Electronic Supplementary Material (ESI) for Nanoscale.
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Tuning nanowire lasers via hybridization with two-dimensional materials

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Electronic Supplementary Information

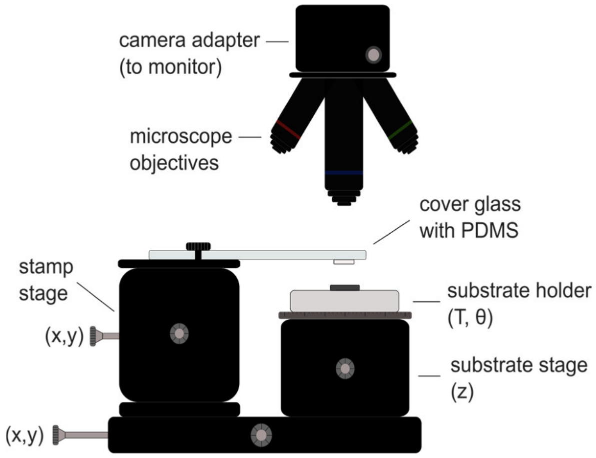

Fig. S1: Sketch of the PDMS transfer setup. The two stages, namely the stamp and the substrate stage, are mounted on the same movable base. Contact between stamp and substrate is established by moving the substrate stage in the z-direction. In addition, the substrate holder is heatable and rotatable. Long working distance objectives allow for a precise operation and observation of the transfer process.

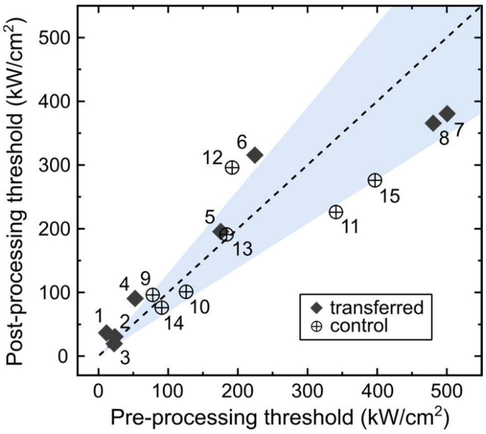

Fig. S2: Post-processing threshold (second measurement) plotted over the pre-processing threshold (first measurement) for each NW. The values vary between 15 and 500 kW/cm^2, indicating high differences of the optical quality between the wires. The light-blue segment depicts the area given by the standard deviation of the relative threshold change of the control group (30%).

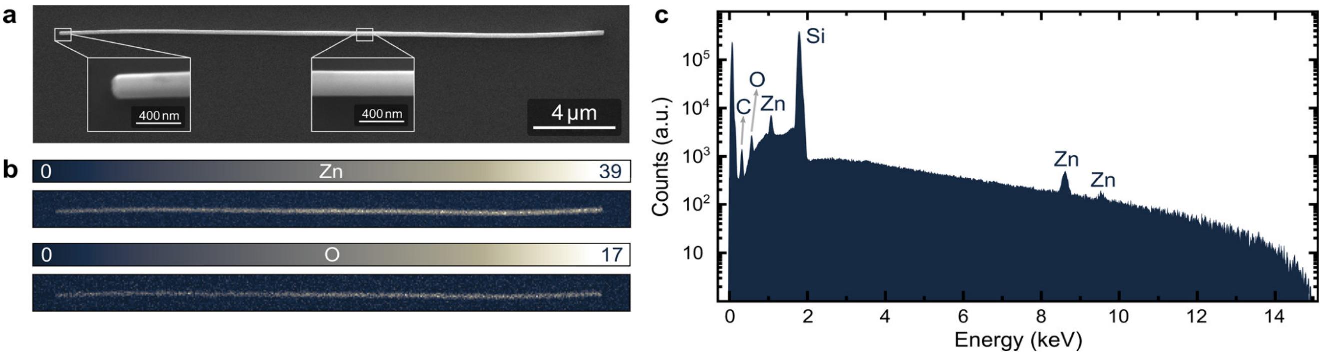

Fig. S3: (a) SEM image of an imprinted ZnO NW on a silicon substrate. The NW shown here exhibits a length of about 26 µm and a diameter of roughly 230 nm. (b) Elemental EDS maps of the NW shown above. Top: Zn $L_{\alpha1,2}$ map, bottom: O $K_{\alpha1}$ map. The corresponding signal intensity is given in arbitrary units (a.u.) (c) EDS sum spectrum of the investigated area revealing the stoichiometric composition of ZnO (Zn:O $\approx$ 1:1).

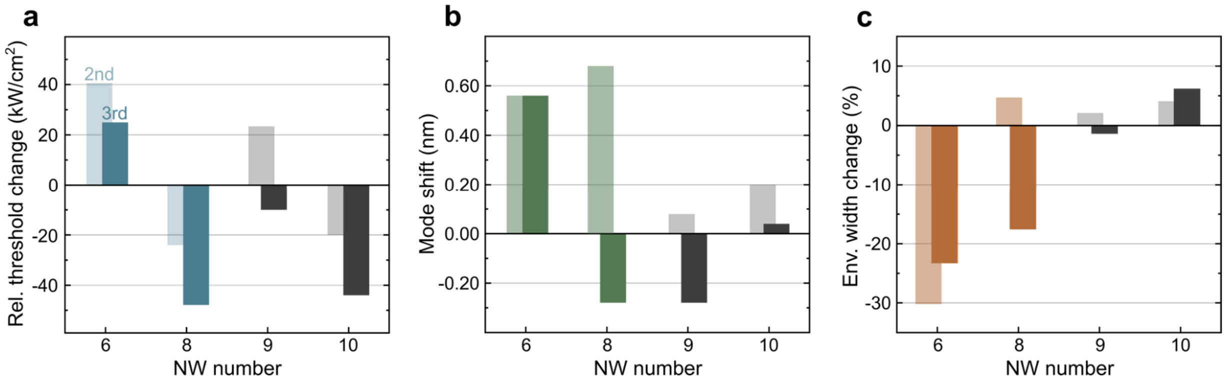

Fig. S4: Lasing characteristics of the repeatedly transferred NWs and the control group. The left and the right bars for each NW correspond to the changes after the second and the third measurements, respectively. The first measurement was taken as the reference for the calculations. The colored bars represent the transferred NWs, whereas the wires of the control group are represented by the grey bars.

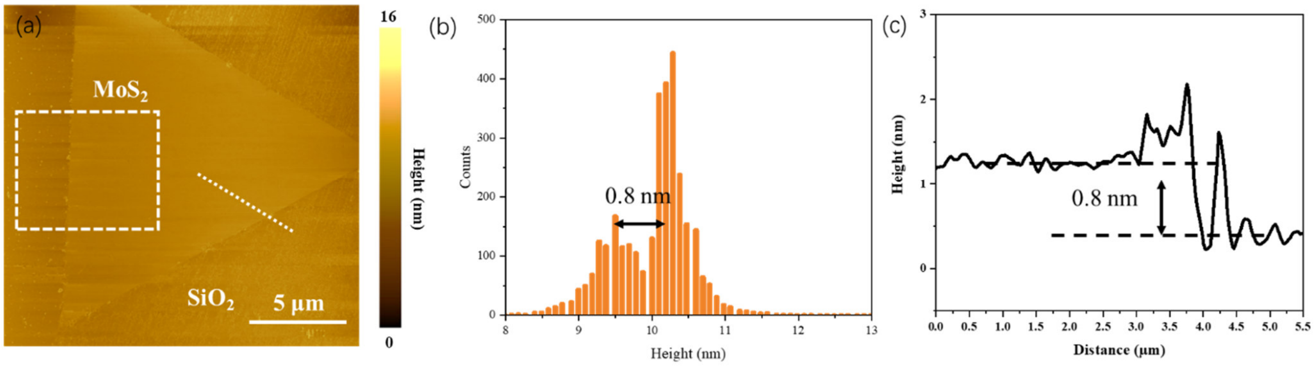

Fig. S5: (a) Atomic force microscopy (AFM) height image of CVD-grown monolayer MoS_2 on SiO_2/Si substrate. (b) Height distribution histogram between the SiO_2/Si substrate and the MoS_2 crystal. (c) Height profile between the SiO_2/Si substrate and the MoS_2 crystal. The thickness of the MoS_2 crystal is estimated to be (0.8 ± 0.2) nm which corresponds to a monolayer. (The AFM measurements were performed with a Ntegra (NT-MDT) system in tapping mode at ambient conditions using n-doped silicon cantilevers (NSG01, NTMDT) with resonant frequencies of 87 - 230 kHz and a typical tip radius of < 6 nm.)

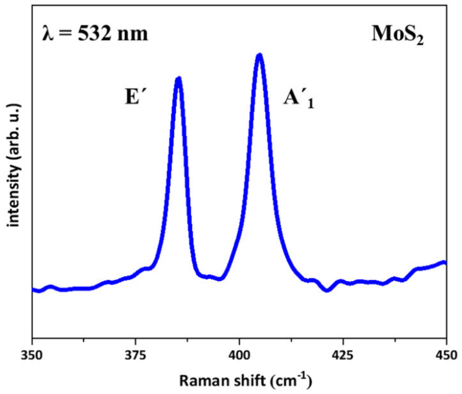

Fig. S6: Typical Raman spectrum of CVD-grown monolayer MoS_2. Two characteristic modes of MoS_2 are E´ at 385 cm^{-1} (originates from in-plane vibrations of Mo-S bonds) and A´$_1$ at 405 cm^{-1} (originates from out-of-plane vibrations of S atoms) can be observed. The difference between the two peak positions is about 20 cm^{-1}, which confirms the formation of monolayer MoS_2. (The Raman spectra were acquired using a Bruker Senterra spectrometer operated in backscattering mode at ambient conditions. The measurements were carried out using a 532 nm, frequency-doubled Nd:YAG laser, a 50x objective and a thermoelectrically-cooled CCD detector. The spectral resolution of the system is 2 - 3 cm^{-1}. The Si peak at 521 cm^{-1} was used for the peak shift-calibration of the instrument.)

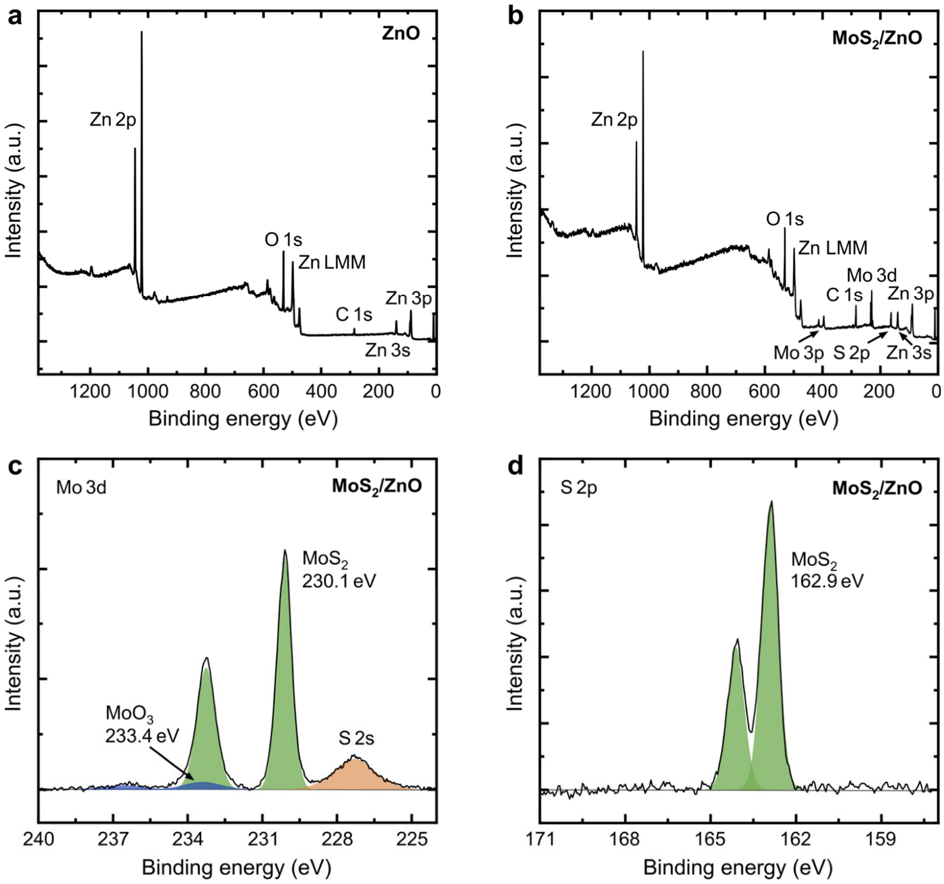

Fig. S7: XP overview spectrum of a bare ZnO single crystal: (a) shows the expected elements, *i.e.* Zn, O and a small contribution of C. After MoS$_2$ was transferred on top of the ZnO sample (b) by using a PMMA-based transfer method, Mo and S were additionally found. High resolution Mo 3d (c) and S 2p (d) XP spectra confirm the high quality of the MoS$_2$ ML. The Mo 3d spectrum mainly shows a species at a binding energy of the Mo 3d$_{5/2}$ signal (230.1 eV) which can, thus, be assigned to MoS$_2$. This species is accompanied by the S 2s signal (orange) and a small contribution of MoO$_3$ (growth precursor). The S 2p signal confirms this high quality as only a single species at a binding energy of 162.9 eV (corresponds to S 2p$_{3/2}$) is found. The elemental ratio of sulfur to molybdenum was found to be (2.1 ± 0.2) : 1, which corresponds well with the expected stoichiometry. In total, the results match well to previously published XPS measurements.[1]

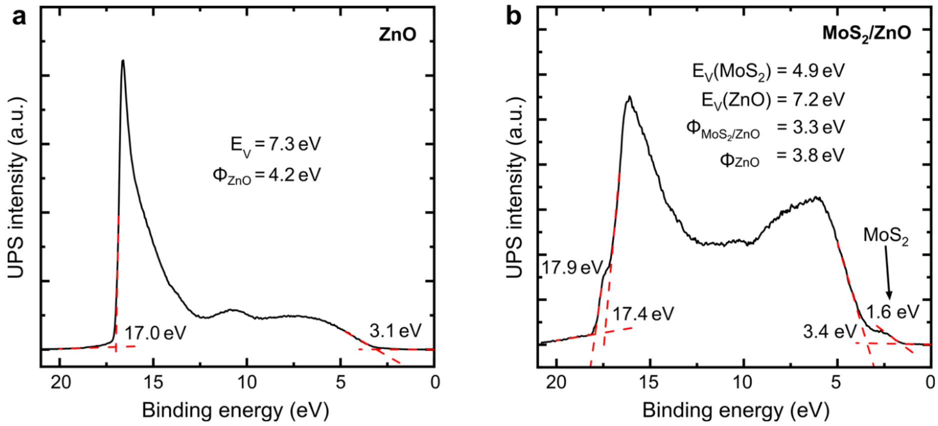

Fig. S8: (a) UP spectrum of a bare ZnO single crystal. The bare substrate shows two broad features at binding energies of ~7 and 11 eV, matching well to previously published spectra of ZnO samples as well as the energy level of the valence band E_V.[2] Using the secondary electron cut-off, the work function Φ_{ZnO} is calculated to 4.2 eV, which corresponds to the literature value.[3] b) UP spectrum of a CVD-grown MoS$_2$ ML transferred on top of the ZnO substrate. The cut-off at lower binding energy corresponds to bare ZnO regions, as seen by the calculated value E_V without the spectral features assigned to MoS$_2$.The work function Φ_{ZnO} and the valence band level E_V(ZnO) of ZnO in the combined system were calculated to 3.8 eV and 7.2 eV, respectively. Calculating the work function $\Phi_{MoS2/ZnO}$ of the MoS$_2$ ML results in reduced value of 3.3 eV, while the energy level of the valence band was determined to E_V (MoS$_2$) = 4.9 eV.

References (ESI)

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