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On the temperature dependence of the Hall factor in n-channel 4H-SiC MOSFETs

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Since SiC MOSFETs enable device operation in a wide temperature range, it is important to characterize the temperature dependence of the transport properties such as the drift mobility μ and the sheet concentration n_{inv} of the carriers in the inversion channel. The most straight-forward method of their characterization is by Hall-effect measurements. However, in order to determine μ and n_{inv}, one has to know the accurate value of the Hall factor r_H, defined as $r_H = <\tau^2>/<\tau>^2$, where $<\tau^2>$ and $<\tau>$ are specially averaged relaxation scattering times. Depending on the types of scattering mechanism involved, r_H may vary between 1 and 1.93, where the highest value of 1.93 indicates the exclusive case of Coulomb scattering [1]. Nevertheless, there is a common practice to use the Hall factor equal to unity and assume it temperature independent. To obtain precisely r_H at the SiO_2/SiC interface, we recently introduced a new method for the calculation of the Hall factor which is based on the strong interdependence with mobility components via the respective relaxation scattering times [2]. There, it was shown that ignoring the Hall factor in n-channel MOSFETs at 300 K introduces failures of some 10% into the values of the sheet carrier concentration and the drift mobility extracted from Hall-effect measurements. In this work, we extend our method and investigate, for the first time, the Hall factor in n-channel MOSFETs as a function of temperature.

The temperature dependence of the Hall factor may be estimated by considering the effect of temperature on the mechanisms by which carriers are scattered in the inversion channel. It is widely accepted that the device performance of SiC MOSFETs is limited due to Coulomb scattering at bulk ionized impurities and at interface charges as well as due to surface scattering and phonon scattering [3]. Each kind of scattering mechanisms has its specific temperature dependence. However, as it was shown, Coulomb scattering at the interface charges is the dominant scattering mechanism in SiC MOSFETs and it plays a fundamental role in the temperature behavior of the device [3]. In comparison to Coulomb scattering at the interface, the contributions from other scattering mechanisms are insignificant for the temperature dependence of the transport properties in SiC.

It is well known that in SiC MOSFETs with increase in temperature drain currents, sheet carrier concentrations, and mobilities in the inversion channel also increase. One of the most important impacts of a temperature increase is the reduction of Coulomb scattering at the interface charges. It can be mainly explained by two coupled effects. The first one is the decrease in the amount of trapped charges due to the change of the Fermi level. The second one is the increase in screening of scattering centers due to the rise in the number of electrons in the inversion channel. Based on the fact that the value of the Hall factor is directly affected by the scattering mechanisms, the reduction of Coulomb scattering at the interface will result, in our case, in the reduction of the Hall factor.

In this study, to characterize electrically n-channel 4H-SiC MOSFETs, current-voltage and Hall-effect measurements as well as numerical simulations were performed from 300 K till 400 K. The numerical simulations were made with Sentaurus Device of Synopsys. To calculate the mobility components and, from them the relaxation scattering times as a function of temperature, the electrical properties of the n-channel MOSFET were described by Near-Interface Trap and mobility degradation models [4]. These models, as shown in Fig. 1, excellently reproduce the temperature dependence of the transfer characteristics.

From the successful simulation of the temperature dependence of the transfer characteristics, the mobility components as a function of gate voltage in the temperature range from 300 K till 400 K were determined. On the basis of the temperature dependence of the mobility components, the respective relaxation scattering times were obtained and used for the calculation of the Hall factor. The result of the calculation is shown in Fig.2. Based on the dependence in Fig.2, the sheet carrier concentrations and the drift mobilities were determined from Hall-effect measurements. In Fig.3 and Fig.4, the respective values are compared to independent simulation results, obtained from the reproduced temperature dependence of the transfer characteristics presented in Fig. 1. These results show that the sheet carrier concentrations and the drift mobilities determined with our new temperature-dependent Hall factor agree very well with simulations. In contrast, if the assumption of the temperature independent Hall factor $r_H = 1$ was used, overestimation of the drift mobilities and underestimation of the sheet carrier concentrations by some 10%, depending on gate voltage, were found for all temperatures.

Fig.1 –Fig. 4 show the temperature dependence of the Hall factor and SiC MOSFET characteristics in the inversion channel from 300 K till 400 K. Lines represent simulations, symbols – measurements.

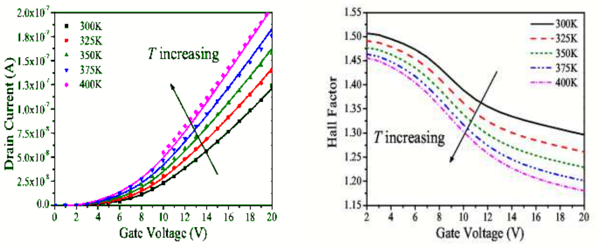

Fig. 1 and Fig. 2. Drain current and Hall factor as a function of gate voltage.

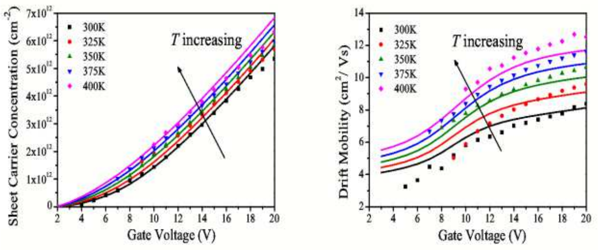

Fig. 3 and Fig. 4. Sheet carrier concentration and drift mobility as a function of gate voltage.

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