Barrier inhomogeneities of Pt contacts to 4H-SiC *

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Abstract
The barrier characteristics of Pt contacts to lightly and highly doped (1×10¹⁶ and 1×10¹⁸ cm⁻³) 4H-SiC are comparatively investigated using current-voltage (I-V) and capacitance-voltage (C-V) measurements in the temperature range of 160-573 K. The abnormal temperature dependence of barrier height and ideality factor estimated from the thermionic emission (TE) model could be successfully explained in terms of a single Gaussian distribution of inhomogeneous barrier heights for lightly doped sample, however a double Gaussian distribution of inhomogeneous barrier heights for highly doped sample, which could be attributed to modification of the current transport process by electron tunneling for the highly doped sample in the low temperature range.

Keywords
SiC, Barrier inhomogeneities, Thermionic emission, Thermionic field emission

1. Introduction
To develop high-performance SiC-based electronic devices, one of the main challenges to overcome is the fabrication of high-quality Schottky and Ohmic contacts, whose electrical properties are mainly determined by the Schottky barrier height at the interface of metal contacts to SiC. However, it is very difficult to control the Schottky barrier of metal/SiC contact precisely.¹,² Therefore, it is of great interest to understand the barrier formation and the conduction process involved on a fundamental basis. In this study, the temperature dependent electronic properties of Pt contacts to lightly and highly doped n-type 4H-SiC were comparatively investigated by I-V and C-V measurements in the temperature range of 160-573 K.
2. Experimental

The samples (A and B) are Si-face (0001) of 4° off-axis n-type 4H-SiC with epitaxial layers doping concentration of $1 \times 10^{16}$ and $1 \times 10^{18}$ cm$^{-3}$, respectively. Prior to Pt deposition, the surfaces were chemically cleaned using the standard Radio Corporation of America solution, and then treated by hydrogen plasma for 3 min with electronic cyclotron resonance plasma system.$^{[3,4]}$ Then circular Pt contacts with a diameter of 300 μm and thickness of 200 nm were fabricated on the epitaxial surfaces by sputtering through a metal contact mask to serve as Schottky contacts. After that, Ti contacts were deposited as the back side Ohmic electrodes on the substrates without annealing.

3. Results and Discussion

Figure 1 shows the temperature dependence of barrier height ($q\Phi_{BE}^{TE}$) and ideality factor ($n_{TE}$) which were estimated from the I-V characteristics based on the thermionic emission (TE) model for the samples.$^{[3-5]}$ There are manifested temperature dependent variations of $q\Phi_{BE}^{TE}$ and $n_{TE}$ for both samples A and B (i.e. $q\Phi_{BE}^{TE}$ increases and $n_{TE}$ decreases with increase in measuring temperature). These non-ideal electrical behaviors cannot be understood by TE model, in which $q\Phi_{BE}^{TE}$ and $n_{TE}$ should be constant with temperature ($T$). In addition, the barrier heights obtained from C-V measurements ($q\Phi_{BE}^{CV}$), which are expected to be equal to the mean barrier height,$^{[5]}$ are found to be insensitive to $T$ and much higher than $q\Phi_{BE}^{TE}$. The abnormal temperature dependences of $q\Phi_{BE}^{TE}$ and $n_{TE}$, as well as the big discrepancies between $q\Phi_{BE}^{CV}$ and $q\Phi_{BE}^{TE}$ are often ascribed to the barrier inhomogeneities.

![Figure 1](image)

Figure 1. (a) $q\Phi_{BE}^{TE}$ and (b) $n_{TE}$ as a function of $T$ for samples A and B.

A Gaussian distribution of barrier heights proposed by Werner et al.$^{[6]}$ is employed to analyze the abnormal electrical behaviors.$^{[7-10]}$ In this model, $\Phi_{BE}^{TE}$ is related to the mean barrier height ($\Phi_{BE}^{0}$) by

$$\Phi_{BE}^{TE}(T) = \Phi_{BE}^{0}(T = 0) - (q\sigma_{e}^{2} / 2kT),$$

where $\sigma_{e}$ is the standard deviation. The temperature dependence of $n_{TE}$ is given by

$$n_{TE}^{-1} - 1 = -\rho_{2} + (q\rho_{3} / 2kT),$$

where $\rho_{2}$ and $\rho_{3}$ are the voltage coefficients. The plots of $q\Phi_{BE}^{TE}$ vs $q/2kT$ and $n_{TE}^{-1}$ vs $q/2kT$ are shown in Fig. 2(a) and (b). For sample A, the good linearities in both figures are clear evidences of a Gaussian distribution of barrier height. However for sample B, two linear regions are observed in the temperature ranges of 160-323 K and 373-573 K respectively. Similarly, as shown in Fig. 2(c), the $\ln(I_{s} / T^{2}) - (q\sigma_{e}^{2} / 2k^{2}T^{2})$ vs $1/kT$ plots also...
exhibit a straight line for sample A. However, two linear regions also in the temperature ranges of 160-323 K and 373-573 K respectively. It is indicated that the anomalies for the highly doped sample B can be explained by assuming the presence of a double Gaussian distribution of barrier heights.

![Figure 2](image)

**Figure 2.** \( q\phi_{\text{BS}} \) and (b) \( n_{\text{TE}}^{-1} \) versus \( 1/2kT \) plots, and (c) Modified Richardson plots \( \ln(I_0/T^2) - (q^2\sigma^2)/2k^2T^2 \) versus \( 1/kT \) of samples A and B according to Gaussian distribution.

The determined parameters obtained from Gaussian distribution are summarized in Table I. For sample A and sample B in the high temperature range, \( \bar{\phi}_{\text{BS}0}^{\text{CV}} \) values are reasonably consistent with the mean values of \( \bar{\phi}_{\text{BS}}^{\text{CV}} \) (also shown in Table I). In addition, the obtained values of \( A^* \) are in very close agreement with the theoretical value of 146 A cm\(^{-2}\) K\(^{-2}\) for n-type 4H-SiC. However, for sample B in the low temperature region, not only the determined \( \bar{\phi}_{\text{BS}0}^{\text{CV}} \) are low compared to \( \bar{\phi}_{\text{BS}}^{\text{CV}} \), but \( A^* \) is much lower than the theoretical value. It is inferred that the electronic transport mechanism may be not dominated by TE for sample B at low temperatures.\(^{[11]}\)

<table>
<thead>
<tr>
<th>sample</th>
<th>temperature (K)</th>
<th>( \bar{\phi}_{\text{BS}0}^{\text{CV}} ) (eV)</th>
<th>( \bar{\phi}_{\text{BS}}^{\text{CV}} ) (eV)</th>
<th>( \bar{\phi}_{\text{BS}0}^{\text{TFE}} ) (eV)</th>
<th>( \bar{\phi}_{\text{BS}}^{\text{TFE}} ) (eV)</th>
<th>( A^* ) (A cm(^{-2}) K(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>160-573</td>
<td>1.88</td>
<td>1.88</td>
<td>-</td>
<td>147.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>160-323</td>
<td>1.68</td>
<td>1.77</td>
<td>1.775</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>373-573</td>
<td>1.78</td>
<td>1.77</td>
<td>-</td>
<td>150.7</td>
<td></td>
</tr>
</tbody>
</table>

The ideality factor is further analyzed by plotting \( n_{\text{TE}}kT \) as a function of \( kT \) for samples A and B as shown in figure 3 (a). As seen, \( n_{\text{TE}}kT \) data for sample A could be fitted by a straight line parallel to that of the ideal Schottky contact behavior (\( n=1 \)). This behavior is commonly referred as the \( T_0 \) anomaly, which is typical to Schottky barrier diode with a distribution of barrier inhomogeneities, where \( T_0 \) is a constant related to the degree of barrier inhomogeneity.\(^{[6]}\) However, for sample B, the plot of \( n_{\text{TE}}kT \) vs \( kT \) can not be explained by the behavior of \( T_0 \) anomaly. Interestingly, it fits well with the theoretical \( E_0 \) data according to thermionic field emission (TFE) model. The barrier height estimated from the \( I-V \) curves based on TFE model (\( \bar{\phi}_{\text{BS}}^{\text{TFE}} \)) is also found to be insensitive to \( T \) and consistent with \( \bar{\phi}_{\text{BS}}^{\text{CV}} \) as shown in Fig. 3 (b).\(^{[12]}\) In addition, the temperature dependence of \( E_0=n_{\text{TFE}} \)
$kT$ is consistent with the theoretically $E_0$ from TFE model [also see Fig. 3 (a)]. Therefore, it is concluded that the TFE model is more appropriate in explaining the carrier transport for the highly doped sample B in the low temperature range.

![Figure 3](image)

**Figure 3.** (a) $n_{TE} kT$ and $n_{TFE} kT$ as a function of $kT$, and (b) $q\phi_{n}^{TE}$, $q\phi_{n}^{TFE}$ and $q\phi_{n}^{CV}$ as a function of $T$, for sample B at the temperature range of 160-323 K.

### 4. Conclusions

The Gaussian distribution model has been employed to analyze the abnormal temperature-dependent barrier height and ideality factor from the TE model due to the barrier inhomogeneities for Pt contacts to 4H-SiC with doping concentration of $1 \times 10^{16}$ and $1 \times 10^{18}$ cm$^{-3}$, respectively. For the lightly doped sample, the decrease of $q\phi_{n}^{TE}$ and increase of $n_{TE}$ with decreasing $T$ as well as large discrepancy between $q\phi_{n}^{CV}$ and $q\phi_{n}^{CV}$ could be explained by considering a single Gaussian distribution of barrier heights with the values of $q\phi_{n}^{CV} = 1.88eV$ and $A^* = 147.8$ A cm$^{-2}$ K$^{-2}$, which are in very close agreement with the actual mean value of $q\phi_{n}^{CV}$ and the theoretical value of $A^*$ (146 A cm$^{-2}$ K$^{-2}$), respectively. However, for the highly doped sample, the anomalous behaviors from the TE model could be attributed to barrier inhomogeneities by assuming a double Gaussian distribution of barrier heights. However, in the low temperature region, not only $q\phi_{n}^{CV} = 1.88eV$ is lower than the value of $q\phi_{n}^{CV}$, but also $A^* = 18.1$ A cm$^{-2}$ K$^{-2}$ is low compared with the theoretical value. This could be ascribed to the fact that the current transport is dominated by the TFE mechanism at low temperatures.

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### References