Electron Mobility Degradation Mechanisms in HfSiON MISFETs under the Real Operating Condition

Ryosuke Iijima, *Mariko Takayanagi, Takamitsu Ishihara, Takeshi Yamaguchi and Akira Nishiyama

Advanced LSI Technology Laboratory, Corporate Research & Development Center, Toshiba Corporation,

*SoC Research & Development Center, Toshiba Corporation Semiconductor Company

Phone: +81-45-770-3693, Fax: +81-45-770-3578, E-mail: ryosuke.iijima@toshiba.co.jp

1. Introduction

For the application of high-k gate dielectrics, it is important to understand the mobility characteristics of MISFETs with high substrate impurity concentration (N_{sub}) in high surface carrier concentration (N_s) and high temperature regions. However, the systematic study has not been carried out yet under such conditions.

In this paper, for the first time, it is systematically proved that the electron mobility of HfSiON MISFETs with high N_{sub} in high N_s and high temperature regions is degraded by two scattering mechanisms. One is severe Coulomb scattering associated with charges in dielectrics and the other is scattering with soft phonon in HfSiON, which has a strong screening effect at high temperature [7,8]. Therefore, these results shown in Fig.5 indicate that the mobility degradation is caused by another scattering inherent to HfSiON, especially in high N_s and high temperature regions. In addition, assuming that the screening effects at 473K are similar to these at 223K, Coulomb scattering hardly contributes to the mobility degradation in high N_s and high temperature regions. We consider this scattering inherent to HfSiON to be scattering with soft phonon in HfSiON.

Furthermore, we investigate the mobility characteristics of HfSiON MISFETs with high N_{sub} in high N_s and high temperature regions. Such conditions correspond to the actual CMOS operating conditions. Fig.6 shows \( \Delta \mu_{HfSiON} \) and \( \mu_{SiO2} \) at 473K of MISFETs with low N_{sub} (3x10^{15}cm^{-3}) and high N_{sub} (3x10^{17}cm^{-3}) as a function of \( E_{eff} \). Then, \( \Delta \mu \) extracted from this experimental mobility is plotted as a function of \( N_s \) (Fig.7). It is found that \( \Delta \mu \) of MISFETs with high N_{sub} is lower than that of MISFETs with low N_{sub}. In MISFETs with high N_{sub}, inversion-layer electrons are confined in the steep triangle potential. In order to systematically investigate the relationship between \( \Delta \mu \) and the configuration of the inversion layer, \( \mu_{HfSiON} \) and \( \mu_{SiO2} \) were measured under the substrate biasing conditions. The steepness of the triangle potential is determined by the surface concentration of the depletion charge (\( N_{depl} \)), which was intentionally controlled by both N_{sub} and the substrate voltage (\( V_{sub} \)). Fig.8 shows \( \Delta \mu \) as a function of \( N_{depl} \). Then, \( \Delta \mu \) at high N_{sub} (5x10^{15}cm^{-3}) is plotted as a function of \( N_{depl} \) (Fig.9). It is found that \( \Delta \mu \) depends only on N_{depl} independent of the combination of N_{sub} and V_{sub}, which confirms that the lowering of \( \Delta \mu \) shown in Fig.7 is caused by the increase in the steepness of the triangle potential. We consider this mechanism as follows. As the triangle potential becomes steep, the average position of inversion-layer electrons approaches the interface as shown in Fig.9 and consequently these electrons are more affected by Coulomb potential of charges in dielectrics. As a result, the electron mobility of HfSiON MISFETs with high N_{sub} in high N_s and high temperature regions is severely degraded by Coulomb scattering as well as scattering with soft phonon. Assuming that the decrease in \( \Delta \mu \) shown in Fig.9 is mainly due to the degradation of the mobility limited by Coulomb scattering, it is estimated that the influence of Coulomb scattering is roughly comparable to that of scattering with soft phonon under the real operating condition. However, for the minute and quantitative analysis of the mobility determined by each scattering mechanisms, the further investigation is required.

4. Conclusions

By the systematic analysis, it is found that the electron mobility of HfSiON MISFETs with high N_{sub} in high N_s and high temperature regions is degraded by two scattering mechanisms. One is Coulomb scattering associated with charges in dielectrics, which is serious for electrons in the thin inversion layer. The other is scattering with soft phonon in HfSiON, which has a considerable impact on the mobility at high temperature.
Acknowledgements
The authors would like to thank T. Watanabe, K. Nagatomo, S. Inumiya, K. Sekine, M. Sato, A. Kaneko, H. Oguma, K. Eguchi, Y. Tsunashima and N. Fukushima for their continuous support.

References

Fig. 1 The frequency dependence of the charge pumping current.

Fig. 2 The EOT dependence of the threshold voltage defined as the gate voltage at N_s of 1x10^{11} cm^{-2}.

Fig. 3 Experimental mobility of MISFETs with N_{sub} of 3x10^{16} cm^{-2} as a function of E_{eff} at temperatures from 223K to 473K.

Fig. 4 The additional mobility component ∆µ of HfSiON MISFETs as a function of N_s at various temperatures.

Fig. 5 The temperature dependence of the additional mobility component ∆µ of HfSiON MISFETs at low and high N_s.

Fig. 6 Experimental mobility at 473K of MISFETs with low N_{sub} (3x10^{16} cm^{-2}) and high N_{sub} (3x10^{17} cm^{-2}) as a function of E_{eff}.

Fig. 7 The additional mobility component ∆µ of HfSiON MISFETs with low and high N_{sub} as a function of N_s.

Fig. 8 The additional mobility component ∆µ of HfSiON MISFETs with low and high N_{sub} under the substrate biasing conditions as a function of N_s.

Fig. 9 The additional mobility component ∆µ of HfSiON MISFETs as a function of N_dpl controlled by both N_{sub} and V_{sub}. The average thickness of the inversion layer [6] is also plotted, which was calculated with taking account of only the lowest sub-band.