Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information for

Enhanced Interactions of Excitonic Complexes in Free-standing WS_2

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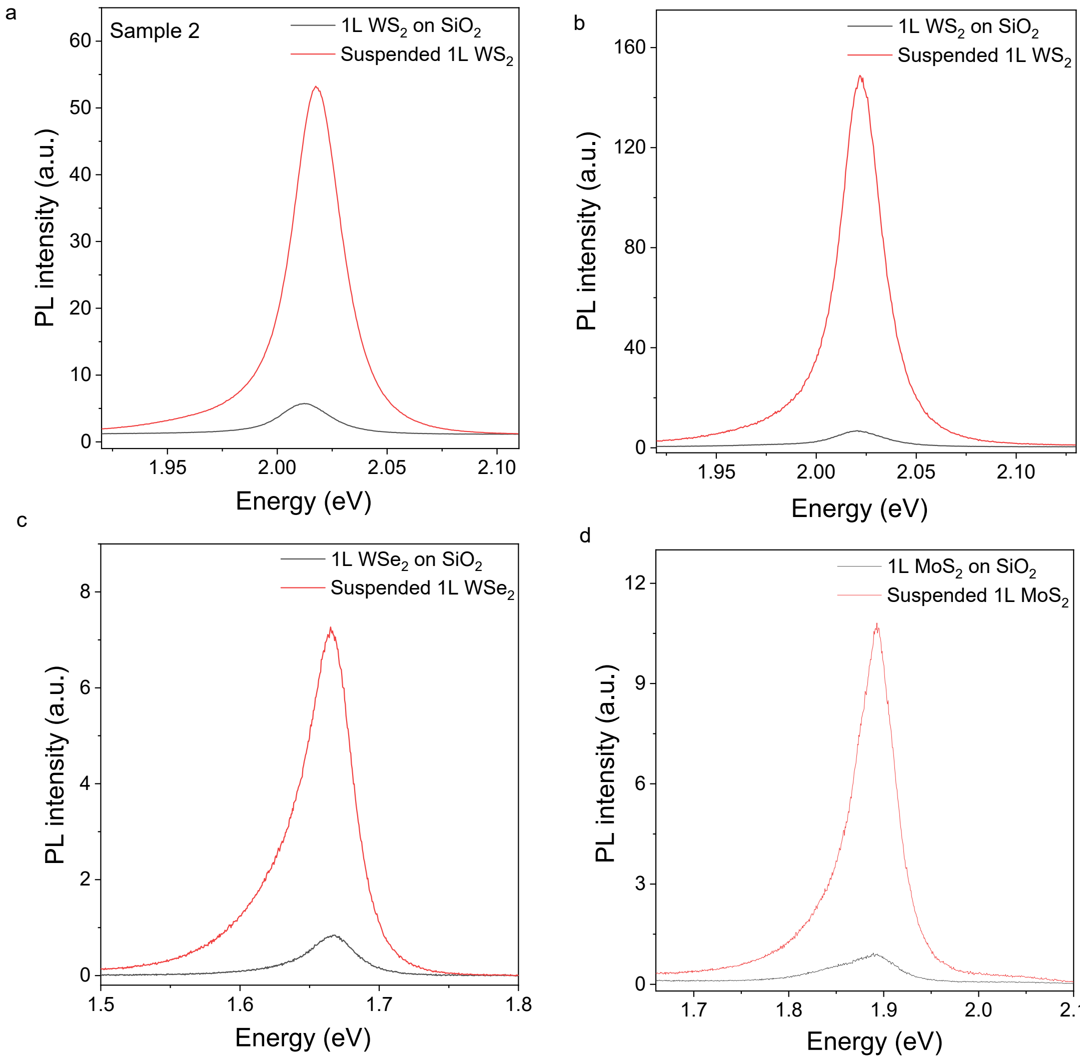
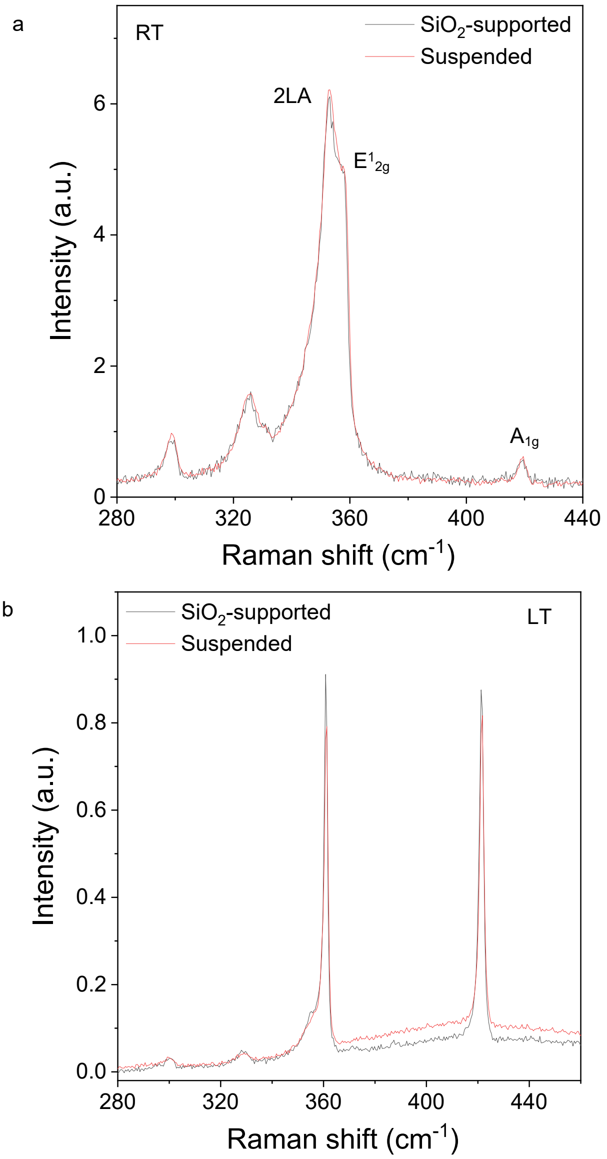
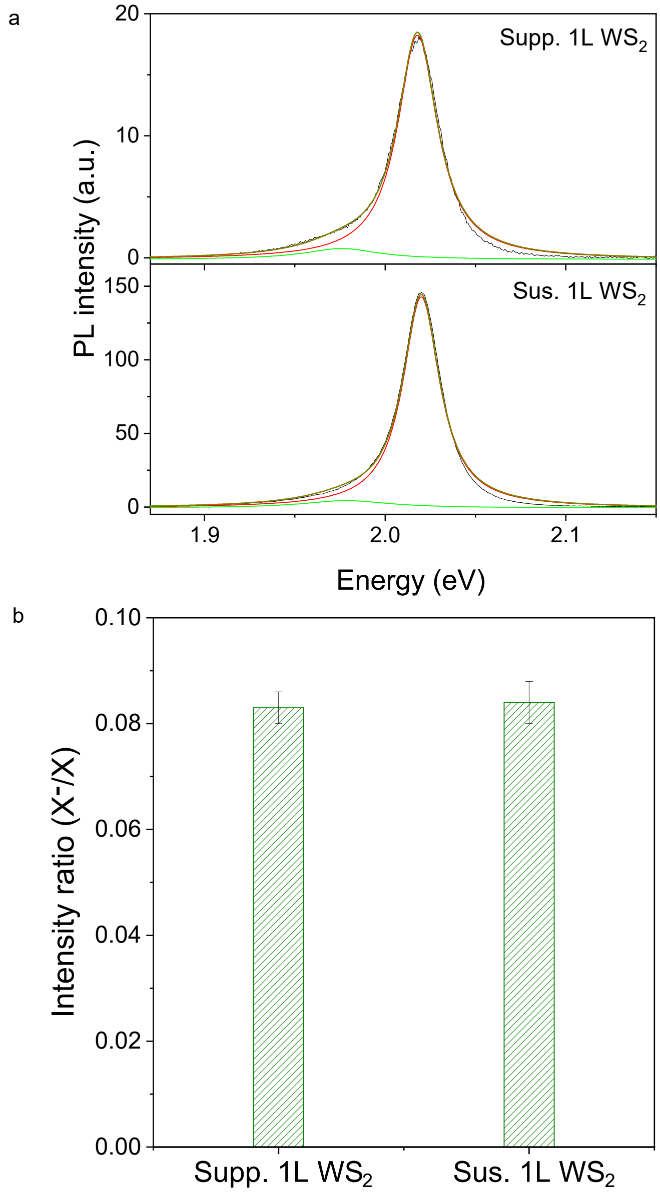


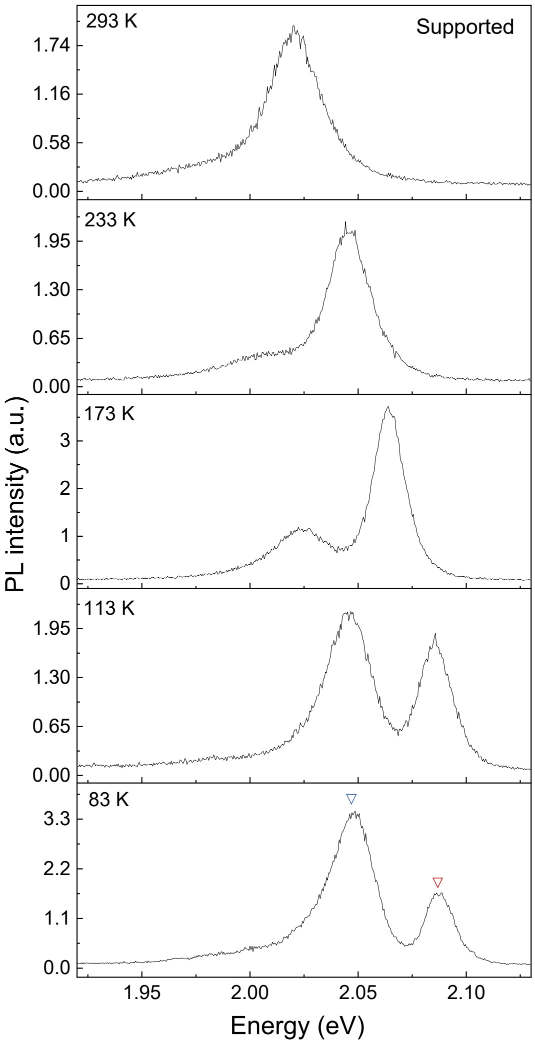
Supplementary Figure S1│Measured PL spectra from 1L SiO_2-supported and suspended monolayer WS_2 sample 2 (**a**) and sample 3 (**b**), monolayer WSe_2 sample (**c**) and monolayer MoS_2 sample (**d**) at room temperature.



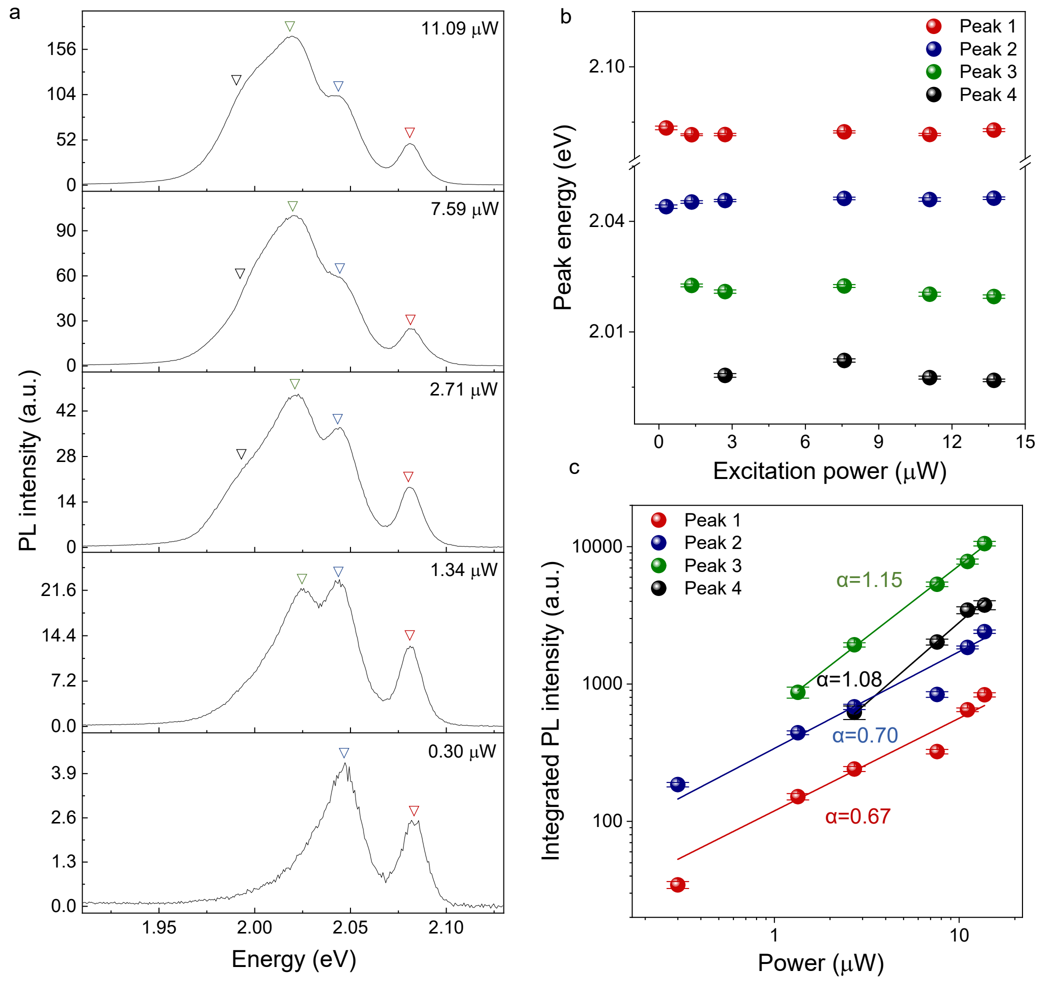
Supplementary Figure S2 | Measured Raman spectra from 1L SiO_2-supported and suspended monolayer WS_2 at room temperature (**a**) and 83K (**b**).



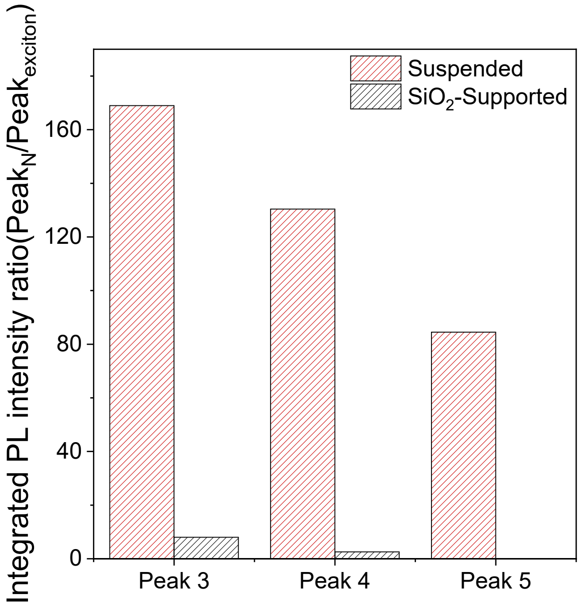
Supplementary Figure S3 │ a, Measured PL spectra from the SiO_2-supported (top panel) and suspended (bottom panel) monolayer WS_2 at room temperature. The spectrum was fitted with trion (green curve) and exciton (red curve) peaks. Black and dark yellow curves are experimental data and accumulative fitting curve, respectively. **b**, The extracted intensity ratio of trion (X^-) to exciton (X) for SiO_2-supported and suspended monolayer samples, indicating the value of around 0.083 ± 0.003 and 0.084 ± 0.004, respectively.



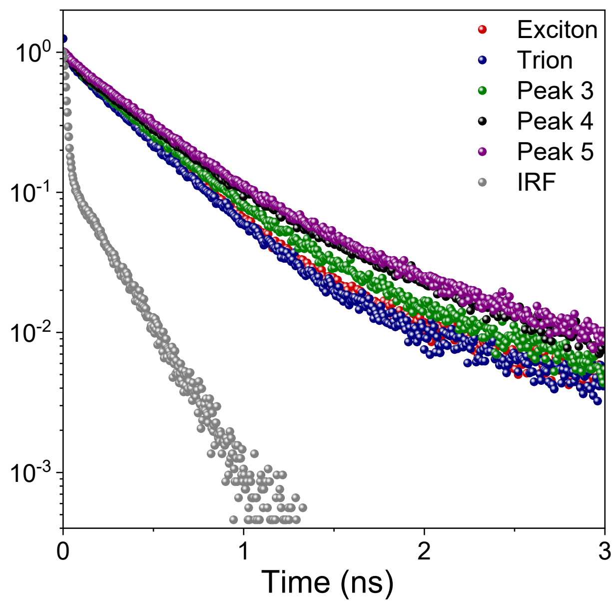
Supplementary Figure S4 | Measured temperature-dependent PL spectra from a SiO_2-supported WS_2 monolayer, under an excitation power of 0.3 μW with a 532 nm CW laser.



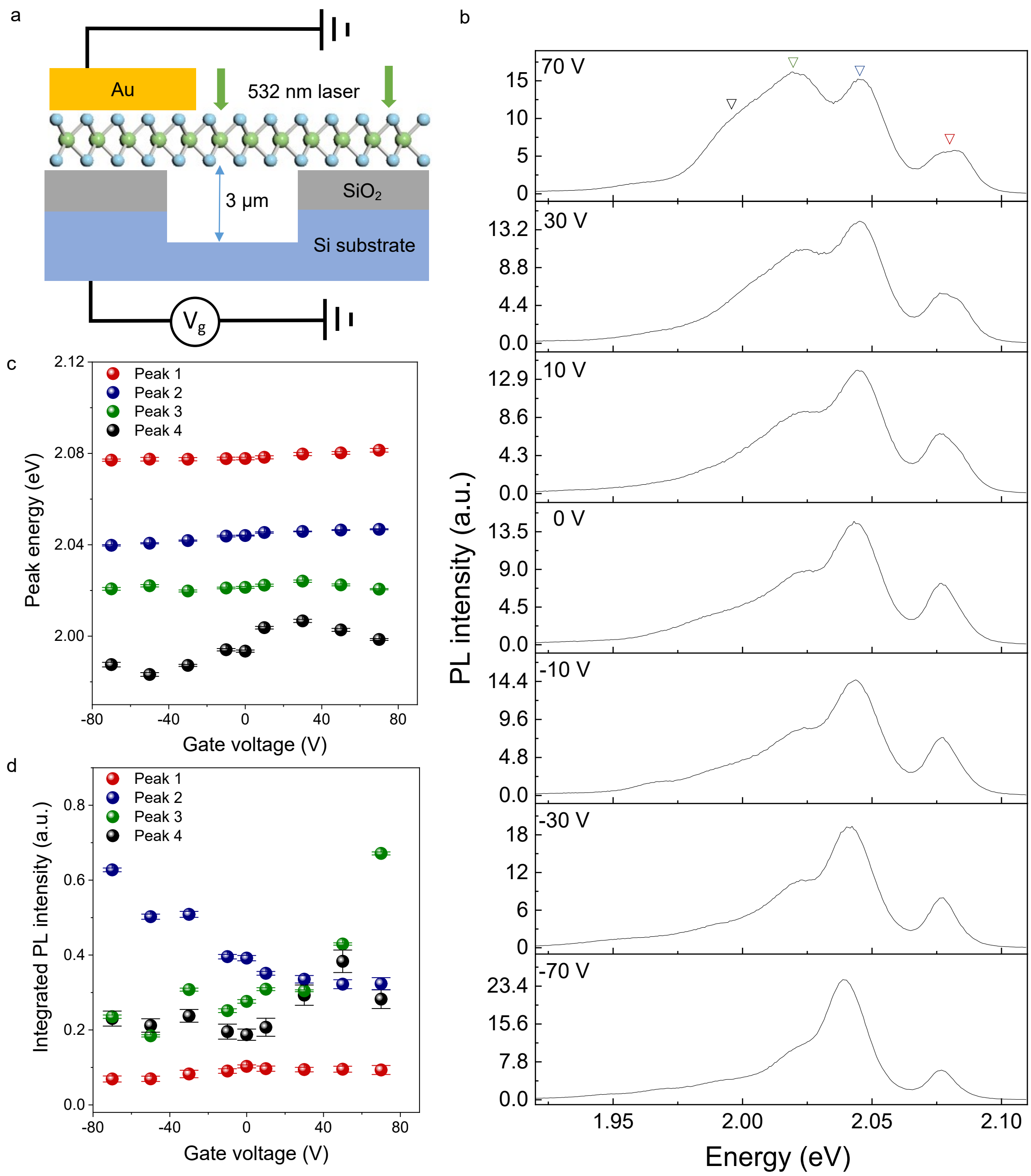
Supplementary Figure S5 | Excitation power-dependent PL spectra from the SiO_2-supported WS_2 monolayer at 83K a, Measured excitation power dependent PL spectra from the SiO_2-supported WS_2 monolayer with pumping power ranging from 0.3 μW to 11.09 μW. **b**, Extracted peak energy of exciton peaks as a function of excitation power. **c**, Extracted integrated PL intensity of the exciton peaks as a function of excitation power. The fitting curves give rise to a slope of 0.67, 0.70, 1.15 and 1.08 for Peak 1 to peak 4, respectively. The error bars in (**b**) and (**c**) represent the fitting uncertainty obtained from multiple fitting analysis (>3).



Supplementary Figure S6 | Extracted PL intensity ratio (η) of additional emission peaks from samples with different dielectric screening, suspended and SiO_2-supported structures, using the measured PL spectra displayed in Figure 3a and S5a at the same excitation power of 2.71 μW.



Supplementary Figure S7 | Time-resolved PL emission (normalized) obtained from different emission peaks from freestanding WS_2 monolayer at 83K. The decay curve was fitted by deconvoluting the data from the instrument response function (IRF), yielding a lifetime of 377 ps, 368 ps, 476 ps, 524 ps and 552 ps, for exciton (red), trion (blue), biexciton quasiparticles (green, black and purple), respectively.



Supplementary Figure S8 | Electrical modulation of the exciton dynamics for SiO_2-supported WS_2 monolayer at 83K a, Schematic plot of a 1L WS_2 device structure, showing the sample used for modulating the doping in both freestanding and SiO_2-supported monolayer using back gate voltage. The gold electrode was grounded, covering both supported and freestanding samples, and a doped Si substrate was employed as the back gate to provide uniform electrostatic doping. **b**, Measured gate dependent PL spectra from a SiO_2-supported WS_2 monolayer at 83 K with gate tuning changing from from 70 to -70V. **c**, Extracted peak energy of exciton peaks as a function of back gate voltages. **d**, Extracted integrated PL intensity of the exciton peaks as a function of back gate voltages. The error bars in (**c**) and (**d**) represent the fitting uncertainty obtained from multiple fitting analysis (>3).