微細集積回路の設計自動化技術

Variation-aware electrical design automation

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目的, Purpose

継続的微細化を実現する設計技術の研究

- ばらつき要因の統計学的考察
- 統計的回路解析・最適化技術
- 微細化に適する回路性能向上技術

Design methodologies for quality-enhancing miniaturization

- Statistical device modeling under process variation
- Statistical analysis and optimization
- Variation-aware circuit design

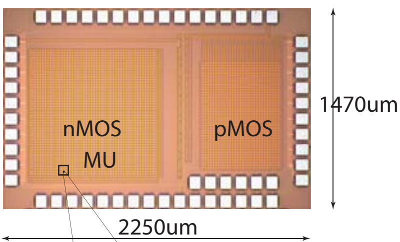
ハイライト, Highlights

- トランジスタアレイによる微小漏れ電流／チャネル長の高精度測定と大域・局所ばらつき成分の最適分離
- ノンパラメトリック統計による任意分布統計的タイミング解析

- Array based sub-threshold current / channel-length measurement and optimal systematic trend determination
- Non-parametric statistical static timing analysis for arbitrary delay distribution

詳細技術, Details

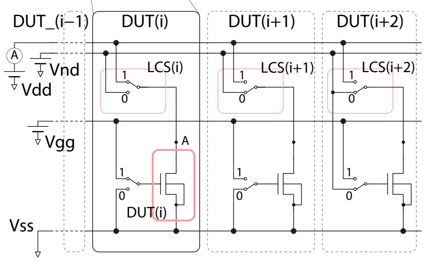
Array-based device-variation evaluation



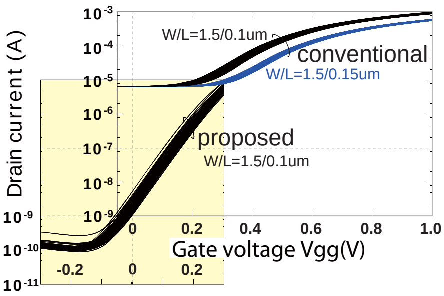
Shared source/drain for high device density

16x16 Matrix Unit (MU)

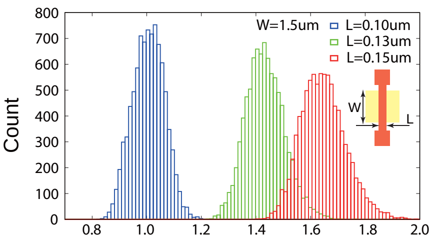
20 different size DUT and 4 resistors



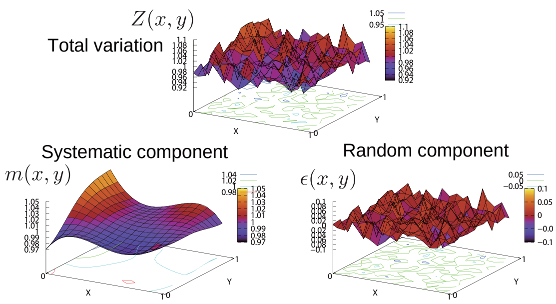
DUT: Device under test, LCS: Leakage cutoff switch



pA-order precision for 1-k DUT array



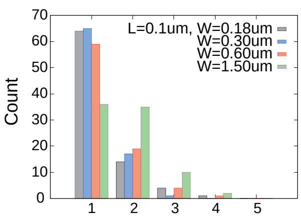
Estimated variation of poly-Si gate length



$$Z(x,y) = \hat{m}(x,y) + \hat{\epsilon}(x,y)$$

Variation decomposition for accurate modeling

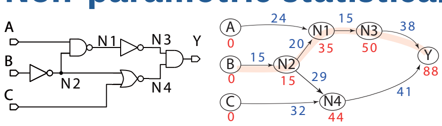
Too complex model may result in overfit problem



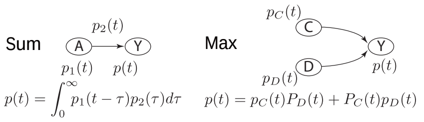
Optimal model order for a chip

Proposed flow based on Akaike information criteria (AIC) suggests the 1-st order polynomial is sufficient to model systematic component

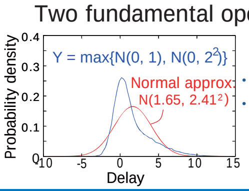
Non-parametric statistical static timing analysis



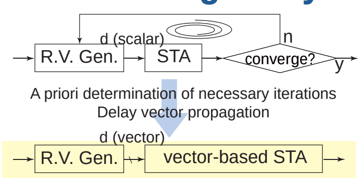
Timing graph and critical path



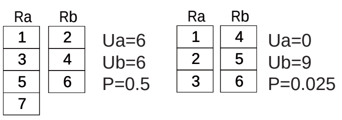
Two fundamental operations for STA



- max: nonlinear func.
- Approx. using parametric distribution is inaccurate



Iteration-free Monte Carlo STA



Fundamental ops. for vectors

		Determ. STA	Statistical	
			Conventional SSTA	Non-parametric STA
Delay repr.		Deterministic val.	Parametric probability distribution	Delay vector
Fund. op.	max	Scalar max	Gaussian that matches both mean and variance to max(A, B)[1]	Vector selection by Mann-Whitney U
	sum	Scalar sum	Prob. variables add (convolution)	Element-wise add
Criticality			Tightness[2], etc.	Mann-Whitney U, P-value
Memo			• Normal distribution • Canonical delay model • Repetition of 2-input procedure	• Arbitrary distribution • Arbitrary delay model • Single procedure for multiple input

1) Clark (1961), 2) Visweswariah (2004)