Experimental Determination of Electrical, Metallurgical, and Physical Gate Lengths of Submicron MOSFET's

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A simple, empirically-based method, which is based on the "$I_{crit}@V_{t0}$" L_{eff}-extraction method [1], is developed for extraction of deep-submicron (DSM) surface-channel MOSFET's effective channel length (L_{eff}) with critical-dimension correction to poly-gate length (L_g) and correlation to metallurgical channel length (L_{met}). A self-consistent compact model for the lightly-doped drain (LDD) lateral diffusion is proposed, which can be correlated to the extracted L_{eff}. For the first time, the electrical, metallurgical, and physical gate lengths of DSM MOSFET's are determined experimentally with a very simple algorithm based on one set of I–V measurement. The combined experimental determination of L_{eff}, L_{met}, and L_g provides important applications in statistical process control and monitoring as well as DSM technology characterization and MOSFET's modeling.

Conventional methods for L_{eff} extraction are all based on the "ideal" model [2], with the measured total resistance (R_{tot}) in linear mode (small V_{ds}) partitioned into two parts: $R_{tot} = V_{ds}/I_{ds} = R_{sd}(V_{gt}) + r_{ch}(V_{gt})L_{eff}$, in the hope that R_{tot} versus L_g at different gate overdrive $V_{gt} = V_{gs} - V_t$ would "merge" to one point. However, this linear relationship starts to deviate in the DSM regime [3], which, in principle, invalidates all the conventional methods unless some kind of averaging method is adopted to minimize (or neglect) the bias dependence of S/D series resistance, channel resistance, or both (Fig. 1). The observed nonscaling $R_{tot} - L_{drawn}$ behavior [3] is most pronounced at low V_{gt}, at which L_{eff} is known to be close to the bias-independent L_{met} [4]–[6]; however, the linear-mode assumption will be violated at low V_{gt}. Another common concern is to avoid, or to correct, the influence of R_{sd} in the measured linear threshold voltage (V_{t0}) with the maximum-g_m definition [2]. On the other hand, the "$I_{crit}@V_{t0}$" L_{eff}-extraction method takes advantage of the fact that the information on R_{sd} is contained in the measured $I_{crit}@V_{t0}$ data, and L_{eff} is extracted at zero V_{gt} based on averaging over L_{drawn} rather than V_{gt}.

A simple model (Fig. 2) for the physical poly-gate length, $L_g = L_{drawn} - \Delta_{CD}$, is assumed, where Δ_{CD} is the *critical-dimension correction* that accounts for process variations in mask/gate lithography and poly etching. The "unmeasurable" L_{met} is modeled by $L_{met} = L_g - 2\sigma x_j$, where x_j is the LDD junction depth and σ is the *LDD lateral-diffusion* parameter. Following the two-step "calibration–extraction" algorithm of the "$I_{crit}@V_{t0}$" method, L_{eff} can be extracted and its parameters can be empirically correlated to Δ_{CD} (Fig. 3). The difference $\delta_L = \langle L_{eff} \rangle - L_{met}$ provides a measure of the short-channel effects of LDD structures as well as a model for the LDD lateral diffusion (Fig. 4). The empirical L_{eff} expression with L_{drawn}, Δ_{CD}, and x_j as inputs can be used to study device electrical parameter (V_t and I_{dsat}) fluctuations due to process (Δ_{CD} and x_j) variations; or combined with Δ_{CD} and x_j measurements to estimate LDD lateral diffusion and its fluctuations (Fig. 5). The model results have been extracted from and compared with the 0.25-µm technology data.

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Topic: ***Model Calibration and Validation*** **Application**: ***Semiconductors and Microelectronics***

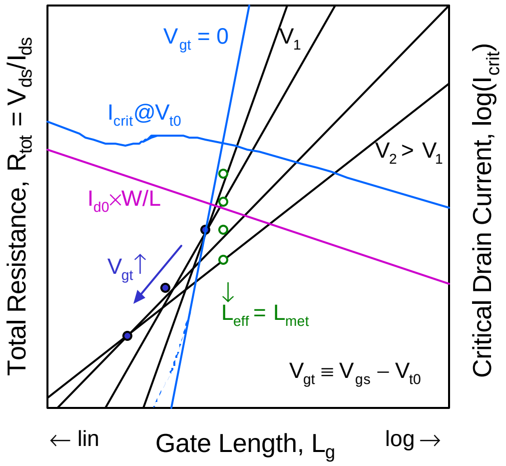

Fig. 1 Comparison of the "$I_{crit}@V_{t0}$" method [1] with existing L_{eff}-extraction methods (solid circle: [5]; open circle: [6]; dotted line: equivalence of this work, similar to [3]). L_{eff} reduction due to 2-D short-channel effects is assumed to be contained in the total linear drain current I_{ds0} at $V_{gs} = V_{t0}$ with the maximum-g_m definition.

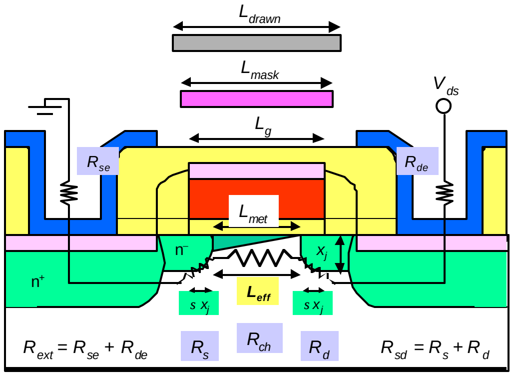

Fig. 2 The MOSFET model depicting the various lengths and the parameters used in the "$I_{crit}@V_{t0}$" L_{eff}-extraction method.

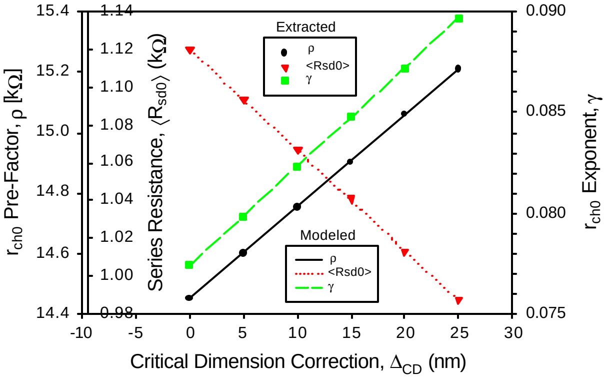

Fig. 3 Extracted (symbols) and modeled (lines) parameters r, g, and $\langle R_{sd0}\rangle$ as a function of Δ_{CD} obtained by fitting the I_{crit}–L_{drawn} data.

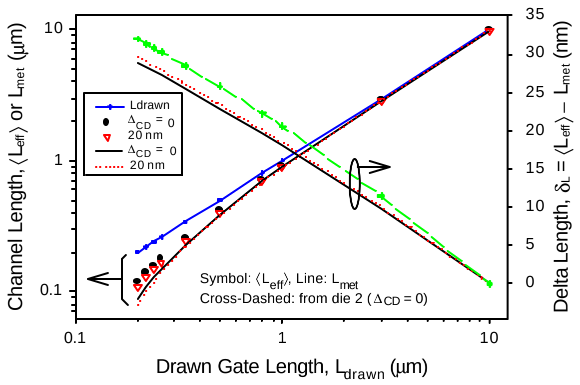

Fig. 4 Left axis: $\langle L_{eff}\rangle$ versus L_{drawn} (symbols) and L_{met} versus L_{drawn} (lines) based on calibrating $\langle L_{eff}\rangle = L_{met}$ at long channel. The difference $d_L = \langle L_{eff}\rangle - L_{met}$ is shown on the right axis with two values of $\Delta_{CD} = 0$ and 20 nm. d_L from the second die ($\Delta_{CD}=0$) is shown by the cross-dashed line.

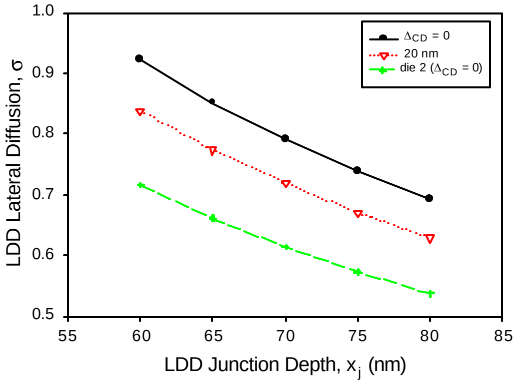

Fig. 5 The modeled s versus x_j with two values of Δ_{CD}. s from the second die ($\Delta_{CD} = 0$) is shown by the cross-dashed line.

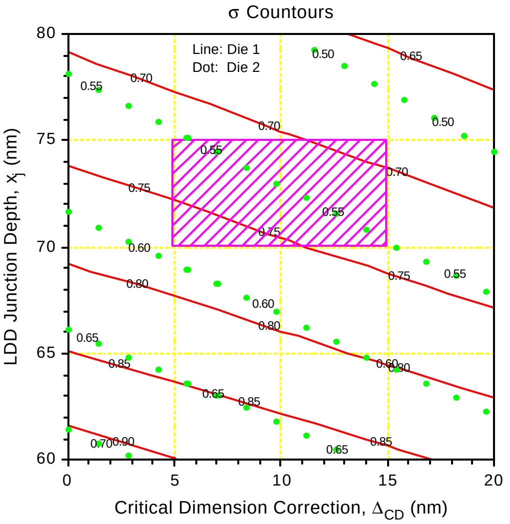

Fig. 6 s contours from die 1 (solid line) and die 2 (dot) as a function of x_j and Δ_{CD}. Estimated x_j and Δ_{CD} uncertainties are shown with the shaded region.