Supplementary information for Ultrasensitive photodetectors based on monolayer MoS$_2$

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DEVICE MOBILITY MEASUREMENTS

The device is first characterized in the dark state by applying a constant drain-source voltage V_{ds} = 100 mV and sweeping the back-gate voltage V_{bg}. The effective field-effect mobility of the device with 90 nm Au contacts and KOH/O$_2$plasma surface pretreatment is estimated from the back gate sweep using the equation $\square = [dI_{DS}/dV_{BG}] \times [L/WC_iV_{DS}]$ where L=1 μm is the channel length, W = 2 μm channel width C_i= 1.3×10^{-4}Fm^{-2} the back gate capacitance (C_i= $\varepsilon_0\varepsilon_r$/d; ε_r = 3.9, d = 270 nm). For the device shown in Figure 1a in the manuscript, we obtain the field-effect mobility μ = 4 cm^2/Vs, typical of monolayer MoS$_2$ devices.[1,2]
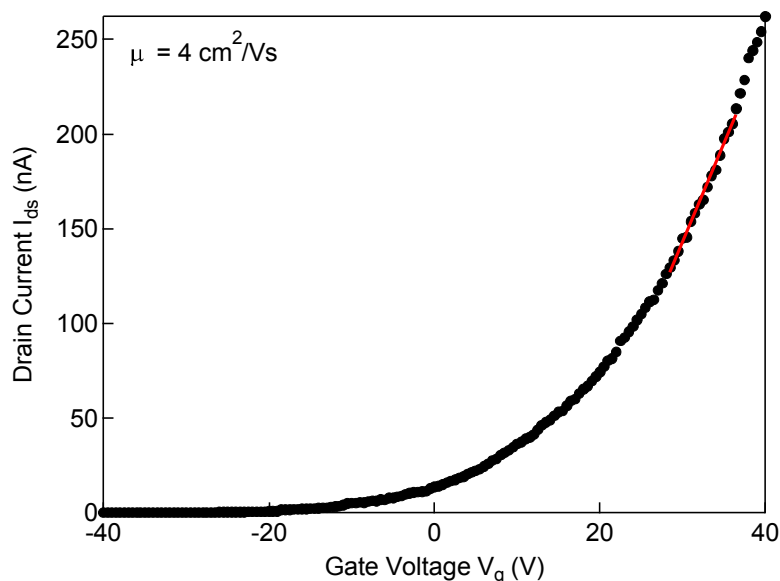
Figure S1. Gating characteristics of the monolayer MoS$_2$ transistor presented in the main manuscript. Room-temperature transfer characteristic of the monolayer MoS$_2$ phototransistor presented in the main manuscript. I_{ds} - V_g sweep is performed at V_{ds}=100 mV .

SUBSTRATE INFLUENCE ON THE DECAY TIME AND RESPONSIVITY

We studied the influence of different pre-deposition surface treatments and contact materials on the photoresponse decay. We find that different surface cleaning treatments can be used to reduce the decay time. This can be explained by differences in resulting level of hydrophobicity of the functionalized SiO$_2$ surface.[3] Using a different growth technique to deposit SiO$_2$ (wet vs. dry oxidation) results in further decrease of the characteristic decay time τ_{decay}. We used the following SiO$_2$ surface treatments preceding micromechanical exfoliation:

KOH – SiO$_2$ substrates were soaked for 30 min in a 30% KOH solution in water at room temperature. This was followed by 20 min O$_2$ plasma treatment with an RF power of 270 W, followed by exfoliation.

Piranha - SiO_2 substrates were soaked for 45 min in a piranha cleaning solution (H_2SO_4:H_2O_2 3:1). This was followed by 20 min O2 plasma treatment with an RF power of 270 W, followed by exfoliation.

HF - SiO_2 substrates were soaked for 30 sec in 2 ml 50% vol of HF with 70 ml of DI-water. This was followed by 20 min O2 plasma treatment with an RF power of 270 W, followed by exfoliation.

Using different contacting metals such as Ti/Au (10/50nm) or Cr/Au (10/50nm)results on further decrease of the decay time but at the expense of photoresponsivity with the lowest decay time τ_{decay} reaching 320 ms for a device employing Cr/Au contacts and SiO_2 grown using wet oxidation.
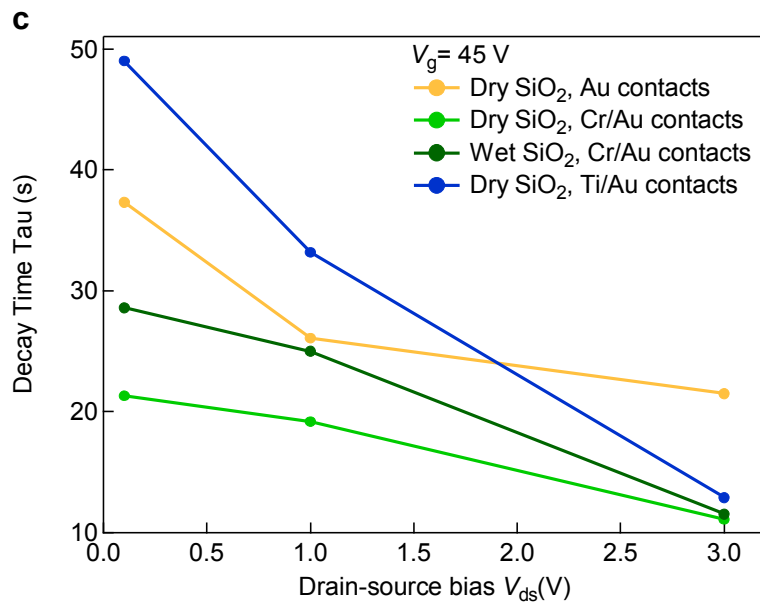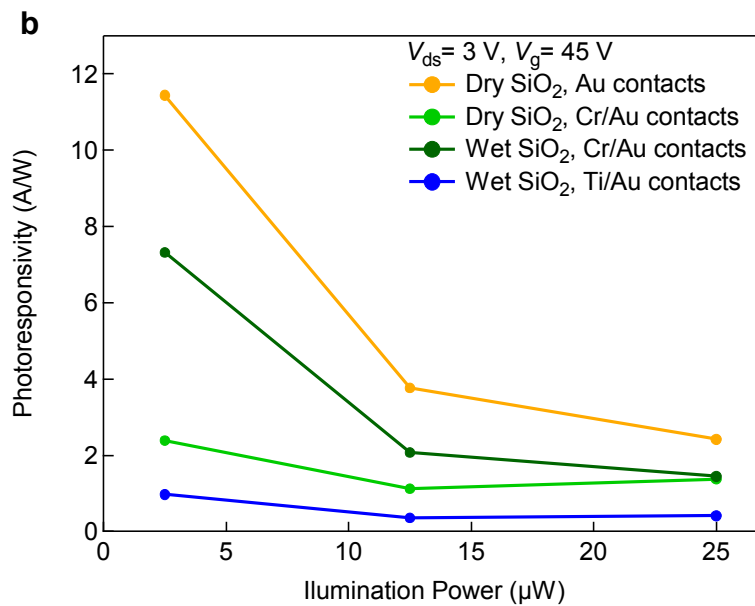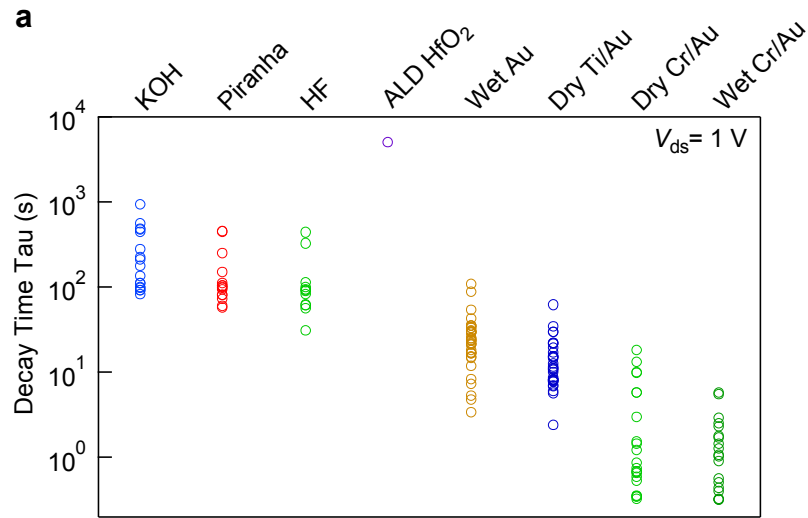
a

b

c

Figure S2. Photoresponse dynamics. a, Photoresponse decay times recorded for devices exposed to a broad white light of Olympus KL 1500 LCD of 0.073 W/cm^2 with various surface treatments and contact materials, including a deposition of 30 nm HfO$_2$ layer on top of MoS$_2$, grown by atomic layer deposition (ALD). **b,** Dependence of the photoresponse decay time on the drain-source bias V_{ds} recorded for samples exposed to 561 nm laser with 2 μm spot size with different surface treatments and contact materials. We find no significant dependence of the photoresponse on the gate voltage V_g. **c,** Dependence of the photoresponsivity on the illumination power recorded for samples with different surface treatments and contact materials exposed to 561 nm laser with a 2 μm spot size.

DETERMINATION OF THE NOISE EQUIVALENT POWER (NEP)

In order to calculate the noise equivalent power (NEP) of the single-layer MoS$_2$ phototransistor, we measure the dark current of the device with a source-drain voltage V_{ds} = 8 V and back-gate voltage V_g = -70 V. The noise power spectrum is shown on Figure S3. At 1Hz, we get $S(f = 1\text{Hz}) = 2.42 \times 10^{-24}$ A^2 Hz^{-1}. With the responsivity R = 880 A/W we extract a NEP of 1.8×10^{-15} W Hz$^{-1/2}$.
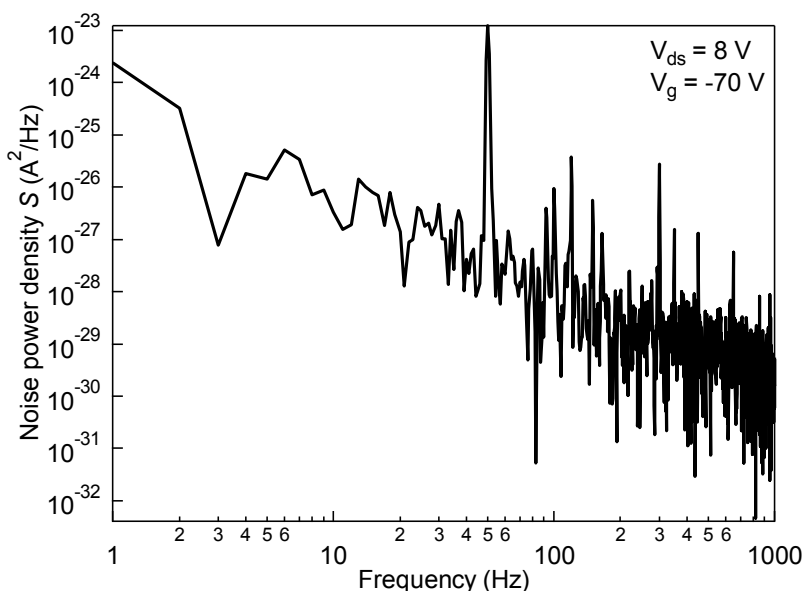

Figure S3. Noise level determination. Noise power density of the dark current of the single-layer MoS$_2$ photodetector measured for V_{ds} = 8 V and back-gate voltage V_g = -70 V, corresponding to the same conditions in which we measured its photoresponsitvty.

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