# The Changing IC Devices

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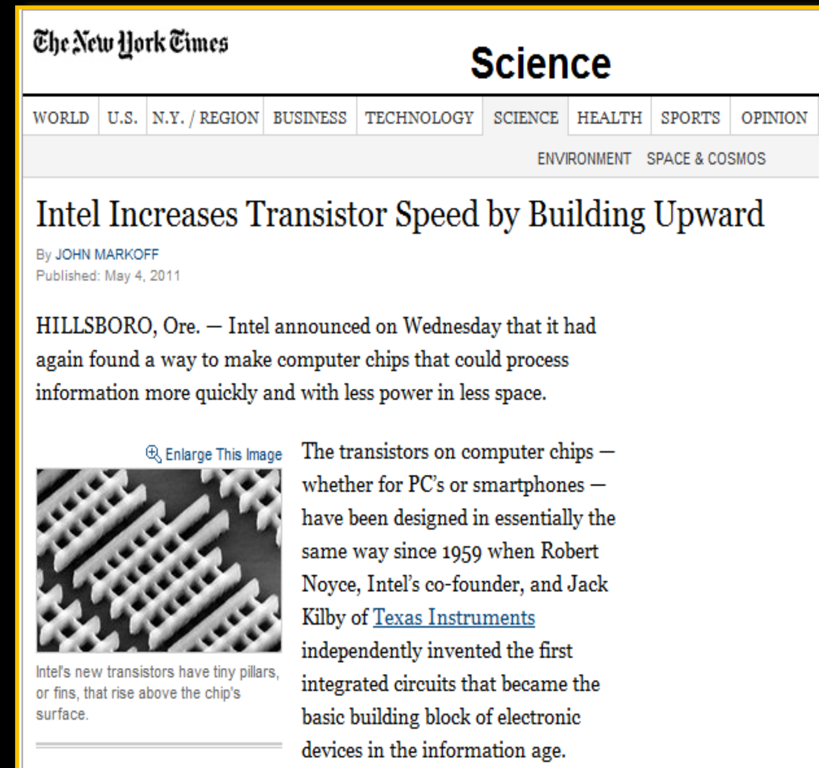
Santa Clara, CA

# May 4, 2011 Exclusive News
# The New York Times Front Page

- Intel will use 3D FinFET at 22nm
- Most radical change in 4 decades
- There is a competing SOI technology



The New York Times Science

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

ENVIRONMENT SPACE & COSMOS

## Intel Increases Transistor Speed by Building Upward

By JOHN MARKOFF
Published: May 4, 2011

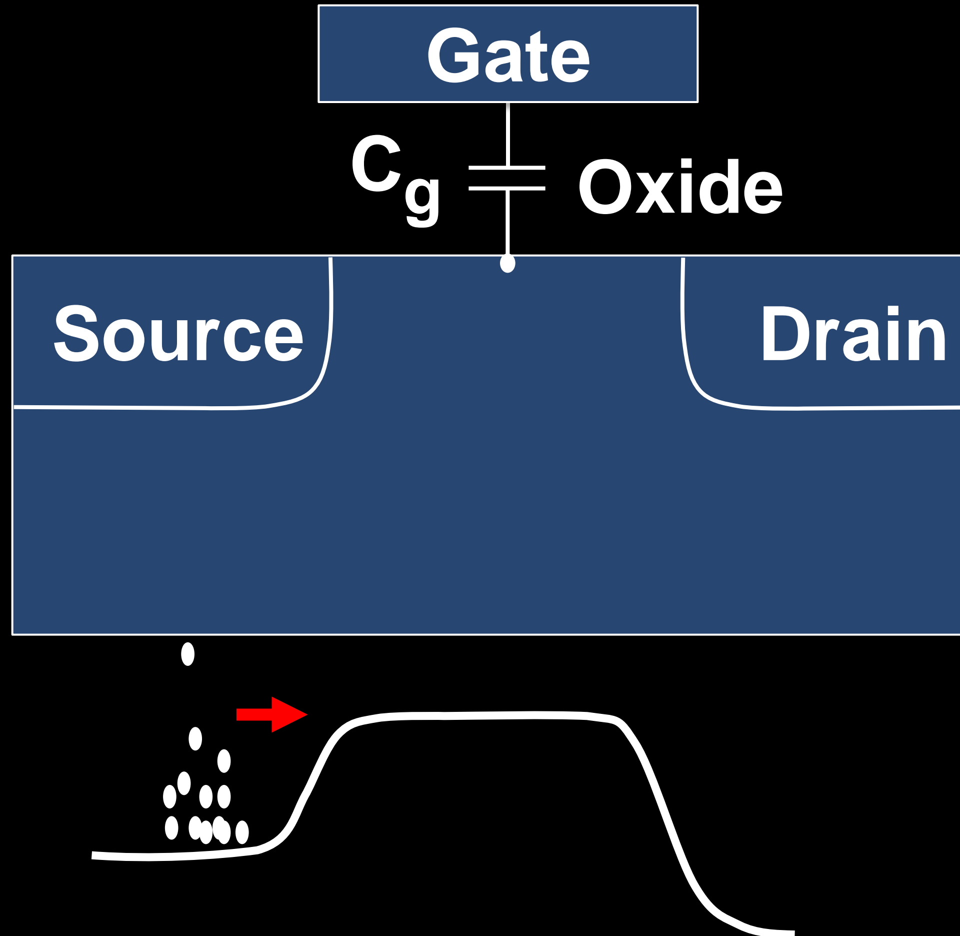
HILLSBORO, Ore. — Intel announced on Wednesday that it had again found a way to make computer chips that could process information more quickly and with less power in less space.

Enlarge This Image

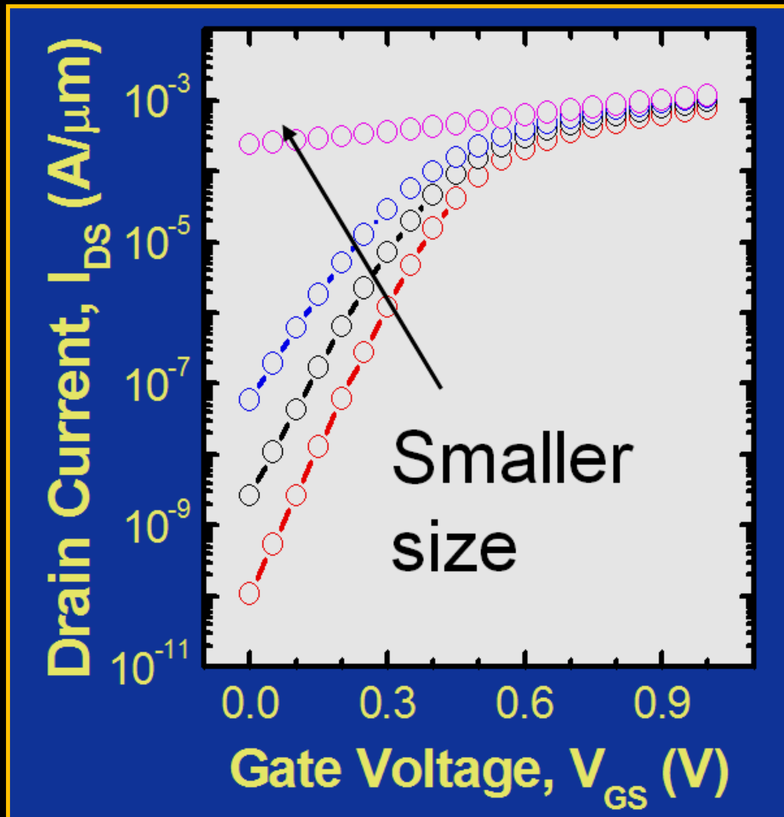
Intel's new transistors have tiny pillars, or fins, that rise above the chip's surface.

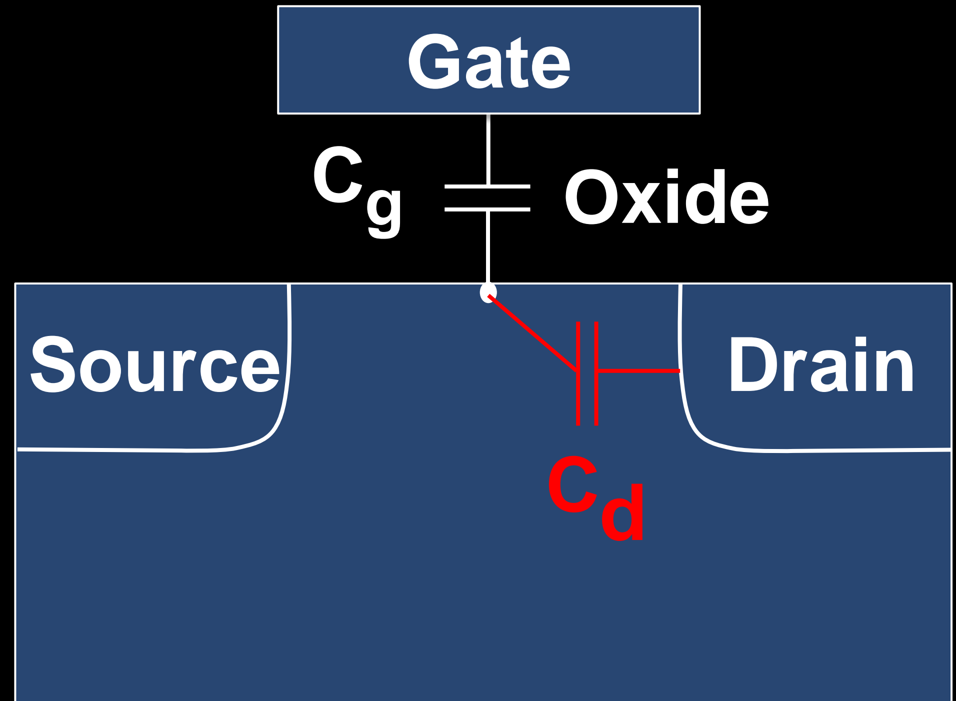
The transistors on computer chips — whether for PC's or smartphones — have been designed in essentially the same way since 1959 when Robert Noyce, Intel's co-founder, and Jack Kilby of Texas Instruments independently invented the first integrated circuits that became the basic building block of electronic devices in the information age.

# Long Channel Transistor



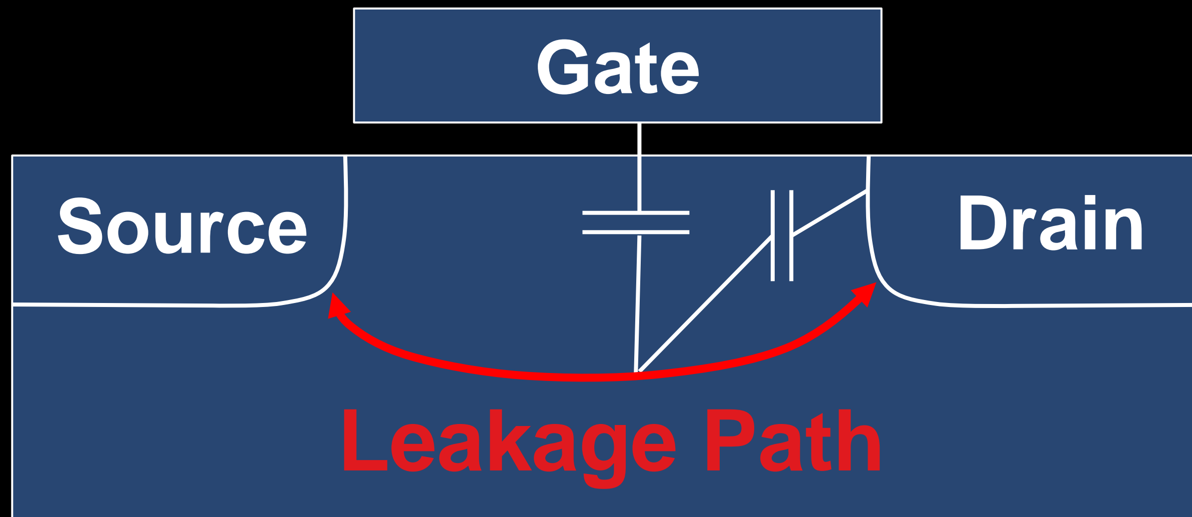
# Short Channel – Problem




**MOSFET becomes "resistor" at small L.**

# Making Oxide Thin is Not Enough

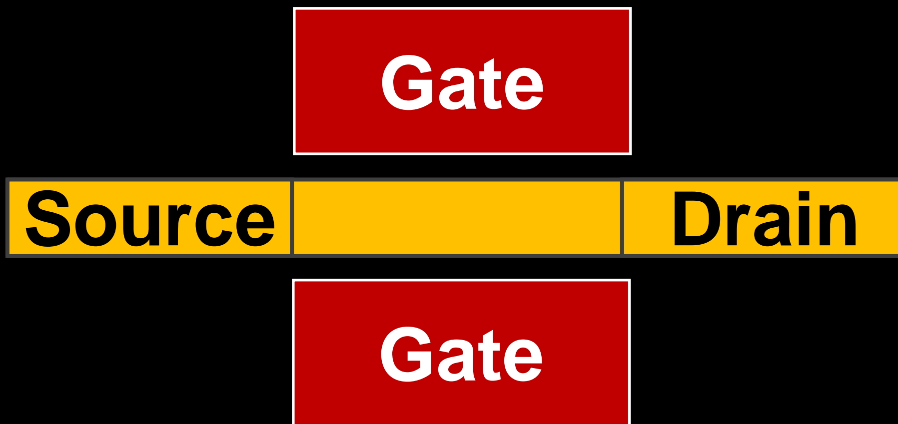



**Gate cannot control the leakage current paths that are far from the gate.**

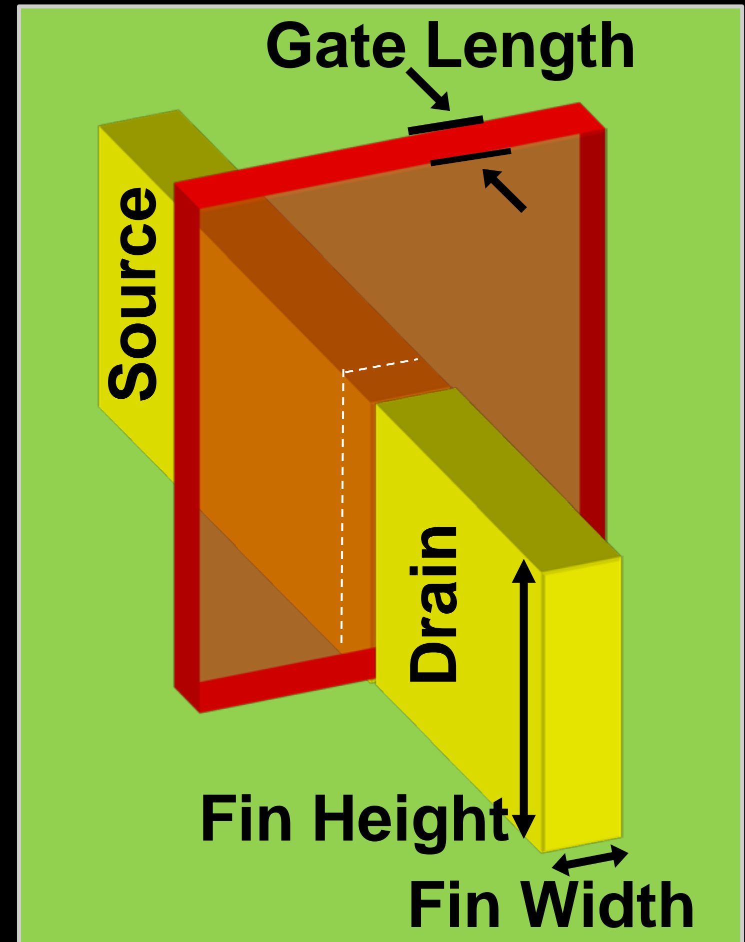
C.Hu, “Modern Semicon. Devices for ICs” 2010, Pearson

# A Structure without Si Far from Gate

**Thin** body controlled by multiple gates.



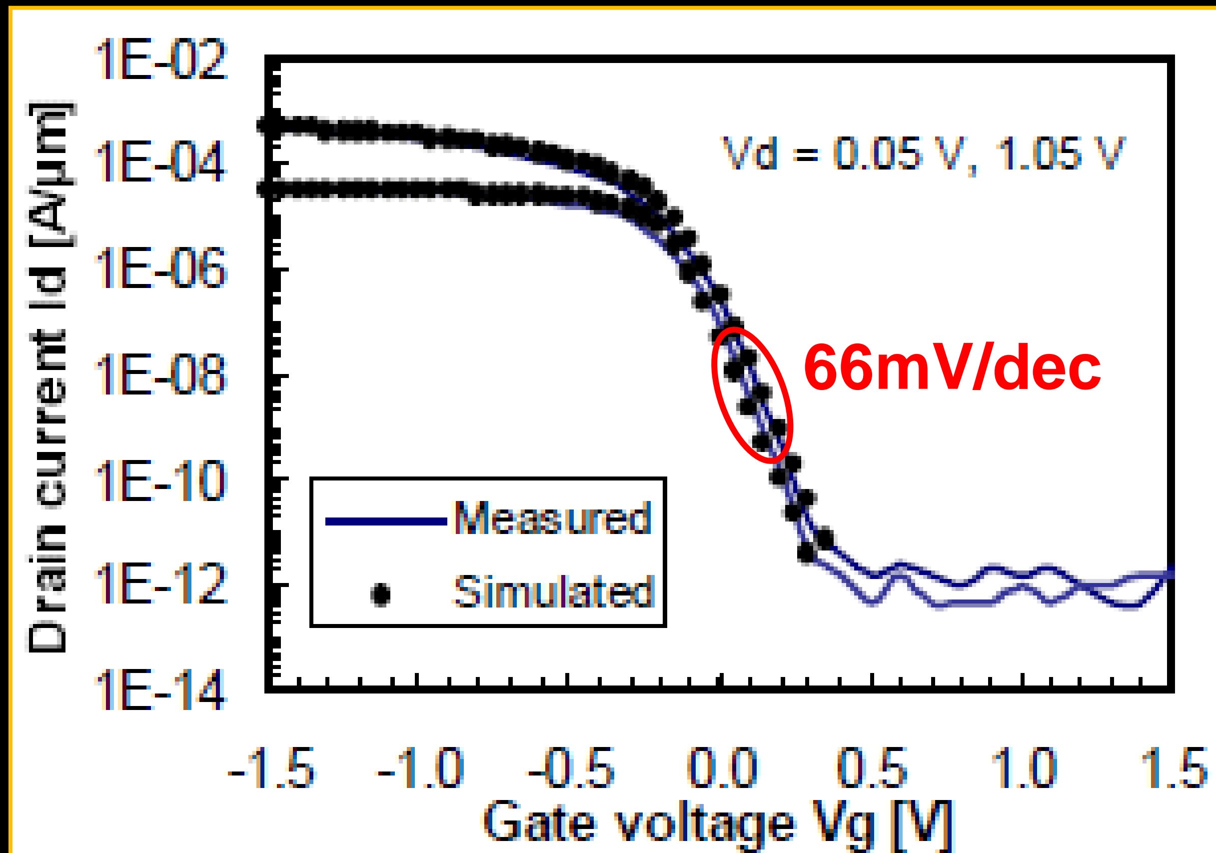

**FinFET** body is a thin Fin.




N. Lindert et al., DRC paper II.A.6, 2001

# 40nm FinFET – 1999

**30nm Fin allows 2.7nm SiO2 & undoped body ridding random dopant fluctuation.**

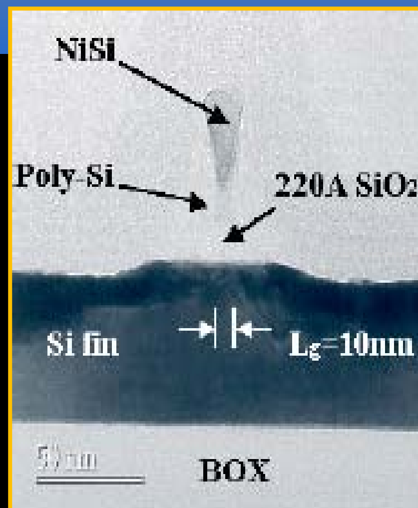


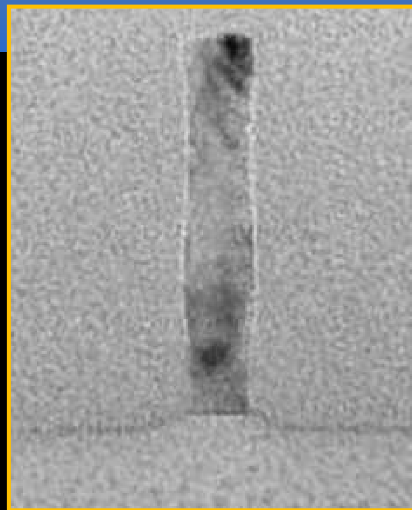

X. Huang et al., IEDM, p. 67, 1999

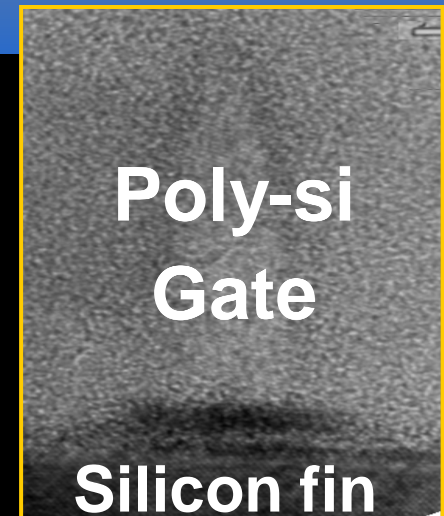
# Introduced a New Scaling Rule

## Leakage is well suppressed if
## Fin thickness < Lg

| 10nm Lg<br>AMD<br>2002 IEDM | 5nm Lg<br>TSMC<br>2004 VLSI | 3nm Lg<br>KAIST<br>2006 VLSI |
|---|---|---|



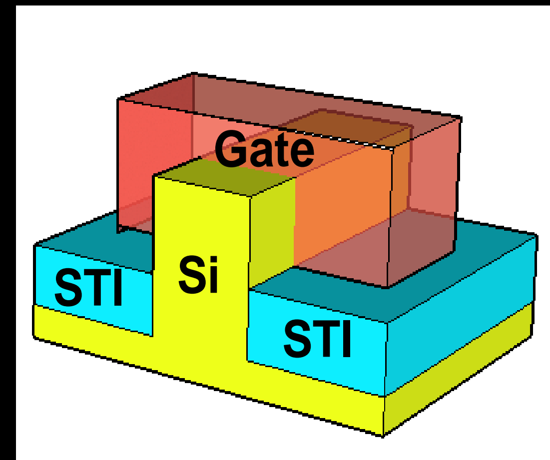





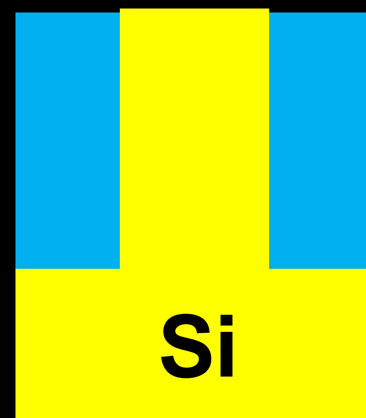
# Two Improvements Since 1999

- 2002 FinFET with thin oxide on fin top.
F.L.Yang et al. (TSMC) 2002 IEDM, p. 225.

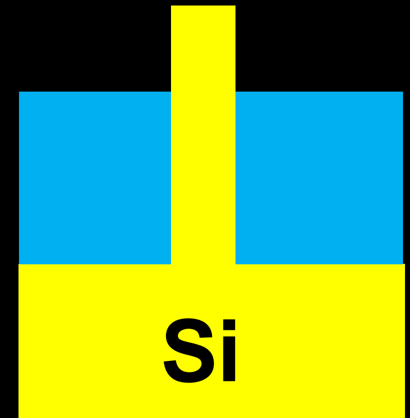
- 2003 FinFET on bulk substrate.
T. Park et al. (Samsung) 2003 VLSI Symp. p. 135.




Planar FET



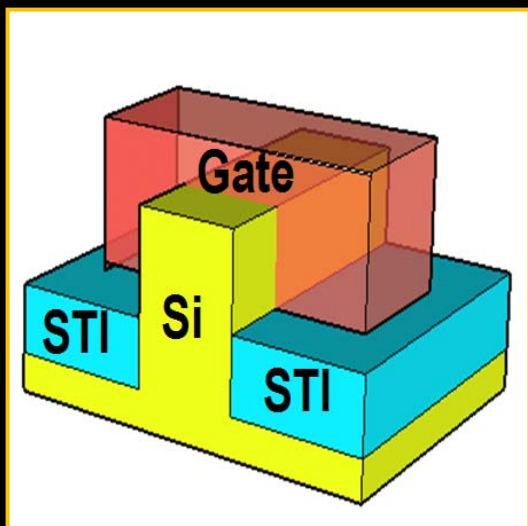

FinFET

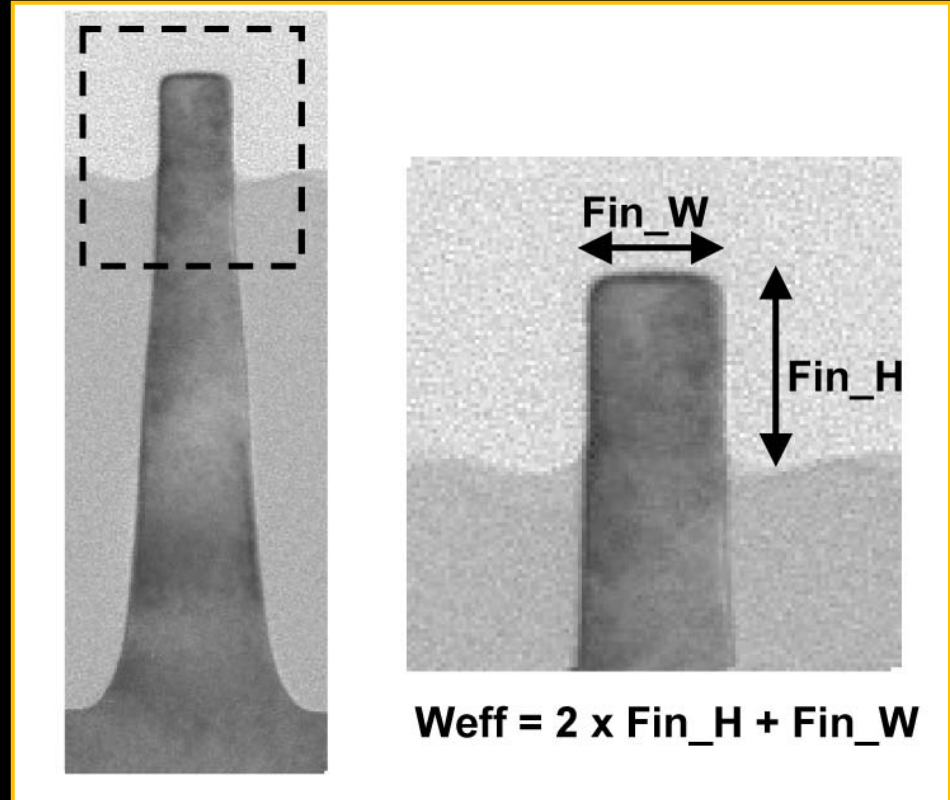


# 20nm FinFET

Planar FET

FinFET



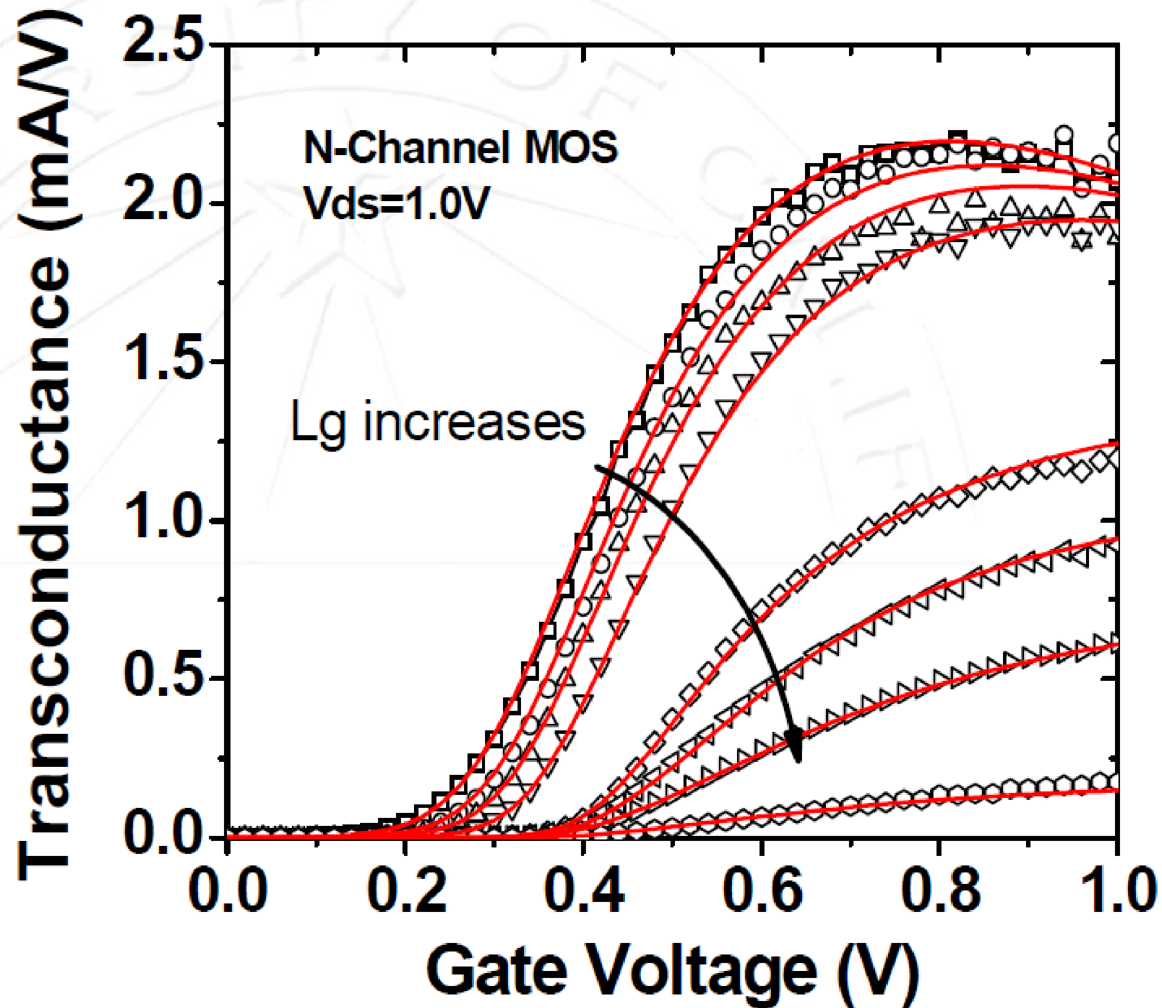




C.C. Wu et al., 2010 IEDM

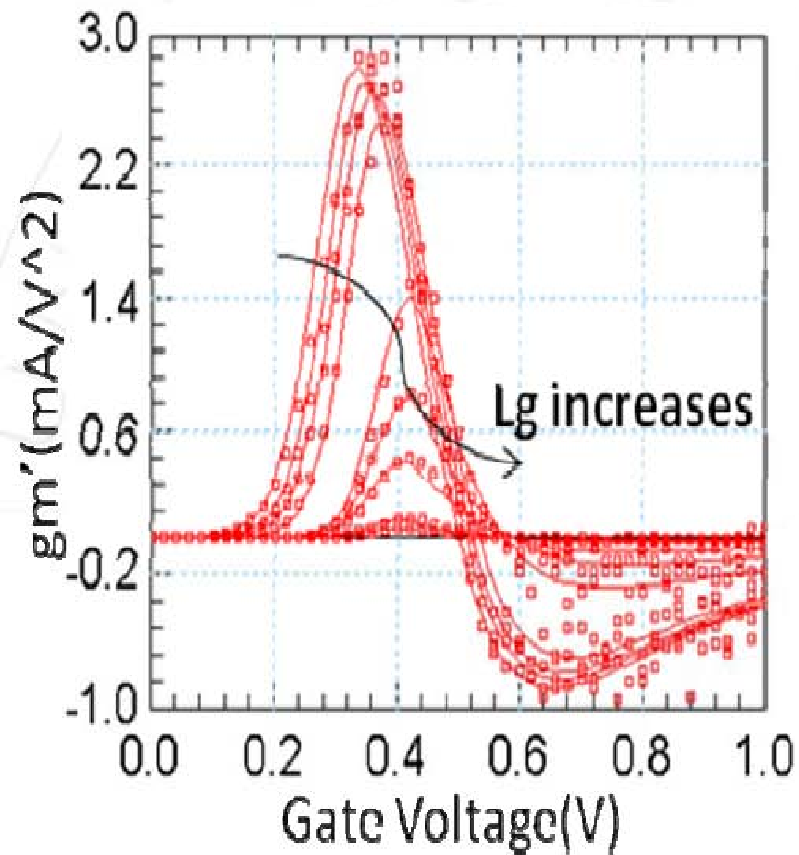
# BSIM

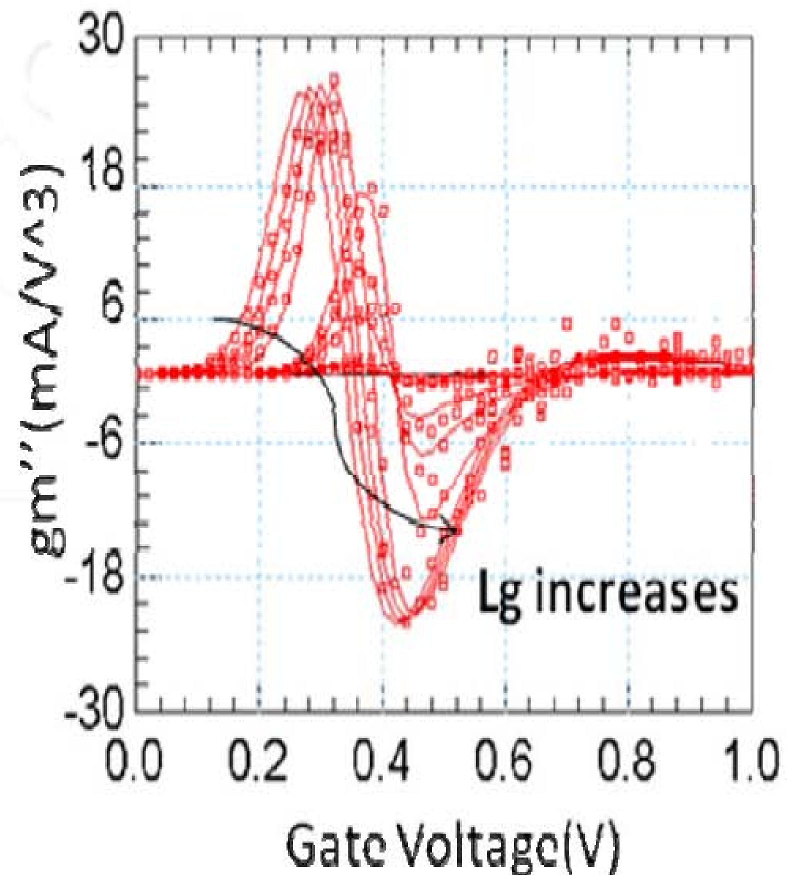
- **Berkeley Short-channel IGFET Model**
- **First industry standard SPICE model for IC simulation**
- **Used by hundreds of companies for IC design since 1997**
- **BSIM FinFET model became industry standard in March 2012**

# Global fitting with 30nm-10um FinFETs



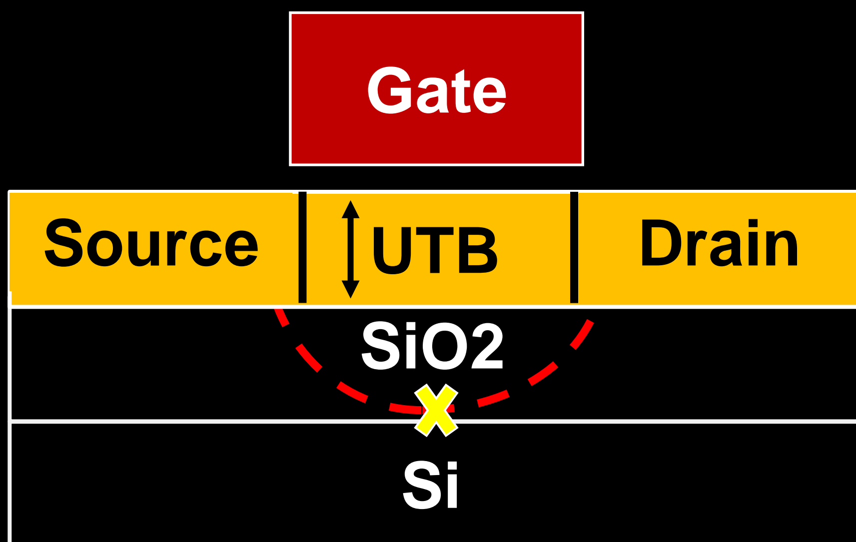
# Global fitting with 30nm-10um FinFETs



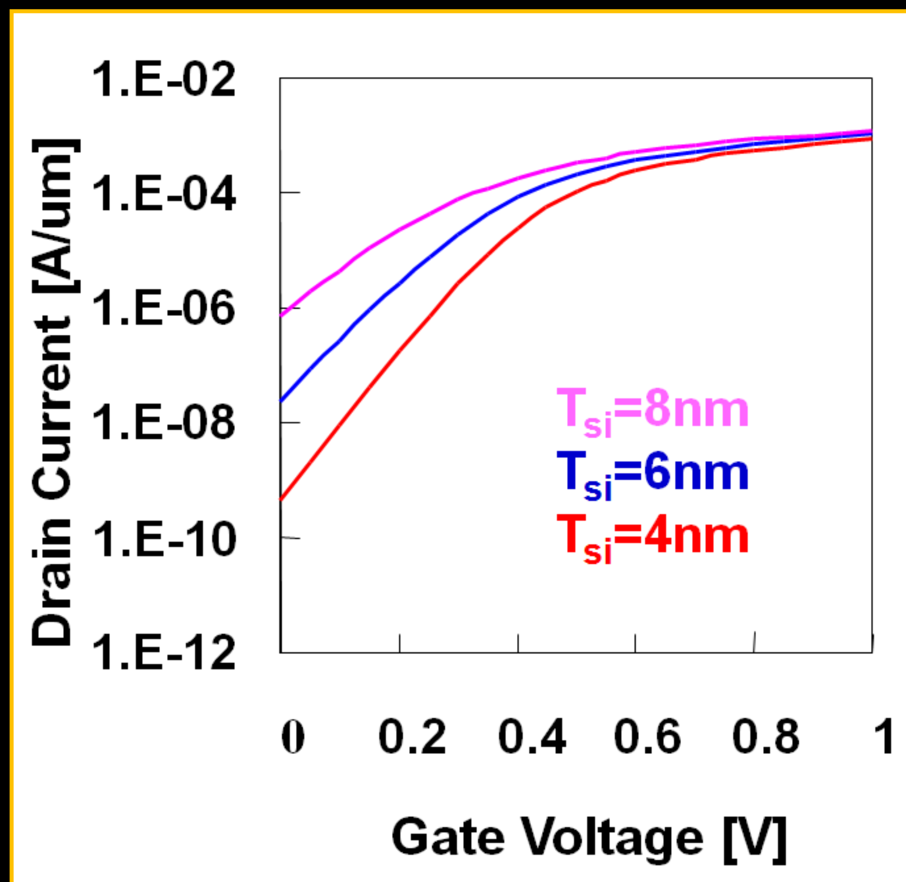



# Another Structure with no Si far from the gate

## Ultra-Thin-Body FET (UTB-FET)

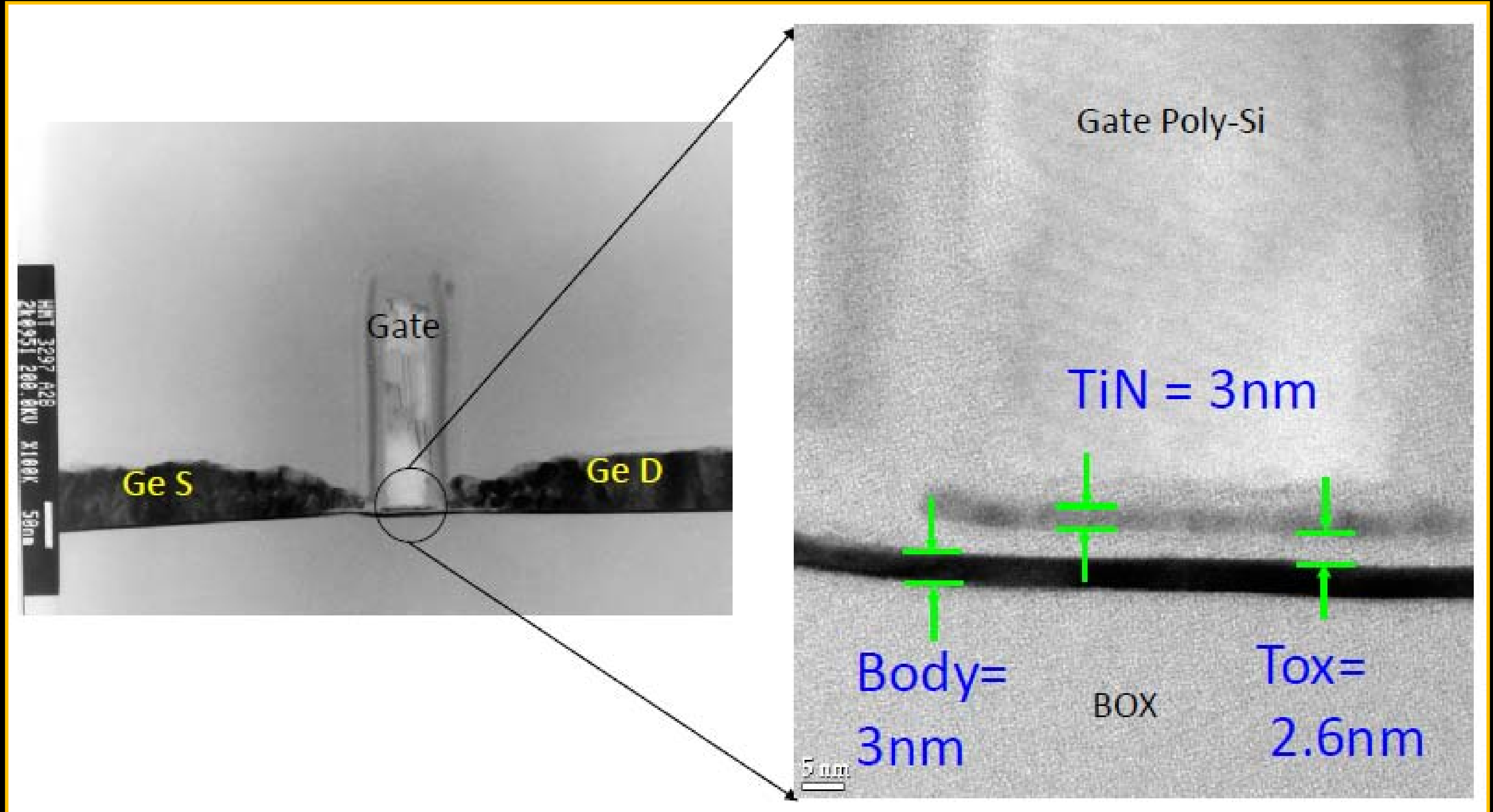



Y-K. Choi, IEEE EDL, p. 254, 2000



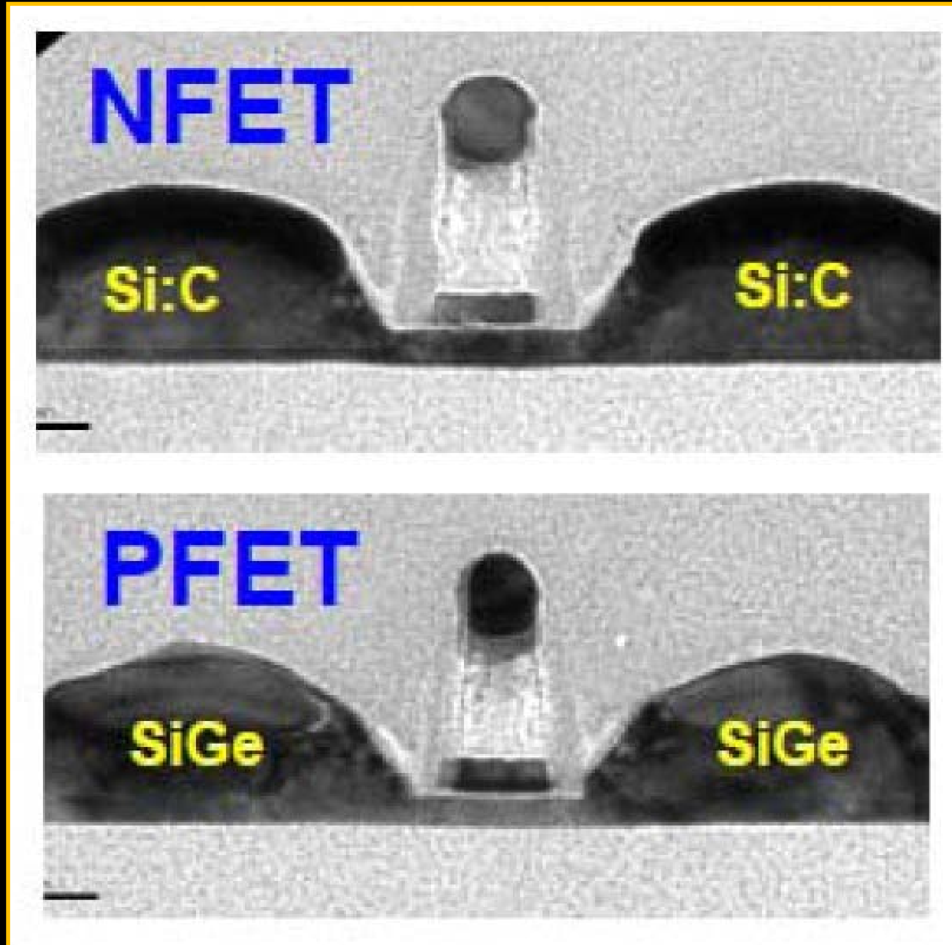
# 2001 UTB-FET

## 3nm Silicon Body, Raised S/D




Y-K. Choi et al, VLSI Tech. Symposium, p. 19, 2001

# 2009 20nm UTB-FET using 5nm-Body




K. Cheng et al, IEDM, 2009

Other Names:

- FDSOI
- UTBB

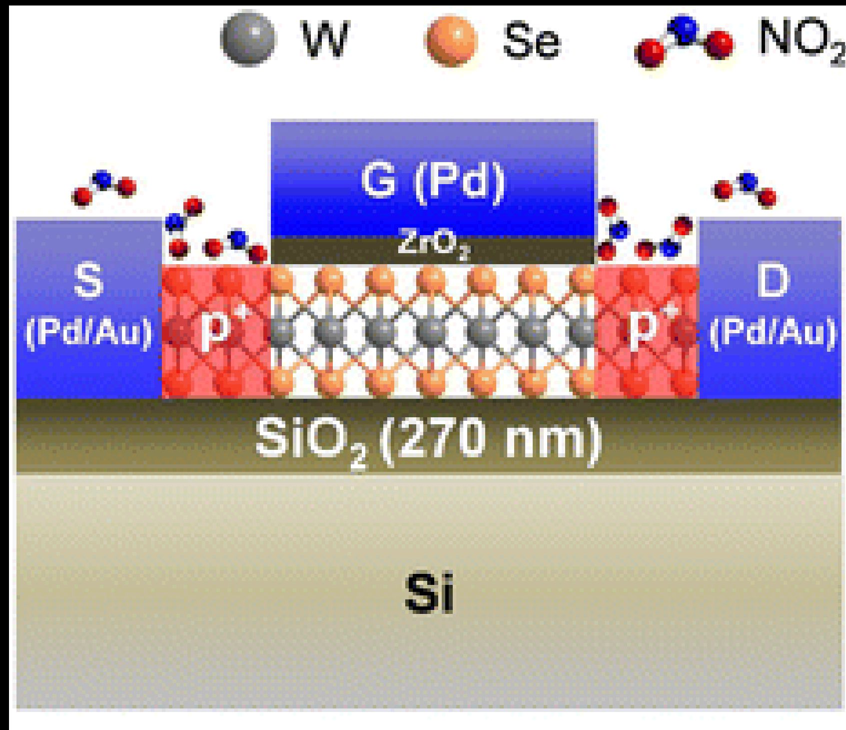
# Outlook

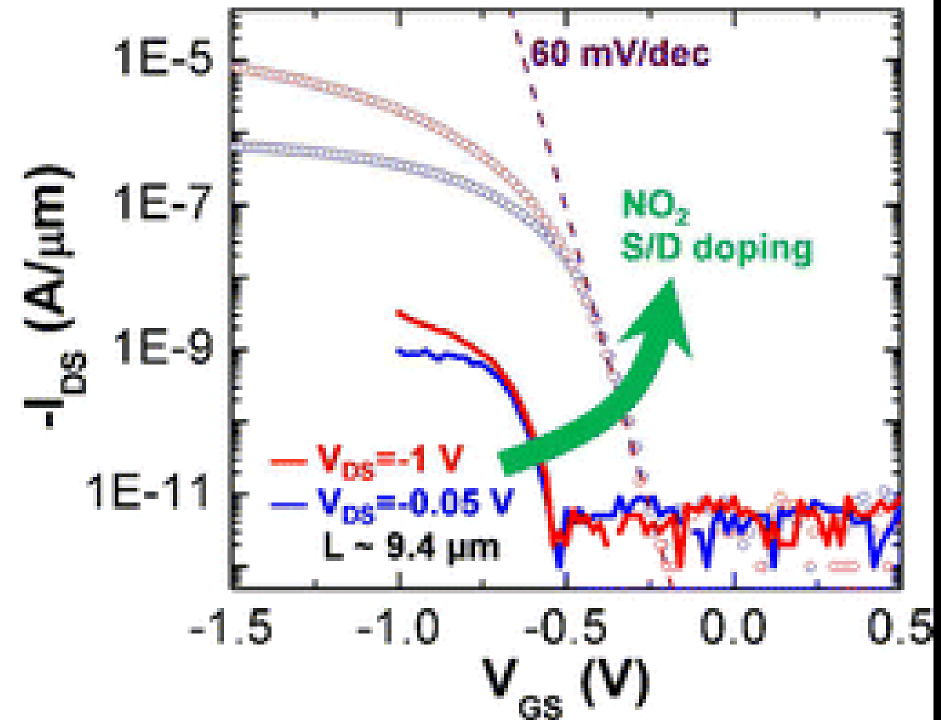
**FinFET** — Intel uses it at 22nm and foundries at 14nm or sooner

**UTB-FET** — ST uses UTB-FET at 28nm, 20nm… against regular CMOS

**Competition will bring out the best of both.**

# $WSe_2$ UTB-FET




60mV/decade experimentally demonstrated

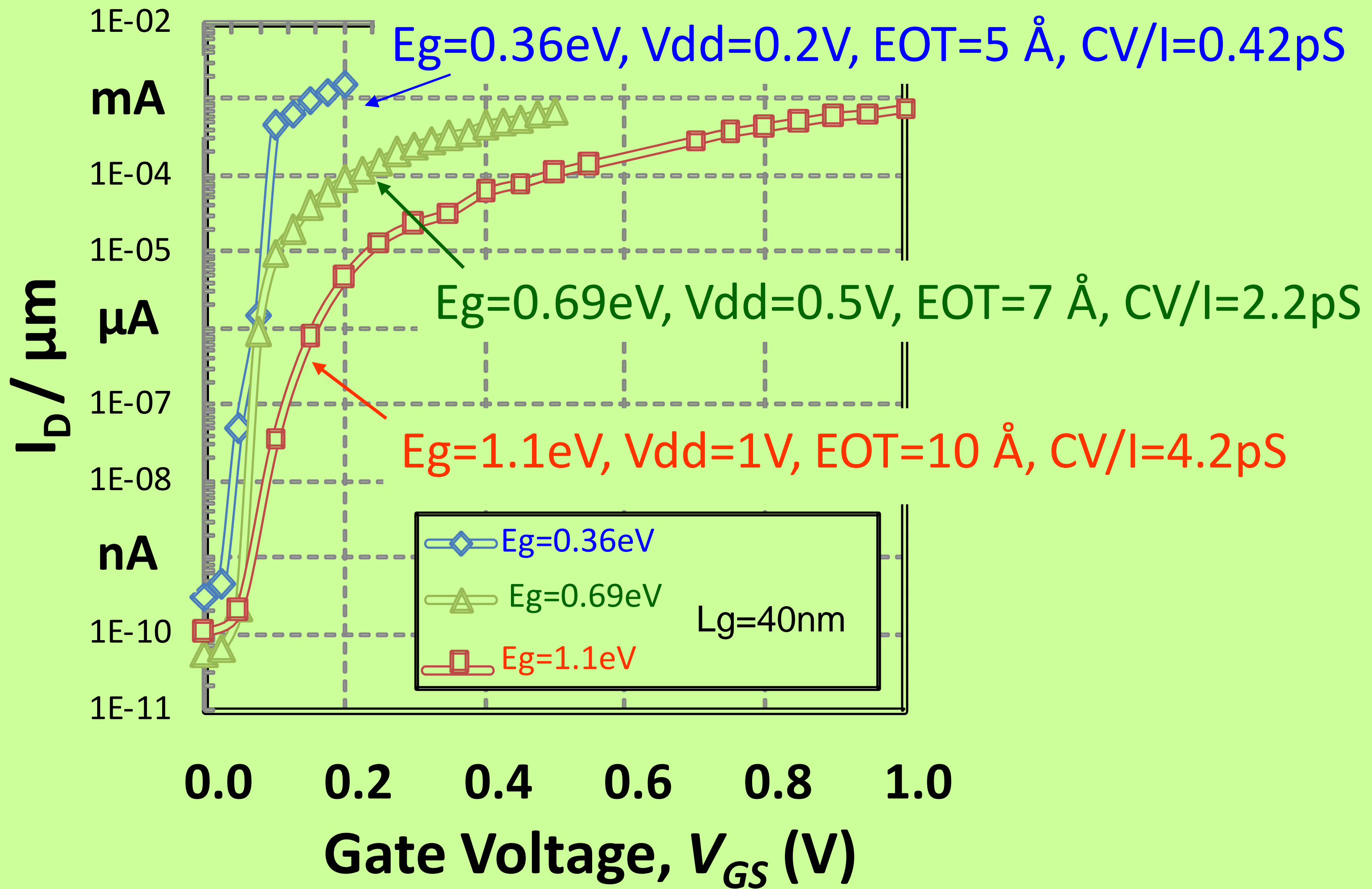
H. Fang et al., *Nano Lett.*, Vol 12, 3788 (2012)

# $P = f\,C\,V^2$

- How to reduce $V_{dd}$ to 0.1V?
- Need a **new transistor** turning on/off with 0.1V change in Vg.

**e.g. Tunneling Transistor**

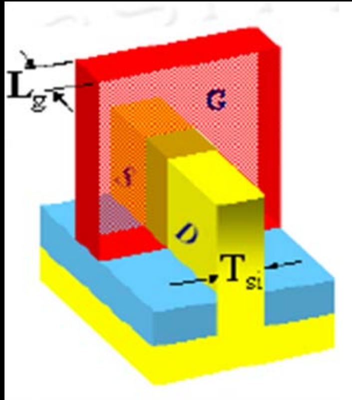
# Scale Vdd by Scaling Eg - Simulation



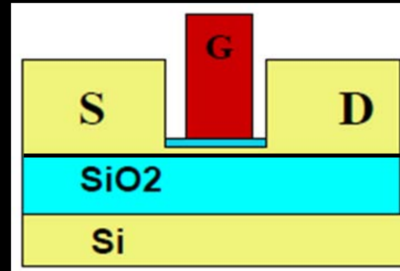

C. Hu, 2008 VLSI-TSA, p.14, April, 2008

**Must:** Thin body thickness/diameter < αLg

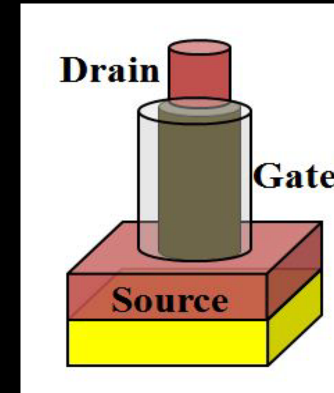
FinFET




UTB




Pillar/nano-Wire




**Want:** High mobility + low contact resistance

**Future Must:** 2D-crystal semiconductor for 3D IC,
e.g., graphene, MoS2, WSe2...

(WSe2 UTB with 60mV/dec: Fang, Javey,.., *Nanolett.*, 2012)

**Future Must:** 100mV Vdd, e.g., TFET, Negative Capacitance FET (Salahudin,..,*Nanolett.*, 2008) ,…

# Gradually Add New Technologies

1. FinFET, UTB, Pillar structure
2. 1 + SiGe/III-V
3. 2 + 0.1V TFET
4. 3 + 2D-crystal materials for true 3D ICs using deposited stacks of semiconductor, dielectric, metal, e.g., MoS2/BN/grapheen

# Summary

- Ultra thin body allows device scaling beyond 10nm.
- 2D-crystal semiconductors are the ultimate UTB-FET materials, great for 3D IC.
- A new transistor will enable 0.1V IC in the 2020's.