Ohmic Contacts with heterojunction structure to N-type 4H-Silicon Carbide by N⁺ Polysilicon Film

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ABSTRACT

The polysilicon ohmic contacts to n-type 4H-SiC have been fabricated. TLM (Transfer Length Method) test patterns with polysilicon structure are formed on N-wells created by phosphorus ion (P⁺) implantation into Si-faced p-type 4H-SiC epilayer. The polysilicon is deposited using low-pressure chemical vapor deposition (LPCVD) and doped by phosphorous ions implantation followed by diffusion to obtain a sheet resistance of 22Ω/□. The specific contact resistance $\rho_{sc}$ of n⁺ polysilicon contact to n-type 4H-SiC as low as $3.82 \times 10^{-5}$Ωcm² is achieved. The result for sheet resistance $R_{sh}$ of the P⁺ implanted layers in SiC is about 4.9kΩ/□. The mechanisms for n⁺ polysilicon ohmic contact to n-type SiC are discussed.

Keywords: Ohmic contact, Silicon carbide, Polysilicon, Specific contact resistance, P⁺ ion implantation

1. INTRODUCTION

Silicon carbide (SiC) is a promising semiconductor material for future high-power and high-frequency electronic devices because of its wide energy bandgap about 3 eV, high critical field strength and good thermal conductivity [1-3]. To utilize the excellent properties of SiC in an electronic device, thermodynamically stable ohmic contacts with low specific contact resistance are important, since parasitic resistances generally limit or even jeopardize device operation [2]. Ohmic contacts to SiC are typically formed by the deposition of transition metals layers (possibly in combination with other metals, silicon or carbon) onto heavily doped silicon carbide (>5×10¹⁸cm⁻³) followed by high-temperature annealing (>900°C), and the SCRs (specific contact resistance) are in the 10⁻⁴-10⁻⁶Ωcm² range [4]. But few contacts to SiC with heterojunction structure are studied, especially ohmic contacts [5].

Polycrystalline silicon (polysilicon) is widely used for Si CMOS process. Its electron affinity (~4.05 eV) is close to that of SiC which makes the barrier height for electrons of n⁺ polysilicon/n-SiC contacts would be very low. Furthermore the interface between polysilicon and SiC is abrupt without any structural problems and thermally stable compared with the interface between metal contact and SiC, which is very important for the high-power and high-temperature application of SiC devices. Therefore the polysilicon ohmic contacts to SiC with heterojunction structure is attempted to fabricate in this study by the popular process, and the mechanism of the ohmic contact formation is discussed.

2. EXPERIMENT AND RESULTS

4H-SiC wafer used in this experiment is purchased from Cree Research Company. Orientation of the substrate is 8°off-axis <1000> direction. The patterns are made on a p-type epitaxial layer with concentration of Na = 1.2×10¹⁶cm⁻³ and depth of 2 μm based on the n-type silicon faced substrate. N-wells are formed by phosphorous ions implantation into epilayer at 550°C. The energies and doses for ion implantation are 100 keV and 8.3×10¹⁴cm⁻², 150 keV and 2.5×10¹⁵cm⁻², respectively. The targeted phosphorus concentration is 1×10²⁰cm⁻³. 100-nm-thick SiO₂ films are deposited on the surface of the SiC wafer. Phosphorous ion implanted penetrates through the oxide film in order to increase the density of effective carriers of the surface region of the SiC wafer. Post-implantation annealing is done at 1650 °C during 15 min in...
Ar ambient, using the crucible coated by poly-SiC. The samples are cleaned in acetone before polysilicon deposition followed by a standard RCA cleaning process.

After HF treatment, approximately 600 nm of polysilicon is deposited using low-pressure chemical vapor deposition (LPCVD) with SiH₄ at 630 °C. The polysilicon is doped by phosphorous ions implantation, and the energies and doses for ion implantation are 70 keV and 1×10¹⁶ cm⁻² respectively. Then it is diffused in N₂ at 1050 °C during 30 min. The process is simulated by the semiconductor process simulator DIOS in ISE TCAD 7.0, and the uniform effective doping density is about 7.5×10¹⁹ cm⁻³ in polysilicon. Then the sheet resistance Rₚ of polysilicon is measured to obtain the value of 22 Ω/□.

The ohmic contacts are patterned through conventional photolithography and reactive ion etching (RIE) techniques (SF₆/O₂) of the polysilicon. The processing steps and n⁺ polysilicon/N-SiC ohmic contact structure is shown in Fig. 1.

The scanning electron microscopy (SEM) image of the TLM (Transfer Length Method) pattern used in this study is shown in Fig.2 [3]. Fig.3 shows the results of the polysilicon contacts by TLM measurement.

As shown in Fig.3, the lowest value of the specific contact resistances of n⁺ polysilicon/N-SiC is 3.82×10⁻⁵ Ω cm². Furthermore, the value for sheet resistance Rₚ of the implanted layer in SiC is about 4.9 kΩ/□.

3. DISCUSSION

The specific contact resistance ρₖ is proportional to the exponential of the barrier height (Φₚ) divided by the square root of the doping (N), shown in Eq. (1) [6].

\[ \rho_c \propto \exp \left( \frac{\Phi_p}{\sqrt{N}} \right) \]  

\[ \text{(1)} \]

\[ \text{phosphorous ion implantation} \]
\[ \text{and annealing} \]

\[ \text{p-4HSiC substrate} \]

\[ \text{polysilicon deposition} \]
\[ \text{and doping} \]

\[ \text{n⁺ polysilicon} \]

\[ \text{p-4HSiC substrate} \]

\[ \text{patterning and etching} \]

Fig. 1. Schematic illustration of the processing steps and n⁺ polysilicon/N-SiC ohmic contact structure. (The gray areas represent the regions by phosphorous ions implantation).

This relationship is very useful for predicting the trends of contact resistance as a function of barrier height and the semiconductor doping. There are two ways to obtain the low specific contact resistance: increasing the density of effective carriers in the thin layer just near the interface, or lowering the barrier of the contact interface.

The energy band diagram for n⁺ polysilicon contact to n-type SiC is shown in Fig.4. As can be seen from the band diagram, the theoretical heterojunction conduction band offset (∆Eᵥ) is quite low, about 0.25 eV. On the other hand, in SiC, C vacancies, Vᵥ, act as donors for electrons and Si vacancies, Vₛ, act as acceptor for electrons. The ionization energy level of Vᵥ is located at 0.5 eV under the bottom of conduction band, and Vₛ is at 0.45 eV above the top of valence band. High temperature annealing provides the enough Vᵥ, acting as donors, which contributes to the formation of ohmic contact [7, 8]. It should be noted that polysilicon is used in this study, one target of which is that the more C vacancies can be formed in the Si-rich condition to get ohmic contacts easier during high temperature annealing. The
depletion layer width and effective barrier height for the transport of electrons are simultaneously decreased, leading to the reduction of specific contact resistance.

Fig. 2. SEM image of TLM structure.

![SEM image of TLM structure](image)

Fig. 3. TLM results of the polysilicon contacts.

![TLM results of polysilicon contacts](image)

For the excellent properties of SiC in power electronic, the structural problems and the thermal stability of ohmic contacts must to be paid attention to because of the high ambient temperature, the large current and high voltage. For example, Ni contact has the structural problems in contact layer, which is the most widely used metal for fabrication of ohmic contacts to n-type SiC \[3\]. It has been reported that Ni$_2$Si alloy formed by a reaction between Ni and SiC usually contains graphite-state C atoms in the produced contact layer \[9\]. The large voids have also been observed in the vicinity of the interface in the contact layer. The generation of voids has been correlated to the dissociation of SiC during the reaction \[10\]. All of these issues would jeopardize device operation. Whereas, they are not exist in the process of n$^+$

![Energy band diagram for n$^+$ polysilicon contact to n-type SiC](image)
polysilicon/N-SiC contacts, and the ambient temperature of operation also has no effect on the contacts. So the interface between polysilicon and SiC is abrupt without any structural problems and thermally stable.

In the results of Ref. [5], the doping density of $1.7 \times 10^{18}$ cm$^{-3}$ in SiC yielded that the specific contact resistance of polysilicon ohmic contacts to SiC is about $5.3 \times 10^{-5}$ cm$^2$. The value for specific contact resistance $\rho_c$ in this paper is lower than that because of the higher doping. And compared with the results of metal/n-SiC ohmic contacts [4], it is in the current range $(10^{-4}-10^{-5}$ cm$^2$), which is $3.82 \times 10^{-5}$ cm$^2$.

The value for sheet resistance $R_{sh}$ of the implanted layer in SiC is higher compared with the results of Gao et al [1], whose $R_{sh}$ of the P$^+$ implanted layer is 106 $\Omega$. The higher value is perhaps induced by the implantation of higher ion flux and twice, which causes more damage to decrease the carrier mobility of the implanted layer. But it is much lower than the result in Ref. [11], in which $R_{sh}$ of the N$^+$ implanted layer is 30 k$\Omega$.

4. CONCLUSION

In conclusion, the polysilicon ohmic contacts to SiC with heterojunction structure are fabricated. TLM (Transfer Length Method) test patterns with n$^+$ polysilicon/N-SiC structure are formed on N-wells created by P$^+$ ion implantation into Si-faced p-type 4H-SiC epilayer. SiO$_2$ films are deposited on the surface of the SiC wafer, and phosphorous ion implantation is carried out through the oxide film in order to increase the density of effective carriers of the surface region of the SiC wafer. The polysilicon is deposited using LPCVD and doped by phosphorous ion implantation followed by diffusion to obtain a sheet resistance of 22 $\Omega$. The specific contact resistance $\rho_c$ as low as $3.82 \times 10^{-5}$ cm$^2$ is achieved. The result for sheet resistance $R_{sh}$ of the P$^+$ implanted layers in SiC is about 4.9 k$\Omega$. The effects of the barrier height and C vacancies in SiC on the formation of ohmic contact are discussed respectively.

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REFERENCES