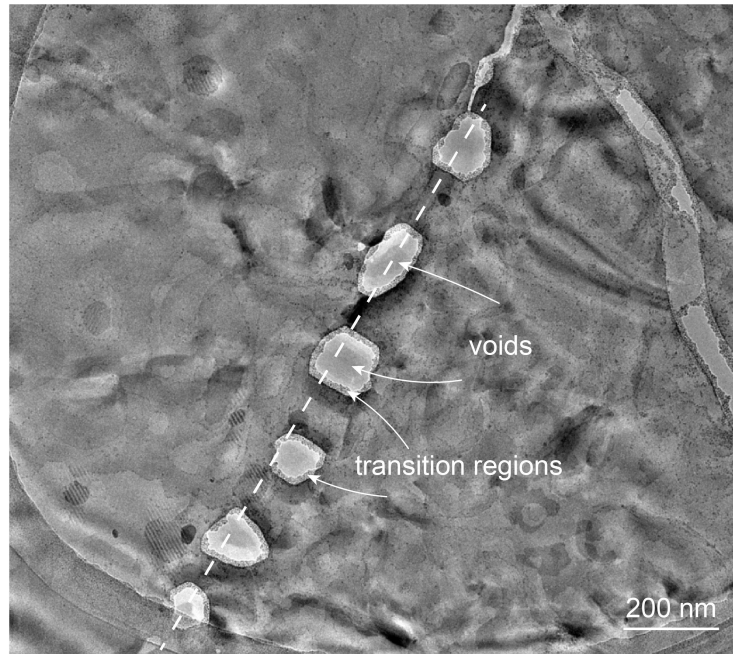
Supplementary Fig. 13 The transfer characteristics of 2H-MoTe₂ FETs as a function of dopant incorporation ratio. The Pd/Au was used for *p*-MoTe₂ and Bi/Au for *n*-MoTe₂. **a** and **b**, Transfer characteristics of the *p*- and *n*-type 2H-MoTe₂ FETs with various doping concentrations. **c**, The transistor threshold voltage of *p*-type (*n*-type) 2H-MoTe₂ increases (decreases) with doping, where the dashed lines with arrows indicate the evolution of threshold voltage with doping concentration. Devices are from Supplementary Fig. 10.



Supplementary Fig. 14 Electrical properties of typical *p*-type (0.20% Nb-doped) and *n*-type (0.24% Re-doped) 2H-MoTe₂ FETs. **a**, Schematic diagram of the structure of a doped 2H-MoTe₂ back-gate FET. The devices utilized a back-gate transistor structure with 20 nm Al₂O₃ dielectric and a channel *W*/*L* of 40/5 μm for *p*-MoTe₂ FETs (*W*/*L* of 40/10 μm for *n*-MoTe₂ FETs). The doped 2H-MoTe₂ films (thickness of 5 nm) were transferred onto the substrate with back-gate electrodes (Ti/Au, 5/20 nm). The Pd/Au was used for *p*-MoTe₂ and Bi/Au for *n*-MoTe₂. And the devices were measured in a vacuum. **b** and **c**, Output characteristics of *p*-type (**b**) and *n*-type (**c**) 2H-MoTe₂ FETs.

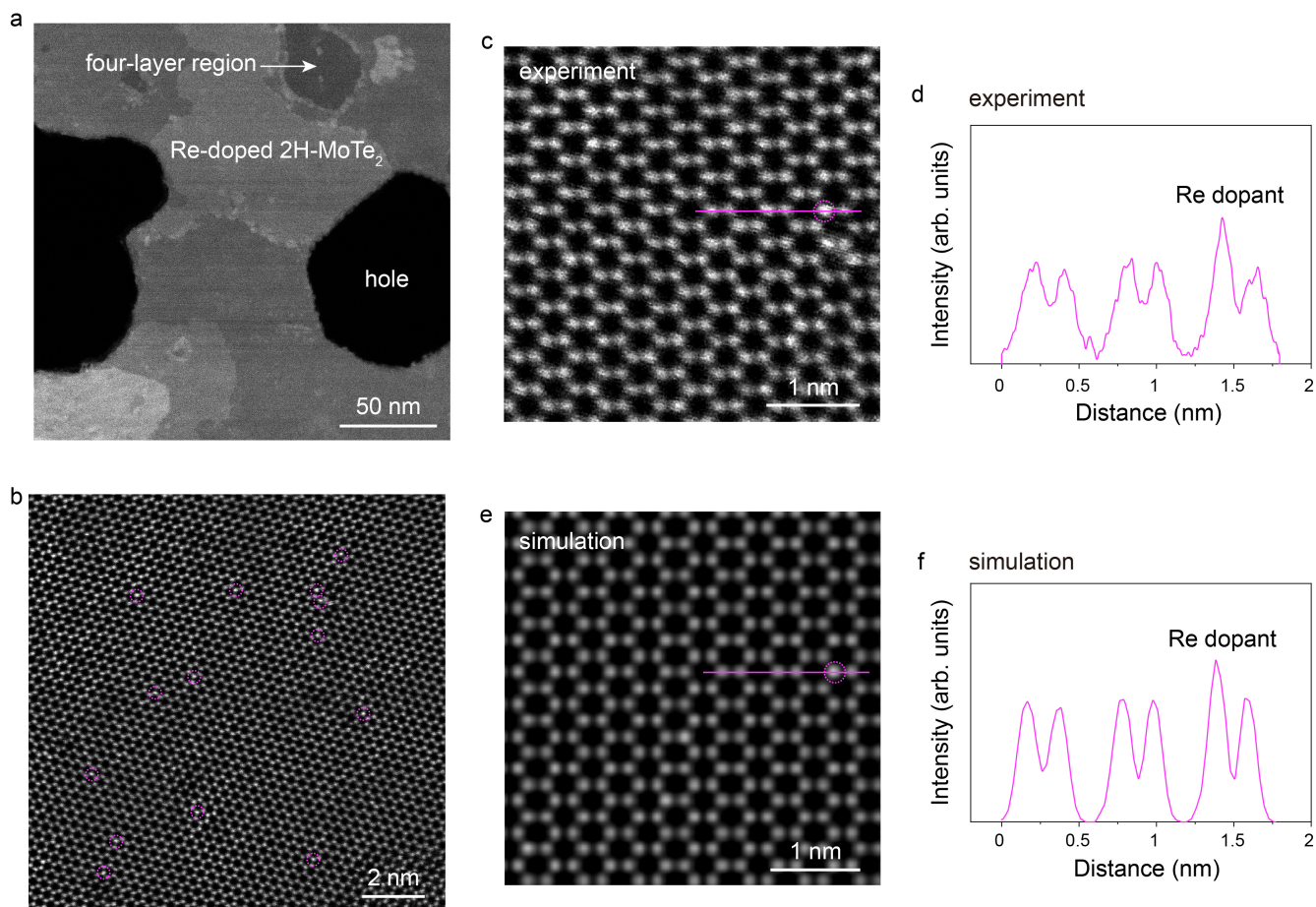


Supplementary Fig. 15 Characterization of atomic structure and crystal orientation at the interface of 2H-MoTe₂ pn structure. **a**, Large field-of-view high-resolution TEM image at the interface of Nb- and Re-doped 2H-MoTe₂ pn structure. **b**, The corresponding SAED pattern at the interface with an aperture size of 800 nm, which shows only one hexagonal lattice of the single crystal.



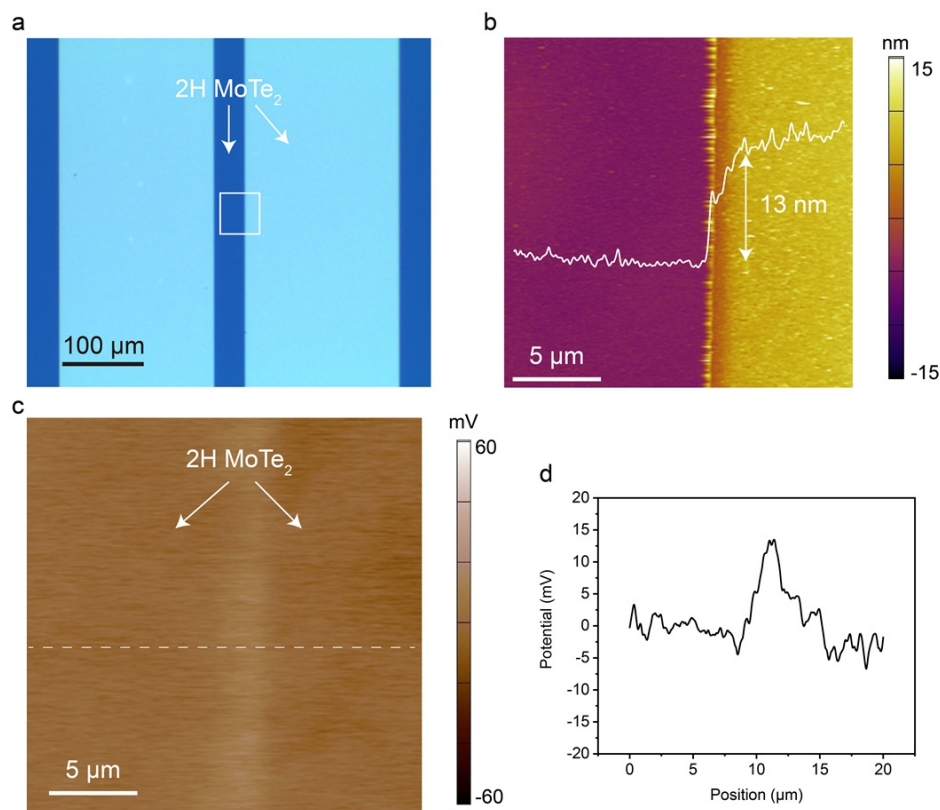
Supplementary Fig. 16 Large-field-of-view high-resolution TEM image at the interface of a Nb-doped and Re-doped 2H-MoTe₂ *pn* structure grown in one step method.

We tested the $I - V$ curve of the 2H-MoTe₂ *pn* junction grown in a one-step process but did not observe obvious rectifying characteristics. These voids' boundaries at the interface may have formed charge-hopping channels, breaking the space charge region and suppressing the rectifying characteristics of the *pn* junction.



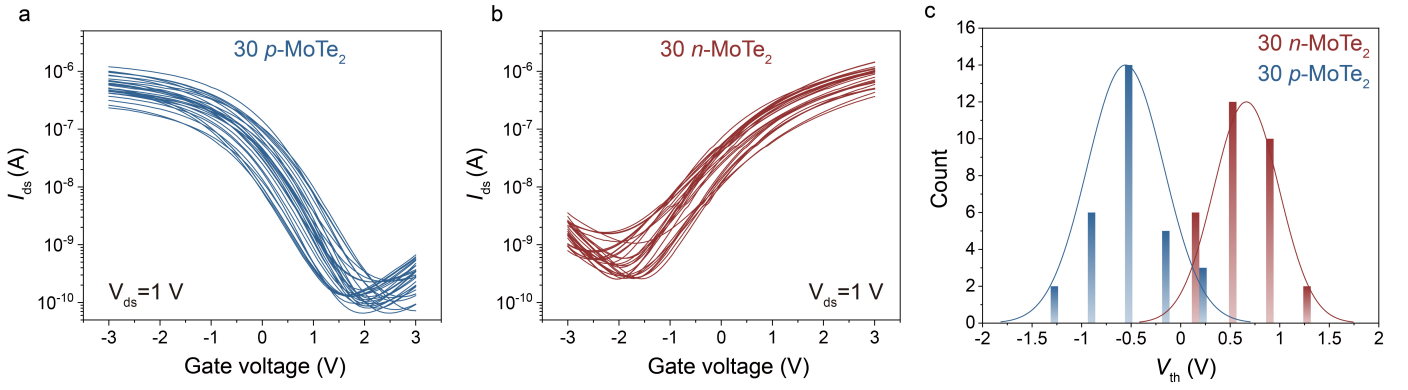
Supplementary Fig. 17 STEM characterizations of the Re-doped thin 2H-MoTe₂ film. **a**, Large field-of-view HAADF-STEM image of a Re-doped 2H-MoTe₂ thin film with some holes and thin four-layer regions. **b**, Zoomed-in HAADF-STEM image of four-layer 2H-MoTe₂ region, showing discernible doping of Re atoms marked by the pink dotted circles. We only selected a small number of brighter sites to highlight them. **c, e**, Experimental and simulated HAADF-STEM images of the four-layer 2H-MoTe₂ doped with Re atoms. **d, f**, Line profiles of the image contrast from experimental (**c**) and simulated (**e**) HAADF-STEM images containing one Re dopant. The intensity at the site containing Re is about 30% higher than that of Mo only, and the experimental and simulation results agree very well.

Due to the large atomic number difference between Re and Mo, it is possible to resolve the atomic substitutional doping of Re in the thin Re-doped 2H-MoTe₂. Therefore, we magnetron sputtered a thinnest Mo film with a Re incorporation ratio of 0.85% on a SiO₂ substrate. Since the thinnest Mo film is discontinuous, we will find a discontinuous 2H-MoTe₂ thin film after tellurization. Under the low-magnification HAADF-STEM image (Supplementary Fig. 17a), we will find some discrete holes, 2H-MoTe₂ of different thicknesses, and occasionally some thinner four-layer regions.

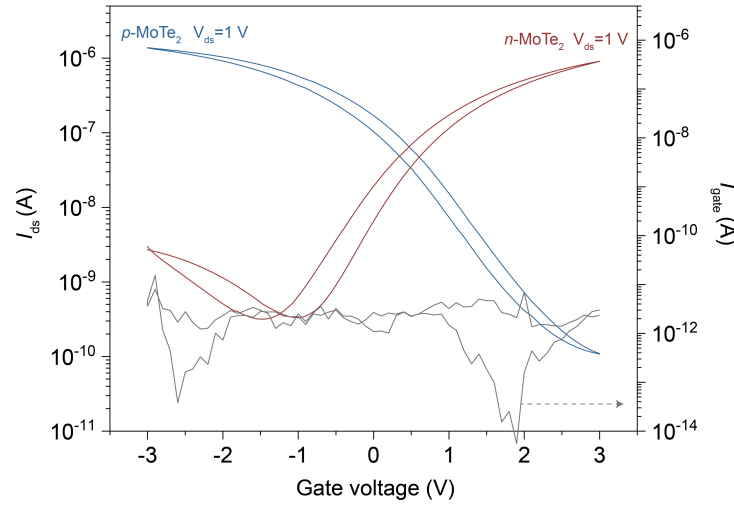


Supplementary Fig. 18 Pristine 2H-MoTe₂ homojunction with thick (20 nm) and thin (7 nm) films, used to analyze the potential properties. **a** Optical image of the 2H-MoTe₂ homojunction with different thicknesses. The white dashed box shows the interface region labeled for height measurements. **b** AFM morphology and height line profile at the homojunction interface, showing a step height of about 13 nm. **c-d** The surface work function image and the potential line profile of the interface, measured by KPFM.

AFM image and line height profile characteristics indicate a thickness difference of approximately 13 nm in the 2H-MoTe₂ homojunctions. However, the corresponding KPFM mapping exhibits a uniform potential (-5 mV to 0 mV), with only slight variations (10 mV) at the step region due to tip fluctuations. Therefore, the KPFM mapping of the 2H-MoTe₂ homojunction demonstrate that for 2H-MoTe₂ films thicker than 7 nm, KPFM results are unaffected by thickness differences.

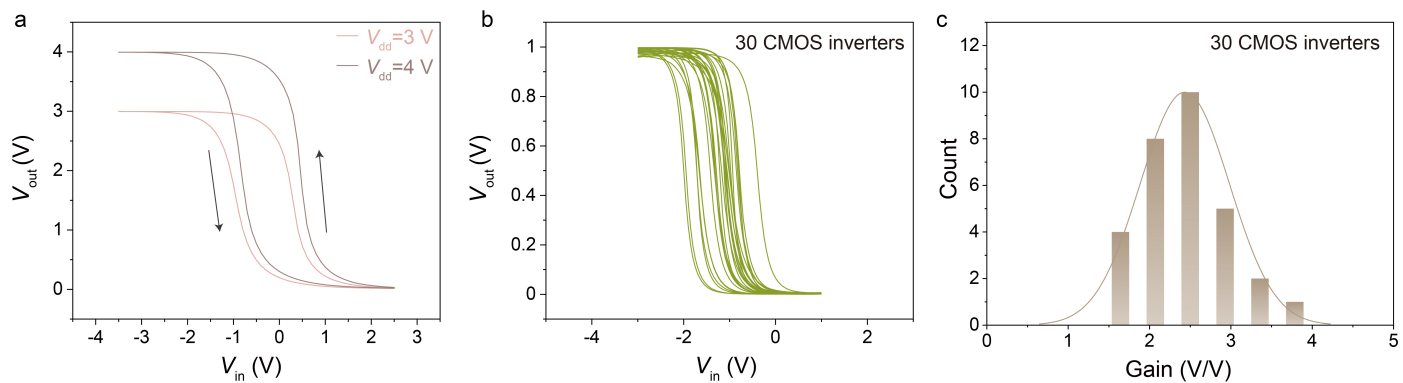


Supplementary Fig. 19 Statistical analysis of the electrical properties of 30 Nb-doped MoTe₂ transistors and 30 Re-doped MoTe₂ transistors. The devices are top-gate doped MoTe₂ transistors as shown in the Fig. 4a-c in the main text. **a-b** I_{ds} - V_g curves of 30 Nb-doped p -MoTe₂ transistors and 30 Re-doped n -MoTe₂ transistors. **c** Corresponding threshold voltage (V_{th}) histograms. Channel lengths and channel widths for all devices measured are 10 μ m and 40 μ m, respectively, and all the parameters were extracted at a drain bias (V_{ds}) of 1 V.

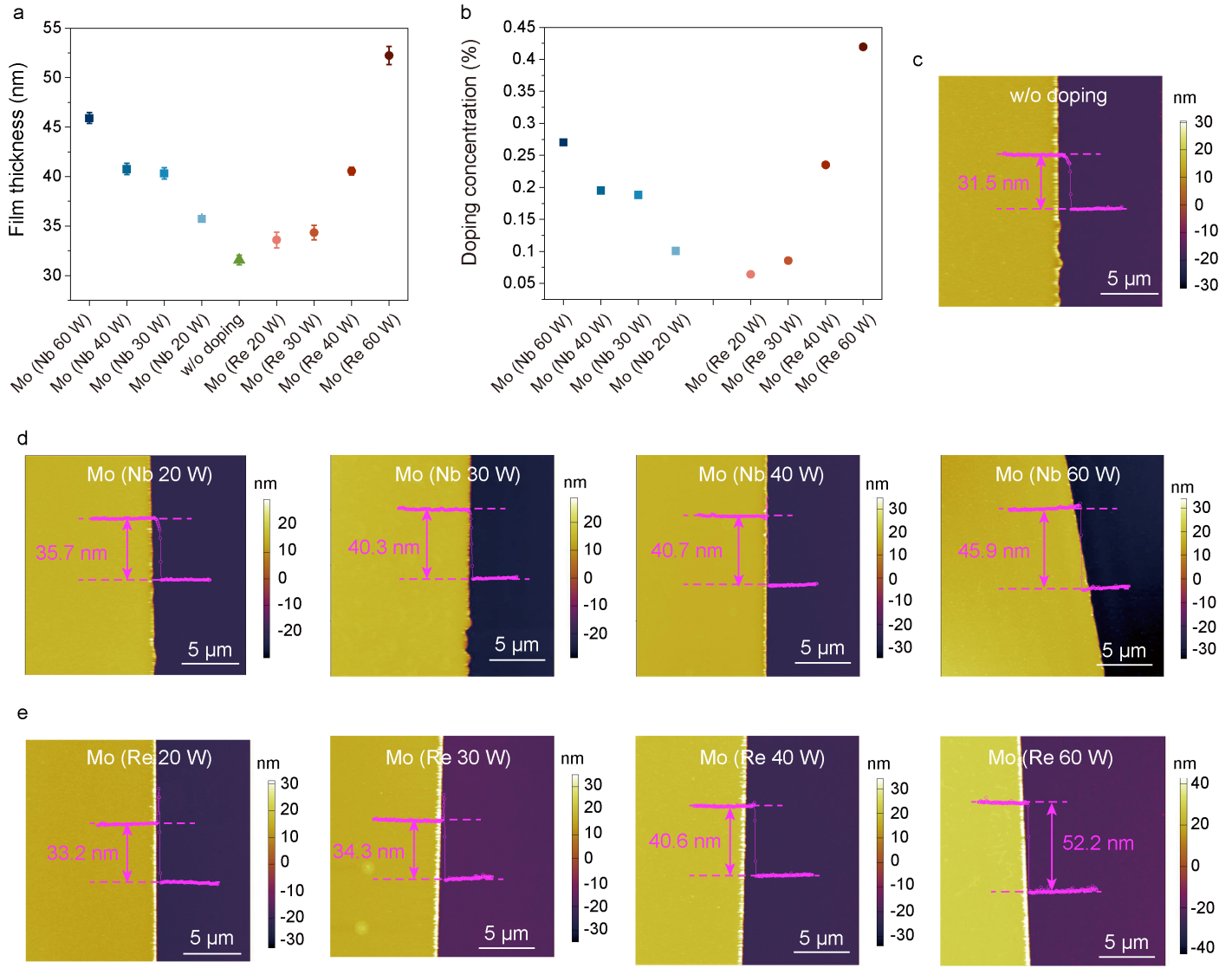


Supplementary Fig. 20 Transfer characteristic curves (I_{ds} - V_g) of p -MoTe₂ and n -MoTe₂ transistors for back-and-forth sweep. The devices are top-gate doped MoTe₂ transistors as shown in the Fig. 4a in the main text.

The maximum hysteresis width during forward and backward sweeps for p -MoTe₂ (n -MoTe₂) is approximately 0.2 V (0.4 V). The hysteresis phenomenon in transistor transfer characteristics is typically associated with charge trapping and charge detrapping induced by defects at the 2D semiconductor-dielectric interface (ACS Applied Materials Interfaces 14.1 (2021): 2185-2193). Maintaining semiconductor surface cleanliness during the device fabrication is an effective method for optimizing the interface between 2D semiconductors and oxides (Advanced Materials Interfaces 8.22 (2021): 2100950). Additionally, the type of gate dielectric material and the Van der Waals interface between the semiconductor and dielectric can also impact the hysteresis window in transistor transfer characteristics (Nature Electronics 4.12 (2021): 906-913) (Nature Electronics 5.12 (2022): 849-858).



Supplementary Fig. 21 Statistical electrical characterizations of CMOS inverter arrays. **a**, Double-sweep transfer characteristic of inverter. **b**, Typical transfer characteristics of 30 inverters composed of *p*-type and *n*-type MoTe₂ transistors. **c**, Statistical histogram distribution of inverter gains in **a** with Gaussian fit.



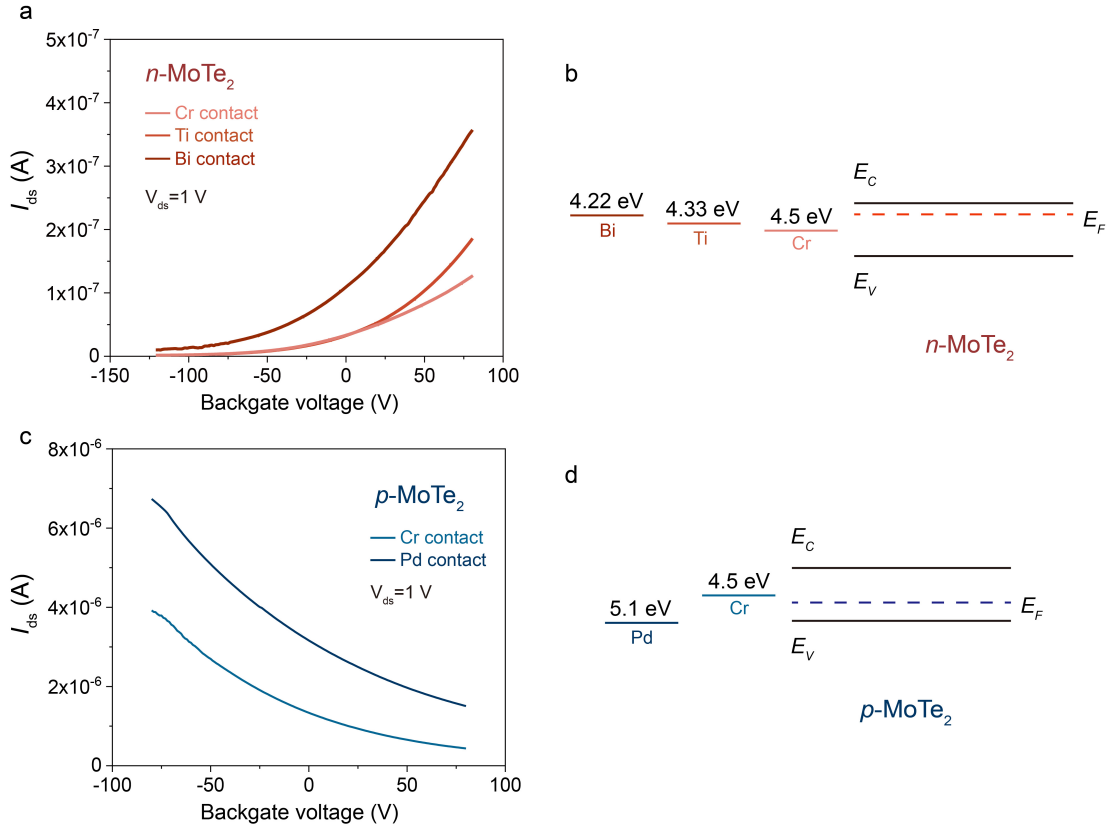
Supplementary Fig. 22 The thicknesses of samples under different doping target power characterized by AFM to calculate the doping concentration. **a**, Film thicknesses measured by AFM after sputtering for 30 min with sputtering powers of doping targets (Mo target containing Nb or Re) of 0 W, 20 W, 30 W, 40 W, and 60 W, respectively. **b**, The doping concentrations of dopants in Mo films were calculated from these samples with different sputtering powers of the doping targets. **c-e**, AFM height images of the samples with different sputtering powers of doping targets.

In this work, co-sputtering was used to control the doping concentration. The Mo target was connected to a DC power supply with a constant power of 10 W, and the Mo target containing 1% Nb or 1% Re was used as a doping target, and was connected to an AC power supply. The sputtering power of the doping target was used to control the doping concentration of the dopant, while the co-sputtering time was used to control the thickness of the resulting Mo film. To accurately calculate the doping concentration, we prolonged the co-sputtering time to 30 min and measured the thickness of the resulting film using AFM. In the absence of doping, the thickness of the Mo film was measured to be 31.5 ± 0.5 nm (Supplementary Fig. 12a and c). In all AFM measurements, 70 positions were selected to measure the film thickness, and the average value was defined as the Mo film thickness. Assuming the sputtering rate remains constant, we can calculate the sputtering rate of the Mo target is about 1.05 nm/min.

During the co-sputtering deposition process, the Mo target was kept at a constant DC power of 10 W, and the AC sputtering power of the doping target was set to 20 W, 30 W, 40 W, and 60 W, respectively. After a 30 min co-sputtering, the thicknesses of the Nb-incorporated Mo films were 35.7 ± 0.32 nm, 40.3 ± 0.57 nm, 40.7 ± 0.58 nm, and 45.9 ± 0.56 nm, while the thicknesses of the Re-incorporated Mo films were 33.2 ± 0.36 nm, 34.3 ± 0.74 nm, 40.6 ± 0.39 nm and 52.2 ± 0.91 nm (Supplementary Fig. 12a, d and e). The increased thickness compared with the case without doping comes from the sputtered thickness of the doping target. As the dopant (Nb or Re) incorporation concentration of the doping target is known (1%), we can calculate the doping concentration of the dopants in the resulting films with different AC powers:

$$\text{Doping ratio} = \frac{(t - 31.5) \times 1\% \times \rho_{\text{dopant}} \times M_{\text{Mo}}}{t \times \rho_{\text{Mo}} \times M_{\text{dopant}}}$$

where t is the measured film thickness, ρ is the mass density, M is the molar mass. Therefore, at AC powers of 20 W, 30 W, 40 W, and 60 W, the calculated incorporation ratios of Nb were 0.10%, 0.19%, 0.20%, and 0.27%, while those of Re were 0.06%, 0.09%, 0.24% and 0.42% (Supplementary Fig. 12b).



Supplementary Fig. 23 Electrical characterization of doped 2H-MoTe₂ transistors with different metal contacts. **a**, I_{ds} - V_g curves of Re-doped 2H-MoTe₂ transistors with Cr, Ti and Bi contacts, respectively. The devices are based on the same batch of Re-MoTe₂ (0.1%) with a thickness of about 8 nm. The devices employ a back-gate transistor structure with a dielectric of 280 nm SiO₂ and a channel W/L of 30/10 μm . **b**, Energy band diagram of the n -type 2H-MoTe₂ film and the contact metals before contacting. **c**, I_{ds} - V_g curves of Nd-doped 2H-MoTe₂ transistors with Cr and Pd contacts, respectively. Devices are from Supplementary Fig. 12. **d**, Energy band diagram of the p -type 2H-MoTe₂ film and the contact metals before contacting.

When evaporating three-dimensional metals on to two-dimensional semiconductors to establish electrical contacts, Fermi-level pinning caused by metal-induced gap states and surface states are commonly encountered, resulting in fixed Schottky barrier heights that significantly impact device contact resistances. In our n -type 2H-MoTe₂ back-gated transistors contacted with Cr, Ti, and Bi (Supplementary Fig. 23a), the transistor drain current for the Bi metal contact is higher than that for Ti and Cr contacts due to Bi's low work function and the semimetallic properties (Nature 593.7858 (2021): 211-217). Similarly, the drain current for p -type 2H-MoTe₂ back-gate transistors contacted with high work function Pd is substantially higher than that contacted with low function Cr (Supplementary Fig. 23c). It is evident from the results that semiconductor polarity is regulated by the doping of 2H-MoTe₂, while the Schottky barrier is influenced by the contacting metal.

	Doping concentration	Wafer scale	Spatial doping	Electrical behavior	On/off ratio	Reference
Re-doped MoTe ₂	0.24 %	Yes	Yes	<i>n</i> -type	10 ⁵	This work
Nb-doped MoTe ₂	0.2 %	Yes	Yes	<i>p</i> -type	10 ⁵	This work
Re-doped MoS ₂	1 %	No	No	<i>n</i> -type	<10	Adv. Funct. Mater. 28.16 (2018): 1706950.
Nb-doped MoS ₂	4 %	Yes	No	<i>p</i> -type	<10	Nano Lett. 20.6 (2020): 4095-4101
Nb-doped MoS ₂	0.8 %	No	No	ambipolar	1.1	ACS Appl. Mater. Interfaces. 12.5 (2020): 6276-6282.
Ta-doped MoSe ₂	3%	No	No	<i>p</i> -type	10 ⁵	Small 17.47 (2021): 2102855.
V-doped WSe ₂	1.9%	No	No	<i>p</i> -type	10 ⁴	Adv. Funct. Mater. 31.42 (2021): 2105252.
V-doped MoS ₂	9.5 %	No	No	<i>p</i> -type	10 ⁵	Adv. Funct. Mater. 32.46 (2022): 2204760.
V-doped MoS ₂	17.4 %	Yes	No	metallic	N/A	Nano Res. 16.2 (2023): 3415-3421.
Nb-doped MoS ₂	1.5 %	No	No	<i>p</i> -type	10 ⁴	Adv. Mater. 35.14 (2023): 2209371.

Supplementary Table 1 Comparison of the doped MoTe₂ in the present study with substitutionally doped 2D semiconductors reported in the literature on the basis of various parameters such as film size, doping concentration and transistor on/off ratio.