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The impact of the surface treatments on the properties of GaN/3C-SiC/Si based Schottky Barrier Diodes

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Abstract In this work, we studied the Ti, Mo, and Ni Schottky contacts on N-GaN/SiC/Si substrates. The effect of surface preparation and substrate temperature during sputter deposition of Schottky contacts have been investigated. For the Ti Schottky, the substrate temperature of 100°C during the sputtering demonstrates the minimum series resistance with Rs about $0.04\Omega cm^2$, while temperatures greater than 300^0C increased reverse bias leakage. The Mott-Schottky plot reveals a barrier height of 1.2V for this Ti Schottky contact. Results for sputtered Ni contacts using different substrate temperatures demonstrate the some reverse bias leakages. We characterized the I-V curves of the Ni contact to investigate the effect of the Ar sputter cleaning before contact deposition. It demonstrates the Ar sputtering increases the reverse bias leakage and forward current. The Mo Schottky contact obtained at 100°C without Ar cleaning shows a promising reverse bias leakage current and a fair forward bias current.

Introduction

At present, practical electronic power devices responsible for power conditioning are largely based on silicon and their performance is approaching the theoretical limit. GaN and SiC are ideal materials to replace silicon because of their superiority due to a wider band gap, which enables them to establish high power, light weight, miniaturized devices [1].

However, for devices based on 4H/6H-SiC, requirements of the substrate means it is impossible to reduce the expense of manufacturing through integration with Si technology. The cost of SiC wafers is so high that the majority of commercial applications focus on some extreme cases such as electronic devices for military and spaceflight etc. As another option, the wide band gap semiconductor, GaN, not only has similar properties to SiC, but also can be made into diodes such as a Schottky barrier diode (SBD) and light emitting diode (LED), and provide a template for the traditional Si material in the production of energy management and power-driven power electronic devices. Theoretically, GaN materials prepared for power electronic devices and white LED's can reduce energy consumption compared with traditional Si-based power electronic devices and traditional lighting by 50% or more. GaN actually promises to provide transistors with a power-bandwidth that is an order-of-magnitude higher than has been possible to date. This may be the most revolutionary advance in electronics since the scaling of silicon transistors in Very Large Scale ICs brought us electronic wristwatches and personal computers. In a recent patent application [2, 3], a high quality 3C-SiC on 6 and 8 inch Si substrate was disclosed in the Queensland Micro- and Nanotechnology Centre (QMNC). The core area of research in QMNC is around the use of the material 3C-SiC grown on silicon. Based on this substrate, device quality GaN can be grown epitaxially. Binari *et al*. has investigated Ti SBDs with barrier height of Ti on GaN of 0.58 eV [4],

Guo *et al*. has done Ni SBDs with barrier height of Ni around 0.56 and 0.66 eV [5]. These SBDs have all been fabricated using GaN on sapphire substrates. Not much attention has been focused on the large dimension n-GaN /3C-SiC/Si for Ti, Ni and Mo SBD application so far.

In this work, we study Ti, Ni and Mo contacts sputtered using different substrate temperatures, as well as the effect of Ar sputter cleaning before contact deposition.

Experiment

Unintentionally doped 3C-SiC films with thicknesses of 50nm were grown on on-axis 150 mm Si(100) substrates in a custom designed LPCVD reactor in QMNC. The growth temperature was $1000^{o}C$ with SiH_4 (99.9999%) and C_2H_2 (99.9999%) used as precursors. Si substrates were cleaned following the standard Radio Corporation of America (RCA) cleaning procedures prior to being loaded into the LPCVD reactor. Then, the reactor temperature was ramped from 600 to $1000^{o}C$ with a ramp up rate of 5 ^{o}C/min. Then the epitaxial growth of 3C-SiC was performed at $1000^{o}C$. GaN films were grown on 3C-SiC /Si substrates by metalorganic chemical-vapor deposition (MOCVD, Veeco K465). Triethylgallium TEGa and ammonia NH_3 were used as the Ga and N sources, GaN growth at 1000°C. The thickness of the GaN layer was about 2 μm.

The Ti, Ni and Mo film, with a purity of 99.999%, was deposited by Surrey NanoSystems γ-1000C sputter**.** Before metal sputtering, Ar sputter cleaning has been performed for 30 seconds unless specified. The metal thickness was about 1000Å. The current–voltage (*I –V*) characteristic of the contact was measured using a HP4145B semiconductor parameter analyzer in a dark, electrically shielded probe station. The Mott-Schottky method was used to determine the Schottky barrier height after measuring the capacitance-voltage characteristic with a HP 4284A LCR meter. The specimens were sputtered at various substrate temperatures from 100 to 500°C in vacuum.

Results and dicussions

The *I–V* characteristics of a Ti Schottky diode with the different substrate temperatures during the sputtering are shown in Figure 1. For the Ti deposition, the substrate temperature of $100^{o}C$ during the sputtering demonstrates the minimum series resistance with Rs about $0.04\Omega cm^2$, while the reverse bias leakage increased significantly at the temperatures greater than $300^{0}C$. The reverse-biased *C–V* characteristics of a Schottky diode is described by the following equation:

$$\left(\frac{A}{C}\right)^2 = \frac{2}{q\varepsilon_r\varepsilon_0 N_d}\left(V_{bi} + V\right) \qquad \text{Equation 1}$$

where A is the contact area, ε_r the relative permittivity of GaN, ε_0 the permittivity of free space, q the electron charge, V the applied voltage, N_d the doping concentration, and V_{bi} the Schottky barrier height. This C-V relationship is known as the Mott-Schottky plot and as shown in Figure 2, yields a barrier height for Ti of 1.2V. Due to the limit of our measurement equipment, we did not perform the breakdown voltage measurement.

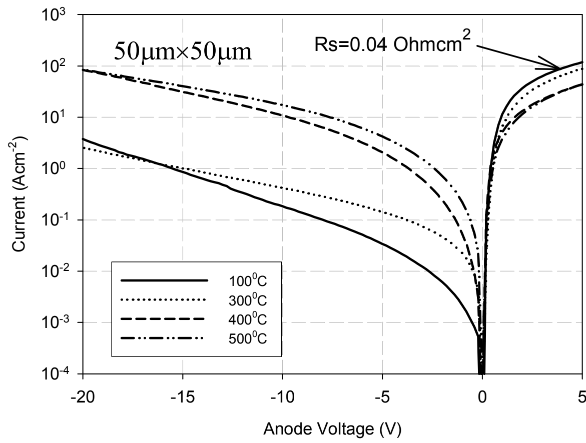

Figure 1. I-V curves of Ti Schottky contacts sputtered with different substrate temperatures

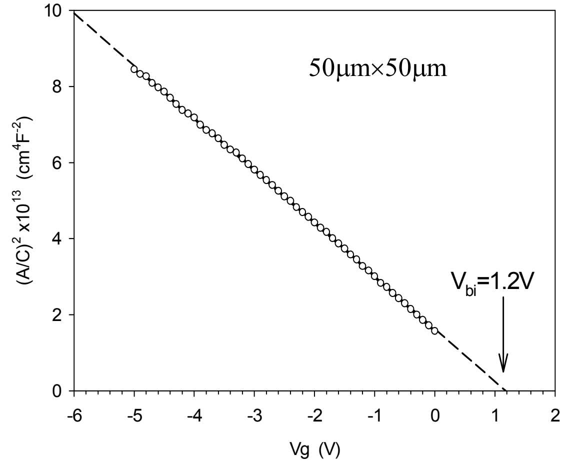

Figure 2. Mott-Schottky plot of Ti contact on N-GaN sputtered at 100^0C

Ni Schottky diodes with the different substrate temperatures are shown in Figure 3. Ni contacts for the samples sputtered at different substrate temperatures all show non-rectifying IV characteristics. We speculate an interfacial reaction might occur to the Ni/GaN system, especially, it was observed that the reverse bias currents are increased with the substrate deposition temperatures. Some SIMS experiments are planned to further investigate the effect of the interdiffusions/interfacial reaction between Ni and GaN.

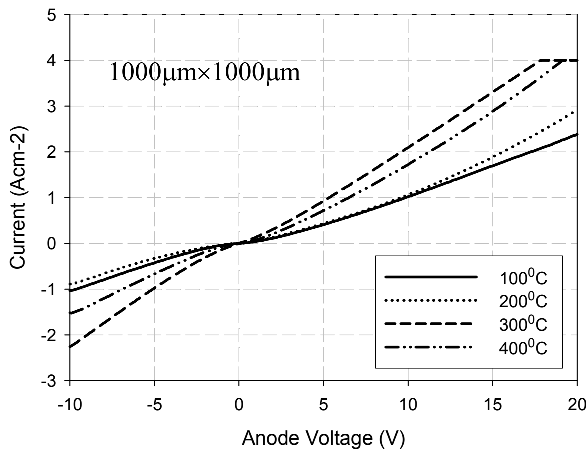

Figure 3. I-V curves of Ni Schottky contacts sputtered with different substrate temperatures

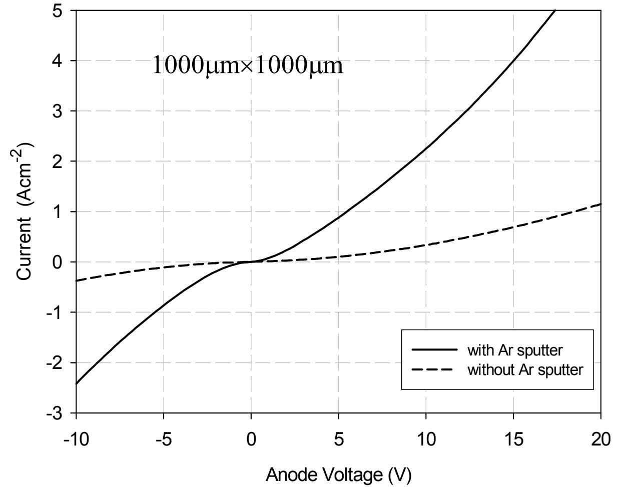

Figure 4 I-V curves of Ni Schottky contacts with and without Ar cleaning before sputtering

To investigate the impact of Ar sputtering cleaning for the Ni Schottky contact, I-V curves of Ni Schottky contacts deposited at 100^oC with and without Ar cleaning before Ni deposition are shown in Figure 4. It demonstrates that Ar sputtering increases the reverse bias leakage and the forward current. The physical bombardment cleaning could damage or roughen the GaN surface which might account for the increased leakage. We also performed Mo sputter deposition without Ar cleaning at 100^oC, and the resulting I-V characteristic of the Mo Schottky contact is shown in Figure 5. Similar to the Ti Schottky contact, the Mo diode demonstrates a promising reverse bias leakage current and a fair forward bias current. From the results of Ti, Ni and Mo Schottky contacts, no obvious interdiffusions between the Ti or Mo film and the GaN are observed.

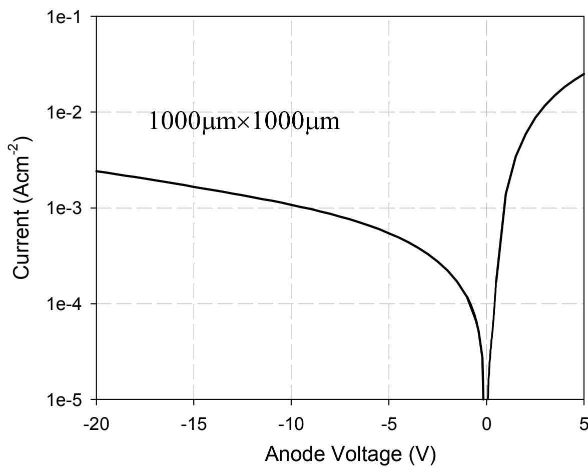

Figure 5 I-V curve of Mo Schottky contact without Ar cleaning before sputtering

Summary

The Schottky contacts of Ti, Ni and Mo metals on n-GaN/3C-SiC/Si were investigated by this work. The Schottky barrier height of Ti on *n*-GaN has been calculated to be 1.2 eV by *C–V*. The Schottky contacts of Ti and Mo deposited at 100°C demonstrate minimum reverse bias leakage current. Ar sputtering cleaning increase the reverse bias leakage current for the Schottky contacts of the three metals. With the increase of the metal deposition temperature, the reverse bias currents of the three metal Schottky contacts all increased. No decent Ni Schottky contact was observed in the conditions performed in this research.

We planned some surface analysis experiment to confirm if there is any interfacial reaction might occur to the Ni/GaN system and also if there is any formation of these nickel nitrides to see the effects of the Ar sputtering cleaning and the deposition temperatures.

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