Variability-Conscious Circuit Designs for Low-Voltage Memory-Rich Nano-Scale CMOS LSIs

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Abstract. Low-voltage scaling limitations of nanoscale CMOS LSIs are one of the major problems in the nanoscale era because they cause the evermore-serious power crises with device scaling. The problems stem from two unscalable device parameters: The first is the high value of the lowest necessary threshold voltage V_t (that is, V_{t0}) of MOSFETs needed to keep the subthreshold leakage low. The second is the variation in V_t (that is, ΔV_t), that becomes more prominent in the nanoscale era. The ΔV_t caused by the intrinsic random dopant fluctuation is the major source of various ΔV_t components. It increases with device scaling and thus intensifies various detrimental effects such as variations in speed and/or the voltage margins of circuits. Due to such inherent features of V_{t0} and ΔV_t , the operating voltage V_{DD} is facing a 1-V wall in the 65-nm generation, and is expected to rapidly increase with further scaling of bulk MOSFETs, thereby worsening the power crisis. To reduce V_{DD} , the minimum operating voltage V_{min} , as determined by V_{t0} and ΔV_t , must be reduced.

In this talk the V_{min} of memory-rich nanoscale CMOS LSIs is investigated in an effort to reduce to below 0.5 V through variability-conscious device and circuit designs. First, V_{min} , as a methodology to evaluate the low-voltage potential of MOSFETs, is proposed on the basis of a tolerable speed variation. Second, V_{mins} of the logic, SRAM, and DRAM blocks are compared, and the SRAM block comprising the six-transistor (6-T) cell turns out to be particularly problematic because it has the highest V_{min} . Third, new devices, such as a fully-depleted structure (FD-SOI) and fin-type structure (FinFET) as ΔV_t -immune MOSFETs, are investigated to further reduce the V_{mins} of the above-described blocks. Also investigated are new circuits to reduce V_{min} of each block. For example, for the logic block, new dual- V_{t0} and dual- V_{DD} dynamic circuits enable the power-delay product to be reduced to 0.09 at a 0.2-V supply owing to gate-source reverse biasing. For the SRAM block, repair techniques, shortening the data line, up-sizing the MOSFETs, control of the common-source line or the word line of the cell, and even the 8-T cell reduce the V_{min} . For the DRAM block, if combined with FinFET DRAM cells, a dynamic sense amplifier minimizes the V_{t0} and thus V_{min} .

Finally, it is concluded that such variability-conscious circuit designs should lead to the achievement of 0.5-V nanoscale LSIs, if relevant devices and fabrication processes are successfully developed.