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Barrier Height Enhancement of AlGaN/GaN Schottky Diodes by $P_2S_5/(NH_4)_2S_x$ Surface Treatments

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High electron mobility transistors (HEMTs) based on AlGaN/GaN heterostucture have great promise in high-power and high-frequency applications. Reliable Schottky contacts are required for AlGaN/GaN HEMTs. Passivations of the modulation-doped $Al_{0.1}Ga_{0.9}N$/GaN Schottky diodes by $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S_x$ treatments, respectively, have been carefully studied. The I-V and C-V curves of these Schottky diodes reveal that the Ti/Pt/Au-$Al_{0.1}Ga_{0.9}N$/GaN Schottky diodes by $P_2S_5/(NH_4)_2S_x$ treatment has the lowest reverse leakage current and highest Schottky barrier height. The XPS analyses indicate that a stable sulfide and phosphide thin layers on the contact surface are responsible for the barrier height enhancements.

Figure 1 shows the I-V curves of Schottky diodes treated by original (no sulfur treatment), $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S_x$,respectively. The $P_2S_5/(NH_4)_2S_x$ –treated diodes have the lowest reverse leakage current, which is at least one order of magnitude lower than the others. Table1 shows the ideality factor n and the Schottky barrier height of diodes caculated from I-V and C-V curves, respectively. The $P_2S_5/(NH_4)_2S_x$-treated samples showed the highest barriers and have the barrier height (0.98eV) and ideality factor (1.75). Figure 2 shows the correspondent XPS spectra measured from those three samples. It is noted that four Ga(A) XPS peaks(370,285,180 and 160eV) appear in the HCl and $(NH_4)_2S_X$ –treated samples but not in P_2S_5 $/(NH_4)_2S_X$ -treated samples. Another two Ga(3p,3d) XPS peaks(100,25eV) come out in the original and $(NH_4)_2S_X$ –treated samples but not in $P_2S_5/(NH_4)_2S_X$treated sample. Instead, the $P_2S_5/(NH_4)_2S_X$ –treated samples show all the S(2s), S(2p), P(2p), P(2p) peaks(225,190,160 and 130eV). The large amount of sulfur and phosphor existed on the $P_2S_5/(NH_4)_2S_X$–treated samples can effectively prevent the surface oxidation. It is consistent with the observation of oxygen peak reduction in the $P_2S_5/(NH_4)_2S_X$–treated samples. It is possible the reason for the reduction of leakage current.

Figure 3 shows the correspondent Al(2p) XPS spectra measured from those three samples. The standard XPS spectra indicate the Al 2p reference bonded energy positions at 72.65eV for Al and at 74.0 eV for Al_2O_3. The XPS peaks appear binding energies at 74.3ev for the original samples and at 78.7ev for the $(NH_4)_2S_X$-treated samples. No peaks are observed in $P_2S_5/(NH_4)_2S_x$ -treated samples. For the original samples, an Al 2p peak is found near the Al-Cl reference energy. On the other hand, the peak of binding energies for $(NH_4)_2S_x$-treated samples shifts apparently to the higher energy side. It can be concluded that no Al_2O_3 existed in $Al_{0.1}Ga_{0.9}N$ surface. The S(2p) XPS spectra of samples by the $(NH_4)_2S_x$ and the $P_2S_5/(NH_4)_2S_x$ treatment is shown in Fig.4. The spectra show one peaks at 167.7 eV in the $(NH_4)_2S_x$–treated samples and two peaks at 164.0ev and 162.8ev in the $P_2S_5/(NH_4)_2S_x$ -treated samples. The peak of 167.7eV in the $(NH_4)_2S_x$–treated samples is corresponding to the sulfur related oxides (SO_2). The two peaks of 164.0 eV and 162.8 eV in the $P_2S_5/(NH_4)_2S_x$ -treated samples are agreed with the S element and the Ga-S bond. It is clear that no related oxides exist in in the $P_2S_5/(NH_4)_2S_x$ -treated samples. Figure 5 shows the P(2p) XPS spectra of samples by the $(NH_4)_2S_x$ and the $P_2S_5/(NH_4)_2S_x$ treatment. The XPS peak at 134.2 eV is probably the formation binding energy of P_2O_3 or P-S bonds. We believed that the P-S formation bond is more possible due to no related oxide peak in other XPS spectra.

In summary, the $Al_{0.1}Ga_{0.9}N$/GaN Schottky diodes by $P_2S_5/(NH_4)_2S_x$ sulfur treatment have been studied and are compared with original ones and $(NH_4)_2S_x$ treatment. It is founded that the $P_2S_5/(NH_4)_2S_x$-treated diodes show higher barrier height than those by original or $(NH_4)_2S_x$ treatment. It is believed that a very thin sulfur or phosphorus layer having a higher chemical binding energy is formed on the $Al_{0.1}Ga_{0.9}N$/GaN surface. It is responsible for the barrier height enhancement.

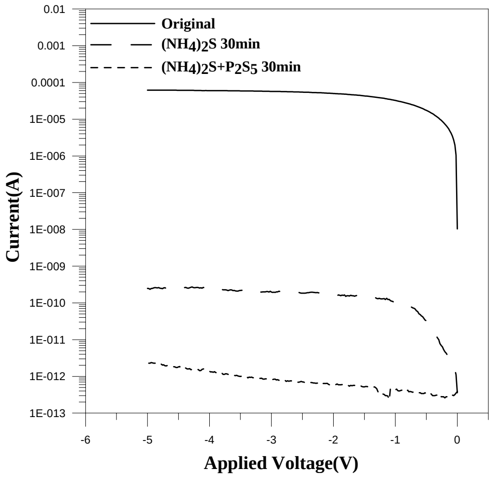

Fig.1 The I-V curves of Schottky diodes treated by original (no sulfur treatment), $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S_x$,respectively.

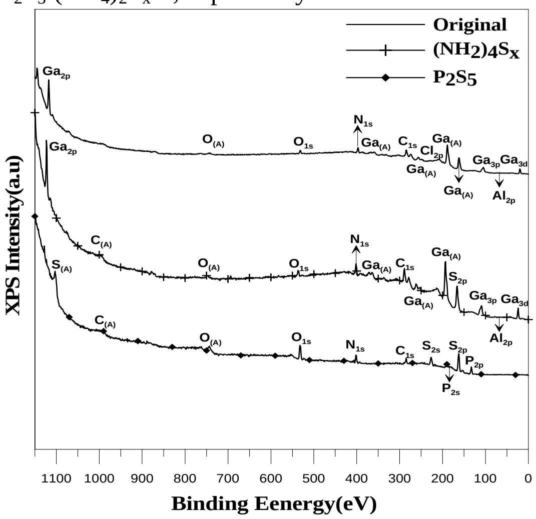

Fig.2 The correspondent XPS spectra measured from those three samples.

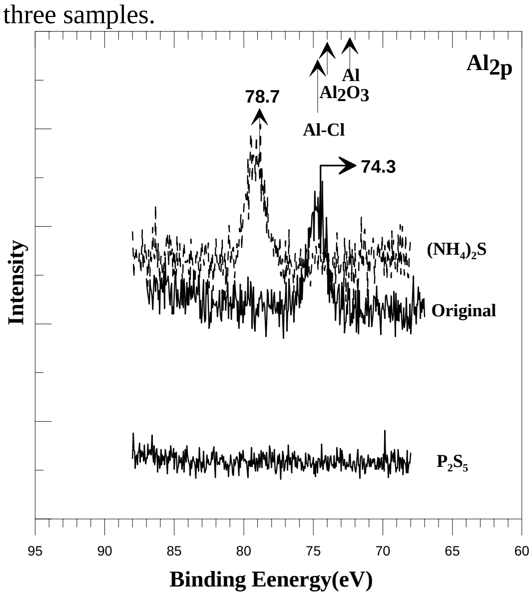

Fig.3 The correspondent Al(2p) XPS spectra measured from those three samples.

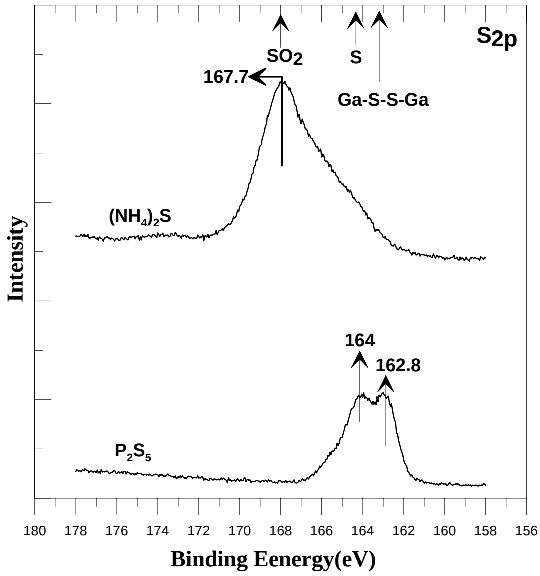

Fig.4 The S(2p) XPS spectra of samples by the $(NH_4)_2S_x$ and the $P_2S_5/(NH_4)_2S_x$ treatment.

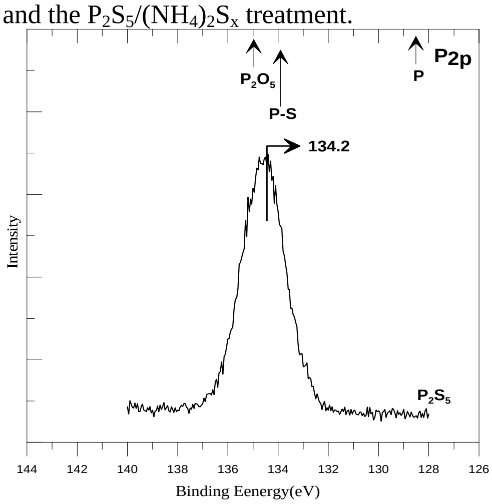

Fig.5 The P(2p) XPS spectra of samples by the $(NH_4)_2S_x$ and the $P_2S_5/(NH_4)_2S_x$ treatment.

Table1 The Schottky barrier height and the ideality factor n caculated from the I-Vand C-V curves of AlGaN Schottky diodes

samples	N	Barrier Height(I-V)	Barrier Height(C-V)
Original	2.58	0.45	0.54
$(NH_4)_2S_x$-treated	1.65	0.77	0.91
$P_2S_5/(NH_4)_2S_x$-treated	1.75	0.98	0.98