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Improvement of S-factor method for evaluation of MOS interface state density

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Introduction Accurate interface state density (D_{it}) evaluation of MOSFETs is still quite important, because the superior MOS gate stacks and reliability keep being a challenging issue for the advanced gates stacks and channels. Among a variety of the techniques, the S-factor method is taken as one of the simple and easy methods for evaluating D_{it} of MOSFETs [1-3]. However, to our best knowledge, the accuracy of D_{it} evaluated by the present S-factor method has not been examined yet.

In this paper, we provide two modifications to the S-factor method for higher accuracy of extracted D_{it} and obtaining D_{it} as a function of the surface potential (φ_s). One is more accurate determination of φ_s by using C_d extracted from C_{gb} and C_{gc} and the other is to use more rigorous expression of the S factor by adding a new term. The correctness of D_{it} extracted by the modified method is quantitatively evaluated.

Experiment Conventional Si nMOSFET with gate area 100 μm x 100 μm is used for device simulation as well as experiments. A constant mobility model is employed in the simulation. I_S-, C_{gb}- and C_{gc}-V_g curves with and without D_{it} are simulated for nMOSFETs with different gate oxide thickness (T_{ox}) and substrate impurity concentration (N_A).

Results and discussion In the S factor method, as shown in Fig. 1, the slopes of $\log_{10}I_s$-V_g curves in sub-threshold region, the S factor are used for D_{it} extraction. The analysis of the S factor is divided into two parts, the evaluation of φ_s under an equivalent capacitance model and the validity of the diffusion current model. A constant C_d value at φ_s of $1.5\varphi_B$ is used, in the conventional S factor method [2, 3], under a series capacitance model of oxide capacitance (C_{ox}) and C_d for obtaining average D_{it}. In order to obtain the energy distribution of D_{it}, C_d must be determined as a function of V_g and φ_s. Fig. 2 shows the comparison between constant and extracted V_g-dependent C_d. The difference in C_d can lead to some error in D_{it} extraction as shown in Fig. 3.

Fig. 4 shows the results with different T_{ox} and N_A, respectively. It is observed that D_{it} of meaningful orders, which is inappropriately detected from interface-state-free MOSFETs. This fact suggests that the accuracy of any factors related to the diffusion current model is not sufficient. It is found, on the other hand, that, when differentiating this equation with respect to φ_S, a term proportional to S/φ_S should be added to the conventional expression of D_{it}. The relationship between D_{it} and S including the new term is given by

$$D_{it} = \frac{1}{q}\left(\frac{qS}{kT\ln\mathbf{10}} - \frac{S}{2\varphi_s\ln\mathbf{10}} - \mathbf{1}\right)C_{ox} - \frac{C_d}{q} - \frac{C_{inv}}{q}$$

Fig. 5 shows the energy distributions of D_{it} extracted by the new equation for MOSFETs without any D_{it} with different T_{ox} and N_A, respectively. It is found that, by taking the new term into account, the remaining error component of D_{it} becomes lower by around one order of the magnitude than that in Fig.4. The minimum D_{it} is around 2×10^{10} cm^{-2}eV^{-1}, which can be the resolution limit of the present S-factor method. Fig. 6 shows the energy distributions of D_{it} extracted from the improved S factor method for MOSFETs with 1×10^{11} and 5×10^{11} cm^{-2}eV^{-1}. The good agreement between extracted and assumed D_{it} values demonstrates the validity of the improved S factor method.

Conclusion We have improve the S factor method in terms of the accuracy of D_{it} of MOSFETs by including V_g-dependent C_d, based on C_{gb} and C_{gc}, and the correction term for the analytical equation of the S factor, allowing us to obtain the energy distribution of D_{it}.

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Reference[1] R. Overstraenten et.al, IEEE TED. ED-31, 282 (1975).[2] S. Witczak et al, Solid-State Electronics. 35,345 (1992).[3] S. Zhuet al, JAP, 98, 113404-1(2005).[4] C. G. Sodini et al., Solid-State Electronics.25, 833(1982). [5]Y.Taur et al., Fundamentals of Modern VLSI Devices.Chap.3

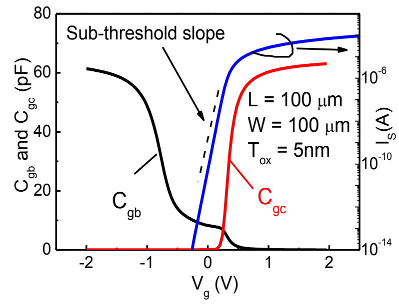

Fig. 1 C_{gb}, C_{gc} and I_S-V_g curves in order to determine C_d and sub-threshold slope

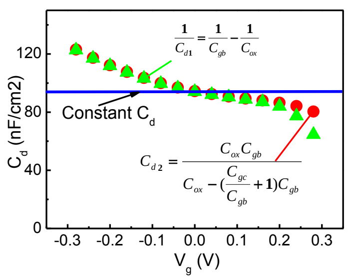

Fig. 2 C_d from different extraction method.

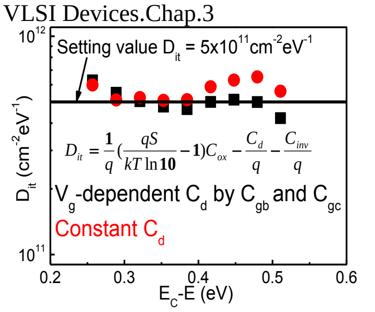

Fig. 3: D_{it} energy distribution determined by constant C_d and V_g-dependent C_d.

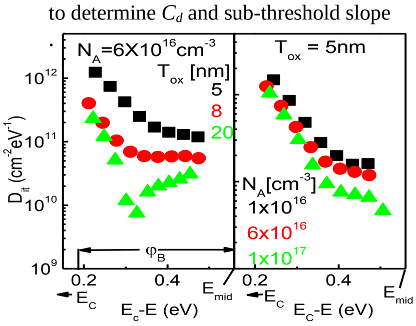

Fig. 4: D_{it} extracted from S-factor method with different T_{ox} and N_A for the interface-state- free devices.

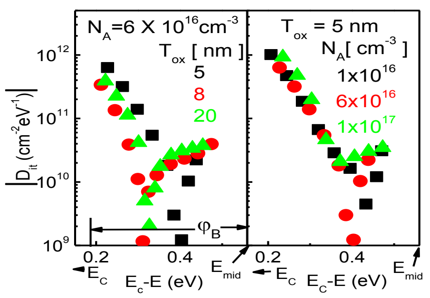

Fig. 5 D_{it} extracted from improved S-factor method with different T_{ox} and N_A for the interface-state-free devices.

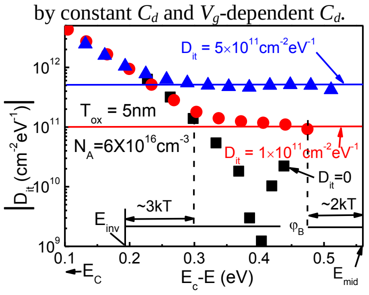

Fig. 6 Energy distribution of D_{it} for nMOSFET with given D_{it} values. Dotted line is the calculation result; Solid line is the D_{it} values used in the simulation.