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A Simple Method of Surface Parameter Extraction for Gate Schottky Contact in 4H-SiC MESFETs*

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Abstract: We investigate the effects of the surface states on the Schottky contacts in 4H-SiC MESFET. The Ti/Pt/Au gate metal contacts are deposited by electron beam evaporation and patterned by a lift-off process. Based on thermionic theory, a simple parameter extraction method is developed for determination of the surface states in metal/4H-SiC Schottky contacts. The interface state density and interface capacitance are calculated to be $4.386\times10^{13}cm^{-2}\cdot eV^{-1}$ and $6.394\times10^{-6}F/cm^2$, which are consistent with the device's terminal characteristics.

Key words: silicon carbide; Schottky contact; surface states; device modeling.
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1　Introduction

Among various type of SiC polytypes and electronic devices, the 4H-SiC MESFET shows the highest potential for high frequency operations. However, since 4H-SiC is at a young technological stage, many questions have been raised concerning the capabilities and design of 4H-SiC devices[1]. The fabrication of reliable MESFET requires stable gate characteristics. To date, SiC MESFETs have suffered from poor stability due to the presence of surface states that influence the Schottky barrier height (SBH) and cause degradation of both DC and RF performance[2]. Many authors have investigated the characteristics of Schottky contacts using *I-V* and *C-V* methods[3,4], but none gave a method to calculate the interface capacitance and the neutral interface level of SiC Schottky contacts that are unknown. A simple method is needed to obtain the parameters of Schottky contact properties.

In this paper, a simple method is presented to extract the parameters of Schottky contact properties, including the ideality factor n, SBH ϕ_B, specific resister R_s, interface state density D_{it}, interface capacitance C_i, and neutral interface level ϕ_0. A 4H-SiC MESFET is designed and fabricated and its gate Schottky contacts performance is measured and analyzed with the presented method in detail.

2　Experiment

The basic device structure of the MESFET is presented in Fig. 1. The epitaxial layer structures were prepared by CVD on n$^+$ (0001) substrates with an off-axis of 7.88° supplied by CREE. This layer consists of three layers: a p-type buffer layer with a thickness of 5μm and a doping of $2.0\times10^{15}cm^{-3}$, an n-type active layer 0.12～0.2μm thick and doping $N_d=1.15\times10^{17}cm^{-3}$, and an n$^+$ contact layer with thickness and doping of 0.2μm and $N_d=10^{19}cm^{-3}$. The gate contact was first formed by reactive ion etching. Ohmic contacts to the source and drain were formed by sintering nickel. The gate was 0.8μm long and was patterned

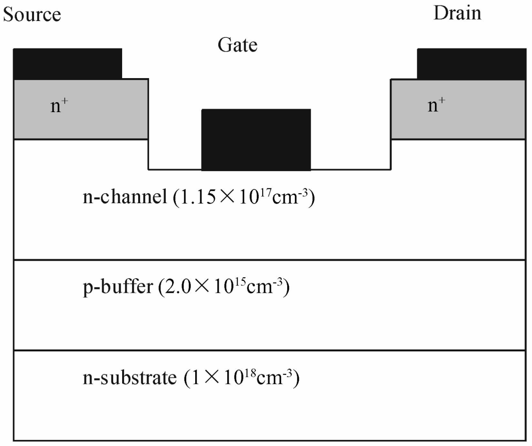

Fig.1　Schematic cross section of MESFET

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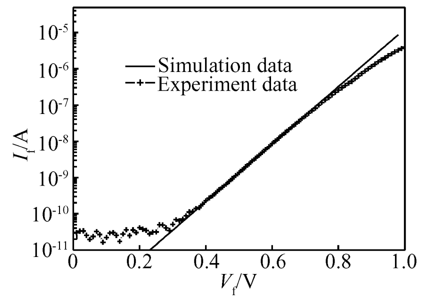

Fig. 2 Forward voltage-current characteristics of 4H-SiC Schottky diodes

using electron beam lithography and a lift-off process. The Ti/Pt/Au gate metal contacts were deposited by electron beam evaporation and patterned by a lift-off process. The source gate distance is 0.3μm and the gate drain distance is 0.8μm.

3 Model and discussion

Using the thermionic emission theory, the current though the SiC Schottky contact can be expressed as

$$I = AA^* T^2\exp\left(-\frac{q\phi_B}{kT}\right)\left[\exp\left(\frac{qV}{nkT}\right)-1\right] \tag{1}$$

where A is the diode area and A^* is Richardson's constant. At a low forward voltage, the ideality factor is given by

$$n = \frac{q}{kT}\times\frac{\partial V}{\partial \ln I} \tag{2}$$

At higher forward voltage, Equation (1) is written as

$$I = AA^* T^2\exp\left(-\frac{q\phi_B}{kT}\right)\left\{\exp\left[\frac{q}{nkT}(V-IR_s)\right]-1\right\} \tag{3}$$

where

$$R_S = \left(1-\frac{\partial \ln I}{\partial V}\times\frac{nkT}{q}\right)\Big/\left(\frac{\partial I}{\partial V}\right) \tag{4}$$

is the series resistance.

Figure 2 shows the *I-V* characteristics of the Schottky diodes. The symbols represent the measured data and the line is the simulated results. From Eqs. (2) and (4), we can obtain the ideality factor $n = 2.12$, and the series resistance $R_s = 3.7\times10^4\Omega$ ($35.5\text{m}\Omega\cdot\text{cm}^2$). The ideality factor n is large, which comes from the interface states, residual defects, and surface roughening of the Schottky barrier diode.

For low reverse voltage, we assume that the current-voltage characteristics of a SiC Schottky contact obey the thermionic current theory:

$$I = AA^* T^2\exp\left(-\frac{q\phi_B}{kT}\right)\left[\exp\left(\frac{qV}{kT}\right)-1\right] \tag{5}$$

where the barrier height can be expressed as

$$\phi_B = -\frac{kT}{q}\ln\left|\frac{AA^* T^2 I}{\exp\left(\frac{qV}{kT}\right)-1}\right| \tag{6}$$

Taking the interface electric field into account, the SBH can be described as[5]

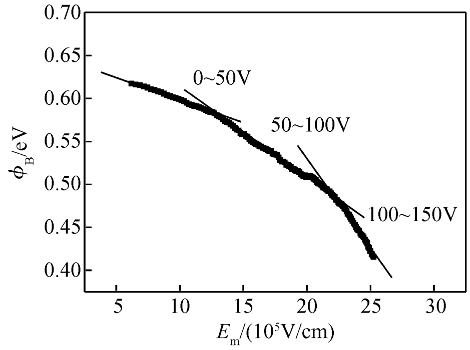

Fig.3 Dependence of barrier height and image force lowering on electric field strength

$$\phi_B = \phi_{B0} - \lambda E_M - \sqrt{\frac{qE_M}{4\pi\varepsilon_0\varepsilon_s}} \tag{7}$$

The term with the square root dependence on the electric field corresponds to the image force, while the linear term corresponds to the interface layer. ϕ_{B0} is the zero-field barrier height, λ is a constant with the dimension of thickness, ε_s is the relative dielectric permittivity of the semiconductor, and E_M is the magnitude of the electric field at the metal/semiconductor interface, which can be obtained by

$$E_M = \sqrt{\frac{2qN_d(V_{bi}-V-kT/q)}{\varepsilon_0\varepsilon_s}} \tag{8}$$

From Eqs. (2), (3) and (4), an approximately linear relationship between $\phi_B + \sqrt{\frac{qE_M}{4\pi\varepsilon_0\varepsilon_s}}$ and E_M is concluded. From the lines shown in Fig. 3, three linear regions at 0～50V, 50～100V and 100～150V are fitted. However, only at low reverse voltage does the thermionic current theory hold. In this region, parameter λ can be extracted as[6]

$$\lambda = \varepsilon_0\varepsilon_s\left(qD_{it}+\frac{\varepsilon_i}{\delta}\right)^{-1} \tag{9}$$

where ε_i and δ are the permittivity and the thickness of the interfacial layer, respectively. The calculated values are $\phi_{B0} = 0.75$eV, $\lambda = 2.83$nm. When the interface states are in equilibrium with the semiconductor, the equation can be written as[7]

$$qD_{it} = \frac{\varepsilon_i}{\delta}(n-1) - C_{sc} \tag{10}$$

where C_{sc} is the space charge capacitance, which varies with the applied voltage as

$$C_{sc} = \sqrt{\frac{q\varepsilon_0\varepsilon_s N_D}{2\left(V_{bi}-V-\frac{kT}{q}\right)}} \tag{11}$$

By combining Eqs. (9)～(11), $D_{it} = 4.386\times10^{13}\text{cm}^{-2}\cdot\text{eV}^{-1}$ and $C_i(\varepsilon_i/\delta) = 6.394\times10^{-6}\text{F/cm}^2$ can be obtained.

According to the interfacial layer model, ϕ_{B0} can be expressed as[8]

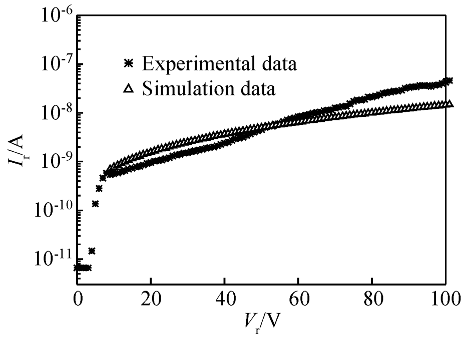

Fig.4 Measured and simulated reverse voltage-current characteristics of 4H-SiC Schottky diodes

$$\phi_{B0} = \gamma(\phi_m - \chi) + (1-\gamma)\left(\frac{E_g}{q} - \phi_0\right) \qquad (12)$$

$$\gamma = 1/(1 + qD_{it}/C_i) \qquad (13)$$

ϕ_m is the work function of the metal, χ is the electron affinity of the semiconductor, E_g is the band-gap energy of the 4H-SiC material, and ϕ_0 is the neutral level of the interface states measured from the top of the valence band E_v. Substituting the values of the parameters obtained above in Eqs. (12) and (13), the neutral level of the interface states $\phi_0 = 0.66$eV.

Figure 4 shows the reverse *I-V* characteristics of the Schottky contact calculated with the extracted parameters. Compared with the measured data, the simulation data is in good accordance with the experimental data in the range of less than 50V. The small discrepancy is due to the tunneling current, which increases as the electric field increases. When the reverse voltage exceeds 50V, there is a significant discrepancy between the two curves since the Thermionic theory is no longer suitable.

4 Conclusion

A simple parameter extraction method based on thermionic theory has been developed for metal/4H-SiC Schottky contacts. By comparing the experimental data and the simulation results, we extract many of the functional material characteristics and device parameters for 4H-SiC devices. Among the functional parameters extracted are the ideality factor n, Schottky barrier height ϕ_B, specific resister R_s, interface state density D_{it}, interface capacitance C_i, and neutral interface level ϕ_0. The extracted interface states parameters are consistent with the devices' terminal characteristics.

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4H-SiC MESFET 肖特基栅接触的界面参数提取*

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摘要： 研究了界面态对 4H-SiC MESFET 的肖特基栅接触的影响.栅接触工艺主要采用 Ti/Pt/Au 蒸发，经过剥离后形成.基于热电子理论提出了一种参数提取方法，得到界面态密度和界面电容分别为 $4.386\times10^{13}\mathrm{cm^{-2}\cdot eV^{-1}}$ 和 $6.394\times10^{-6}\mathrm{F/cm^2}$，这与测量得到的器件端特性一致.

关键词： 碳化硅；肖特基接触；表面态；器件模型
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