Study of Parasitic Resistance Behavior and Its Extraction Method on Deeply Scaled MOSFETs


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INTRODUCTION

The mobility enhancement by the stress induced technique has been seriously studied to improve the transistor performance; accordingly, the suppression of parasitic resistance is required for increasing transistor performance [1]. Therefore, the accurate analysis of parasitic resistance ($R_{para}$) on scaled MOSFETs is significant [2] [3]. Terada’s method has been widely used because of its simplicity [4] [5]. However, additional calculations were needed to extract $R_{para}$ of advanced MOSFETs because spreading and accumulation resistance have the strong dependency of gate voltage [6]. Since extremely scaled MOSFET utilizes strong halo scheme, non-uniform resistivity in channel regions makes it difficult to extract effective channel length and $R_{para}$ [7].

In this paper, precise analysis of $R_{para}$ is described focusing on 32-nm node technology for the first time. In addition, modified Terada’s method for analyzing the $R_{para}$ in scaled MOSFET is proposed; moreover, this method is verified by hardware experimental data.

MODIFIED TERADA’S METHOD

Basic device structure of 32-nm node nMOSFETs was used in this simulation (Fig.1) and calculated threshold voltage (Vth) roll-off behaviour is shown in Fig.2. By using Terada’s method, a proportional relationship in $R_{para}$-$L_{eq}$ is obtained for each different gate overdrive conditions ($V_{gs}$-$V_{th}$) (Fig. 3). Here, the intersection of these lines gives $R_{para}$ and the overlap length between S/D extension (SDE) regions and gate electrode ($\Delta L = L_{g} - L_{ext}$). In this case, however, calculated $\Delta L$ indicates negative value (~7.1 nm) even though $\Delta L$ is set as positive in the original structure (See in Fig. 1). It is important to know the source of its inaccuracy. $R_{para}$ values derived from quasi-Fermi potential as a function of gate overdrive indicates that $R_{para}$ has strong dependency on gate overdrive even in the case of 32-nm node MOSFET with highly doped SDE (Fig. 4). Therefore, the extraction method of $R_{para}$ and $\Delta L$ using gate overdrive modulation is not appropriate.

To solve this problem, the channel conductivity is modulated by channel impurity concentration instead of gate overdrive modulation in the modified Terada’s method. Here, it was previously confirmed that $R_{para}$ modulation by changing channel impurity concentration is negligible. $R_{ext}$-$L_{eq}$ plots with fixed gate overdrive is evaluated (Fig. 5), where channel impurity concentrations are varied by $1.5 \times 10^{18}$ cm$^{-3}$ ~ $6.0 \times 10^{18}$ cm$^{-3}$. It is confirmed that three lines intersect at one point, and that $R_{para}$ and $\Delta L$ indicate good agreement in the values derived from quasi-Fermi potential and metallurgical junction position (Table 1). The conventional Terada’s method results are also shown as a reference. Consequently, it is proven that modified Terada’s method eliminates uncertainty in $R_{para}$ extraction due to the gate overdrive effect on SDE resistance. These are also evaluated by hardware experimental results, where channel concentration was changed with multiple lithography and implantation steps within a wafer. As a result, it was verified that accurate $R_{on}$ and $\Delta L$ extraction was achieved by this method.

EVALUATION OF PARASITIC RESISTANCE IN DEEPLY SCALED DOWN MOSFET

To suppress short channel effect, strong halo implantation is indispensable with device geometry scaling. However, increased dosage of halo implantation degrades the linearity of the $R_{on}$-$L_{eq}$ plot due to the lack of uniform channel doping (Fig.7). Fig. 8 shows the simulation results using same mobility value which is independent of halo impurity dosage. These results clarify that inaccuracy of $R_{para}$ extraction in strong halo scheme is due to carrier mobility modulation resulting from non-uniform channel doping.

Based on these analyses, modified Terada’s method is discussed. In the case of long channel regions (Fig.9 (a)), halo implanted areas of source and drain regions are separated. Then, the halo regions produce an additional resistance due to lowered mobility ($R_{halo}$). $R_{halo}$ is constant in gate length variation; therefore, $R_{para}$ is described as sum of external resistance ($R_{ext}$) and $R_{halo}$ ($R_{para} = 2R_{ext} + 2R_{halo}$). On the other hand, in the case of short channel regions (Fig.9 (b)), halo implanted areas of source and drain regions are fully overlapped. The overlapped region is used as channel ($R_{ch}$). Therefore, $R_{para}$ is simply expressed as sum of external resistances ($R_{ext}$) ($R_{para} = 2R_{ext}$). Extracted $R_{para}$ from long channel regions is higher than that from short channel regions (Fig.10). This difference is caused by $R_{halo}$. Therefore, $R_{para}$ extraction from short channel region is required to evaluate accurate external resistances ($R_{ext}$). Fig. 11 verifies that $R_{para}$ and $\Delta L$ extracted from short channel regions with channel doping modulation method are in good agreement with $R_{para}$ and $\Delta L$ calculated from quasi-Fermi potential and metallurgical junction position.

CONCLUSION

Modified Terada’s method is proposed, in which channel resistivity is modulated by channel impurity concentration instead of gate overdrive modulation. It was also proven that this method is valid to 20 nm or less gate length MOSFETs’ $R_{para}$ extraction. In the case of strong halo condition, parasitic resistance should be extracted by $R_{on}$ values analyzed from short channel region.

REFERENCES
Fig. 1. Dopant distribution profile of the simulated nMOSFET.

Fig. 2. $V_{th}$ roll-off characteristic of the simulated nMOSFET.

Fig. 3. $R_{on}$-$L_g$ characteristics as a function of gate overdrive. These are evaluated in triode region ($V_{th}$=10 mV). $R_{on}$ is expressed as $R_{on}(V) = V_{th}/I_{th}(V)$.

Table 1. Comparison of $R_{para}$ and $\Delta L$ in three types of extraction methods:

<table>
<thead>
<tr>
<th>Extraction method</th>
<th>$R_{para}$ ((\Omega \mu m))</th>
<th>$\Delta L$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate overdrive</td>
<td>14</td>
<td>-7.1</td>
</tr>
<tr>
<td>Channel concentration</td>
<td>76</td>
<td>7.2</td>
</tr>
<tr>
<td>Quasi-Fermi potential/metallurgical junction</td>
<td>64</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Fig. 4. Dependence of $R_{para}$ on gate overdrive extracted from quasi-Fermi potential. Strong dependency of $R_{para}$ on gate overdrive is observed.

Fig. 5. $R_{on}$-$L_g$ characteristics using modified Terada’s method. Precise extraction of $R_{para}$ and $\Delta L$ is verified.

Fig. 6. Experimental results of $R_{on}$-$L_g$ characteristics in nMOSFET. Higher channel concentration is applied to device B.

Fig. 7. Comparison of $R_{on}$-$L_g$ plots at different halo dopant concentration. High halo dosage degrades the linearity of $R_{on}$-$L_g$ plot.

Fig. 8. Comparison of $R_{on}$-$L_g$ plots at constant electron mobility.

Fig. 9. Schematic views of halo effect.
(a) Halo implantation make gate edge resistance high and increase $R_{para}$.
(b) Halo regions are overlapped at entire the channel regions. This makes channel resistivity high at short channel.

Fig. 10. Parasitic resistance extraction at 40–100 nm region (a) and 15–25 nm region (b). Halo concentration is $1.0 \times 10^{19}$ cm$^{-3}$ for each case.

Fig. 11. Halo dosage dependence of $\Delta L$ and $R_{para}$. Extraction from short channel region is required for precise analysis of $\Delta L$ and $R_{para}$.