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Original Paper

Dopant Profiling on 4H Silicon Carbide P^+N Junction by Scanning Probe and Secondary Electron Microscopy

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The availability of two-dimensional (2-D) dopant profiling techniques to Silicon Carbide (SiC) pn junction is discussed. We compared the results of scanning capacitance microscopy (SCM), scanning spreading resistance microscopy (SSRM), and secondary electron microscopy (SEM), where the cross-sections of a SiC wafer with n-type epi-layers and highly-doped p^+ and n^+ regions were used. The SSRM current image was very similar to the contrast in the SEM image. The junction depth derived from the SSRM profiles and SEM images showed a good agreement with that of secondary ion mass spectrometry (SIMS) data. On the contrary, the junction depth obtained from the SCM measurements was considerably underestimated. At present, the complementary use of SSRM and SEM is thought to be effective for the quantitative 2-D dopant profiling of SiC devices.

1. Introduction

Silicon Carbide (SiC) is presently one of the most promising semiconductors for power device applications due to its wide bandgap, high breakdown field, and high thermal conductivity. In order to take advantage of those material properties, the precise control of dopant profiles in the device is indispensable. Therefore, accurate two-dimensional (2-D) dopant profiling techniques are of key importance.

Recently, scanning probe and/or secondary electron microscopy have been applied to SiC devices to obtain quantitative information of dopant profiles [1-2]. We examined the results of scanning capacitance microscopy (SCM), scanning spreading resistance microscopy (SSRM), and secondary electron microscopy (SEM). In this paper, we discuss the availability of 2-D dopant profiling techniques to SiC devices.

2. Experiment

We used 4H-SiC samples composed of a n-type epitaxial layer ($N=2\times10^{15}$ cm^{-3}) on a 8°-off n-type substrate. As shown in Fig. 1, highly doped p^+ wells ($N_A=2\times10^{18}$ cm^{-3}) and n^+ regions ($N_D=5\times10^{19}$ cm^{-3}) were formed in the epitaxial layer by the ion implantation. The sample was cross-sectioned and polished using diamond lapping films and colloidal silica.

The SCM and SSRM data acquisition were carried out using a commercial SPM system (Digital Instruments Dimension 3100 system equipped with a module for SCM and SSRM measurements). A platinum-coated conductive probe and a Boron-doped diamond-coated conductive probe were employed for SCM and SSRM measurements, respectively.

The SEM used is a cold field emission Hitachi S-4800 equipped with an in-lens E×B detector. The image was acquired at an accelerating voltage of 1.0 kV and a beam current of 20 pA. The contrast of the pn junction in SEM images arises as a consequence of the potential contrast due to the build-in potential, which produces a stray electric field irradiating from the surface of the semiconductor sample [2].

The one-dimensional depth profile of the p-type dopant was also analyzed by Secondary Ion Mass Spectrometry (SIMS) using oxygen-molecule ions (O_2^+) with an acceleration voltage of 8.0 kV as primary ions.

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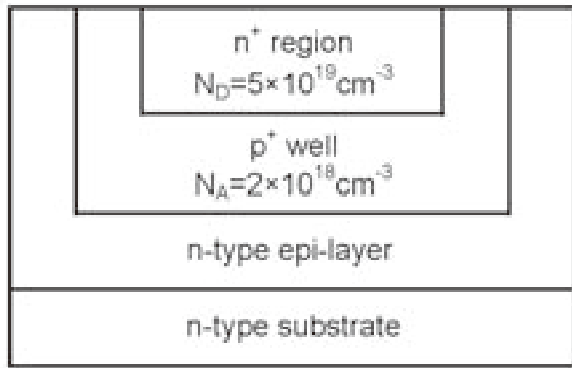

Fig. 1. Cross section of the SiC structure under investigation.

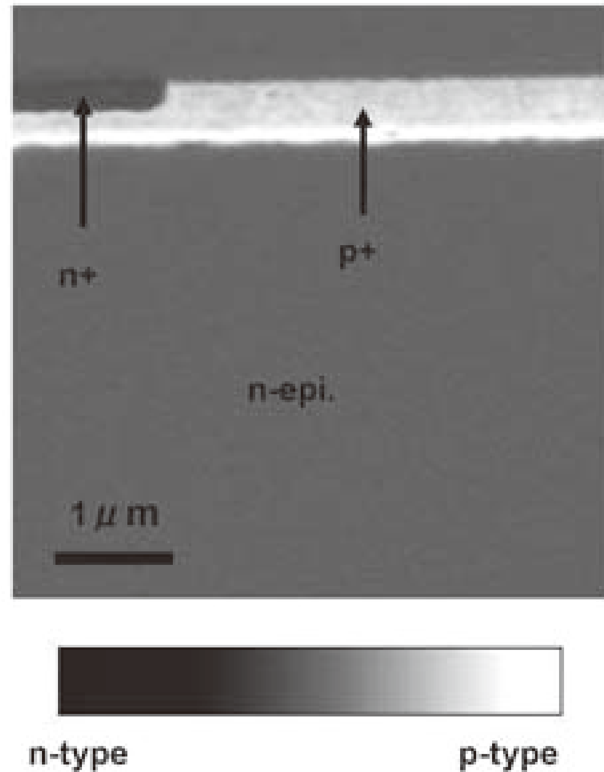

Fig. 2. SCM Image of the sample.

3. Results and Discussion

Fig. 2 shows the 2-D SCM image. The measurement was carried out where the sample biased at Vdc=0.0 V and Vac=0.5 V with a frequency of 90 kHz. The SCM signal is positive for p-type (bright contrast in the image) and negative for n-type (dark contrast in the image). The p^+ and n^+ doped regions in the sample surface are detected clearly. The variation of the contrast in the p^+ region corresponds to the dopant concentration. On the contrary, the low-doped epitaxial n-layer displays a very low dC/dV signal (almost zero) as compared to the highly doped n^+ areas. This suggests that the sensitivity of the SCM measurement is insufficient for the low doped region. Further studies with modified sample preparation methods are necessary to improve the sensitivity.

The SSRM image of the sample is presented in Fig. 3. The image was acquired at 4.0 V negative dc sample bias. The low resistance regions correspond to the n-type regions which form the forward biased pn junction with the Boron-doped diamond coating of the tip, when negative dc bias is applied to the sample [3]. It is noted that the depth of the p^+/n junction is considerably deeper than that of the SCM image, while the depth of the n^+/p^+ junction is in good agreement with that of the SCM image.

The SEM image at 1.0 kV acceleration voltage is shown in Fig. 4. In the case of SEM observations, sample polishing using colloidal silica caused a degradation of the image qualities, possibly due to the formation of thick oxide layer by chemo-mechanical effects. Therefore, the sample was polished using diamond lapping films only. Although there remain many scratches in images, both n^+ and p^+ layers are clearly observed. Furthermore, the SEM image was similar to the SSRM im

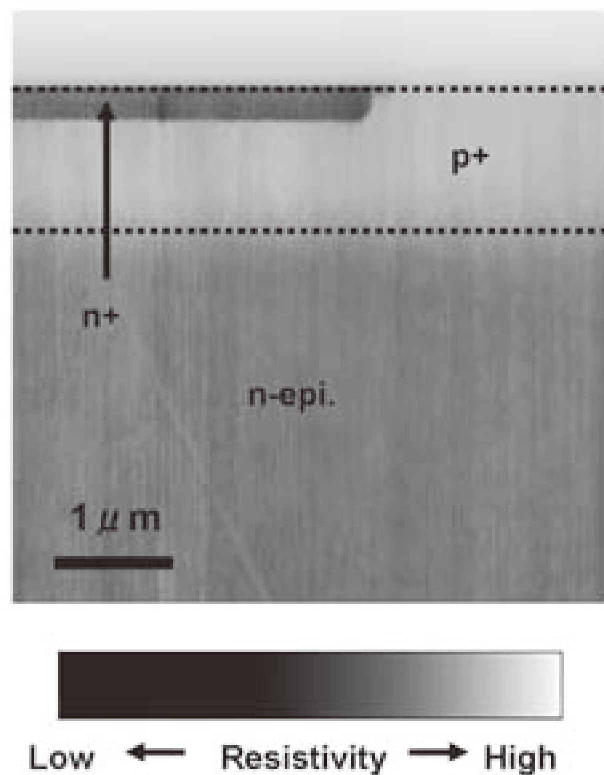

Fig. 3. SSRM image of the sample.

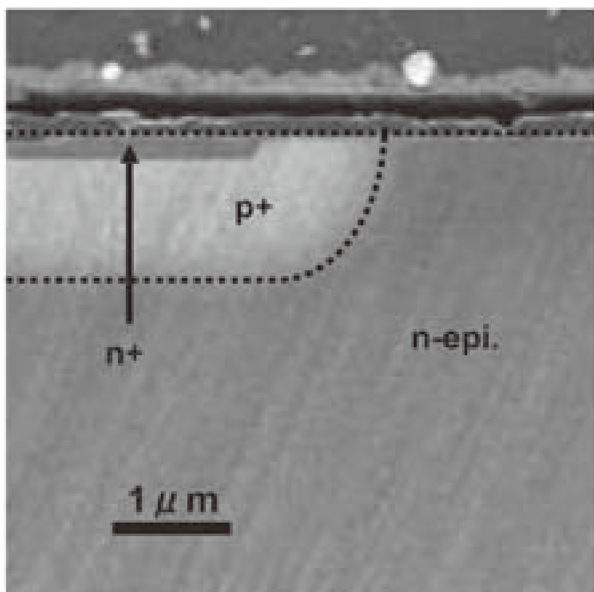

Fig. 4. In-lens secondary electron Image of the sample.

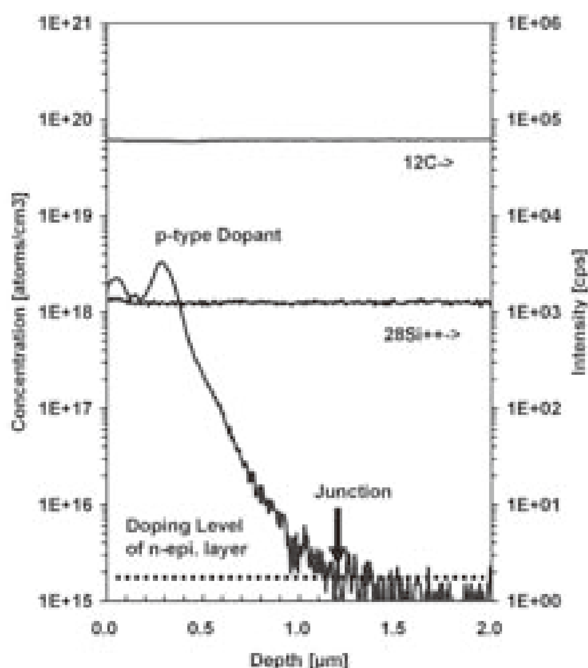

Fig. 5. SIMS Profile of the p-type dopant.

age rather than the SCM image.

We estimated the junction depth of the sample. Table 1 summarizes the results. For the n^+/p^+ junctions, all the results were in good agreement. However, the junction depth of the p^+/n junction showed a big difference. That is, the value of the junction depth obtained from the SCM measurements was considerably smaller than the data obtained from other measurement methods. In order to confirm the accuracy of the measurements, we checked the SIMS profile of the p-type dopant shown in Fig. 5. Since the doping level of the epitaxial n-layer is considered around 2×10^{15} cm^{-3}, the junction depth is assigned to 1.2 μm. That is, the junction depth derived from the SSRM profiles and SEM images is in good agreement with that of SIMS data. In the case of the SCM measurements, we presume that the oxide layer formed by the polishing procedure was thick, which caused the decrease of the dC/dV signals in the p^+ regions. However, more systematic studies are necessary with improved surface preparation methods to confirm this.

Table1. Estimation of the junction depth.

	n^+/p^+ [μm]	p^+/n [μm]
SCM	0.25	0.59
SSRM	0.25	1.19
SEM	0.22	1.2
SIMS	-	1.2

4. Conclusions

We compared the results of scanning capacitance microscopy (SCM), scanning spreading resistance microscopy (SSRM), and secondary electron microscopy (SEM), where the cross-sections of a SiC wafer with n-type epi-layers and highly-doped p^+ and n^+ regions were used. The junction depth derived from the SSRM profiles and SEM images showed a good agreement with that of secondary ion mass spectrometry (SIMS) data. On the contrary, the junction depth obtained from the SCM measurements was considerably underestimated.

At present, the complementary use of SSRM and SEM is thought to be effective for the quantitative 2-D dopant profiling of SiC devices.

5. References

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