第 29 卷 第 4 期
2008 年 4 月

半 导 体 学 报
JOURNAL OF SEMICONDUCTORS

Vol.29 No.4
Apr.,2008

Fabrication of n^+ Polysilicon Ohmic Contacts with a Heterojunction Structure to n-Type 4H-Silicon Carbide*

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Abstract: 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 a 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 ρ_c of n^+ polysilicon contact to n-type 4H-SiC as low as $3.82 \times 10^{-5} \Omega \cdot cm^2$ is achieved. The result for sheet resistance R_{sh} of the phosphorous ion implanted layers in SiC is about 4.9kΩ/□. The mechanisms for n^+ polysilicon ohmic contact to n-type SiC are discussed.

Key words: ohmic contact; silicon carbide; polysilicon; specific contact resistance; P^+ ion implantation
PACC: 7340C; 6170T
CLC number: TN405 **Document code**: A **Article ID**: 0253-4177(2008)04-0637-04

1 Introduction

Silicon carbide (SiC) is a promising semiconductor material for high-power and high-frequency electronic devices because of its wide energy bandgap, high critical field strength, and good thermal conductivity[1~3]. To use 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 ($>5 \times 10^{18} cm^{-3}$) followed by high-temperature annealing (>900℃), and the SCRs (specific contact resistance) are in the $10^{-4} \sim 10^{-6}$ $\Omega \cdot cm^2$ range[4]. But few contacts to SiC with a heterojunction structure have been studied, especially ohmic contacts[5].

Polycrystalline silicon (polysilicon) is widely used for Si CMOS processes. Its electron affinity (≈4.05eV) is close to that of SiC, which possibly makes the barrier height for electrons of n^+ polysilicon/n-SiC contacts very low. Furthermore, a good contact interface between polysilicon and SiC can be formed and excellent thermal stability can be obtained compared with that between metal contact and SiC, which is very important for high-power and high-temperature applications of SiC devices. However, the ohmic contact between polysilicon and metal is so mature that it is easier to obtain metal ohmic contacts to SiC. In this study, polysilicon ohmic contacts to SiC with a heterojunction structure are attempted by the normal process and the mechanism of the ohmic contact formation is discussed.

2 Experiment and results

The 4H-SiC wafer used in this experiment was purchased from the Cree Research Company. Orientation of the substrate is 8° off-axis in the ⟨1000⟩ direction. The patterns are made on a p-type epitaxial layer with a concentration of $N_a = 1.2 \times 10^{16} cm^{-3}$ and a depth of 2μm based on the n-type silicon faced substrate. N-wells are formed by phosphorous ions implantation into the epilayer at 550℃. The energies and doses for ion implantation are 100keV and $8.3 \times 10^{14} cm^{-2}$, 150keV and $2.5 \times 10^{15} cm^{-2}$, respectively. The targeted phosphorus concentration is $1 \times 10^{20} cm^{-3}$. 100nm-thick SiO_2 films are deposited on the surface of the SiC wafer. The implanted phosphorous ion penetrates the oxide film in order to increase the density of effective carriers near the surface region of the SiC wafer. Post-implantation annealing is done at

* Project supported by the National Natural Science Foundation of China (No.60476007) and Xi'an Applied Materials Innovation Fund (No.XA-AM-200704).

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Received 19 September 2007, revised manuscript received 16 November 2007

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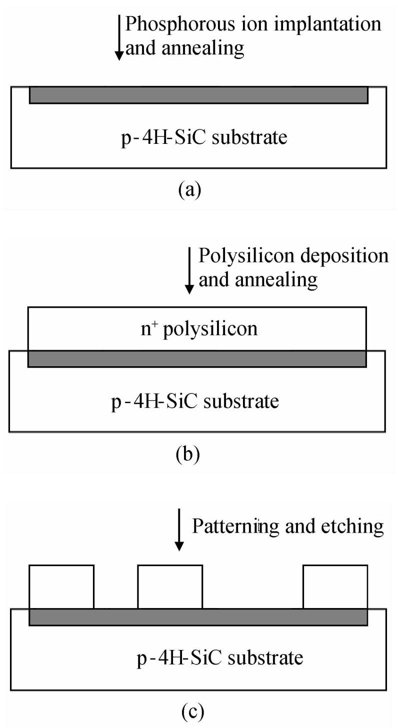

Fig. 1　Schematic illustration of the processing steps and n$^+$ polysilicon/n-SiC ohmic contact structure (The gray areas show the regions implanted by phosphorous.)

1650℃ for 15min 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 600nm of polysilicon is deposited using low-pressure chemical vapor deposition (LPCVD) with SiH_4 at 630℃. The polysilicon is doped by phosphorous ion implantation, and the energies and doses for ion implantation are 70keV and 1×10^{16} cm^{-2}, respectively. Then, phosphorous diffusion is processed in N_2 ambience at 1050℃ for 30min. The profile of doping concentration is simulated by the semiconductor process simulator DIOS in ISE TCAD 7.0, and the uniform effective doping density is about 7.5×10^{19} cm^{-3} in polysilicon. Next, the sheet resistance R_{sh} of polysilicon is measured to obtain the value of 22Ω/□, which is consistent with the simulation result. The ohmic contacts are patterned through conventional photolithography and reactive ion etching (RIE) techniques (SF_6/O_2) of the polysilicon. The processing steps and n$^+$ polysilicon/n-SiC ohmic contact structure are 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]. Figure 3 shows the results of the polysilicon contacts by TLM measurement.

As shown in Fig. 3, the lowest value of the specif-

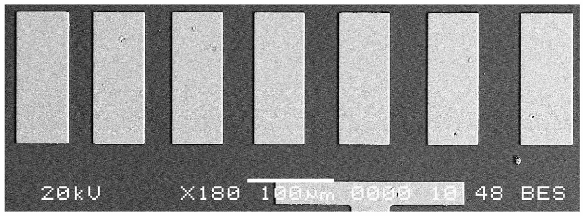

Fig. 2　SEM image of TLM structure

ic contact resistances of n$^+$ polysilicon/n-SiC is $3.82 \times 10^{-5} \Omega \cdot cm^2$. Furthermore, the value for sheet resistance R_{sh} of the implanted layer in SiC is about 4.9kΩ/□.

3　Discussion

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

$$\rho_c \propto \exp\left(\frac{\Phi_B}{\sqrt{N}}\right) \qquad (1)$$

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

The energy band diagram for an 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 (ΔE_C) is quite low, about 0.25eV. On the other hand, in SiC, C vacancies, V_C, act as donors for electrons and Si vacancies, V_{Si}, act as acceptors for electrons. The ionization energy level of V_C is located at 0.5eV below the bottom of the conduction band, and V_{Si} is at 0.45eV above the top of valence band. High temperature annealing provides enough V_C, acting as donors, which contributes to the formation of an ohmic contact[7,8]. One target

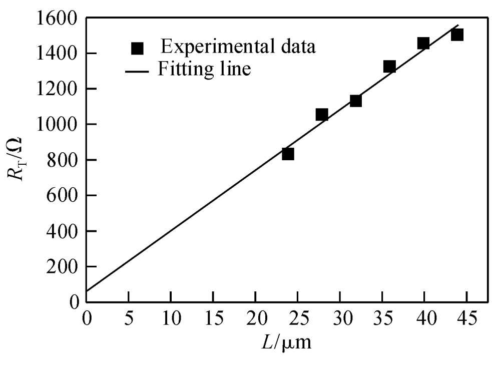

Fig. 3　TLM results of the polysilicon contacts

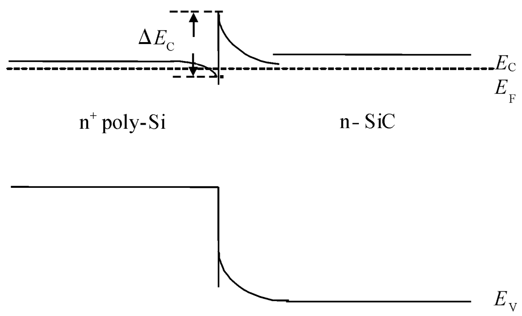

Fig.4　Energy band diagram for n^+ polysilicon contact to n-type SiC

of polysilicon used in this study is to produce more C vacancies in the Si-rich condition to make ohmic contacts easier during high temperature annealing. The depletion layer width and effective barrier height for the electron transport are simultaneously decreased, leading to the reduction of specific contact resistance.

For the excellent properties of SiC in power electronics, great attention must be paid to the structural problems and the thermal stability of ohmic contacts because of the high ambient temperature, the large current, and high voltage. For example, Ni contact has structural problems in the contact layer even though it is the most widely used metal for fabrication of ohmic contacts to n-type SiC[3]. Ni_2Si alloy formed by a reaction between Ni and SiC usually contains graphite-state C atoms in the resulting 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 jeopardize device operation. However, they do not exist in the process of n^+ polysilicon/n-SiC contact and the ambient temperature of operation also has no effect on the contacts. Thus, the interface between polysilicon and SiC is abrupt and thermally stable, which will not induce structural problems. Compared with the results of metal/n-SiC ohmic contacts[4], the lowest value of the specific contact resistances of $3.82 \times 10^{-5} \Omega \cdot cm^2$ is in the current range of $10^{-4} \sim 10^{-6}\ \Omega \cdot cm^2$.

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 $5.3 \times 10^{-5} \Omega \cdot cm^2$. The value for specific contact resistance ρ_c in this paper is lower than that because of the higher doping. But, the polysilicon contacts to SiC in Ref. [5] contained the silicide, which was not premeditated.

The value for sheet resistance R_{sh} of the implanted layer in SiC is higher than the results of Gao *et al*.[1], whose R_{sh} of the phosphorous ion implanted layers is 106Ω/□. The higher value is perhaps induced by the higher ion flux and double implantations, which cause more damage and decrease the carrier mobility in the implanted layer. But, the value is much lower than the result in Ref. [11] in which R_{sh} of the nitrogen ion implanted layer is 30kΩ/□.

4　Conclusion

In conclusion, the polysilicon ohmic contacts to SiC with heterojunction structure were fabricated. TLM test patterns with n^+ polysilicon/n-SiC structure are formed on n-wells created by P^+ ion implantation into a 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 near the surface region of the SiC wafer. The polysilicon is deposited using LPCVD and doped by phosphorous ions implantation followed by diffusion to obtain a sheet resistance of 22Ω/□. A specific contact resistance ρ_c as low as $3.82 \times 10^{-5} \Omega \cdot cm^2$ is achieved. The result for sheet resistance R_{sh} of the phosphorous ion implanted layers in SiC is about 4.9kΩ/□. The effects of the barrier height and C vacancies in SiC on the formation of ohmic contact were discussed.

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异质结 n^+ 多晶硅/n 型 4H-SiC 欧姆接触的制备*

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摘要： 从理论和实验的角度研究了 n 型 4H-SiC 上的多晶硅欧姆接触.在 p 型 4H-SiC 外延层上使用 P^+ 离子注入来形成 TLM 结构的 n 阱.使用 LPCVD 淀积多晶硅并通过 P^+ 离子注入及扩散进行掺杂，得到的多晶硅方块电阻为 22Ω/□.得到的 n^+ 多晶硅/n-SiC 欧姆接触的比接触电阻为 $3.82\times10^{-5}\Omega\cdot cm^2$，接触下的注入层的方块电阻为 4.9kΩ/□.对 n^+ 多晶硅/n-SiC 欧姆接触形成的机理进行了讨论.

关键词： 欧姆接触；SiC；多晶硅；比接触电阻；P^+ 离子注入

PACC： 7340C；6170T

中图分类号： TN405 **文献标识码：** A **文章编号：** 0253-4177(2008)04-0637-04

* 国家自然科学基金（批准号：60476007）和西安应用材料创新基金（批准号：XA-AM-200704）资助项目

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2007-09-19 收到，2007-11-16 定稿

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