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Evaluation of Hall Effect Mobility for SiC MOSFETs with Increasing Nitrogen Implantation into Channel Region

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Abstract

The Hall effect mobility (μ_{Hall}) of the SiC MOSFETs with N -implanted channel region was investigated by increasing the dose of nitrogen (N). The μ_{Hall} in channel region was systematically examined from the viewpoint of the channel structure, that is, the surface and buried channel. It is experimentally demonstrated that the increase in the dose of N results the improvement of μ_{Hall} in channel region due to the formation of the buried channel. However, further increase of N was found to decrease the μ_{Hall} in channel region, resulting from the degradation of electron mobility in bulk region.

1. Introduction

The enhancement of the peak field effective mobility has been reported for 4H-SiC MOSFTEs with the counter doped structure and the buried channel structure formed by N ion implantation [1,2]. The effect of the N ion implantation is considered to be the reduction of Coulomb scattering probability in channel region. That is, Coulomb scattering at the SiC/SiO_2 interface can be reduced by the relaxed electric field [1] or the electron position away from the MOS interface [2]. In order to clearly understand the carrier transport properties in the SiC MOS inversion layer, it is important to evaluate the μ_{Hall} in channel region. Different from the field effect mobility, the Hall effect measurement allows us to investigate the μ_{Hall} in channel region separately from the surface carrier density (N_S), which is affected by high amount of the interface traps at the SiC/SiO_2 interface. However, the experimental studies on the μ_{Hall} in channel region of the SiC MOSFETs with the N ion implantation are very limited [3, 4]. A study by V. Mortet *et.al.* has revealed the μ_{Hall} in channel region with the depletion mode behavior [3]. With increasing the dose of N implantation up to 1×10^{13} cm^{-2}, the μ_{Hall} in channel region keeps increasing. On the other hand, another study by F. Mouscatelli *et.al.* has pointed that higher concentration of N below the MOS interface reduces the μ_{Hall} in channel region by using the device, whose N concentration is higher than 5×10^{18} cm^{-3} [4]. Therefore, the effect of increasing N ion implantation into SiC MOSFETs has not been consistently understood yet for the wide range.

In this study, we evaluated the μ_{Hall} in channel region with increasing the dose of the N ion implantation into the p-type well region. Both the devices with the surface channel and buried channel were systematically examined through the N dose dependence of the μ_{Hall} in channel region.

2. Experimental sample structure

The planar-type Si-face 4H-SiC MOSFETs with the hall bars were fabricated on the ion-implanted region (Fig. 1). The ion-implanted well region were formed by the Aluminum (Al) and N ion implantation. In order to examine N dose dependence of the μ_{Hall} in channel region, the dose of N implantation was changed up to 2.4×10^{13} cm^{-2} with the energy of 40 keV. The gate oxide was formed by thermal oxidation with the post nitridation process.

3. Results and Discussion

3.1. Surface channel device

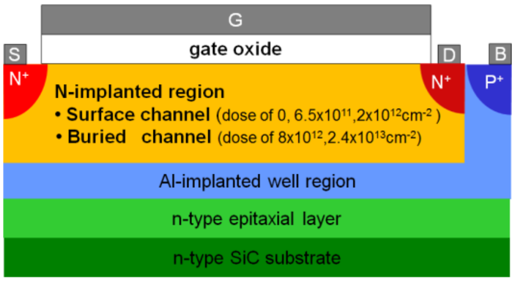

Fig. 1 Schematic of the fabricated SiC MOSFETs with N-implanted region on Al-implanted well region.

When the ion-implantation energy is 40 keV and the dose of N is less than 2×10^{12} cm^{-2}, the fabricated devices work as the surface channel devices at room temperature by simulation. With increasing the dose of N from 0 to 2×10^{12} cm^{-2}, the μ_{Hall} in channel region increases when comparing at

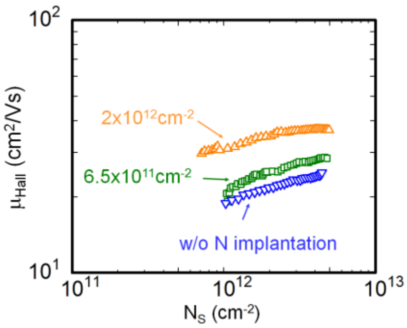

Fig. 2 μ_{Hall} in channel region as a function of N_S for the devices with the dose of N from 0 to 2×10^{12} cm^{-2}

the same N_S (Fig. 2). This is a similar result as in Ref. 3. It is noteworthy that the μ_{Hall} in channel region proportionally increases to the power of N_S, suggesting that μ_{Hall} in channel region is mainly dominated by Coulomb scattering [5]. It is considered that the relaxed electric field at the same N_S by increasing the dose of N results in the suppression of Coulomb scattering probability of the electrons in the surface channel.

3.2. Buried channel device

When the dose of N is more than 8×10^{12} cm^{-2}, the fabricated devices work as buried channel devices at room temperature by simulation. We compared the surface channel devices and a buried channel device, whose does of N is 8×10^{12} cm^{-2}. It is found that a buried channel device shows higher μ_{Hall} in channel region when comparing at the same N_S (Fig. 3 (a)).

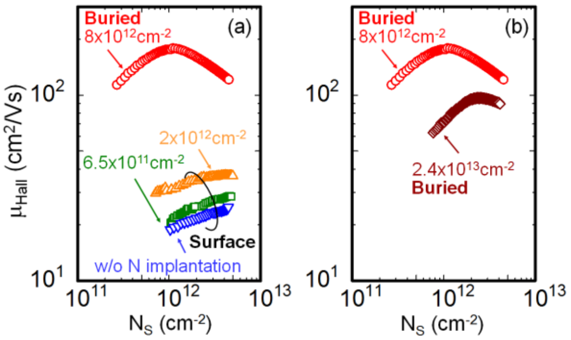

Fig. 3 (a) μ_{Hall} in channel region as a function of N_S for the surface channel and buried channel devices. The device whose does of N is 8×10^{12} cm^{-2} works as the a buried channel device. (b) μ_{Hall} in channel region as a function of N_S for the buried channel devices. The dose of N is 8×10^{12} cm^{-2} and 2.4×10^{13} cm^{-2}, respectively.

It is found that the power-law coefficient of the μ_{Hall} in channel region as a function of N_S is different from that of the surface channel device in low N_S region. This experimentally indicates that a fabricated device with the N dose of 8×10^{12} cm^{-2} works as buried channel, as expected. Furthermore, we fabricated the device with higher dose of N, which is 2.4×10^{13} cm^{-2}. The degradation of the μ_{Hall} in channel region was found at the same N_S by increasing the dose of N from 8×10^{12} cm^{-2} to 2.4×10^{13} cm^{-2} (Fig. 3 (b)). This means that the μ_{Hall} in channel region decreases with too much dose of N when the devices operate as the buried channel device and the electrons flow in the bulk region.

3.3. Transition from buried channel to surface channel

It is important to experimentally confirm that μ_{Hall} in low N_S region in Fig. 3 (b) is representing the electron conduction in the bulk region of the buried channel device. For this purpose, we have applied the body bias at room temperature. It is expected from the simulated carrier distribution at the MOS interface that applying the body bias enables the transition from the buried channel to the surface channel. (Fig. 4 (a)). It is clearly observed that applying the body bias results in the reduction of the μ_{Hall} in channel region at the same N_S. (Fig. 4 (b)). The power-law coefficient of μ_{Hall} in channel region as a function of N_S becomes closer to the value of the surface channel device.

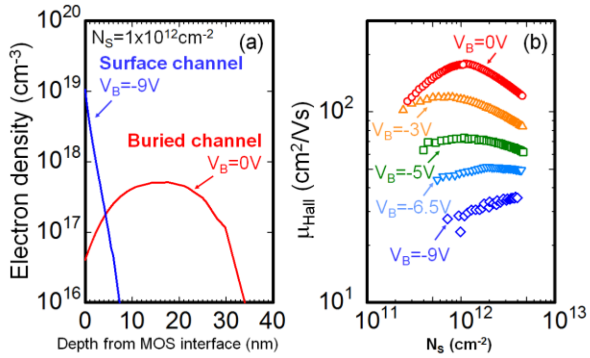

Fig. 4 (a) simulated carrier distribution of the SiC MOSFETs at the MOS interface with applying body bias (b) μ_{Hall} in channel region as a function of N_S with the body bias. The dose of N was 8×10^{12} cm^{-2}.

In addition, the temperature dependence of the μ_{Hall} in channel region was measured between 177 K to 348 K. The reduction of the μ_{Hall} in channel region at the same N_S was found in low N_S region with the elevation of temperature (Fig. 5). This is considered to be corresponding to the reduction of the electron mobility in the bulk region at higher temperature.

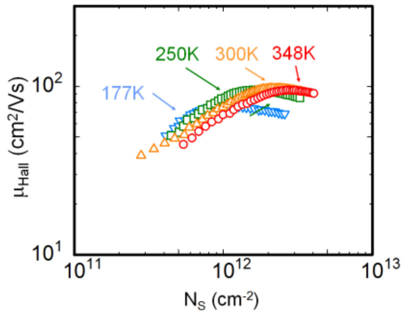

Fig. 5 μ_{Hall} in channel region as a function of N_S with changing temperature. The dose of N was 2.4×10^{13} cm^{-2}.

4. Conclusions

The Hall effect mobility of the SiC MOSFETs with N-implanted channel region was investigated by increasing the dose of N. As the device changes from the surface channel to the buried channel, the improvement of the μ_{Hall} in channel region was found. However, further N implantation decreases the μ_{Hall} in the channel region due to the degradation of the electron mobility in the bulk region. This understanding was confirmed by applying the body bias and changing temperature.

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