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W ohmic contact for highly doped *n*-type GaN films

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Abstract

Ohmic contacts with low resistance and low barrier height were fabricated on *n*-type GaN films using W metallization. The *n*-type GaN films were grown by low pressure metalorganic chemical vapor deposition (LP-MOCVD) with Si as the dopant. Ohmic characteristics were studied for GaN films with Si carrier concentration varying from 1.4×10^{17} to 1.8×10^{19} cm^{-3}. The specific contact resistivity were reduced with increasing Si-doping concentration on as-deposited W/GaN films, and the lowest value was 3.6×10^{-4} $\Omega\mathrm{cm}^2$ on *n*-type GaN with a concentration of 1.8×10^{19} cm^{-3}. After rapid thermal annealing (RTA) treatment on W/GaN films at 1000°C for 30 s, the specific contact resistivity were reduced to 1×10^{-4} $\Omega\mathrm{cm}^2$. The W metal on *n*-type GaN films, show that good thermal stability varied the annealing temperatures. The barrier height of as-deposited W metal on GaN is calculated to be 0.058 eV. © 2000 Elsevier Science Ltd. All rights reserved.

Gallium nitride (GaN) is a promising material for UV/blue light emitting diodes and high power-temperature devices. These electronic and optical electronic devices include visible light emitting diodes (LED) [1], metal semiconductor field effect transistors (MESFET) [2], high electron mobility transistors (HEMT) [3], UV photo conductive detectors [4] and UV photovoltatic detectors. Rapid and promising developments on III–V nitride materials for the application of optical devices as well as electrical devices have occurred. Laser diodes [5], and microwave field effect transistors (FETs) have been demonstrated. A problem in achieving high performance GaN-based devices is the realization of good reliable metal contacts. Conventional metallization gives high contact resistance, thereby limiting the performance of GaN-based devices [6]. Research on both ohmic and Schottky contacts for GaN are of current interest [7–9]. However, Lin and co-workers achieved low resistance ohmic contacts to *n*-GaN using Ti/Al bilayer metallization by annealing at 900°C for 30 s. The lowest value for the specific contact resistivity is 8×10^{-6} $\Omega\mathrm{cm}^2$. The performances of GaN devices have often been limited by contact resistances [10]. Early attempts for better ohmic metals include those of Foresi and Moustakas [11] and Lin et al. [12]. Foresi and Moustakas employed Al and Au, and achieved about 10^{-3} $\Omega\mathrm{cm}^2$ after a 575°C anneal for 10 min. Recently, Fan et al. [13] realized a very low specific contact resistance of 8.9×10^{-8} $\Omega\mathrm{cm}^2$ utilizing reactive ion etching (RIE) treatment and multi-metal-layers (Ti/Al/Ni/Au) [14]. W was found to produce low resistance ohmic contact to n^+ GaN ($\rho_c \sim 10^{-4}$ $\Omega\mathrm{cm}^2$) with little interaction between the semiconductor and the metal up to 800°C [15]. And the formation of the β–W_2N and W–N inter-

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facial phases were deemed responsible for the electrical integrity.

In this letter, Ohmic contacts of W metal were sputtered on n^+ Si-doped GaN films with various doping concentrations. Electrical characteristics were observed using the rectangular transmission line measurements method (TLM). The barrier height of W on n-type GaN was also calculated using the various alloy temperatures.

GaN films were grown on c-face sapphire substrates. The LP-MOCVD system is a horizontal type reactor with water cooling, and the pressure of growth chamber is at 100 mbar. Trimethylgallium (TMGa) and ammonia (NH_3) were used as the Ga and N sources, and hydrogen (H_2) was used as the carrier gas. The SiH_4 was used as the source of n-type dopant. Optical-grade polished sapphires with the (0001)-orientation (C face) were used as the substrates. Before film growth, the substrate was heated at 1130°C for 10 min in a pure H_2 ambient. A thin GaN buffer layer (250 Å) was deposited at 530°C first, then the epitaxial GaN was grown at 1100°C. The growth rate was about 2 μm/h. The surfaces of the films were smooth and the thicknesses of these specimens used in this work were about 2 μm, measured by scanning electron microscopy (SEM). GaN films were patterned and then etched by reactive ion etching (RIE) to generate the mesa area for the TLM measurements. The pattern of metalization was defined using a photoresist lift-off technique. The dimensions of linear configuration of rectangular pads were 200 μm wide and 100 μm long. The gaps between the contact pads varied, from 20 to 120 μm with 20 μm as the increment. Before the evaporation, specimens were cleaned in HCl enchant for about 1 min. The 2000 Å W metal were sputtered with Ar^+ plasma on n-type GaN films, varying with the doping concentration. The base pressure of the sputter system was below 2×10^{-5} torr with the diffusion pump. The Ar flow rate was fixed at 6 sccm and the operation pressure was 5 mtorr. In our growth procedure, there is a thin undoped GaN layer between the GaN buffer layer and Si doped GaN film. The undoped GaN layer is a so called second buffer layer. The growth condition is similar to the Si doped GaN film, just without the doping source SiH_4. These samples were alloyed by RTA treatment varying the temperature from RT to 1000°C for 30 s in an N_2 ambient.

The various specific contact resistivies with the RTA treated temperatures were shown in Fig. 1. For the as-deposited W metal pads on n-type GaN, the ρ_c values were reduced from 1.5×10^{-2} Ωcm^2 to 3.6×10^{-4} Ωcm^2 on different Si doping level GaN films varied from 8.4×10^{17} to 1.8×10^{19} cm^{-3}. But the W metal on GaN films with 1.4×10^{17} cm^{-3} carrier density shows the slightly Schottky property from the I–V curves. When the contact deposited on GaN film with high doping concentration, the tunneling process will dominate, and the specific contact resistivity ρ_c is given as [16]:

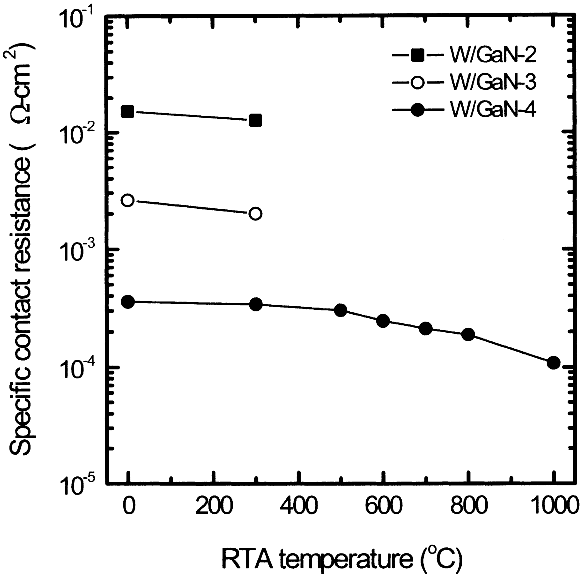

Fig. 1. The specific contact resistivity as the function of RTA alloy temperatures on different Si-doping concentration n-type GaN films.

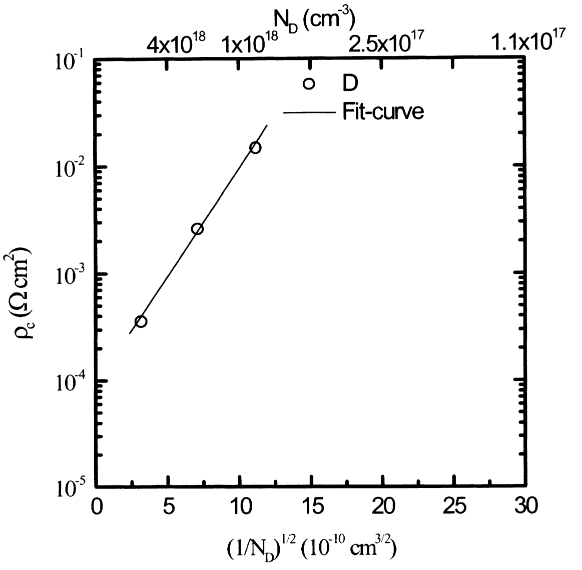

Fig. 2. A plot of the calculated values of ρ_c as a function of $1/\sqrt{N_D}$.

$$\rho_{\mathrm{c}} \infty \exp\left(\frac{q\phi_{\mathrm{Bn}}}{E_{00}}\right) = \exp\left[\frac{2\sqrt{\epsilon_{\mathrm{s}} m^*}}{(h/2\pi)}\left(\frac{\phi_{\mathrm{Bn}}}{\sqrt{N_{\mathrm{D}}}}\right)\right], \qquad (1)$$

where ρ_s is the semiconductor permittivity, m^* is the effective mass and h the Planck constant. Eq. 1 shows that in the tunneling process, the specific contact resistivity strongly depends on the doping concentration. As the Si-doping concentration of the GaN films is increased, the slope of the I–V curve is improved with the reducing contact resistance. The specific contact resistivity, ρ_c, is obtained from the I–V data by measurement resistance vs TLM pattern's gap spaces. Fig. 2 shows the plot of the measured values of ρ_c as a function of $1/\sqrt{N_D}$. When the carrier concentration of the specimen is larger than 8×10^{17} cm^{-3}, ρ_c decreases rapidly with increased doping concentration. The ratio of ϵ_s/ϵ_0 is 9.5 and m^* equals 0.19 m_0 [17] for C-face GaN. By fitting the ρ_c vs $1/\sqrt{N_D}$ curve and using Eq. (1), the ϕ_{Bn} of W is calculated to be 0.058 eV ϕ_{Bn} of the semiconductor for a Schottky barrier on an *n*-type semiconductor is related to the metal work function (ϕ_m) and the χ_s by $\phi_{Bn} = \phi_m - \chi_s$. The Schottky barrier height of W on GaN films shows the thermal stability as the value of 0.058 eV with and without 300°C RTA treatment. The I–V curve shows the linear property of W metal with the RTA treated temperatures above 300°C on *n*-type GaN films with the carrier concentration below 1×10^{19} cm^{-3}. The electron mobility as the function of carrier density shows the linear property in Fig. 3. The Si as the *n*-type doping source shows the better activation efficiency on the undoped GaN films with 4.5×10^{16} cm^{-3} and 560 cm^2/V.s of the background carrier concentration and mobility. The decreasing mobility values have the traditional behavior characteristic of ionized impurity scattering with the increasing electron concentration.

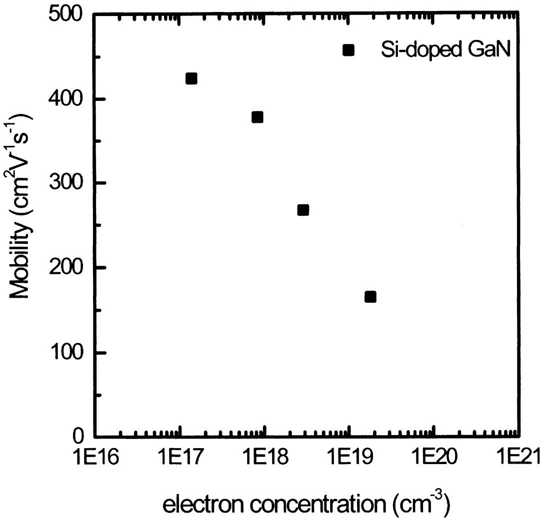

Fig. 3. The electron mobility as the function of electron concentration shows the ionized impurity scattering process at heavy doping GaN films.

In summary, low ohmic contact resistivity and thermal stable W metal on n^+-type GaN films were achieved. The dependence of specific contact resistivity on the doping concentration of *n*-type GaN is investigated. Good ohmic characteristics on GaN films were observed with a carrier concentration higher than 8.4×10^{18} cm^{-3} without thermal treatment, and the specific contact resistivity of 3.6×10^{-4} Ωcm^2 is obtained without thermal annealing on n^+ GaN (1.8×10^{19} cm^{-3}). The barrier height of W on *n*-type GaN is calculated to be 0.058 eV, and the W metal barrier height shows the thermal stability as a value of 0.058 eV for as-deposition and 300°C RTA treatment W metal. After rapid thermal annealing (RTA) treatment on W/GaN films (1.8×10^{19} cm^{-3}) at 1000°C for 30 s, the specific contact resistivity were reduced to 1×10^{-4} Ωcm^2.

Acknowledgements

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