Modeling of Threshold Voltage with Reverse Short Channel Effect

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Advanced MOSFETs are non-uniformly doped as a result of complex process flow. Therefore, one of the key factors to model threshold voltage accurately is to model its non-uniform doping profile. Currently, there are many V_{th} models [1-6] that are able to model the vertical non-uniform doping profile of MOSFET. However, all the V_{th} models for lateral non-uniform doping profile resulting in Reverse Short Channel Effect (RSCE) are empirical [7-12], which are normally modeled by exponential functions. In this paper, a physically-derived effective channel-doping model for two-dimensional profile is proposed. The model has successfully transformed both the vertical and horizontal non-uniform doping profiles into an effective value, which can model the RSCE accurately.

The basis of the model is by assuming two Gaussian pile-up profiles at the source and drain edge of the MOS device, as illustrated in Fig. 1. Two parameters are used to characterize the lateral Gaussian profiles. They are the characteristic length l_b (which determines the lateral spread of the pile-up profile) and the peak concentration N_{pile} (which determines the amount of pile-up). The effect of l_b and N_{pile} on the roll-up part of the V_{th} against L_g curve is clearly illustrated in Fig. 2. The final effective concentration expression is an error function of its metallurgical channel length as well as the peak value and characteristic length of its pile-up profiles.

The derived model has employed an error function instead of the empirical hyperbolic cosine function as proposed in [7]. Although it is less computationally efficient for error function as compared to hyperbolic cosine function, the proposed model have shown more accurate and physical results. Figures 3a and 3b plot the same set of Medici simulated V_{th} data for three different characteristic lengths (l_b = 0.08, 0.1 and 0.12 μm) in three different symbols. The lines in Fig.3a represent the newly proposed model, whereas the lines in Fig. 3b are the hyperbolic V_{th} model [7]. It can be clearly seen from the figures that the new model has a better match as compared to the hyperbolic function. As observed from Fig. 3a, the line is more accurate for profile with a larger characteristic length. This is because the formulation of the model is based on the average of the individual local profiles that becomes more accurate as the pile-up profile becomes more gradual. Therefore, the proposed model can be applied in most practical cases, which usually have gradual profiles after many manufacturing steps. Fig. 4 shows the new RSCE V_{th} model as compared to the experimental data for a 0.25 μm CMOS technology for ten different channel lengths and different V_{bs} conditions. As clearly shown, the proposed model can accurately model the actual experimental V_{th} data.

In conclusion, an RSCE V_{th} model specially for lateral non-uniform channel doping structures has been proposed. To the authors' knowledge, this is the first physically-derived model to successfully integrate RSCE into a compact threshold voltage model. In addition, it is relatively easy to use and has good value to technology development.

Topic: ***Process, Device and Circuit Simulation*** (Special Session: *Compact Modeling for Deep-Submicron Technology Development and Device/Circuit Design*)

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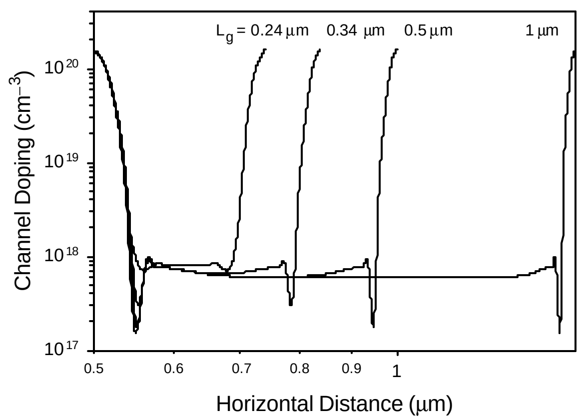

Figure 1: MEDICI simulated doping profiles across MOSFET channel for L_g = 0.24, 0.34, 0.5 and 1 mm.

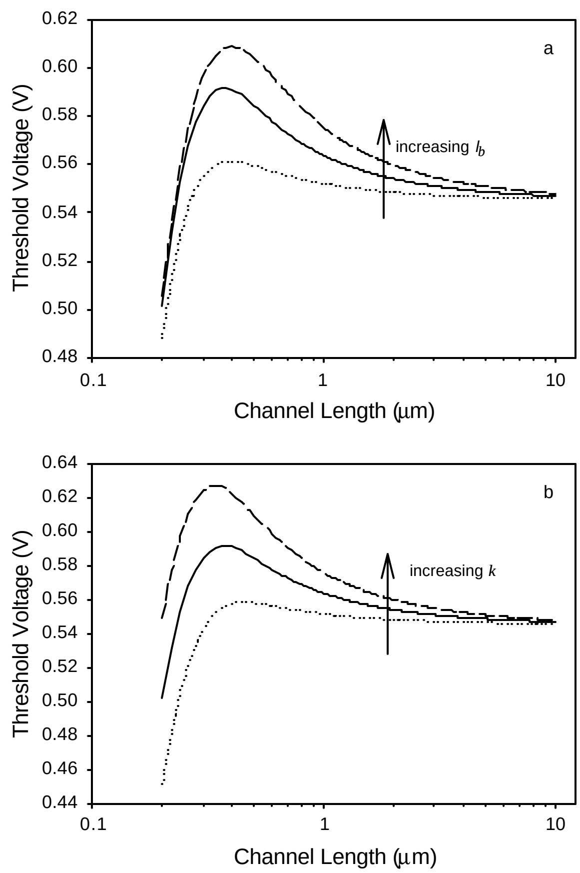

Figure 2: Threshold voltage against channel length for (a) l_b variation and (b) k variation.

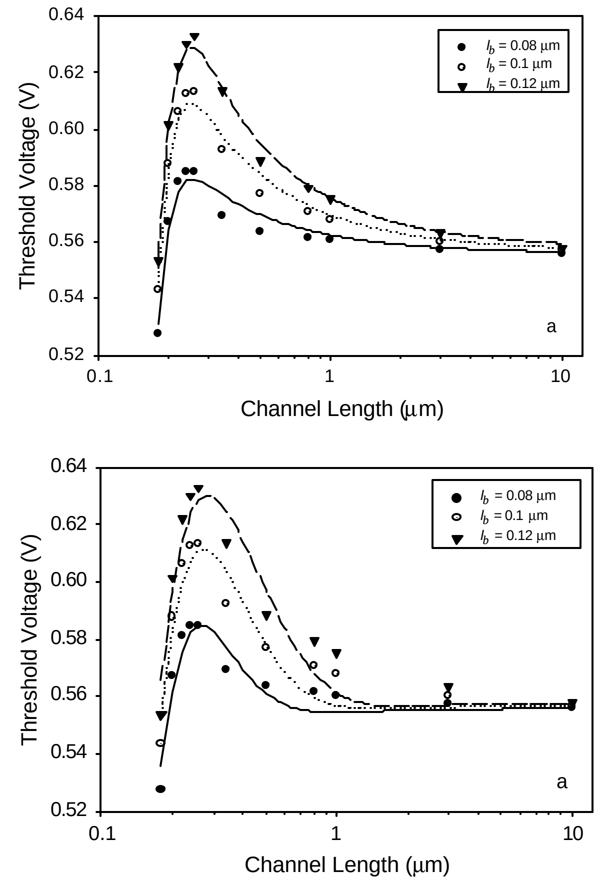

Figure 3: Threshold voltage against channel length for three different characteristic lengths. (a) proposed RSCE model; (b) hyperbolic cosine model [7]. Symbols: experimental data, Lines: calculated data.

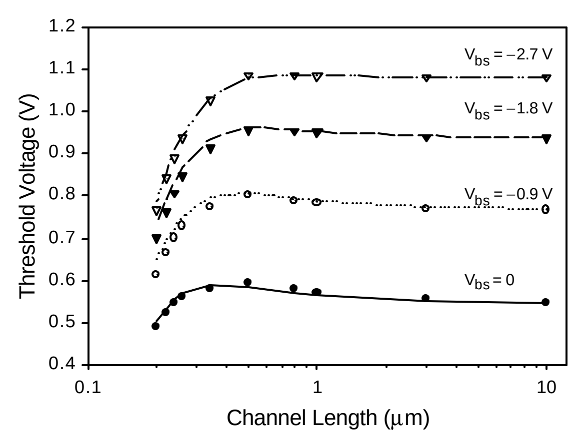

Figure 4: Threshold voltage for various substrate biases.