Study of Short Channel Effect on the characteristics of a VTCMOS
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The performance of a Variable threshold voltage CMOS (VTCMOS) is mainly determined by the body effect factor ($\gamma$) informing that how sensitively the threshold voltage changes ($\Delta V_{th}$) under substrate bias ($V_{bs}$), the sub-threshold slope ($S$), and relation between $\gamma$ and $S$ \cite{1}\cite{2}. In this study, we present the study of the short channel effect on $\gamma$ and $S$, and resulting performance degradation of a VTCMOS.

Fig 1 shows the analytically calculated $\gamma$ at $V_{bs}=-1\text{V}$ and $S$ at $V_{bs}=0\text{V}$ for uniformly doped VTCMOSs with various channel lengths. For the calculations, the substrate doping concentration ($N_a$) changes from $3\times10^{17} \text{cm}^{-3}$ to $6\times10^{18} \text{cm}^{-3}$. Larger $\gamma$ corresponds to higher $N_a$. The thick and dotted lines represent the relation between $\gamma - S$ with no SCE and with SCE, respectively. The solid curves represent the contour lines of the $N_a$ values used for each calculation. As $L$ becomes shorter or $N_a$ becomes lower, $\gamma$ decreases whilst $S$ increases.

New empirical relation between $\gamma$ and $S$ taking into account the SCE can be expressed as:

$$S = \frac{dS}{d\gamma} (\gamma - 0.8) + 115 \text{ in the unit of mV/decade}, \quad (1)$$

where $dS/d\gamma$ is the slope in the $\gamma - S$ plane, and is around 70mV/decade for a long channel VTCMOS. As the SCE takes place, $dS/d\gamma$ decreases. Thus, $dS/d\gamma$ can be used as an indicator showing the strength of the SCE. Fig 2 shows the calculated relative $I_{on}(\alpha)$ with different $dS/d\gamma$ values in (1), 70 and 45 mV/decade respectively, as a function of $V_{bs}$ and $\gamma$. For both calculations, $I_{off}(\alpha)$ is fixed at 0.1pA/$\mu\text{m}$ and other modeling parameters are the same. Note again that smaller value of $dS/d\gamma$ implies worse SCE. As clearly demonstrated in this comparison, $I_{on}(\alpha)$ calculated with larger $dS/d\gamma$ is more enhanced at any given $\gamma$ and $V_{bs}$, relative to that with smaller $dS/d\gamma$. It is certain that the $I_{on}(\alpha)$ enhancement is due to the improved sub-threshold slope ($S$) at given values of $\gamma$ and $V_{bs}$. We have also found that the characteristic $V_{th}$ referred as $V_{th}$, where $I_{on}(\alpha)$ looks rarely-dependent on $\gamma$, decreases with decreasing $dS/d\gamma$. Its physical origin will be discussed.