Schottky Barrier Height Tuning on Platinum-gated ZnO Metal-Semiconductor Field Effect Transistors by In-Situ Surface Modification

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Abstract. *The effect of an in-situ surface preparation before the Schottky contact deposition on the Schottky barrier and MESFET transfer characteristic is presented. Conventional lithography and lift-off process were used to fabricate top contact coplanar MESFETs. Argon treated surfaces show a decrease in the barrier height from 0.64 to 0 with treatment time which suggests defect formation in the top surface. For the case of an oxygen treated surface, there is an improvement of the barrier height from 0.64 to 0.75 V which suggests defect passivation on the top surface. Oxygen treated MESFETs shows current ratios in the range of* $5x10^3$ *and* V_{on} *of -0.25 V. Argon treated MESFETs show current ratios in the range of* $5x10^2$ *and* V_{on} *of -2.2 V. The mobility obtained for all the working devices is close to 0.1* cm^2/Vs *which is comparable with the mobility obtained by Hall effect measurements.*

Introduction. The key active device for current analog and digital electronic technology is the metal-oxide-semiconductor field effect transistors (MOSFET) that use Si, because of its high level of integration and performance. However, the main disadvantages are (a) the noise immunity which can be limited by carrier scattering at the insulator-semiconductor interface due to the near-interface carrier transport and (b) its implementation in large-areas. TFTs were introduced to overcome the large-are integration problem of MOSFET. However, they don't address the noise problem. Metal semiconductor field effect transistors (MESFETs) are another kind of FET device that relies on bulk transport rather than near-interface transport as in the case of MOSFET and TFTs. This could enable low noise and high mobility in large area and transparent electronic applications. Therefore, the study of oxide-based MESFETS is proposed to enable large area and low-noise transparent electronic applications.

Device fabrication and characterization. A ZnO (target purity of 99.99%, purchased from Kurt J. Lesker Co.) thin film of about 67 nm is deposited on a SiO_2 wafer using a conventional RF magnetron sputter system at 700 °C, 10 mTorr and 10/10 O_2/Ar flow ratio. Next, the conventional photolitography process is used to pattern the semiconductor (channel region) to ensure the current flows directly from the source to drain in the semiconductor region under the gate. Subsequently, 100 nm of Al is deposited by electron beam evaporation and patterned using a lift-off process to define the source and drain contacts. Finally, platinum (used as a Schottky-gate contact) is reactively DC sputtered under 5/5 ratio of O_2 and Ar at 15 mTorr followed by a metallic capping layer of Pt under pure Ar atmosphere, a similar process showed previously by Frenzel and Allen, but adjusted to our ZnO film[1,2]. Prior to the Schottky-gate contact deposition, the effect of an in-situ Ar or O_2 plasma treatment at 15 W and 30 mTorr is evaluated on the of Schottky-contact formed and on the MESFETs transfer characteristics.

Result and discussion. Fig. 2 shows a cross-sectional view of the fabricated co-planar MESFET devices while figure 1(a) shows an optical image of the fabricated Pt-gated MESFET with a width of 50 µm and length of 5 µm. Fig. 3 shows the obtained band diagram for the ZnO-Pt Schottky contact, which shows a built-in potential (V_{bi}) of about 0.9 eV. Figure 3(a) and 4(a) shows the Schottky current as a function of V_{GS} for argon and oxygen plasma treatments, respectively. The 60 s Ar treatment decreases the total series resistance of the diode, while the barrier remains at the same level. However, for longer Ar treatment, the effective barrier height is overcome by induced defects (oxygen vacancies) at the top surface. For the case of oxygen treatment, the barrier height is enhanced from 0.64 to 0.77 eV and remains at the same level for longer O_2 treatment. A possible explanation for the increase in forward current is the removal of a hydroxide-induced highly doped layer in the ZnO just above the ZnO metal interface as proposed by Coppa, et al[3]. In addition, the bombardment of oxygen ions to the ZnO surface is presumed to decrease the oxygen vacancies concentration, and therefore, the barrier height is enhanced. Figure 3(b) and 4(b) shows the transfer characteristics of the fabricated MESFETs for argon and oxygen treatment, respectively. All devices are normally on, which is a normal state for MESFET devices. The barrier height has a significant effect on the space charge region (SCR) created underneath the gate contact. Therefore, surface preparation has a significant effect on the rectifying properties of MESFETs. For oxygen treated surfaces, the treatment time induces a smaller V_{on} with a subthreshold slope and current ratio improvement. For the case of an Argon treated surface, the current ratio is reduced. This suggests that the SCR is smaller compared with the non-treated device. In summary, we demonstrate the fabrication of ZnO-based MESFET using a highly rectifying Pt Schottky contact as the gate. The surface preparation before the Schottky contact deposition has an important role on the resulting barrier height. Argon treated surfaces reduces the barrier height while oxygen treated surface increases it. The resulting barrier height tuning has a strong impact on the MESFET transfer characteristic, due to the change in the space charge region that can be formed underneath the gate contact.

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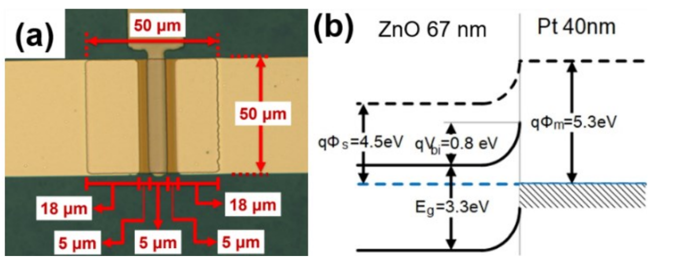

Fig. 1. (a) Optical image of the MESFET with W=50 and L=5 µm. (b) Measured band diagram for ZnO-Pt Schottky contact.

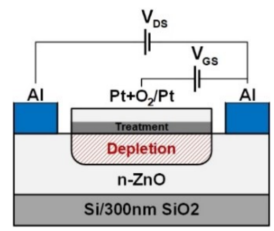

Fig. 2. Schematic representation of MESFET structure. Voltage nomenclature is illustrated.

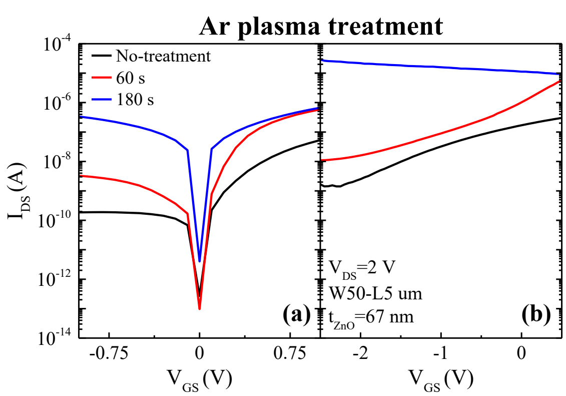

Fig. 3. (a) I-V Schottky-gate current representative characteristics, and (b) I_{DS} – V_{GS} MESFET representative characteristic for different time of in-situ Argon plasma treatment.

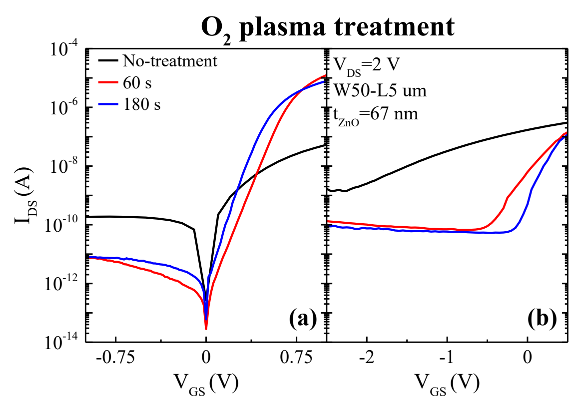

Fig. 4. (a) Representative I-V Schottky-gate current characteristics, and (b) I_{DS} – V_{GS} MESFET representative characteristic for different times of in-situ oxygen plasma treatment.

Table 1. Schottky contact and MESFET parameters for argon plasma treatment.

	η	V_{bi}	$I_{Ratio,\ gate}$	$I_{Ratio,MESFET}$	V_{on}	SS (mV/DEC)	μ_{ch} (cm^2/Vs)
No-treatment	2.88	0.64	$2.86x10^2$	$3.02x10^2$	-2.2	869	0.1
Ar 60s	1.85	0.60	$1.80x10^2$	$5.6x10^2$	-2.2	1216	0.1
Ar 180s	-	-	$2.86x10^0$	-	-	-	-
O2 60s	1.72	0.77	$1.67x10^6$	$2.15x10^3$	-0.58	198.6	0.1
O2 180s	1.57	0.75	$9.75x10^5$	$1.8x10^3$	-0.25	139.5	0.1

[1] H. Frenzel, et al., Advanced Materials, vol. 22, pp. 5332-5349, 2010.
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[3] B. J. Coppa, et al., Journal of Applied Physics, vol. 97, p. 103517, 27005.