RuO_2 Related Schottky contact for GaN/AlGaN device

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RuO_2/GaN and related contacts were investigated for Schottky contacts in GaN-Based optical and electronic devices. We demonstrated that an RuO_2 film forms a stable Schottky contact on a GaN layer with a barrier height (ϕ_B) of 1.46 eV and transmittance of 70 % in the visible and near UV region. RuO_2/GaN Schottky diode showed a breakdown at over –50 V and leakage current of only 0.3 nA at –5 V. The RuO_2/GaN Schottky type photodetector had the UV/Visible rejection ratio of over 10^5 and the responsivity of 0.23 A/W at 330 nm. The RuO_2 gate AlGaN/GaN HFET exhibited high drain current (I_d) of 689.3 mA/mm and high transconductance (g_m) of 197.4 mS/mm. Cut-Off frequency (f_t) and maximum operating frequency (f_{max}) were measured as 27.0 GHz and 45.5 GHz, respectively.

1. Introduction

The Ⅲ nitride materials are promising for use in UV-Blue optoelectronic devices and high power and high temperature electronic devices because they have short wavelength selectivity, wide bandgap, high breakdown electric field, and high electron saturation velocity. For rectifying contacts, Pt and Pd have been widely used on GaN and related materials. For RuO_2 exhibits a high conductivity due to a partially filled conduction band and high thermal stability[1], it has been investigated for diffusion barrier application. We investigated properties of RuO_2/GaN Schottky contact and applied RuO_2/GaN Schottky contact to UV detector and RuO_2/AlGaN Schottky contact to HFET[2].

Table 1. Optical properties for GaN/AlGaN photodetector using wide gap semiconductors[2-8]

Type / Parameter	GaN			$Al_{1-x}Ga_xN$		
	Schottky	PIN	MSM	Schottky	PIN	MSM
Spectral range[nm]	180 ~ 365	180 ~ 365	180 ~ 365	180 ~ 365	180 ~ 365	180 ~ 365
Peak responsivity[A/W]	0.18	0.2	0.4	5mA/W at 257nm	0.11A/W at-10V	7.2A/W at 45nm
Response time	118 ns	8.2 μs	10 ns	20 ns	-	20 ns
UV/Visible ratio	~10^5	~10^6	-	~10^4	-	10^5

2. Experimental

For the UV ptotodetector, to create a high quality UV photodetectors, their structures and dimensions are all optimized. For the fabrication process in the current study, undoped GaN (0.5 ㎛)/ n^--GaN (0.1 ㎛)/ n^+-GaN (1.5 ㎛) layers with 8×10^{16}, 3×10^{17}, and 10^{18} cm^{-3} carrier concentrations were grown on (0001) sapphire substrate by MOCVD. After mesa etching the undoped and n^--layer with sensing windows (500, 700, and 1000 ㎛ in diameter), Al ohmic metal was deposited 2000 ~ 2500 Å thickness using thermal evaporator in 2×10^{-6} torr vacuum. And we checked the contact resistance using transfer length method(TLM) after heating about 600 ℃, 10 minutes in N_2 atmosphere. The ohmic contact resistivity of Al contact was 1.15×10^{-5} Ω · ㎠. After defining the pattern for Schottky metal deposition, we deposited semi-transparent Pt metal electrode of 100 Å thickness and RuO_2 that of 70 Å by the sputtering method in 2×10^{-6} torr vacuum. We deposited a gold layer of 2000 ~ 3000 Å thickness using thermal evaporator and formed pad for Schottky electrode bonding by lift off process. This figure 1 showed a schematic cross-sectional view of the designed device. For the HFET, the AlGaN/GaN HFET was fabricated with RuO_2 Schottky contact. The HFET structure was consisted of a 220 Å thick undoped $Al_{0.25}Ga_{0.75}N$, 2.4 μm thick undoped GaN buffer layer and a 270 Å LT-GaN buffer layer on sapphire substrate. Dry etching was performed mesa isolation of the device. The ohmic contact Source-Drain metallization consisted of Ti/Al/Pt/Au annealed in N_2 at 850 ℃ for 1 minute and the result of Al contact resistivity was $3 \times 10^{-6}\ \Omega \cdot cm^2$. The Schottky contact metallization consisted of RuO_2/Au. After contact formation, the samples were passivated with Si_3N_4. Then, gold was plated for the Air-Bridge interconnection. A Cross-Sectional of the device structure is shown in Figure 2.

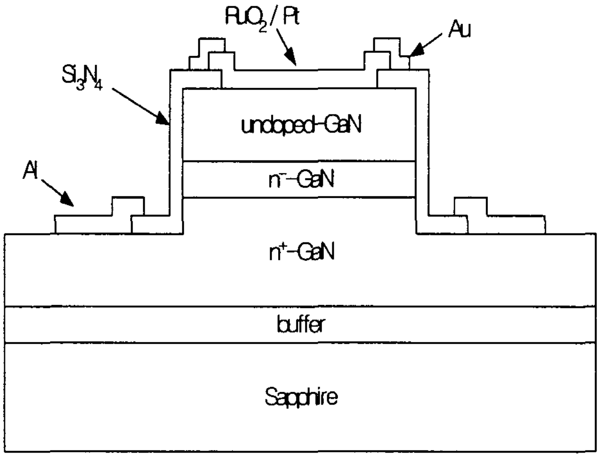


Fig. 1. Cross-Sectional view of the fabricated Schottky photodetector

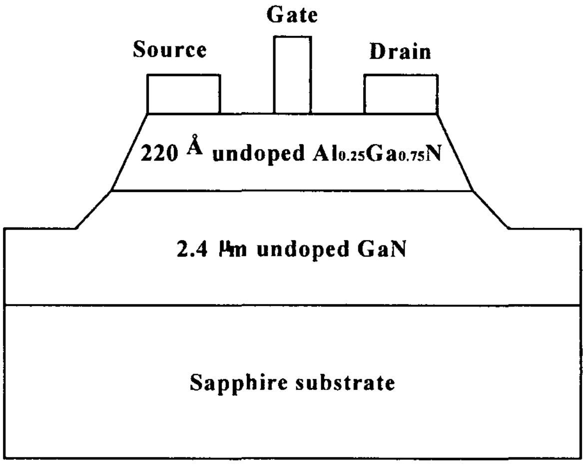
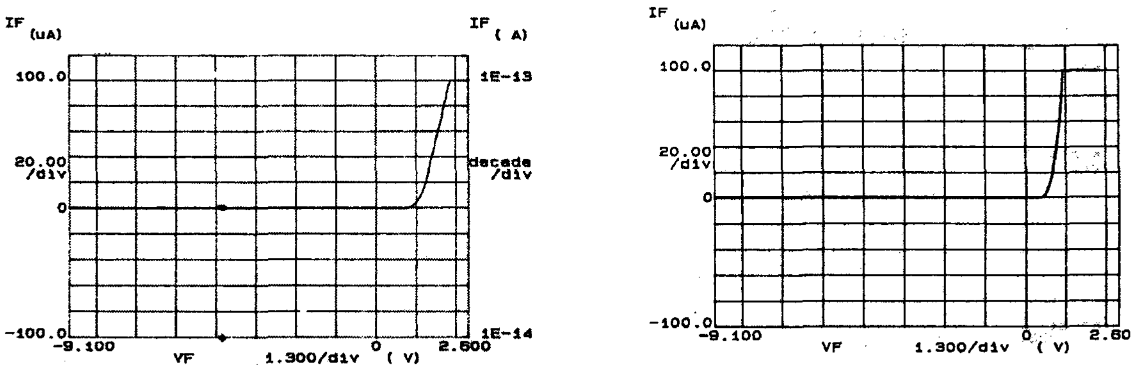


Fig. 2. Cross-Sectional of the AlGaN/GaN HFET

3. Results and Discussions

For the UV phtotodetector, by means of calculating results of ionized impurity concentration of RuO_2/GaN Schottky diode through C-V method, it showed $2.3 \times 10^{16}\ cm^{-3}$ impurity concentration which lower than undoped single layer thin film $6 \times 10^{16}\ cm^{-3}$. This is judged that RuO_2 thin film decreases effective electron concentration near the surface of GaN crystal layer. RuO_2/GaN Schottky diode showed about 1.46 eV of barrier height and 1.2 of ideality coefficient. Figure 3 showed I-V characteristics of Pt/GaN and RuO_2/GaN Schottky diode.



(a) (b)

Fig. 3. I-V characteristics of Pt/GaN (a) and RuO_2/GaNSchottky diode(b)

These results showed that RuO_2/GaN Schottky diode was much lower leakage current than Pt/GaN Schottky metal, and a breakdown voltage was higher than Pt/GaN Schottky diode. In the result of measurement of leakage current about 500 ㎛ ~ 1000 ㎛ diameter, it showed that it had 0.3 nA ~ 10 nA of low stable leakage current at reverse voltage 5 V.

Figure 4 showed the comparison of leakage currents respective to the Pt/GaN Schottky diode and RuO_2/GaN Schottky diode. RuO_2/GaN Schottky diode showed one order of magnitude lower than that of Pt/GaN Schottky diode on the same epitaxial condition.

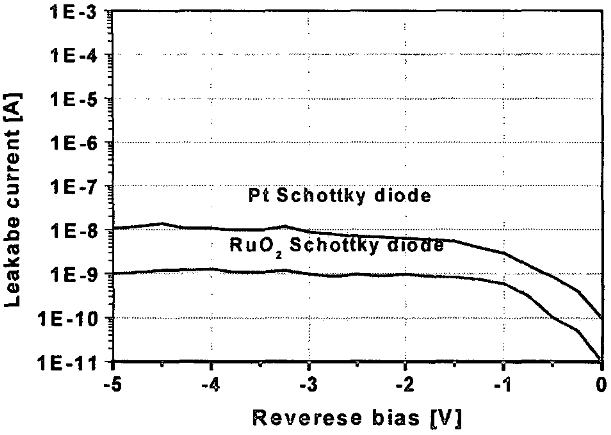


Fig. 4. Comparison of leakage currents respective to the Schottky metal(500 ㎛)

Figure 5 showed spectral response of etching type UV detector of 1000 um diameter as irradiating 300 nm ~ 480 nm wavelength using the Xenon-Lamp which was source of light. In case of Pt/GaN, maximum response is 0.15 A/W, but in the case of RuO_2/GaN, it is 0.23 A/W at 330 nm wavelength. As shown in the figure, UV-Visible rejection ratio of RuO_2 contact is higher than 10^5.

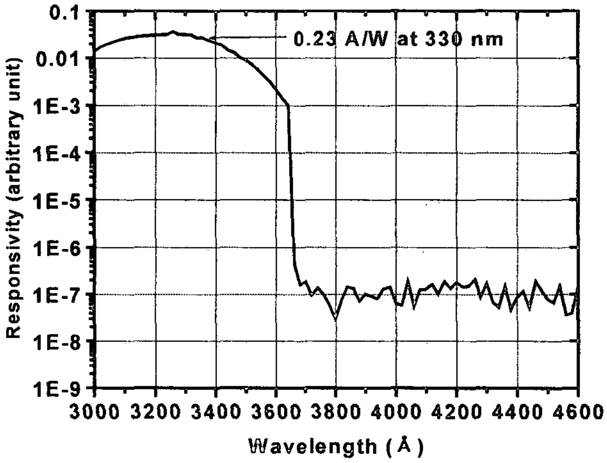


Fig. 5. Spectral photoresponse of RuO_2/GaN Schottky photodetector

Figure 6 showed that the characteristics of spectral photoresponse of RuO_2/GaN Schottky diode and Pt/GaN Schottky diode with 700 ㎛ diameter device. As expected from the data of electrical properties, RuO_2/GaN Schottky diode was superior to Pt/GaN Schottky diode in visible extinction ratio and responsivity. For the HFET, the alteration the ratio of TMGa/TMAl and that of NH_3/H_2 flow rate grew

AlGaN/GaN heterostructures. When the Al mole fraction was from 42 % to 25 %, the mobility was increased from 640 $cm^2/V \cdot s$ to 830 $cm^2/V \cdot s$. The AlGaN surface usually becomes very rough as Al mole fraction increases. The interface scattering was expected to increase.

Figure 7 shows the drain I-V characteristics of the RuO_2-Gated AlGaN/GaN HFET with gate length L_g= 0.8 ㎛ and gate width W_g= 90 ㎛ x 4 ㎛. The range of gate bias ranged from –4 V to +1 V. The gate breakdown voltage was over –50 V and the maximum drain current density of the device was as high as 689.3㎃/㎜ at V_g= +1 V and V_{ds}= 6 V. At high current levels, there was a gradual decrease in current as the V_{ds} increased. This is due to the decreased channel mobility, caused by the increased device temperature as the current increases. The threshold voltage is around –3.8 V. The maximum transconductance is 197.4 mS/㎜ at V_g= –2 V and V_{ds}= 6 V, which is one of the highest values from the devices with 0.8 ㎛ gate length.

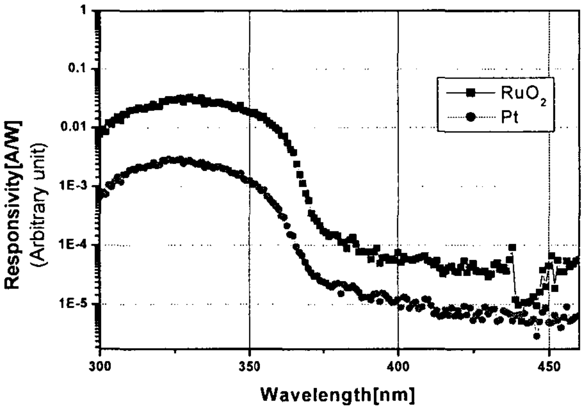


Fig. 6. Spectral photoresponse of RuO_2/GaN and Pt/GaN Schottky detector

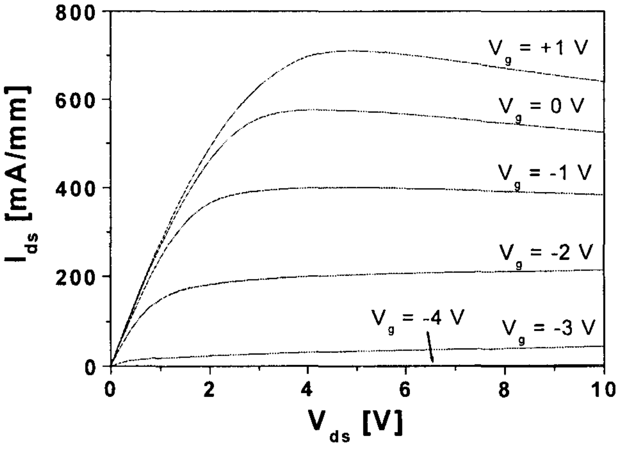


Fig. 7. Drain I-V characteristics of the AlGaN/GaN HFET

Figure 8 showed Gate-Drain I-V characteristics diode of fabricated device. The gate breakdown of reverse bias was excellent about –230 V and exhibited lower leakage current. Table 2 made a summary of Schottky contact properties.

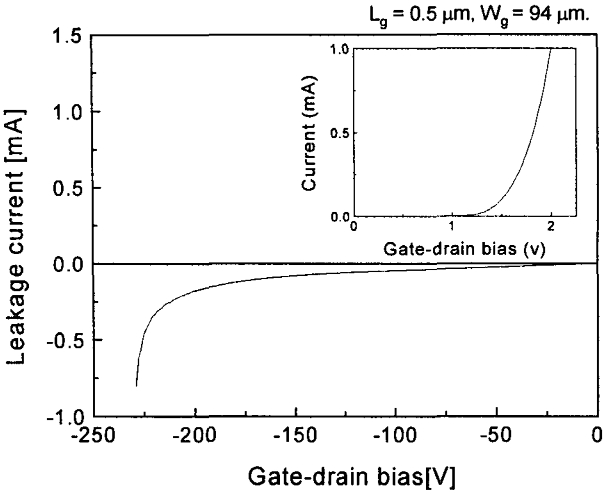


Fig. 8. Gate-Drain I-V characteristics of recessed gate AlGaN/GaN HFET

Table 2. Summary of Schottky contact properties

	Leakage Current at V_{GD}= –20 V	Forward Turn-on Voltage	Break -down Voltage
RuO_2/Au	–12.7 uA	1.6 V	–230 V
Pt/Au	–34.6 uA	1.3 V	–80 V
Ni/Pt/Au	–133.9 uA	1.1 V	–60 V

Figure 9 shows the small signal RF characteristics of AlGaN/GaN HFET. Cut-Off frequency (f_t) and maximum operating frequency (f_{max}) were measured as 27 ㎓ and 45.5 ㎓, respectively. These results show superior to the other research groups.

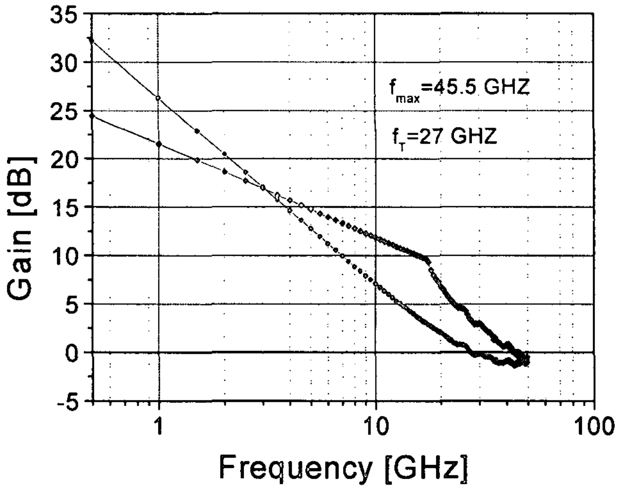


Fig. 9. Small signal RF characteristics of the AlGaN/GaN HFET

4. Conclusions`

For the UV ptotodetector, RuO_2/GaN Schottky diode showed about 1.46 eV of barrier height and 1.2 of ideality coefficient. UV sensor fabricated of Schottky diode showed ideality characteristics that photoresponse rapidly decreases about 365 nm wavelength, Cut-Off wavelength of GaN when exposing 300 nm ~ 480 nm wavelength. Photoresponse of RuO_2/GaN has 0.23 A/W in 330 nm wavelength and UV-Visible extinction ratio is 10^5. UV detector using RuO_2 electrode fabricated in this experiment showed that leakage current was very improved and response was high quality when compared with same structure detector of Pt electrode. For the HFET, high qualities of AlGaN/GaN heterostructures were grown by MOCVD. The fabricated RuO_2 gate HFET exhibited high drain current (I_d) of 689.3 mA/mm at V_{gs}= 1 V and V_{ds}= 6 V and high transconductance(g_m) of 197.4 mS/mm at V_g = –2 V and V_{ds}= 6 V, which is one of the highest values from the devices with 0.8 μm gate length. Cut-Off frequency (f_t) and maximum operating frequency (f_{max}) were measured as 27.0 GHz and 45.5 GHz, respectively. These results showed that RuO_2/GaN and related contacts were very prominent gate material for HFET and Schottky contact for UV photodetector.

Acknowledgments

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