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Low resistivity ohmic contact to n-type poly-GaN using a Ti/Au/Ni/Au multilayer metal system

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Abstract

A low resistivity ohmic contact to poly-GaN was achieved using the multilayer metal combination of Ti (50 Å)/Au (100 Å)/Ni (100 Å)/Au (3000 Å). Exactly how rapid thermal annealing (RTA) affects the specific contact resistivity (ρ_c) was also studied by varying the temperature and duration of annealing. An improvement in ρ_c of over one order of magnitude was achieved over the as-deposited condition with good reproducibility by RTA treatment for a total duration of 120 s. In particular, by optimizing the annealing temperature to 400 °C a relatively low ρ_c of $1.6 \times 10^{-5}\ \Omega\,cm^2$ was yielded for the contact of Ti/Au/Ni/Au to poly-GaN with a carrier concentration of $(5–6) \times 10^{17}\ cm^{-3}$. Related mechanism for the improvement in ρ_c was discussed based on the results obtained from X-ray diffraction analysis and transmission electron microscopy observations.

Keywords: Ohmic contact; MOCVD; TLM; Polycrystalline GaN; Contact layer

1. Introduction

GaN has become a widely used material because of its wide band-gap, high breakdown voltage and thermal stability, explaining its diverse range of applications including in light emitting diodes, laser diodes, photodetectors, display and related optoelectronic technologies. Moreover, in the area of electronic devices, high electron mobility transistors (HEMTs) [1] and heterojunction bipolar transistors (HBTs) [2] have been studied. The development of such devices depends on low resistivity and reliable ohmic contacts. Numerous works of the ohmic contact of single crystalline GaN have been published. For n-type single crystalline GaN, low specific contact resistivities in the range 10^{-6}–$10^{-8}\ \Omega\,cm^2$ were presented [3–7], while for p-type one, a range of 10^{-3}–$10^{-6}\ \Omega\,cm^2$ has been claimed by using different multilayer metal systems [8–14]. However, the lattice mismatch and the misfit in the thermal expansion coefficients between GaN and the widely used sapphire or Si substrate are large. Therefore, growing high-quality and crack-free single crystalline GaN on top of these substrates has been very difficult. Recently, polycrystalline GaN (poly-GaN) has been variously applied in the field of opoelectronics [15–17]. Accordingly, if the resistivity of an ohmic contact to poly-GaN can be made as low as that to a monocrystalline GaN, then the temperature of device fabrication can be reduced, preventing devices from being destroyed at high processing temperatures, raising the possibility of large-area and low-cost optoelectronic device fabrication using polycrystalline GaN grown on a wide range of substrates.

Nevertheless, to our knowledge, so far the ohmic contact to poly-GaN has never been studied and relevant

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works are scarce. Hence, this study examines the conditions for forming a low resistivity ohmic contact to n-type poly-GaN using a Ti/Au/Ni/Au multilayer metal system.

2. Experiment

GaN films with the thickness of 300 ± 10 nm were grown by a home-made atmospheric-pressure metal-organic chemical vapor deposition (MOCVD) system. The substrates employed herein were (1 1 1)-oriented 2-in. Si wafers, which have a p-type conductivity with a carrier concentration of around 10^{17} cm^{-3}. Before the growth of GaN, an Si_3N_4 film was deposited at 825 °C for around 85 nm to suppress the conductive effect of the underlying layer. Then GaN film was grown at 635 °C for 30 min using a TMG flow of 4 sccm, an NH_3 flow of 0.889 slm and an H_2Se flow of 27.9 sccm. X-ray diffraction (XRD) analysis revealed that the GaN grown film is polycrystalline and has a wurtzite structure. Capacitance–voltage measurements showed the poly-GaN film to be of n-type conductivity with an electron concentration of as low as $(5\text{–}6) \times 10^{17}$ cm^{-3}. For characterizing the ohmic contact, the metal system deposited on the poly-GaN was processed into a transmission line model (TLM) test pattern. Fig. 1 schematically depicts the sample structure. Each set of the TLM pattern consists of seven square contact pads (200×200 μm^2), with varied spacings of 10, 15, 20, 25, 30 and 35 μm, respectively. The definition of the TLM test structures was as follows. First, the specimens, after being degreased in trichloroethylene and acetone, were coated with positive photoresist typically about 4.1 μm thick and then formed therein photolithographically a pattern with TLM openings. Before the metal films were deposited, the samples were dipped in HCl:H_2O (1:1) for 3 min to remove native oxide from the poly-GaN film surface. Then, the multilayer metal system Ti (50 Å)/Au (100 Å)/Ni (100 Å)/Au (3000 Å) was evaporated by electron beam evaporation at a pressure of 2×10^{-7} Torr. Finally, the metal lift-off process was completed by removing all the photoresisted regions left. After this process, the semiconductor was further formed into a mesa structure by reactive ion etching. Such a structure was defined to suppress the leakage current through the poly-GaN surface. The Au/Ni/Au/Ti/n-type poly-GaN specimens were then annealed in a rapid thermal annealing (RTA) system in an H_2 environment at temperatures from 300 to 800 °C. RTA treatment was executed twice for a duration of 40 and then 80 s. In some cases, RTA was performed more than twice with a total annealing time of over 4 min, to elucidate the effect of the annealing time. After each annealing, the *I–V* curve of the samples was obtained and analyzed.

The room temperature current–voltage (*I–V*) characteristics of the contacts with 40 s RTA were examined between two pads with a spacing of 35 μm. The total resistances (R_T) of samples between the pads of spacings of 10–35 μm were measured and from the TLM resistance-versus-spacing plots the specific contact resistivity (ρ_c) was extracted. The epitaxial relationships for metal/n-type poly-GaN were evaluated by powder XRD using Cu K_α ($\lambda = 1.54$ Å) radiation as the X-ray source. The interfacial microstructures of the contacts were observed by a transmission electron microscope (TEM) at an operating voltage of 200 kV. The elemental composition of the contacts was analyzed using an energy-dispersive spectrometer (EDS).

3. Results and discussion

Fig. 2 plots the *I–V* characteristics of the Ti (50 Å)/Au (100 Å)/Ni (100 Å)/Au (3000 Å) contact to poly-GaN after RTA treatment for 120 s at various temperatures between 300 and 800 °C. A linear relationship is evident in the *I–V* characteristic of the as-deposited sample, demonstrating that an ohmic contact to poly-GaN was already formed

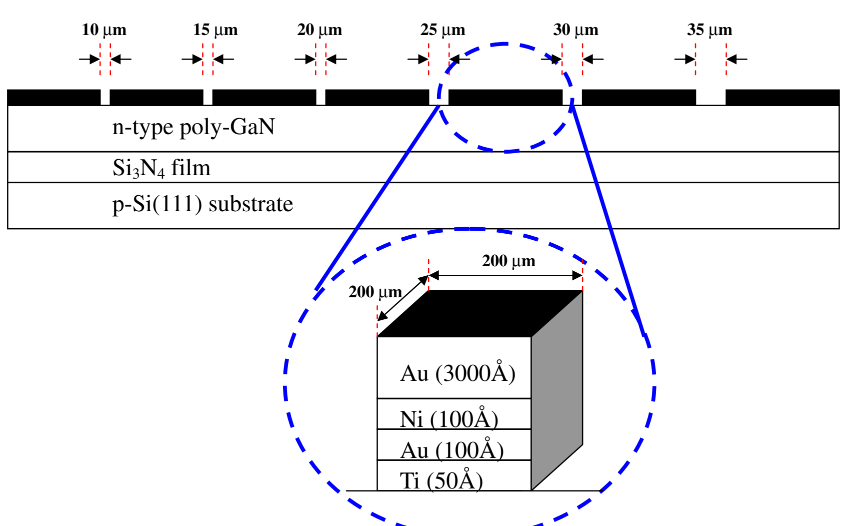

Fig. 1. A schematic diagram of the sample structure.