# 매몰공핍형 MOS 트랜지스터의 3차원 특성 분석

# 3-D Characterizing Analysis of Buried-Channel MOSFETs

M. H. Kim
Bucheon College
mhkim@hangil.bucheon.ac.kr

We have observed the short-channel effect, narrow-channel effect and small-geometry effect in terms of a variation of the threshold voltage. For a short-channel effect the threshold voltage was largely determined by the DIBL effect which stimulates more carrier injection in the channel by reducing the potential barrier between the source and channel. The effect becomes more significant for a shorter-channel device. However, the potential, field and current density distributions in the channel along the transverse direction showed a better uniformity for shorter-channel devices under the same voltage conditions. The uniformity of the current density distribution near the drain on the potential minimum point becomes worse with increasing the drain voltage due to the enhanced DIBL effect. This means that considerations for channel-width effect should be given due to the variation of the channel distributions for short-channel devices. For CCDs which are always operated at a pinch-off state the channel uniformity thus becomes significant since they often use a device structure with a channel length of > 4 ㎛ and a very high drain (or diffusion) voltage. This mechanism can only be analyzed by a 3-D simulation [1, 2]. The subthreshold current characteristics and output characteristics confirmed the short-channel effect. The threshold voltage sharply varied for L <3 ㎛. The device with L=1 ㎛ showed a punch-through of the depletions around the drain/source due to the strong penetration of the drain-induced field into the channel. Thus, DIBL effect is very significant for shorter-channel devices [2].

For narrow-channel devices as the channel width becomes narrower the subthreshold current decreased due to the increase of the potential barrier between the source and channel resulting in the decreased charge carriers in the channel. This resulted in the increase of the threshold voltage. The location of the potential minimum gradually approaches the surface due to the reduced surface potential barrier with decreasing the channel width. For W=1 ㎛ the device operated as a surface-channel device due to no surface potential barrier. The effective channel width was much improved by reducing the $p^+$-implanted dose. The widest effective channel width was achieved with zero implanted dose [2]. Also, the use of the increased $p^+$-implanted dose allowed an increase of the threshold voltage. It was demonstrated from the simulated results that the threshold voltage variation was sharp and the substrate bias effect was insignificant for W < 4 ㎛ [3]. The DIBL effect was negligible for narrow-channel effect devices, as observed in Fig. 1.

For small-geometry devices the subthreshold current is negligibly lower due to the increased potential barrier, as observed in the case of the narrow-channel devices, as the channel area decreases. The DIBL effect was insignificant for a channel area of > A2 (which is designated as 2(L)x2(W) ㎛$^2$ ) but becomes important for a channel area of <A2. While the substrate bias effect

becomes significant for a channel area of $\leq$A8 (which is designated as 8(L)x8(W) $\mu m^2$). The uniformity of the channel along the transverse direction becomes worse and thus the effective channel width is narrower with decreasing the channel area. For A1 it is operated under the punch-through of the depletions due to a strong short-channel effect, resulting in large current densities near the source/drain regions. While the narrow-channel effect increased the threshold voltage due to the reduced channel carriers. The variation of the threshold voltage, describing the small-geometry effect, was very sensitive for a channel area of < A4, as shown in Fig. 2.

It can be concluded from the simulated results that the short-channel effect was dominant factor for L < 3 $\mu m$ due to the significant DIBL effect. The narrow-channel effect becomes important due to the increased potential barrier between the source and channel when the channel width is less than 4 $\mu m$. For the small-geometry devices the variation of the threshold voltage was less sensitive compared with those observed from the short-channel and narrow-channel devices.

**Acknowledgement: This work is partially supported by a research fund from Bucheon College.**

## References

[1] M. H. Kim, Determination of charge handling capability of a deep depletion charge coupled device based on a three-dimensional numerical simulation, Proceedings, SPIE Vol. 2654, Solid State Sensors Arrays and CCD Cameras, pp51-62, 1996.

[2] M. H. Kim, Three-dimensional numerical analysis of astronomical CCD image sensors for X-ray or UV detection, Ph.D Thesis, University of Leicester, UK,(1995).

[3] M. H. Kim and S. H. Lim, Three dimensional numerical simulation of buried channel MOSFETs, Accepted for publication on "The 2000 International Conference on Electronics, Information and Communication", August 9-11, 2000, Shenyang, China

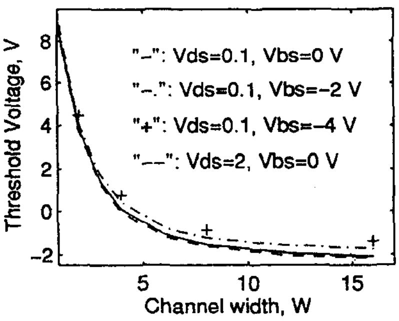

Fig. 1. The variation of the threshold voltage, describing the narrow channel effect, or different channel widths as a function of substrate voltage or drain voltage.

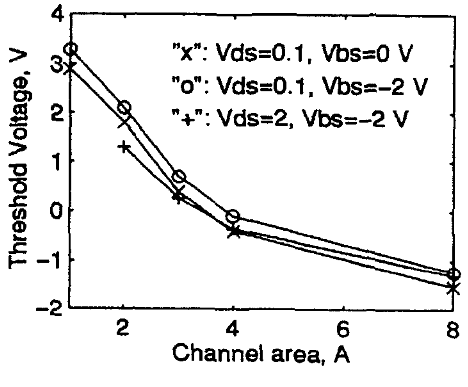

Fig. 2. Variation of the threshold voltage, describing the small-channel effect, for different small devices of 8 x 8, 4 x 4, 2 x 2, and 1 x 1 $\mu m^2$ as A8, A4, A2, respectively, as a function of substrate voltage and drain voltage