

Quick Start Micro Training LLC, Dr. Ted Dellin

Quick Start Submicron CMOS Challenge Course

Quick Start Micro Training LLC *Quick Start™*
Submicron CMOS Challenge Course

SAMPLE SLIDES FROM COURSE

Dr. Ted Dellin
Quick Start Micro Training LLC, www.quickstartmicro.com
(retired) Chief Scientist, Microsystems Ctr., Sandia National Labs.
(retired) Reliability Lead, International Tech. Roadmap for Semiconductors
dellin@ieee.org, 1-505-401-8707
©2004-2009, Dellin, All rights reserved.
May not be copied or transmitted in any form without express written permission.

quickstartmicro.com Version 1.0 – 3/11/09

Scaling Dimensions & Voltages Results In Faster, Better and Cheaper ICs

1.0µm (Mid-1980s)

0.1µm (Early-2000s)

~100,000's Transistors/IC
Speed ~ 10's MHz
5V Power Supply
~0.1 ¢ / transistor

~100,000,000's Transistors/IC
Speed ~ 3,000 MHz
1.2 V Power Supply
~0.00005 ¢ / transistor

quickstartmicro.com

We Need to Reinvent Microelectronics To Sustain The Moore's Law Cycle

Scaling
into the
deep
sub-
micron
region

Fundamental
Physical and
Material Limits

- Large Power Consumption
- Harder to Achieve Performance Gains
- Processing, Design, Reliability & Test Issues

Replace Almost
All of the
Traditional
Materials Used
In ICs

New Device Structures

Design for Manufacturing
(Litho, Process Variability, ...)

.....

????

quickstartmicro.com

Scaling Today: Reduce Feature Sizes By 0.7 But Voltages By Only 0.85

Reduce
Dimensions
By ~0.70

Reduce
Voltages
More Slowly,
By 0.85

Transistor Speed	🟩
Interconnect Speed	
Local	🟩
Global	🔴
# Transistors/IC	🟩
Active Power/IC	🔴
Standby Power/IC	🔴🔴
Electric Field	🔴
Current Density	🔴
Reliability Margin	🔴
Noise/Crosstalk	🔴

🟩 = Gets Better 🟩 = Stays Same 🔴 = Gets Worse

quickstartmicro.com

Subthreshold Leakage

- Subthreshold leakage is source to drain current when $V_{GATE} < V_{THRESHOLD}$.
 - Especially interested in current when $V_{GATE}=0$ since this is a major contributor to standby power consumption
- Subthreshold current (standby power) at $V_{GATE}=0$
 - Increases exponentially if threshold voltage is lowered
 - Increases exponentially if temperature is raised
 - Increases if doping in channel is raised (needed for scaling)

quickstartmicro.com

It Really Should be Called the "RELATIVELY Short Channel Effect"

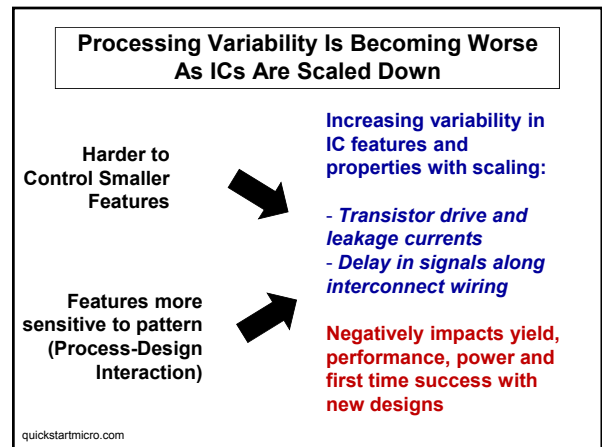
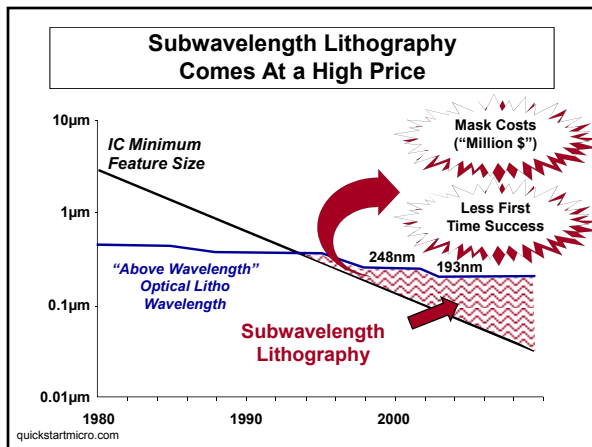
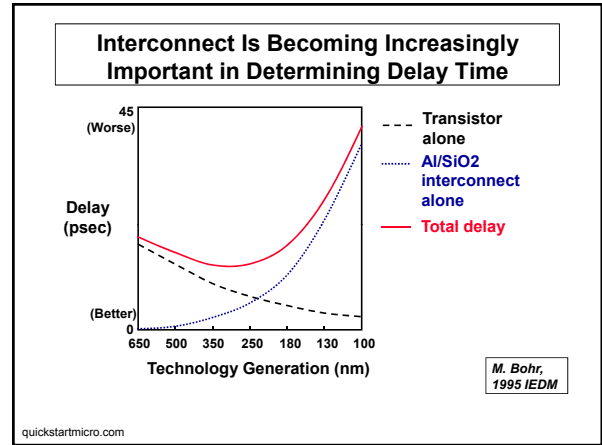
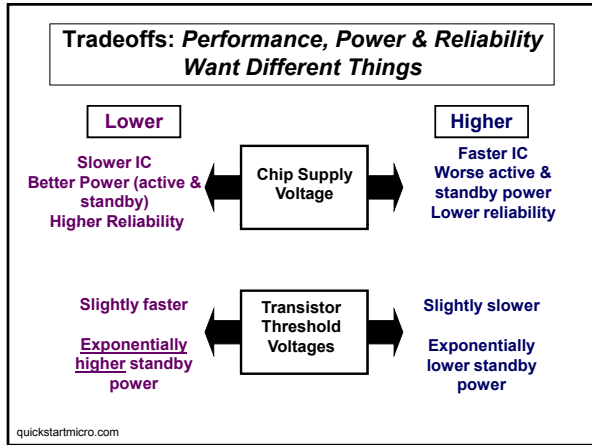
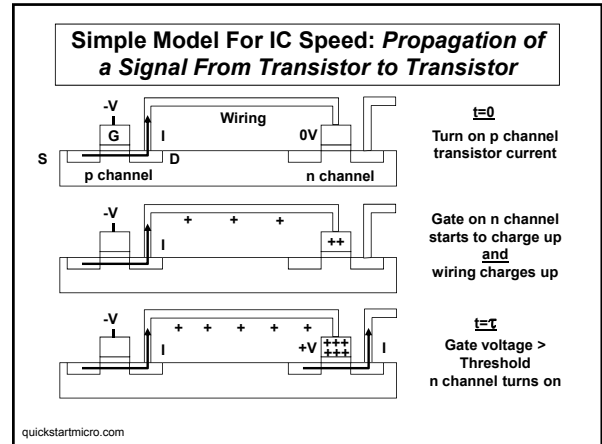
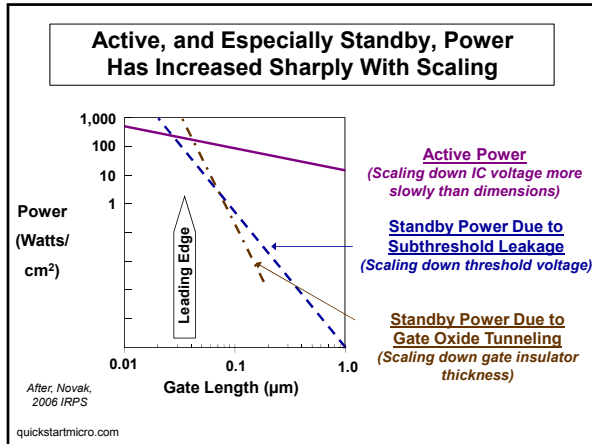
Source, Drain and Oxide Scaled Down With Channel Length
NO SHORT CHANNEL EFFECT

Source, Drain and/or Oxide Not Scaled Down With Channel
SHORT CHANNEL EFFECT

quickstartmicro.com

Quick Start Micro Training LLC, Dr. Ted Dellin

Quick Start Submicron CMOS Challenge Course



Quick Start Micro Training LLC, Dr. Ted Dellin
Quick Start Submicron CMOS Challenge Course

Reinventing CMOS With New Materials and Structures Is Well Under Way

Interconnect Insulator	Silicon Dioxide	→ "Low k"	→ "Lower k"
Interconnect Conductor	Aluminum & Tungsten	→ Copper	→ "??"
MOS Gate Conductor	Poly Silicon	→ 2 Metals	
MOS Gate Insulator	Silicon Dioxide	→ "High k"	
Semiconductor	Silicon	→ Strained Silicon; SOI	

Analytical Solutions, Inc.
 quickstartmicro.com k = Dielectric Constant

High k and Metal Gate Need To Be Introduced At the Same Time

Metal 1 with work function near conduction band
 Metal 2 with work function near valance band

- Difficult to find metals with the right work functions.
- Significant process integration and reliability challenge
- Intel is the first company to introduce high k/metal gate into production

quickstartmicro.com

Copper

- Copper has a lower resistivity than Al
 - Cu lines will have less resistance than Al lines
 - Leads to faster ICs
- Copper has better electromigration lifetimes
- Copper requires new processing
 - Difficult to etch
 - Use Damascene process
- If Cu reaches the Si or the transistor gate bad things happen

Courtesy of IBM. Unauthorized use prohibited.
 quickstartmicro.com

As The Intermetal Dielectric Constant Is Reduced Other Properties Are Degraded

GOOD NEWS	BAD NEWS			
Dielectric Constant	Mechanical Strength	Adhesion	Electric Breakdown Strength	Thermal Conductivity
↓	↓	↓	↓	↓
Improves IC Speed & Reduces Crosstalk	More Mechanical Failures (Cracking, Delamination)		Worse Electrical Breakdown	Higher On Chip Temperature
	Worse Electromigration		Worse Electromigration	Worse Electromigration

Unlike copper, implementation of low k proved to be very difficult

quickstartmicro.com

Local Strained Silicon Improves Transistor Currents: p Channel Needs Compression

p Channel MOS

Silicon Nitride Cap Under Compression

- Channel **compressive** strain
 - SiGe source/drain
 - Compressive nitride cap
- Improves drive current by ~ 50%

Increased performance WITHOUT a power penalty

quickstartmicro.com

State-of-the-Art Planar MOS Transistor

- Metal gate (No polySi depletion)
- High k gate insulator (Reduced tunneling currents)
- Raised source/drain (Reduced resistance)
- Strained Si Channel (Higher mobility)
- Silicon on Insulator (optional) (S/D Capacitance, Leakage)
- Multiple Threshold Voltages (Power vs. Performance)

quickstartmicro.com

Quick Start Micro Training LLC, Dr. Ted Dellin

Quick Start Submicron CMOS Challenge Course

