Study of Titanium Tungsten Nitride and Tungsten Nitride Schottky Diodes on n-GaN

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The Schottky diode behaviors of the $TiWN_x$ and the WN_x Schottky contacts to n-GaN were investigated at different annealing temperatures. Both $TiWN_x$ and WN_x films were deposited by reactive dc sputtering method. The X-ray diffraction data and secondary ion mass spectroscopy analysis showed that no interfacial phases were formed during the thermal treatment process. The WN_x/n-GaN contact exhibited excellent electrical characteristics even after rapid-thermal annealed up to 850? for 10 seconds. The ideality factor and barrier height remained 1.09 and 0.80 eV respectively after 850? annealing. However, the $TiWN_x$/n-GaN contact was thermally stable only up to 650? annealing, the values of the ideality factor and the barrier height were 1.14 and 0.76 eV respectively after 650? annealing and started to degrade when annealed at higher temperatures. The deterioration of the $TiWN_x$/n-GaN contact at higher temperatures was due to the inter-diffusion of the TiWN film and the GaN material.

I. INTRODUCTION

The wide-bandgap GaN and related materials have been extensively investigated in recent years due to their excellent chemical and thermal stability, high breakdown field and high saturation drift velocity. These properties make the GaN material suitable for high temperature, high power and high frequency electronic device applications(1,2). In order to realize the materials for high temperature applications, high quality Schottky contact operating under high temperature without deteriorating the performance of the devices is required. The Schottky barrier heights of a variety of elemental metals including Ni, Au, Pt, and Pd on n-GaN have been investigated(3). In addition, the thermally stable Schottky materials such as Ni, NiSi, Pt, PtSi, Pd, Re, PdIn, and Ni/Ga/Ni have also been reported(4-7).

The refractory metal nitrides exhibit excellent thermal stability and form stable Schottky contact with GaAs after high temperature annealing by the self-aligned gate technology(8). $TiWN_x/Ga_{0.51}In_{0.49}P$ contact with excellent thermal stability and electrical characteristics has also been demonstrated with barrier height and ideality factor of 1.00 eV and 1.04, respectively, after rapid thermal annealing (RTA) at 850? for 10 seconds(9). However, the Schottky contact characteristics of the refractory transition metal nitrides such as titanium tungsten nitride ($TiWN_x$) and tungsten nitride (WN_x) with GaN have never been investigated

In this study, $TiWN_x$ and WN_x films were deposited by reactive dc sputtering method, both the electrical characteristics and material aspects of the GaN Schottky contacts were investigated. The electrical properties were characterized by current-voltage measurement and the material properties were characterized by low angle X-ray diffraction, secondary ion mass spectroscopy (SIMS) methods.

II. EXPERIMENT

The GaN samples used in this study were grown by metal-organic chemical vapor phase deposition (MOCVD). The structure of the samples consists of a 2 µm Si-doped n-GaN with carrier concentration of 1.8×10^{17} cm^{-3} on top of a 300 Å GaN buffer layer on the sapphire (0001) substrate. The GaN samples were first cleaned with acetone and isopropyl alcohol for 5 min, followed by dipping in HCl : H_20 (1:10) solution for 3 min. The samples were then immediately put into an electron-beam evaporating system and pumped down to a pressure of 8×10^{-7} Torr. Rectangular contact pads of Ti/Al/Ni/Au (200Å/2000Å/500Å/600Å) multilayer metals were evaporated on n-GaN and were RTA annealed at 900? for 30 s in nitrogen gas to form Ohmic contacts. The Schottky contact materials, titanium tungsten nitride and tungsten nitride, were deposited by dc-magnetron reactive sputtering of Ti/W (1/10 atomic ratio) target and pure W (99.99%) target in an Ar and N_2 mixture onto GaN.

III. RESULTS AND DISCUSSION

Fig. 1 shows the I-V characteristics of the $TiWN_x$/n-GaN diodes as a function of annealing temperature. The leakage current density of the as-deposited $TiWN_x$ diode was about 3×10^{-5} A cm^{-2} at 1 V and dropped an order of magnitude to about 4×10^{-6} A cm^{-2} at 1 V after annealing at 650? . The I-V characteristics of the WN_x/n-GaN diodes as a function of annealing temperature were shown in Fig. 2. The leakage current densities of the WN_x/n-GaN Schottky diodes remained at the order of 10^{-7} A cm^{-2} after annealing at temperatures up to 850? and the diode remains good Schottky characteristics after annealing up to 850? . The barrier heights and the ideality factors of the $TiWN_x$/n-GaN and WN_x/n-GaN Schottky contacts under different annealing temperatures T_A are listed in Table 1. For the as-deposited $TiWN_x$/n-GaN diode, the barrier height and the ideality factor were 0.71 eV and 1.17 respectively. After annealing at 650? , the diode characteristics were improved and the barrier height became 0.76 eV while the ideality factor became 1.14. This was believed to be due to the removal of sputter-induced damage during annealing process. However, the diode characteristics degraded after 750? annealing and become Ohmic-like behavior after 850? annealing. The barrier height and ideality factor for the as-deposited WN_x/n-GaN were 0.67 eV and 1.15, respectively, similar to $TiWN_x$ Schottky contact, the diode characteristics improved to 0.83 eV and 1.10 after 650? annealing. The WN_x/GaN diode remained stable up to 850? annealing, the barrier height and ideality factor remained at 0.80 eV and 1.09, respectively, even after 850? annealing. Comparing the electrical characteristics of the $TiWN_x$/GaN and the WN_x/GaN contacts, obviously, $TiWN_x$/GaN diode was thermally stable only up to 650? , while the WN_x/GaN Schottky contact remained stable and showed only slight changes on leakage current density, Schottky barrier height and ideality factor after annealing at temperature up to 850? .

To verify what has occurred at the refractory metal nitrides/n-GaN interface, both $TiWN_x$/n-GaN and WN_x/n-GaN samples were subjected to secondary ion mass spectroscopy (SIMS) depth profiling analysis before and after thermal treatment up to 850? . Fig. 3 is the SIMS depth profile of the the $TiWN_x$/n-GaN interface as deposited and after annealed up to 850 ? . The $TiWN_x$/n-GaN interface remained sharp after 650? annealing, however, the atomic inter-diffusion between $TiWN_x$ and GaN materials occurred after 850? annealing as shown in Fig. 3(c). This is in agreement with the electrical data shown in Table 1 which shows that the barrier height of the WN_x/n-GaN diode dropped to 0.62eV and the ideality increased to 1.54 after 850? annealing. For the WN_x/n-GaN contacts, there's no detectable inter-diffusion between WN_x and n-GaN after 850? annealing as can be seen from the SIMS data shown in Fig. 4. The result is in agreement with the data observed in Table 1. From the electrical characteristics of the WN_x/n-GaN Schottky shown in Table 1, the Schottky contact remained quite stable after 850? annealing with the barrier height remained at 0.80 eV and the ideality factor remained at 1.09. The electrical characteristics and the materials analysis showed that the WN_x/n-GaN interface was metallurgically stable up to 850? .

IV. CONCLUSIONS

The electrical characteristics and the materials aspects of the refractory $TiWN_x$ and WN_x films as the Schottky contacts on n-type GaN were studied. The WN_x Schottky contact to n-GaN was thermally stable up to 850? , and the ideality factor and the barrier height remained at 1.10 and 0.80 eV, respectively after 850 ? annealing. The Schottky characteristics of the $TiWN_x$/n-GaN contact remained stable up to 650? annealing with the ideality factor and the barrier height remained at 1.14 and 0.76 eV, respectively. The contact degraded after 750? annealing and become Ohmic-like behavior after 850? annealing. This degradation of the diode was due to the atomic inter-diffusion between $TiWN_x$ and GaN which occurred at higher temperatures as indicated by the SIMS analysis.

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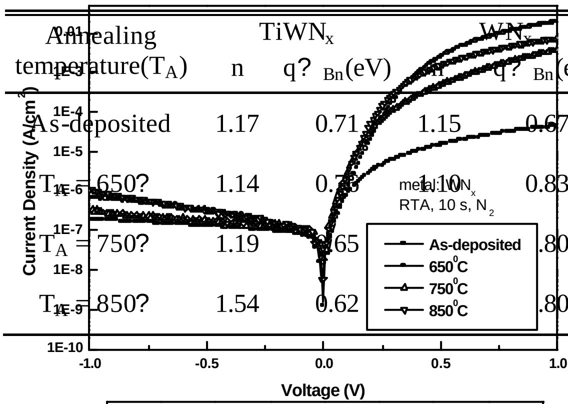
TABLE 1. Electrical characteristics of Schottky contacts on n-GaN under different annealing temperatures.

Annealing temperature(T_A)	TiWN$_x$ n	TiWN$_x$ q? $_{Bn}$(eV)	WN$_x$ n	WN$_x$ q? $_{Bn}$(eV)
As-deposited	1.17	0.71	1.15	0.67
T_A = 650?	1.14	0.73	1.10	0.83
T_A = 750?	1.19	0.65	[illegible]	.80
T_A = 850?	1.54	0.62	[illegible]	.80



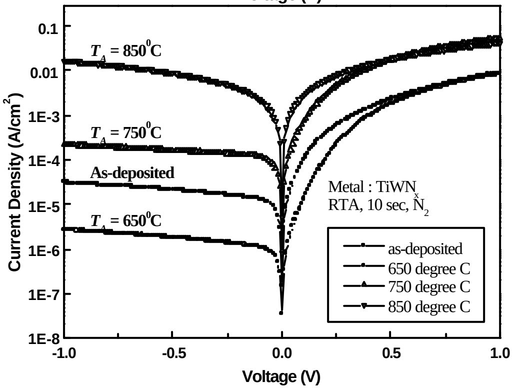
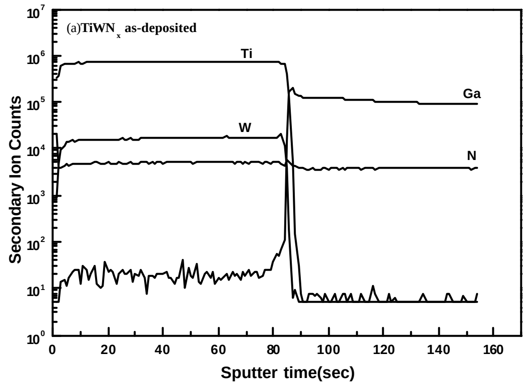


FIG. 1. I-V characteristics of the TiWN$_x$/n-GaN Schottky diodes as a function of annealing temperature.

Fig 2. I-V characteristics of the WN$_x$/n-GaN Schottky diodes as a function of annealing temperature.



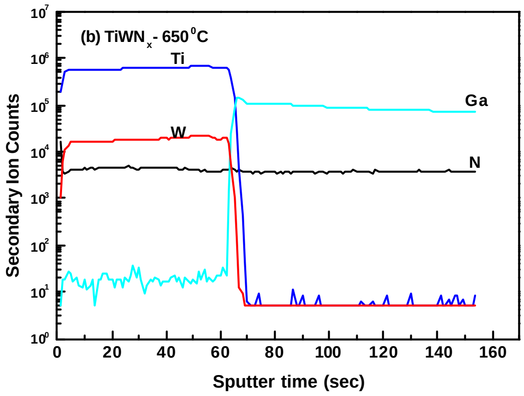
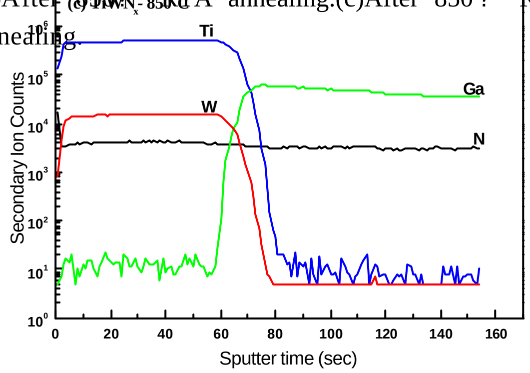
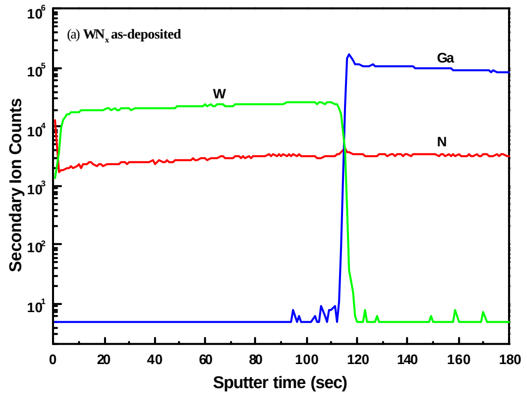


FIG. 3. SIMS depth profiles of the TiWN$_x$/n-GaN contacts after thermal treatments(a) As deposited. (b)After 650? RTA annealing.(c)After 850? RTA annealing.





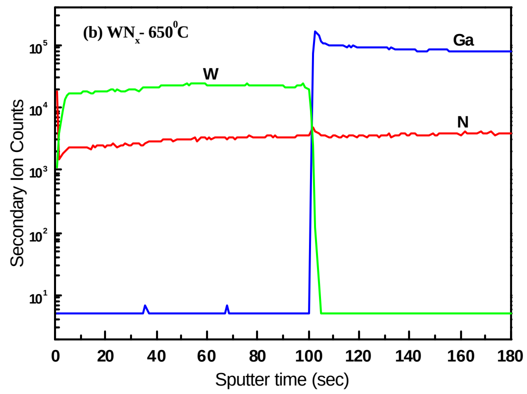


FIG. 4. SIMS depth profiles of the WN$_x$/n-GaN contacts after thermal treatments(a)As-deposited. (b)After 650 ? RTA annealing.(c)After 850? RTA annealing