Temperature-Dependent Electrical Properties of Al₂O₃-Passivated Multilayer MoS₂ Thin-Film Transistors

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Received: 1 February 2018; Accepted: 8 March 2018; Published: 12 March 2018

Abstract: It is becoming more important for electronic devices to operate stably and reproducibly under harsh environments, such as extremely low and/or high temperatures, for robust and practical applications. Here, we report on the effects of atomic-layer-deposited (ALD) aluminum oxide (Al₂O₃) passivation on multilayer molybdenum disulfide (MoS₂) thin-film transistors (TFTs) and their temperature-dependent electrical properties, especially at a high temperature range from 293 K to 380 K. With the aid of ultraviolet-ozone treatment, an Al₂O₃ layer was uniformly applied to cover the entire surface of MoS₂ TFTs. Our Al₂O₃-passivated MoS₂ TFTs exhibited not only a dramatic reduction of hysteresis but also enhancement of current in output characteristics. In addition, we investigated the temperature-dependent behaviors of the TFT performance, including intrinsic carrier mobility based on the Y-function method.

Keywords: transition metal dichalcogenide; molybdenum disulfide; thin-film transistor; passivation; contact resistance; intrinsic mobility

1. Introduction

With the discovery of graphene, two-dimensional (2D) layered materials have been drawing intense research interest. Despite its excellent mechanical, optical, and electrical properties, however, graphene is considered unsuitable as an active component of field effect transistors due to its lack of a band gap [1–3]. In efforts to overcome this limitation, i.e., to produce a band gap in graphene, a great deal of research has been carried out, but the results thus far have only added to the complexity of the processes and reduced mobility [4,5].

In this context, layered 2D transition metal dichalcogenides (TMDs)-based thin-film transistors (TFTs) are drawing considerable attention as promising candidates to lead the next-generation transistor technology. Among the 2D TMDs, molybdenum disulfide (MoS₂) is at the center of attention, and relevant research is underway [6–8]. MoS₂ TFTs have excellent carrier mobility, a high on- and off-current ratio (I_{on}/I_{off}), mechanical flexibility, and a relatively large band gap [9–12]. Despite these properties, when the MoS₂ channel is exposed to atmospheric environments, MoS₂ TFTs exhibit a hysteresis phenomenon in the transfer characteristic. Various research groups have already shown that this hysteresis phenomenon occurs in MoS₂ TFTs due to the effects of oxygen and water in the air [13–15]. To suppress this phenomenon, the surface of a semiconducting active channel must be isolated from the air by passivation layers, e.g., atomic-layer-deposited (ALD) aluminum oxide (Al₂O₃) or hafnium dioxide.

It is known that the surface of pristine (i.e., without any surface modifications) MoS₂ does not react well with trimethylaluminum (TMA), which is used as a precursor to form Al₂O₃ layers, due to the absence of dangling bonds [16–19]. However, high-k dielectric layers without pinholes
and/or cracks are indispensable for nano-electronic devices. To improve the wettability and reactivity between the MoS$_2$ surface and TMA and to ensure complete isolation of the surface from atmospheric environments, some strategies prior to deposition of the passivation layer were proposed, for example, oxygen plasma or ultraviolet-ozone (UV-ozone) treatment [18–23]. Conventional MoS$_2$ TFTs without passivation layers exhibited different electrical properties at high temperatures with respect to the height of the Schottky barrier between the metal electrodes and MoS$_2$ [8,24,25]. For a relatively high Schottky barrier, charge carriers (i.e., electrons) were blocked by the barrier and thus could not pass at a low temperature. However, as the temperature increased, those carriers started to transport into the MoS$_2$ channels through thermionic emission [26]. This led to an increase in carrier mobility with respect to increased temperature. Unlike previous reports on MoS$_2$ TFTs, little research has been conducted on the transport mechanism at high temperatures in passivated MoS$_2$ TFTs.

The present study investigated how passivated MoS$_2$ TFTs with a high Schottky barrier change in a high-temperature environment. First, cross-sectional transmission electron microscopy (TEM) was utilized to visualize the quality of Al$_2$O$_3$ deposited on the MoS$_2$ surface through UV-ozone treatment. The surface morphology of the Al$_2$O$_3$ on the MoS$_2$ channel was investigated by atomic force microscopy (AFM), depending on UV-ozone treatment. Also, the electrical properties of the devices were characterized to assess the effectiveness of Al$_2$O$_3$ passivation. As a result, it was confirmed that carrier mobility improved and that the hysteresis effect decreased significantly; thus, the desired effect of passivation was achieved. After that, the same tests were performed while the temperature was increased from room temperature to 380 K, and the results showed that the mobility also increased with increasing TFT operating temperature. To analyze the increment of the mobility, the Y-function method was employed to examine the intrinsic mobility of the MoS$_2$ TFT by excluding contact resistance between the metal electrode and MoS$_2$ channel.

2. Materials and Methods

2.1. Device Fabrication

Multilayer MoS$_2$ flakes were mechanically exfoliated from bulk MoS$_2$ (SPI Supplies, West Chester, PA, USA) through the conventional Scotch tape method and transferred onto thermally grown silicon dioxide (SiO$_2$) with a thickness of 300 nm used as a gate insulator. A p-type doped silicon (Si) wafer (resistivity $\leq$ 0.005 $\Omega$·cm) was used as a gate electrode and substrate. To remove the organic and inorganic residues resulting from the transfer procedure, the MoS$_2$-covered SiO$_2$/Si substrate was cleaned in acetone and isopropyl alcohol for 1 h 30 min and 30 min, respectively. Titanium/gold (20 nm/100 nm) layers were sequentially deposited by electron beam (e-beam) evaporation, and then source/drain (S/D) electrodes were patterned through conventional photolithography and wet etching processes. To improve the contact between the S/D electrodes and MoS$_2$ active channel, the devices were annealed at 200 °C for 2 h under mixed gas flow (100 sccm of Ar/10 sccm of H$_2$).

2.2. UV-Ozone Treatment

For uniform growth of the Al$_2$O$_3$ layer, as-fabricated MoS$_2$ TFTs were subjected to UV-ozone treatment (UVC-30, Jaesung Engineering Co., Anyang-Si, Korea) at power of 15 to 25 mW for 5 min with wavelengths of 185 nm and 254 nm.

2.3. ALD Al$_2$O$_3$ Passivation

An Al$_2$O$_3$ layer was deposited on the UV-ozone-treated MoS$_2$ TFTs by ALD (Lucida D100, NCD Co., Ltd., Daejeon, Korea). The deposition conditions of the unit ALD sequence consisted of TMA (0.2 s)/N$_2$ (10 s)/H$_2$O (0.2 s)/N$_2$ (10 s) with a chamber temperature of 200 °C. The thickness of the deposited Al$_2$O$_3$ per unit sequence was controlled to be approximately 0.118 nm. The unit sequence was iterated 340 times for a target thickness of 40 nm.
Then a selected area in the Al$_2$O$_3$ deposited on the S/D electrode was eliminated to create the electrical contact during measurements.

2.4. Device Characterization

The cross section of the Al$_2$O$_3$-passivated MoS$_2$ TFT was analyzed by TEM (Titan Cubed 60-300, FEI, Hillsboro, OR, USA). The surface morphologies of the Al$_2$O$_3$ on MoS$_2$ TTFs were investigated by AFM (XE7, Park Systems, Suwon-si, Korea) with noncontact mode operation. The electrical properties of the MoS$_2$ TTFs were measured by using a semiconductor characterization system (4200 SCS, Keithley, Cleveland, Ohio, USA) with a probe station. The temperature dependence of the TFT performance was characterized by using a home-made temperature-controlling vacuum chamber with temperatures ranging from 293 K to 380 K under a moderate vacuum environment (<10$^{-3}$ torr). Before each measurement, the temperature was maintained for 10 min to minimize variations in device performance.

3. Results and Discussion

Figure 1a shows a three-dimensional (3D) schematic illustration of the back-gated TFT encapsulated with Al$_2$O$_3$ on top of the multilayer MoS$_2$ active channel, which was also confirmed in a top-view optical microscope image, as shown in Figure 1b. MoS$_2$ and contact holes in the S/D electrodes are indicated by red dashed and green dotted lines, respectively. It should be noted that we could not find any pinholes or cracks in the Al$_2$O$_3$ layer resulting from UV-ozone pre-treatment, which will be further discussed in relation to Figure 2. Channel length (L) and width (W) of the MoS$_2$ device were 13.06 and 20.32 µm, respectively, used for calculating the TFT performance in relation to various temperatures.

Figure 1c shows a cross-sectional TEM image of the Al$_2$O$_3$-encapsulated MoS$_2$ TFT with UV-ozone pretreatment. It can be seen that the Al$_2$O$_3$ with an average thickness of approximately 42.0 nm uniformly covered the entire MoS$_2$ surface. In addition, the thickness of the MoS$_2$ multilayer was estimated to be approximately 64.6 nm, indicating its nearly bulk-like energy band characteristics. The fast Fourier transform patterns and high-angle annular dark-field imaging of the MoS$_2$ are shown in Figure S1 in the Supplementary Materials.

![Figure 1. 3D schematic structure of multilayer molybdenum disulfide (MoS$_2$) thin-film transistor (TFT) passivated with aluminum oxide (Al$_2$O$_3$); (b) optical microscope and (c) cross-sectional transmission electron microscopy (TEM) images of the MoS$_2$ TFT with Al$_2$O$_3$ passivation, respectively.](image-url)
where

\[ I(V_{ds}, V_{gs}) = \mu_{eff} W C_{Gi} \frac{V_{gs} - V_{th}}{L} \left( \frac{V_{ds}}{2} \right)^2 \]

Figure 2. Atomic force microscopy (AFM) images of Al2O3 surfaces on MoS2 active channel: (a) without and (b) with ultraviolet-ozone (UV-ozone) treatment for 5 min before atomic-layer-deposited (ALD) procedure. RMS: root-mean-square.

Figure 2 compares the surfaces morphologies of the Al2O3 deposited on MoS2 with and without UV-ozone pretreatment, which were measured by AFM scanning in a 1 μm × 1 μm region. Many clusters and boundaries can be observed on the surface of the Al2O3 (thickness of approximately 40 nm) deposited on the pristine MoS2 (Figure 2a). However, in the case of Al2O3 deposited on the MoS2 with UV-ozone pretreatment, it shows complete coverage with high uniformity (Figure 2b). The root-mean-square surface roughness (RMS) of the directly deposited Al2O3 is 0.672 nm, but it decreases to 0.190 nm with a 5-min UV-ozone treatment on MoS2. These results indicate that UV-ozone exposure is an efficient way to achieve uniform growth of Al2O3 on a MoS2 surface.

Previous studies have found that the electrical properties and device performance of MoS2 transistors can be enhanced by high-k dielectric encapsulation [27,28]. Therefore, we measured the electrical properties of the MoS2 TFTs to elucidate the effect of Al2O3 passivation on multilayer MoS2 with UV-ozone pretreatment. Figure 3a compares the transfer characteristic curves \( I_{ds} - V_{gs} \) of the MoS2 TFTs without and with Al2O3 passivation layers with the application of a source-to-drain voltage (\( V_{ds} \)) of 1 V. Before Al2O3 passivation, the pristine MoS2 TFT exhibits a large hysteresis (black-solid lines in Figure 3a). However, after Al2O3 passivation with UV-ozone pre-treatment, represented by the red solid lines in Figure 3a, the transfer curve obtained from a forward \( V_{gs} \) scan closely approached that obtained from a reverse \( V_{gs} \) scan and vice versa, which indicates a distinct reduction of hysteresis behavior (see also Figure S3). It should be noted that reduction of hysteresis was not observed in the MoS2 TFTs with only UV-ozone treatment, i.e., without Al2O3 passivation (Figure S4). For quantitative comparison, we define the difference of threshold voltage (\( \Delta V_{th} \)) by subtraction between the \( V_{th} \) values in the forward and reverse transfer characteristic curves, which are estimated to be 20.1 V and 0.5 V for the pristine and Al2O3-passivated devices, respectively. However, \( I_{eff} \) in the Al2O3-passivated MoS2 TFT increased by about one order of magnitude, resulting in a decrease in the \( I_{on}/I_{off} \) from 10⁶ to 10⁷. The results may be attributed to the fact that excess electrons could be induced in the MoS2 active channel due to the positive fixed charges in the Al2O3 layer [23,28].

According to transport physics in TFTs, the relation among \( I_{ds} \), \( V_{gs} \), and \( V_{ds} \) are expressed for a linear regime (\( |V_{ds}| < |V_{gs} - V_{th}| \)) as in [29]:

\[ I_{ds} = \frac{\mu_{eff} W C_{Gi}}{L} \left( V_{gs} - V_{th} \right) \left( \frac{V_{ds}}{2} \right)^2, \]
metal-oxide-semiconductor (MOS) FETs and a parallel plate model of gate capacitance \([8,29,30]\), \(\mu_{\text{eff}}\) of the TFT can be expressed in terms of transconductance \((g_m \equiv \partial I_{ds}/\partial V_{gs})\) as

\[
\mu_{\text{eff}} = \frac{L g_m}{W C_{\text{ox}} V_{ds}}
\]

where \(C_{\text{ox}}\) is capacitance per unit area of gate insulator \((1.15 \times 10^{-8} \text{ Fcm}^{-2})\). The maximum transconductance of the pristine MoS\(_2\) TFT was \(2.31 \times 10^{-7} \text{ S}\), which was increased to \(3.25 \times 10^{-7} \text{ S}\) after Al\(_2\)O\(_3\) passivation. As a result, the \(\mu_{\text{eff}}\) values for the pristine and Al\(_2\)O\(_3\)-passivated MoS\(_2\) TFTs were calculated to be 40.9 cm\(^2\) V\(^{-1}\) s\(^{-1}\) and 57.6 cm\(^2\) V\(^{-1}\) s\(^{-1}\), respectively. Figure 3b compares the output characteristic curves \((I_{ds} - V_{ds})\) of the MoS\(_2\) TFTs without and with Al\(_2\)O\(_3\) passivation layers under the application of \(V_{gs}\) ranging from \(-30 \text{ V}\) to \(0 \text{ V}\) with a step of \(5 \text{ V}\). At a low \(V_{gs}\) range from \(-30 \text{ V}\) to \(-15 \text{ V}\), the \(I_{ds}\) values of the Al\(_2\)O\(_3\)-passivated MoS\(_2\) TFTs were slightly lower than those of the pristine MoS\(_2\) TFT. However, the clear enhancement of the \(I_{ds}\) of the passivated device has been observed at higher \(V_{gs}\) than \(-10 \text{ V}\), which agrees well with Figure 3a.

![Figure 3](image-url)

**Figure 3.** Comparisons of (a) transfer and (b) output characteristics of MoS\(_2\) TFTs with respect to Al\(_2\)O\(_3\) passivation. Variations of (c) field-effect mobility \((\mu_{\text{eff}})\) and (d) threshold voltage \((\Delta V_{\text{th}})\) of 15 representative Al\(_2\)O\(_3\)-passivated MoS\(_2\) TFTs compared with those of pristine devices. All the Al\(_2\)O\(_3\) layers were deposited after UV-ozone treatment.

It is well known that MoS\(_2\) seems to be very sensitive to oxygen and water when exposed to an ambient environment \([31]\). Oxygen and water molecules can be adsorbed on the defect sites of MoS\(_2\) to induce charge traps, thus leading to a relatively larger and clockwise hysteresis as well as mobility degradation \([13,32]\). High-\(k\) dielectric passivation through ALD can be suggested as an efficient method to isolate MoS\(_2\) from atmospheric environments that include external contaminants \([27,28,33]\). The enhanced \(I_{ds}\) is also attributed to the annealing effect, which decreases the contact resistance between the S/D electrodes and MoS\(_2\) surface. These results are consistent with those of previous
reports on $\text{Al}_2\text{O}_3$-encapsulated $\text{MoS}_2$ devices, which indicates that no significant defect was introduced in the $\text{MoS}_2$ by the UV-ozone treatment [27,28]. The $\text{MoS}_2$ surface before and after UV-ozone treatment were investigated using Raman and X-ray photoelectron spectroscopy (shown in Figure S2).

Figure 3c,d show the statistical distributions of $\mu_{\text{eff}}$ and $\Delta V_{\text{th}}$ for 15 representative $\text{MoS}_2$ TFTs in order to confirm the effect of UV-ozone pre-treatment followed by $\text{Al}_2\text{O}_3$ passivation. The results of all the devices exhibit increments of the $\mu_{\text{eff}}$ as well as reduction of the $\Delta V_{\text{th}}$. The average increment (reduction) rate of $\mu_{\text{eff}} (\Delta V_{\text{th}})$ is 40.4% (4.2%). The individual values of $\mu_{\text{eff}}$ and $\Delta V_{\text{th}}$ are listed in Table 1. These results are evidence that UV-ozone treatment of the multilayer $\text{MoS}_2$ TFTs not only improves the quality of the ALD-grown $\text{Al}_2\text{O}_3$ layer, but also enhances the mobility and stability of the $\text{MoS}_2$ devices.

**Table 1.** Comparison of $\mu_{\text{eff}}$ and $\Delta V_{\text{th}}$ values of 15 representative $\text{Al}_2\text{O}_3$-passivated $\text{MoS}_2$ TFTs.  

<table>
<thead>
<tr>
<th># of TFT</th>
<th>$\mu_{\text{eff}}$ (cm$^2$ V$^{-1}$ s$^{-1}$)</th>
<th>$\Delta V_{\text{th}}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>1</td>
<td>31.58</td>
<td>36.57</td>
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<tr>
<td>2</td>
<td>24.79</td>
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<tr>
<td>3</td>
<td>15.49</td>
<td>23.58</td>
</tr>
<tr>
<td>4</td>
<td>32.07</td>
<td>42.59</td>
</tr>
<tr>
<td>5</td>
<td>36.99</td>
<td>48.32</td>
</tr>
<tr>
<td>6</td>
<td>51.19</td>
<td>75.53</td>
</tr>
<tr>
<td>7</td>
<td>32.79</td>
<td>42.18</td>
</tr>
<tr>
<td>8</td>
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<td>57.62</td>
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</tr>
<tr>
<td>15</td>
<td>32.11</td>
<td>46.63</td>
</tr>
</tbody>
</table>

1 All the $\text{Al}_2\text{O}_3$ layers were deposited after UV-ozone treatment.

To demonstrate the temperature-dependent behavior of the $\text{Al}_2\text{O}_3$-passivated $\text{MoS}_2$ TFT, the electrical properties of the device were measured at 10 different temperatures ranging from 293 K to 380 K under a moderate vacuum condition. Figure 4a presents a semi-logarithmic-scale plot of the temperature-dependent transfer characteristic curves at five different temperatures (293, 310, 330, 350 and 370 K). At the semi-logarithmic-scale of $I_{\text{ds}}$, variation of $I_{\text{ds}}$ on $V_{\text{gs}}$ was not clearly distinguished. To reveal the enhancement of $I_{\text{on}}$, linear scale plots of the transfer curves at five other temperatures (300, 320, 340, 360 and 380 K) are compared in Figure 4b.

As shown in Figure 4, $I_{\text{ds}}$ increased with increasing temperature over the whole $V_{\text{gs}}$ region. The results also confirmed the linear increment of the $I_{\text{ds}}$ values at a $V_{\text{gs}}$ of 40 V with respect to 10 different temperatures, as shown in the inset of Figure 4a. From the transfer characteristic curves, we extracted the $V_{\text{th}}$ at 10 different temperatures, which linearly shifted toward the negative $V_{\text{gs}}$ region with increasing temperature (inset of Figure 4b).

Figure 5a shows the output characteristics of the $\text{Al}_2\text{O}_3$-passivated $\text{MoS}_2$ TFT at 293 K with those at 380 K, which exhibits almost double increments of $I_{\text{ds}}$. The results also imply that high temperature would influence the other aspects of TFT performance. However, our TFT architecture has a two-terminal configuration resulting in contact resistance between the S/D electrodes and the $\text{MoS}_2$ active channel, which should be minimized for further investigation of carrier transport mechanisms.
where \( \mu \) is the intrinsic mobility excluding any contact resistance component. Considering the definition of transconductance, \( g_m \) is also modified using \( \eta \) as follows:

\[
g_m = \frac{\partial I_{ds}}{\partial V_{gs}} = \frac{W C_{GI}}{L} \frac{\mu_0}{[1 + \eta(V_{gs} - V_{th})]^2} V_{ds}.
\]  

Figure 5. (a) Output characteristics of Al2O3-passivated MoS2 TFT under different temperatures of 293 K and 380 K (\( V_{gs} \) from −40 to 0 V in 5 V steps); (b) comparison of \( \mu_{\text{eff}} \) and the intrinsic carrier mobility \( \mu_0 \) at various temperatures ranging from 293 K to 380 K. Inset: temperature-dependent variations of the difference between \( \mu_{\text{eff}} \) and \( \mu_0 \) (\( \Delta \mu \)).

Then, \( \eta \) is eliminated by combining Equations (3) and (4), and the \( Y \)-function can be expressed as

\[
Y = \frac{I_{ds}}{\sqrt{g_m}} = \sqrt{\frac{W}{L} C_{GI} \mu_0 V_{ds} \times (V_{gs} - V_{th})}.
\]
Finally, we can extract the intrinsic carrier mobility $\mu_0$ from the slope of the $Y-V_{gs}$ plot [8].

Figure 5b presents $\mu_{eff}$ and $\mu_0$ of the Al$_2$O$_3$-passivated MoS$_2$ TFT at various temperatures, which were calculated from Equations (2) and (5), respectively. At all temperatures, the results showed that (i) all $\mu_0$ values were higher than $\mu_{eff}$, indicating the existence of relatively high Schottky barriers and subsequent contact resistances in our devices; and (ii) both $\mu_{eff}$ and $\mu_0$ gradually increased with increasing temperature, which can be attributed to reduction of the contact resistance and increased thermionic emission due to high temperature [25,38]. The inset of Figure 5b presents the temperature-dependent variation of the difference between $\mu_{eff}$ and $\mu_0$ ($\Delta\mu$), which shows linear response behavior with respect to temperature increase. The details of $\mu_{eff}$, $\mu_0$ and $\Delta\mu$ are provided in Table 2.

### Table 2. Values of $\mu_{eff}$ and $\mu_0$ at various temperatures.

<table>
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<th>Temperature</th>
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<th>340 K</th>
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<th>360 K</th>
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<td>7.31</td>
<td>7.39</td>
<td>7.61</td>
<td>7.81</td>
<td>7.99</td>
<td>8.14</td>
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<tr>
<td>$\mu_0$</td>
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<td>9.32</td>
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<td>$\Delta\mu$</td>
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<td>1.5</td>
<td>1.64</td>
<td>1.73</td>
<td>2.01</td>
<td>2.08</td>
<td>2.28</td>
<td>2.58</td>
<td>2.82</td>
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### 4. Conclusions

In this paper, we reported on the effects of ALD-Al$_2$O$_3$ passivation on multilayer MoS$_2$ TFTs and the temperature-dependent variation of the TFT performance. High-$k$ Al$_2$O$_3$ layers were uniformly passivated over the entire surface of MoS$_2$ TFTs with the aid of UV-ozone treatment leading to (i) huge reductions of the hysteretic transfer curves; (ii) saturation current enhancement of the output characteristics; and (iii) increases in $\mu_{eff}$ of approximately 40.4%. Based on investigations of the temperature-dependent TFT characteristics including intrinsic carrier mobility ($\mu_0$) extracted by the $Y$-function method, we could conclude that the dominant transport mechanism is thermionic emission in our Al$_2$O$_3$-passivated MoS$_2$ TFTs with a considerable Schottky barrier between the S/D electrodes and active channel. In addition, the proposed approach at relatively high (i.e., realistic device working) temperatures can be employed to realize stable and reproducible electronic devices for robust and practical applications.

**Supplementary Materials:** The following are available online at www.mdpi.com/2076-3417/8/3/424/s1,

Figure S1: (a) Cross-sectional TEM image of a MoS$_2$ encapsulated by Al$_2$O$_3$. Inset: FFT patterns of the MoS$_2$ obtained in the area marked with the white dashed line. (b) HAADF image of a MoS$_2$ TFT with Al$_2$O$_3$ passivation; (c) atomic percentage of the atoms contained in the area marked with red and green rectangles in (b). Figure S2: Raman and (b) XPS spectra of (i) pristine and (ii) UV-ozone treated MoS$_2$. Figure S3: Transfer characteristics of 14 MoS$_2$ TFTs before (black line) and after (red line) Al$_2$O$_3$ passivation. Figure S4: Transfer characteristics of six MoS$_2$ TFTs with and without Al$_2$O$_3$ passivation before (i.e., pristine) and after UV-ozone treatment.

**Acknowledgments:** This research was supported in part by a National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT, MSIT) (No. 2016R1C1B1016344, 2015R1A1A1A05027488) and the Ministry of Trade, Industry and Energy and Korea Evaluation Industrial Technology through the Industrial Strategic Technology Development Program (No. 10079571, 10080348). Support from the Korea Research Fellowship program funded by the MSIT and Future Planning through the NRF (No. 2017H1D3A1A02014116) and the Basic Science Research Program through the NRF funded by the Ministry of Education (No. 2017R1A1A1B030353150) is also gratefully acknowledged.

**Author Contributions:** Y.K.H. and S.K. conceived and designed the experiments. S.H.J. and H.P. performed the experiments. Y.K.H., S.K. and N.L. analyzed the results. All the authors wrote and reviewed the manuscript. S.H.J. and N.L. contributed to this work equally.

**Conflicts of Interest:** The authors declare no conflict of interest.

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