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Schottky barrier inhomogeneities in SiC Schottky contacts

This application note reports our understanding about the Schottky barrier height (SBH) inhomogeneities issue in silicon carbide Schottky contacts. It has been demonstrated that SBH inhomogeneities can be eliminated, controlled and duplicated using reactive ion etching and hydrogen etching as surface modification processes. Based on information gained from SiC defect investigation and various accomplishments reported by other researchers, we propose sharp-apex growth pits as source defects originally controlling the SBH inhomogeneities in SiC Schottky devices.

Since the early stage of SiC Schottky rectifier development, some rectifiers have been observed to have excess reverse leakage current about 2 orders of magnitude higher than the calculated value predicted by thermionic emission theory. These rectifiers usually have excess forward current only at small on-state bias (current density below $1A/cm^2$) showing a nonideal behavior. It has been proven that the edge effect and image-force barrier lowering effect could not be responsible for the excess current in both forward and reverse characteristics. The above nonideal Schottky characteristics can be well explained using a SBH inhomogeneity concept. The nonideal forward characteristic can be mathematically fitted using a simple model called “Two SBH” rectifier in which two Schottky barriers (one high and one low) are connected in parallel.

Theoretically, “nonideal” behaviors in metal/semiconductor Schottky contacts could be quantitatively explained by assuming Gaussian distribution of nano-sized interfacial patches of reduced barrier height. In SiC Schottky contacts, it was reported that all diodes contain a broad intrinsic distribution of shallow patches while the large excess current in highly nonideal Schottky diodes would only be due to an extremely small number in the extreme tail of a Gaussian patch-parameter distribution. A more likely explanation is that the nonideal behavior in SiC is due to a few relatively large defects of extrinsic origin, such as screw dislocations, stacking faults, polytype inclusions, or localized contamination. However, from various experimental results, one frustrating conclusions is that none of these known defects could be claimed as the main factor controlling the large excess current in highly nonideal diodes. The investigated defects include crystallographic defects (micropipes, screw dislocation, edge dislocations, grain boundaries, basal plane dislocations, stacking fault, etc.) and surface morphologic defects (comets, dimples, carrots, half moon, etc.). Micropipes are the device killing defects and high density of screw dislocations may cause deterioration in reverse characteristics when the electric field reaches a critical value, but they were not the major factors responsible for SBH inhomogeneities.

Despite the difficulty in identifying the source defects of SBH inhomogeneities, various device structures and thermal annealing processes have been developed to reduce the reverse leakage current. One main idea is to develop a structure to pinch off the low SBH region by a high SBH, such as JBS structure, MOS structure, dual-metal, and trench

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MOS barrier, etc. However, these solutions usually do not have significant impact on eliminating the SBH inhomogeneities. Besides the trade-off of other device performance, they also increase the complexity of device structure.

The effectiveness of above "pinch-off" methods leads us to think that the source of SBH inhomogeneities might be located in the thin layer of the SiC surface. In order to investigate the Schottky barrier height inhomogeneities in 4H silicon carbide Schottky rectifiers, two surface modification processes were developed to control the influence caused by surface defects. Both forward and reverse electrical characteristics of Schottky contacts, fabricated on different surface conditions, indicated that the inhomogeneities could be precisely controlled, completely eliminated and exactly duplicated using reactive ion etching and hydrogen-etching as surface modification processes (Figure 1). After removing the barrier inhomogeneities, all contacts exhibited a wide linearity region (over nine decades) which can be well explained using thermionic emission theory. The calculated ideality factor n and the Schottky barrier height Φb were in the range of 1.17-1.20 and 1.12eV-1.22eV respectively. Most contacts exhibited a low reverse leakage, about 10^{-6A}/cm2 at the reverse bias of 300V.

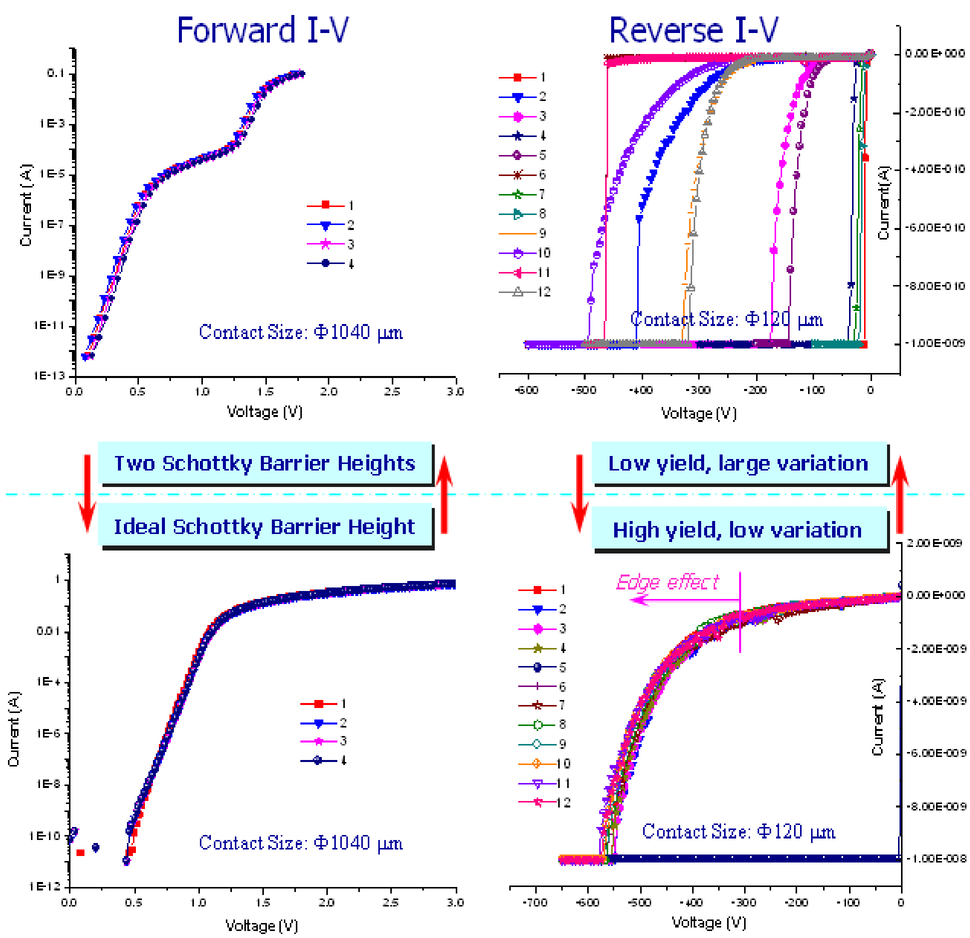

Figure 1, elimination and duplication of Schottky barrier height inhomogeneities in SiC Schottky contacts

 MaxMile App Note, December 2005, ®All rights reserved

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This results support the conclusion that the SBH inhomogeneities and excess leakage current were caused by defects located in the thin layer of epitaxial surface. It has been experimentally proven that, compared to high SBH, the area of low SBH is very small and estimated be about 0.1~0.18 μm^2. To satisfy the above properties, the most possible defects would be growth pits which were revealed recently.

Metal-semiconductor potential barrier can be influenced by defects on the epi-surface. The small growth pits with sharp apex will cause localized electric field enhancement which will inevitably enhance the carrier emission in Schottky barriers. They might be the main factors controlling the SBH inhomogeneities in SiC Schottky rectifiers. It was observed and proven that the low SBH area was submicron in size and the ratio between low SBH and high SBH was independent of the temperature. These experimental observations can be well explained using the growth-pits-initiated SBH inhomogeneities mechanism since the growth pits are submicron in size, and their profiles would not change as the temperature changes.

When using growth-pit-initiated mechanism to interpret the SBH inhomogeneities in SiC Schottky contacts, we believe that it is the electric field enhancement around growth pits, rather than the barrier height lowering, that leads to "inhomogeneities" phenomenon. In other words, the Schottky barrier height is homogenous even at the growth-pit area; the electric field enhancement around the pit originally causes nonideal behavior. Though the non-ideality can be explained using "Two SBH" rectifier model as being done in, such kind of simulation did not reveal the electric field enhancement caused by growth pits. A more precise model is needed to reflect this real situation.

Note:

- For more information about this information, please check our publication entitled "Investigation on Barrier Inhomogeneities in 4H-SiC Schottky Rectifiers".
- For growth pit related information, please check the application note entitled "SiC epitaxial surface defect characterization".

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