Electrical property tuning via defect engineering of single layer MoS_2 by oxygen plasma

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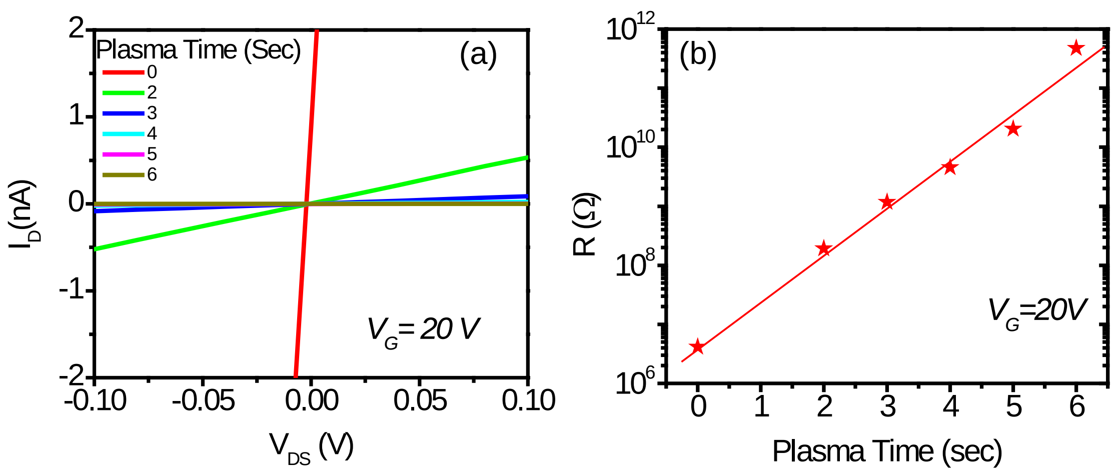
1. Resistance versus plasma time for Vg = 20 V:

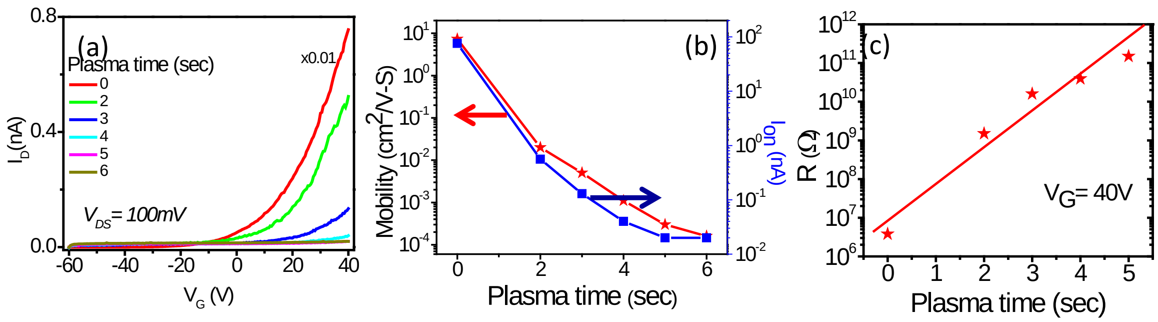
Figure S1(a) shows the I_D-V_{DS} graph of the device at V_G = 20V for different plasma exposure time. Figure S1(b) shows the dependence of resistance on the plasma exposure time. A large



S1. (a) I_D vs V_{DS} characteristics curve for the single layers MoS_2 device at different plasma exposure at V_G=20V. (b) Resistance of the device as a function of plasma exposure time at V_G=20V variation in resistance is observed after plasma exposure which increased exponentially with the plasma exposure time.

2. Effect of oxygen plasma on a second single layer device:

Transfer characteristic of the a second single layer device after different plasma exposure are shown in Figure S2(a). For the convenience of comparison and to obtain a unified view of the curves, we multiplied the curve for 0 sec exposure by 0.01. The on current at V_G=40 V is displayed in a semi-log scale in Figure S2(b) (right axis). The drain current varies exponentially with time from ~76 nA for the as fabricated sample to value of less than 15 pA for 6 sec plasma exposure. Similar to the on-current, the mobility also drops exponentially from 7.3 cm^2/Vs for as

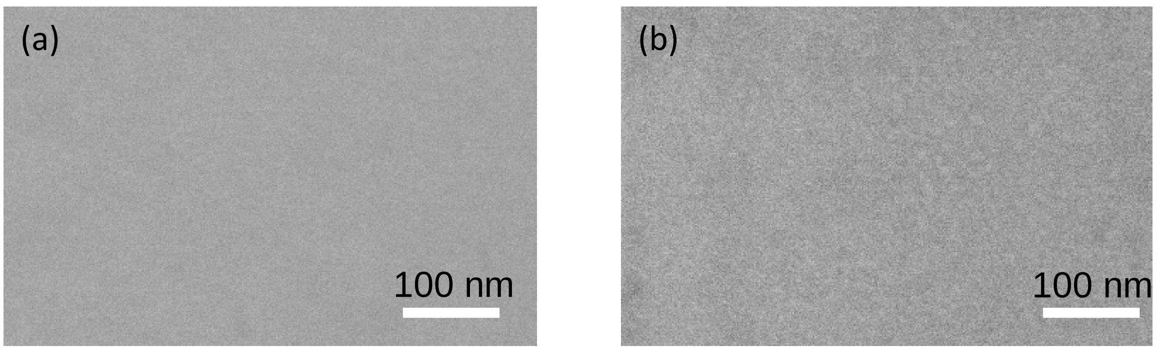


S2. (a) Gate dependence of the source drain current (I_D) for another single layer device. The curve corresponds to plasma exposure time of 0, 2, 3, 4, 5, 6, sec respectively. (b) Effect of plasma exposure on the on current (at V_G=40V) and mobility of the single layers MoS_2 device. (c) Resistance of the device as a function of plasma exposure time.

fabricated sample to 1.6x10^{-4} cm^2/Vs, after the 6 s plasma exposure. Figure S3(c) shows the dependence of with plasma exposure time. A five order increase in resistance is observed with the plasma exposure time.

3. Scanning electron microscope image of plasma exposed MoS_2 flake:

To check any possible change in the surface morphology of the plasma exposed MoS_2 flake we have taken the Scanning electron microscope (SEM) image of a single layer flake before and after plasma exposure. This is shown in figure S3. No signature of etching was observed from

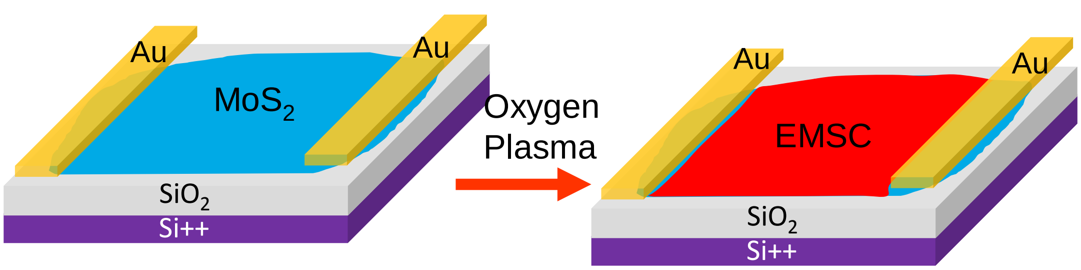


S3. SEM image of a single layer MoS2 flake (a) before and (b) after 6s plasma exposure.

the figure.

4. Theoretical calculation of resistance:

We considered the plasma-treated material as an effective-medium semiconductor (EMSC). This is shown in figure S4, where right side figure show that the intact MoS_2 underneath the gold



S4. Schematic of creating of EMSC region upon plasma exposure showing MoS2 – EMSC heterojunction.

electrode formed a heterojunction with EMSC. The current through a heterojunction with a relatively high built-in potential $\Delta\phi$ has a form similar to the Shockley diode equation,

$$I = I_S\left(e^{eV/nk_BT} - 1\right) \approx I_S \frac{eV}{nk_BT} \quad \text{------- (1)}$$

where V is applied voltage, k_B is the Boltzmann constant, T is temperature, n is the ideality factor. The dependence on the band mismatch at the heterojunction enters this equation through the saturation current

$$I_S\left(\Delta\phi\right) \approx A\,T^2 \exp\left(-\frac{\Delta\phi}{k_BT}\right),$$

where $A = em^* k_B^2 / \left(2\pi^2\hbar^3\right)$ is the Richardson constant. In order to define an effective resistance of the heterojunction we consider the limit of small applied voltage, $V \ll V_T = nk_BT/e \approx 0.2$ V (for $T = 400$ K and $n = 1$) and rewrite Eq. (1) as $I = V/R\left(\Delta\phi\right)$, where $R\left(\Delta\phi\right) = V_T / I_S\left(\Delta\phi\right)$. Thus we find

$$\ln\left[R\left(\Delta\phi\right)\right] = C + \frac{\Delta\phi}{k_BT}.$$

This formula provides the dependence of total resistance on $\Delta\phi$ in the case when the junction under consideration makes the major contribution.