NEMS memory for low power application

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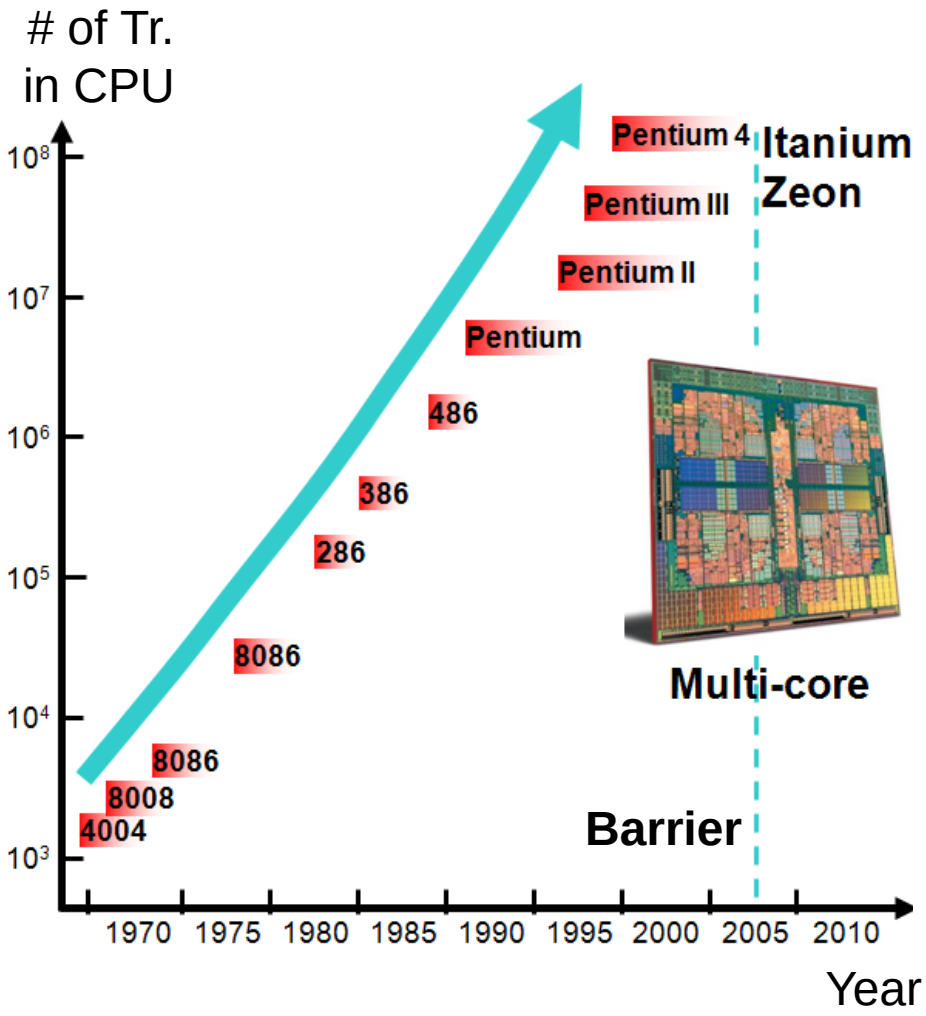
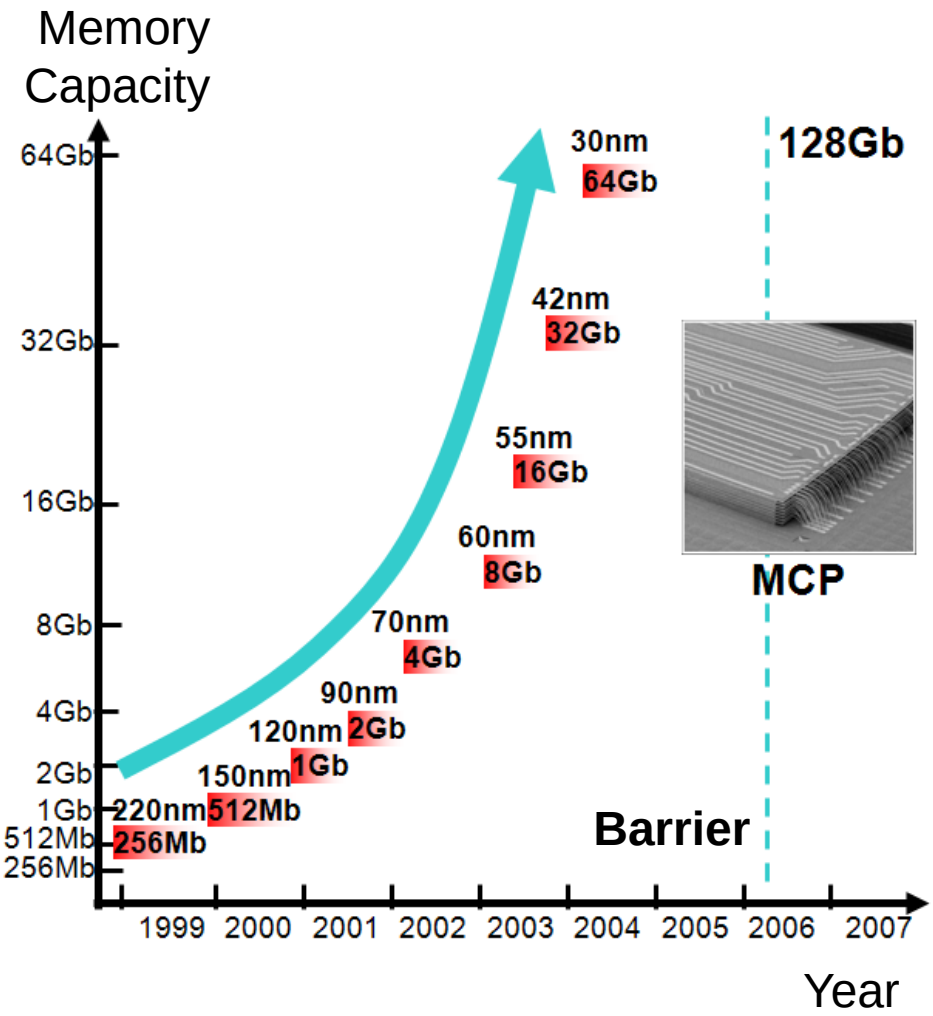
Moore's (Hwang's) Law

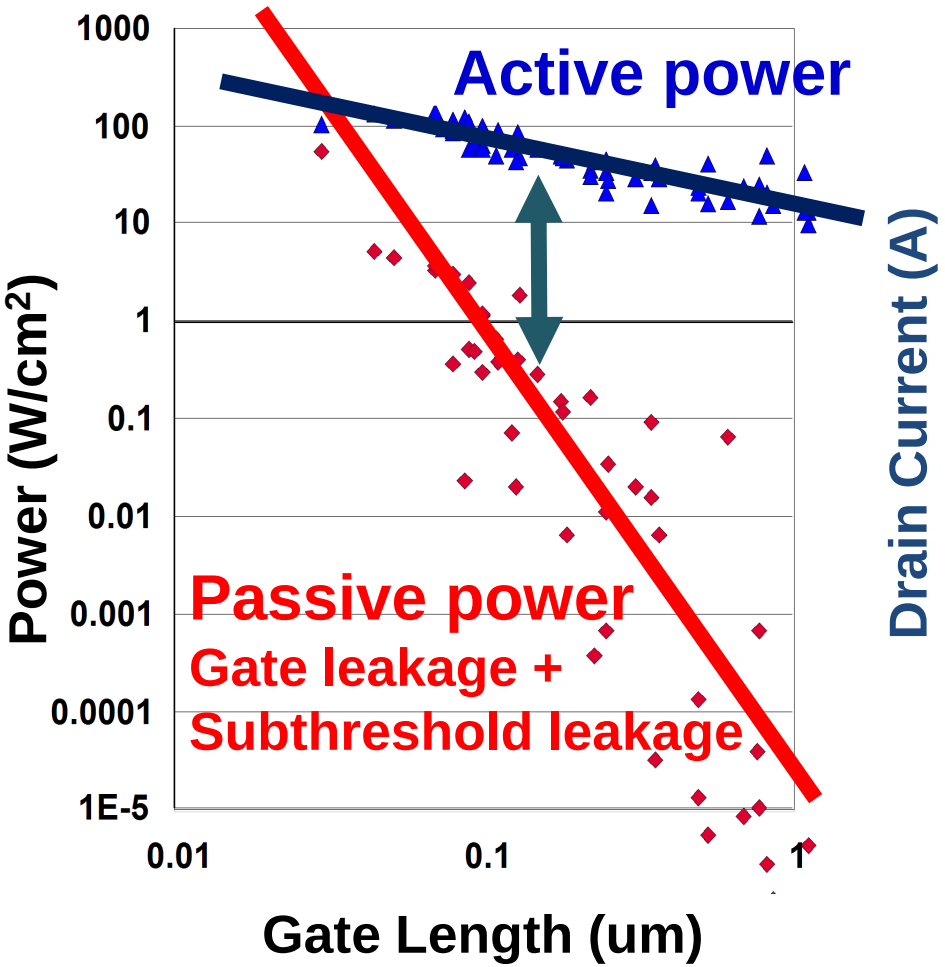


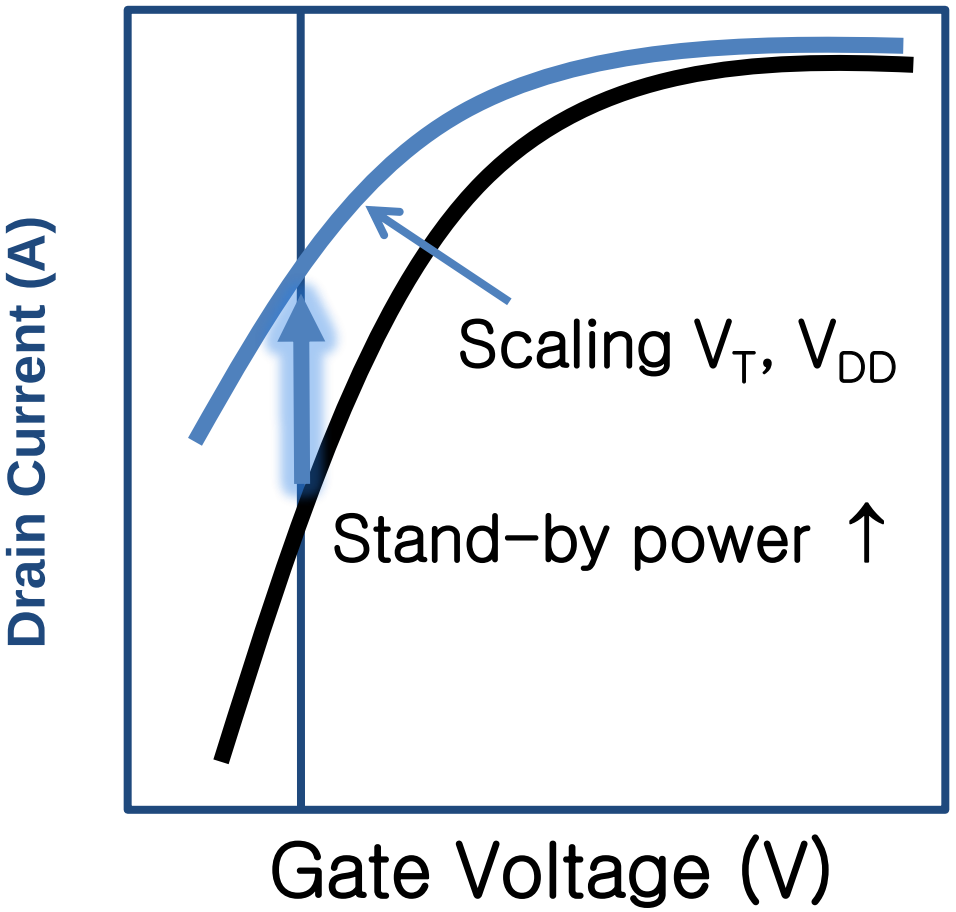
Moore's Law (1965)



Hwang's Law (2002)

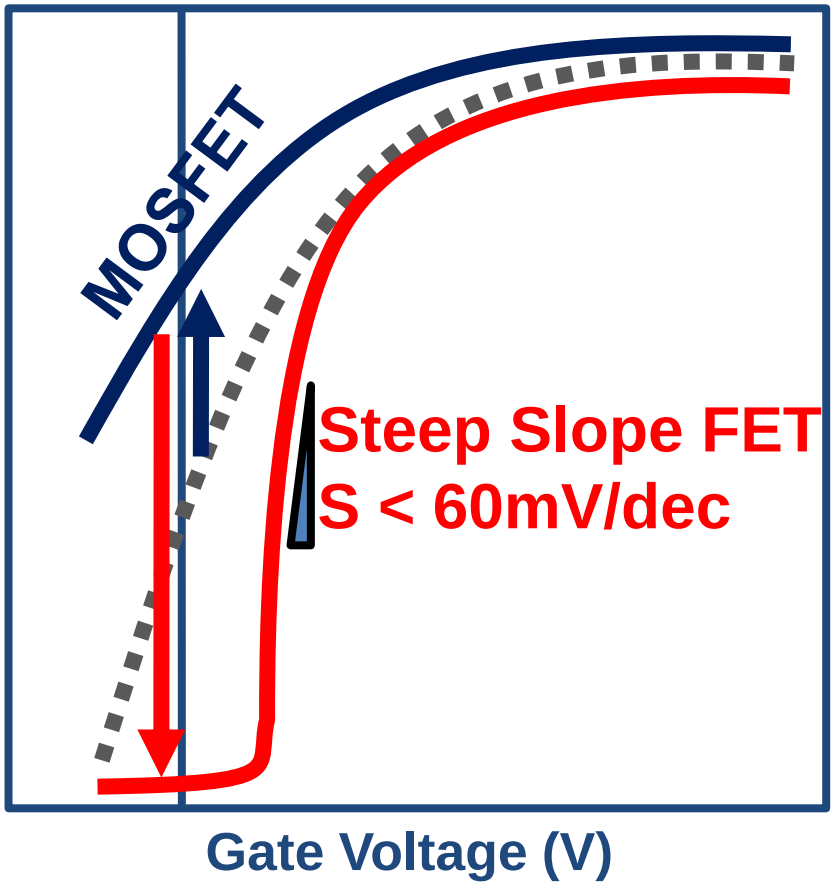
Power Crisis in Scaling





KT/q doesn't scale, lowing V_T increases leakage.

Power Crisis & Steep Slope Transistor



Steep Slope FETs

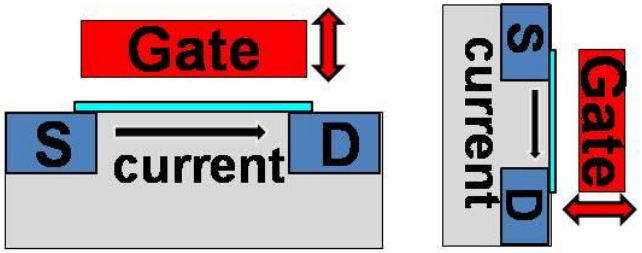
- I-MOS
- T-FET
- Ferroelectric FET
- NEM FET

(Nano-Electro-Mechanical)

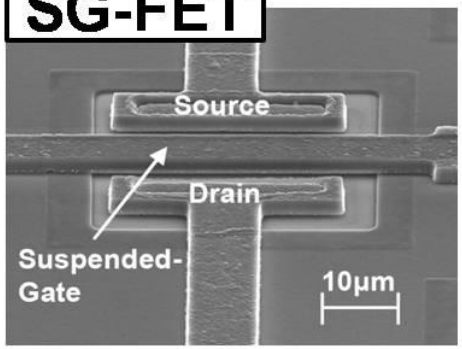
Steep slope device suppresses the stand-by leakage

Nano-Electro-Mechanical Switches

Suspended-Gate Type

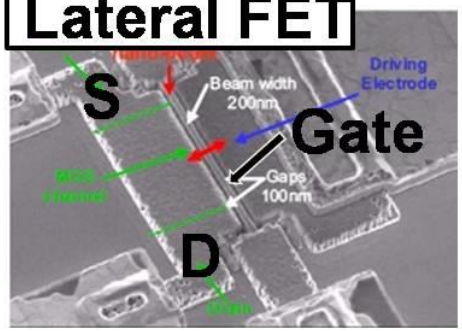


SG-FET



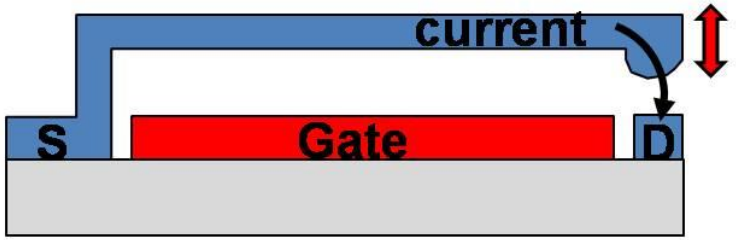
EPFL
IEDM 2006
UC Berkeley
IEDM 2005

Lateral FET

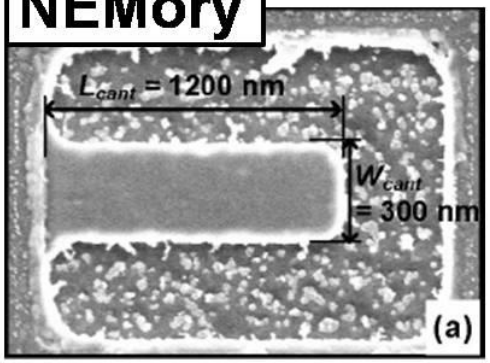


CEA-LETI
MEMS 2008

Cantilever Type

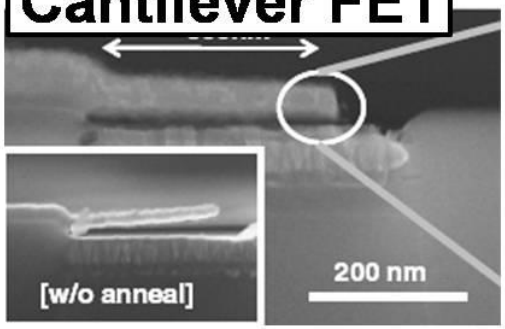


NEMory



UC Berkeley
IEDM 2007

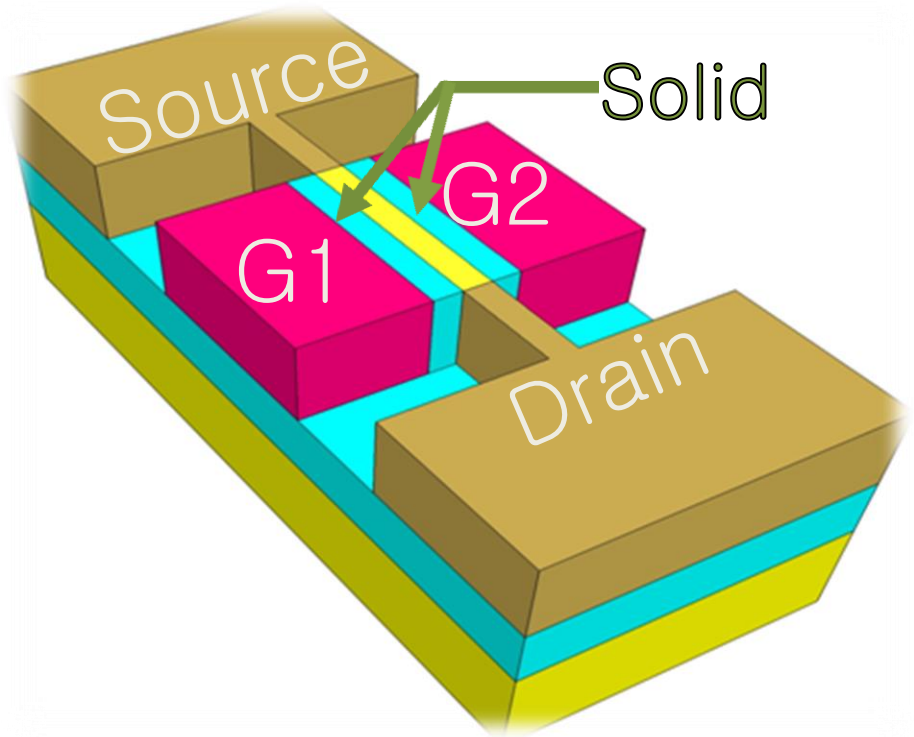
Cantilever FET



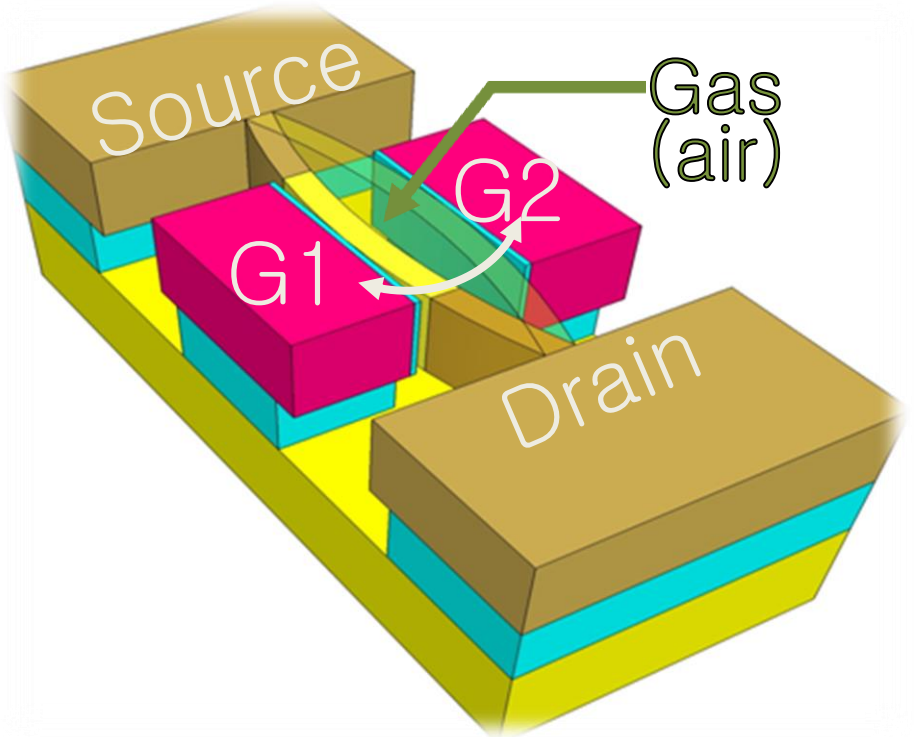
KAIST
APL 2008
Stanford
IEDM 2007

Our NEM Switch

Gate oxide removal and re-oxidation

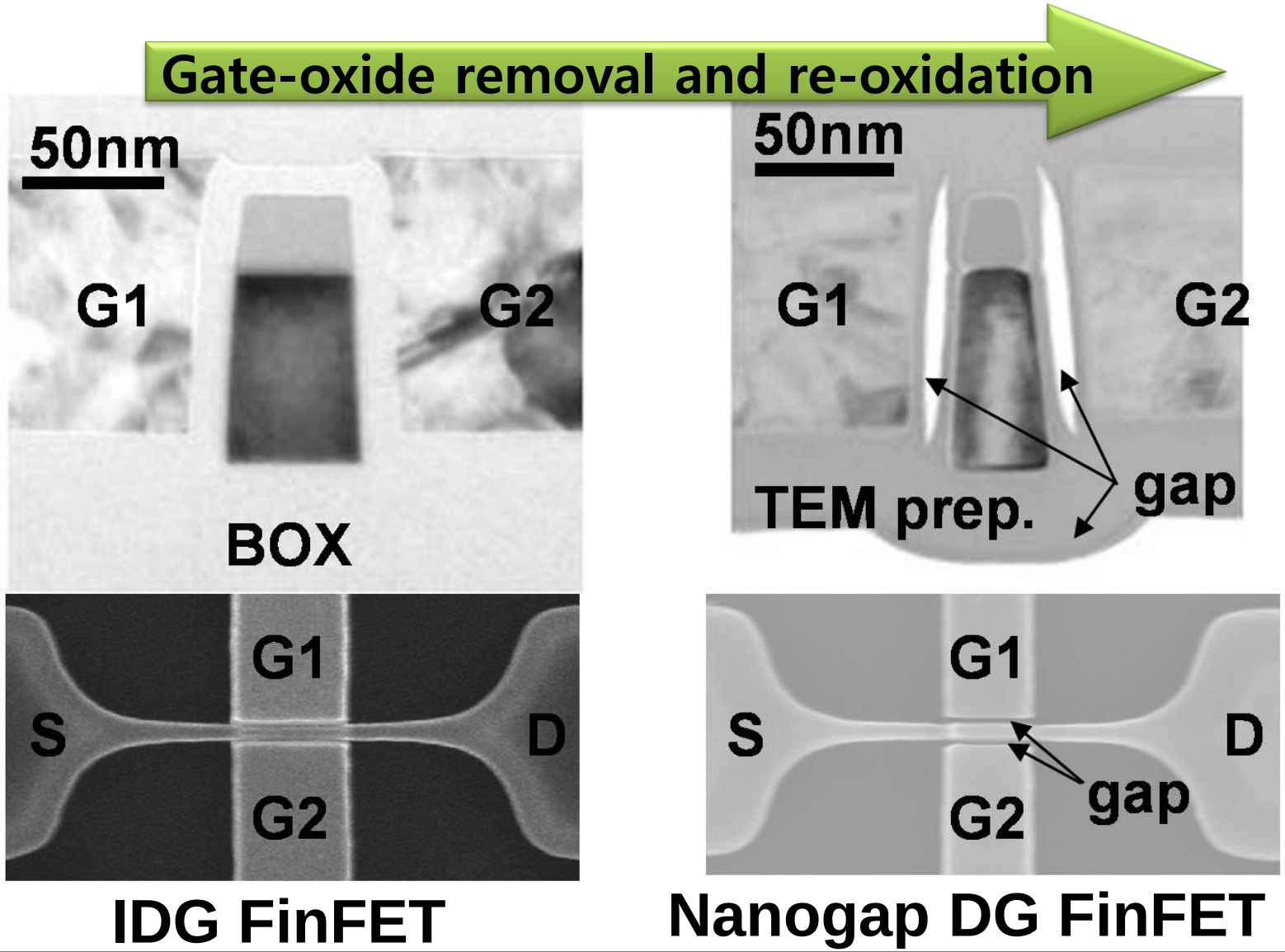


Independent gate FinFET

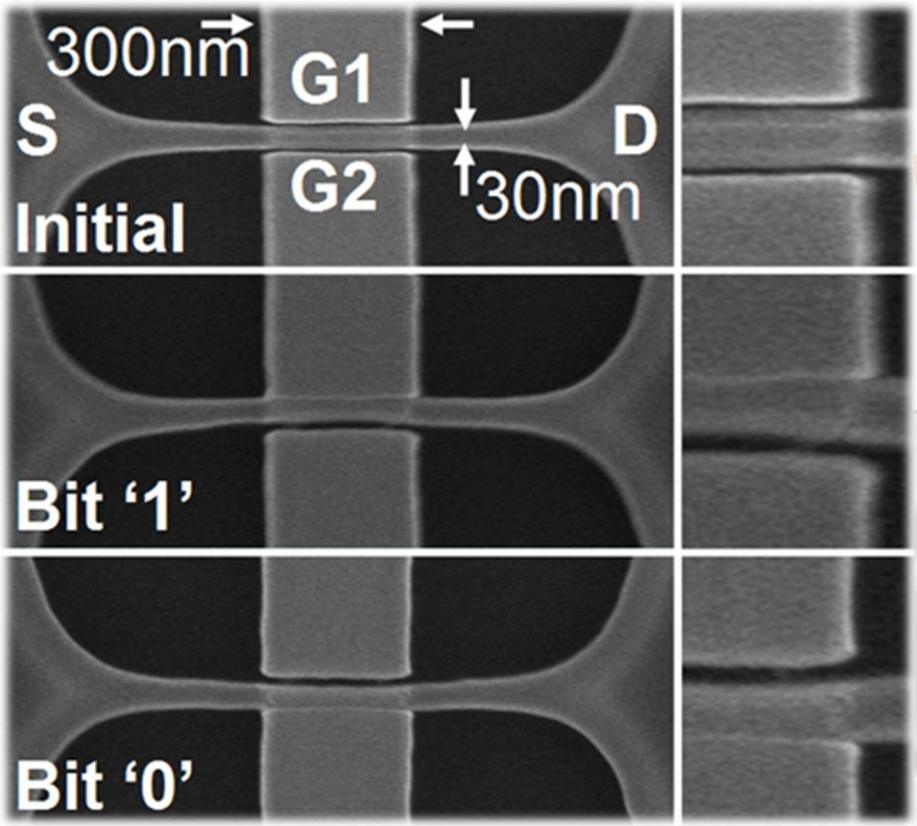


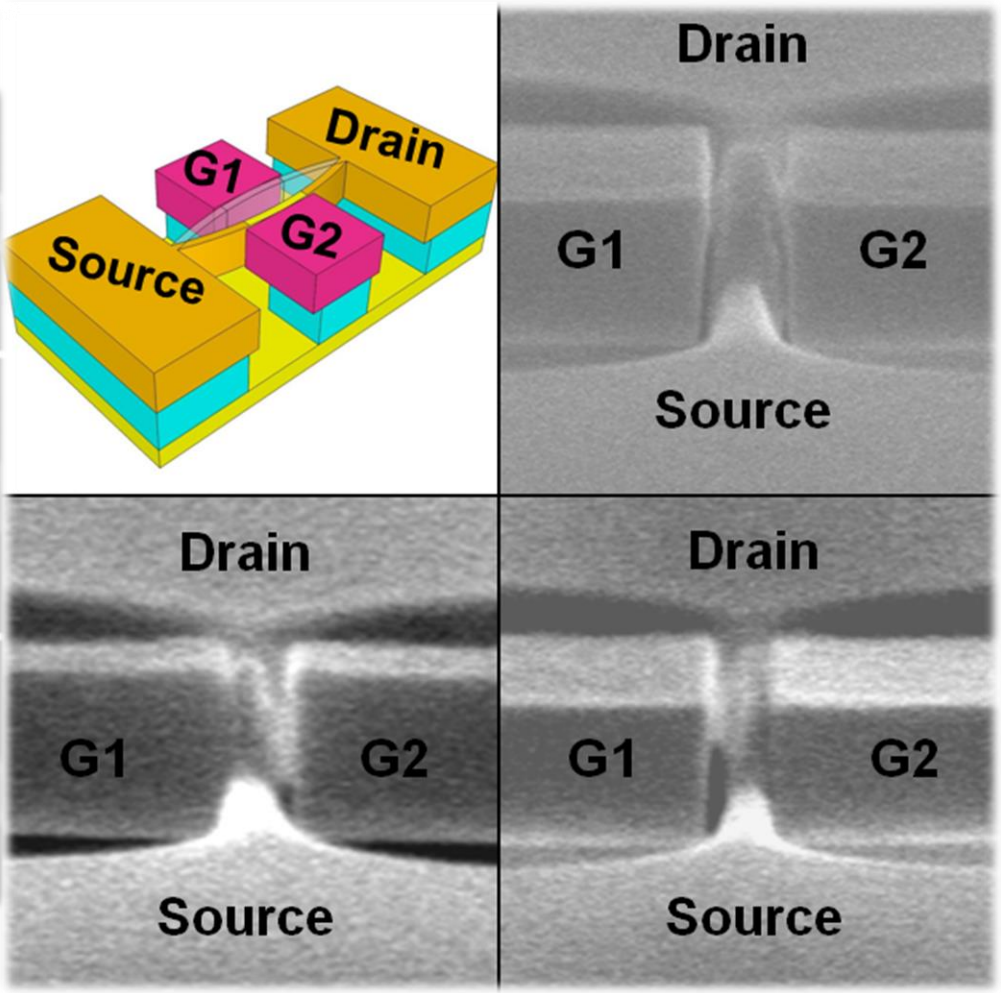
Fin Flip-Flop FinFET

TEM/SEM Images

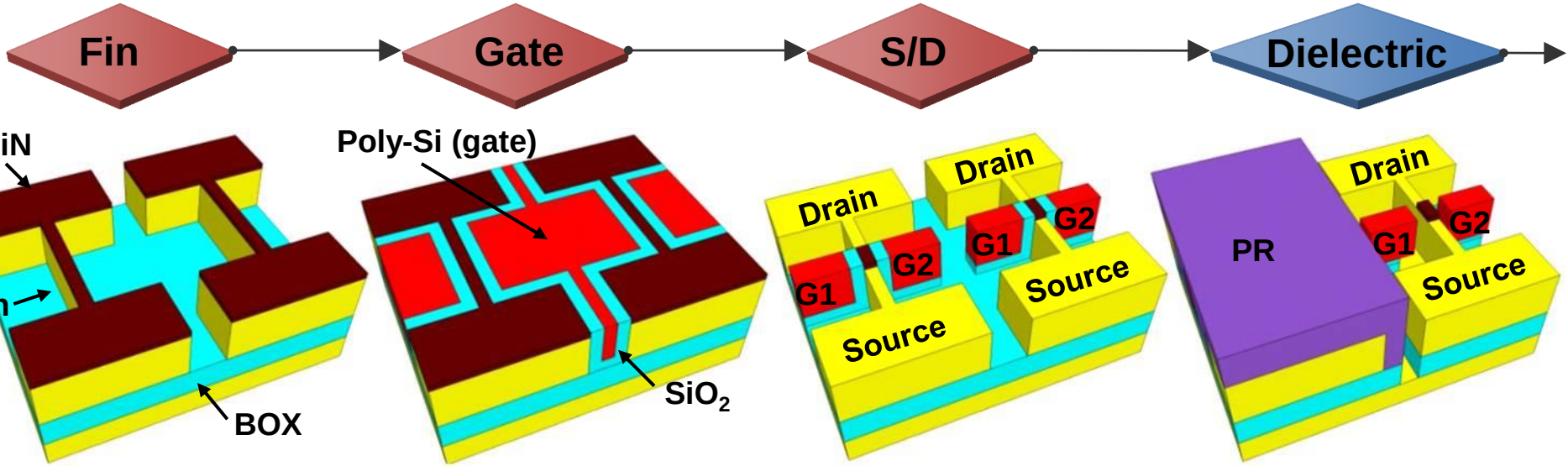


TEM/SEM Images





Monolithic Integration with IDG FinFET



- (100) 8” SOI Wafer
- Channel IIP
- SiN dep. (50nm)
- Fin formation (30nm)

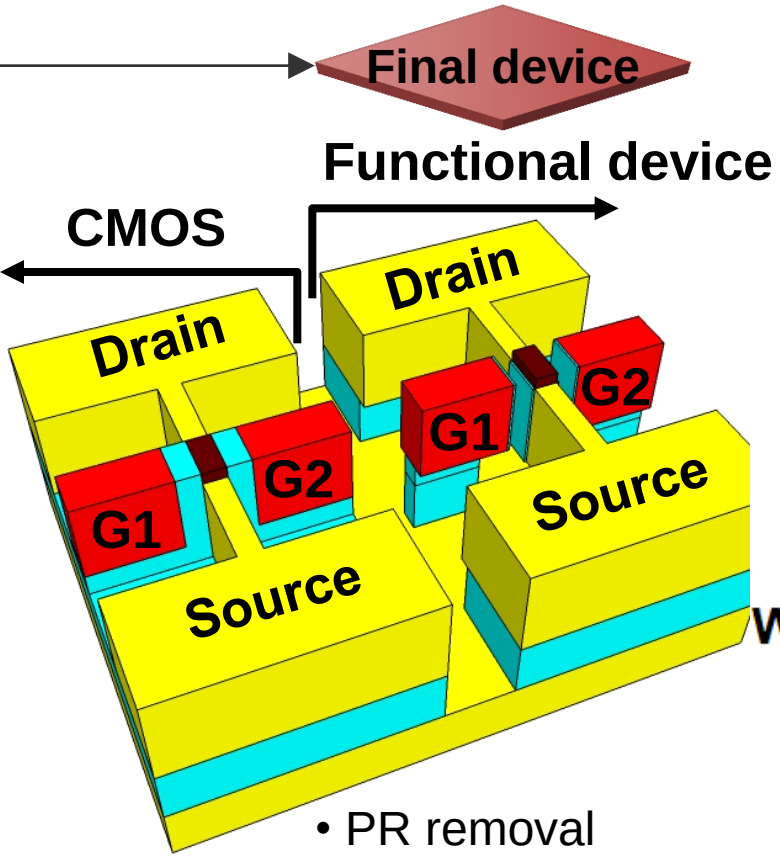
- SiO_2 depo. (20nm)
- Poly-Si depo. (100nm)
- Poly-Si CMP

- Poly-Si patterning
- S/D IIP
- Activation

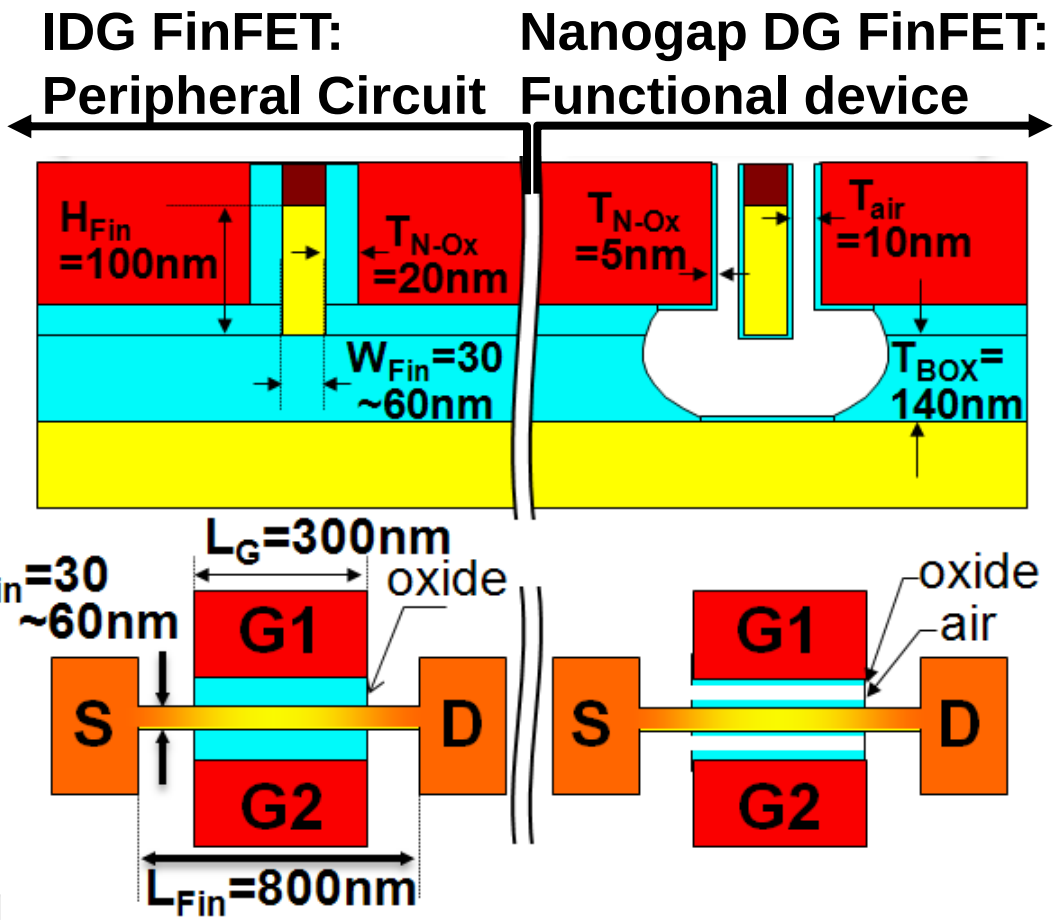
- PR shelding
- SiO_2 removal

*** 0.18μm CMOS foundry technology**

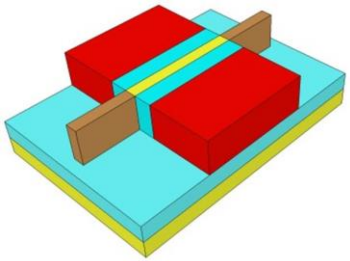
Monolithic Integration with IDG FinFET

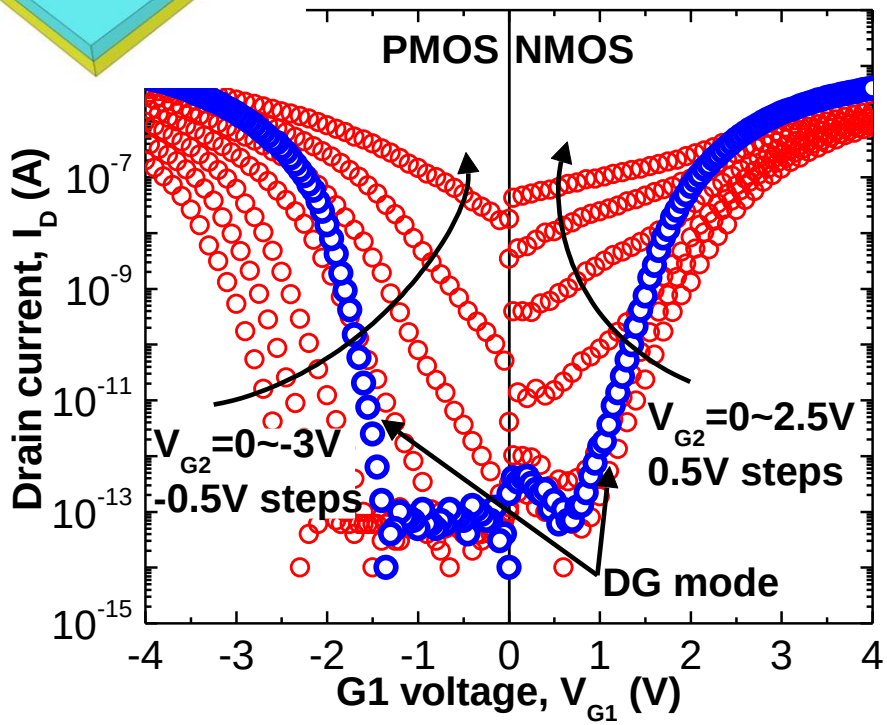


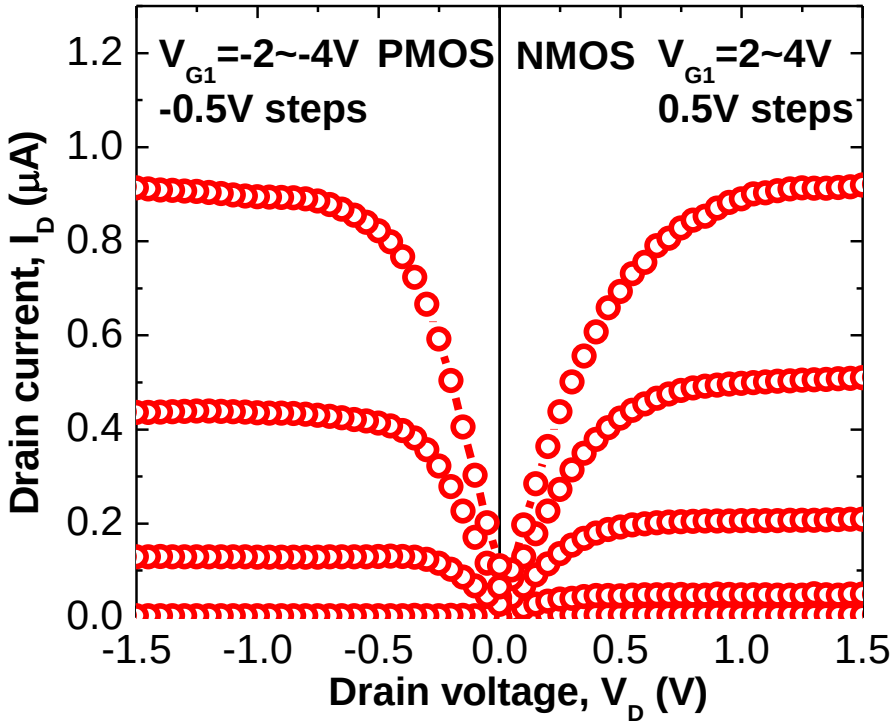
- PR removal
- Reoxidation
- Forming gas annealing



IV Characteristics of IDG FinFET





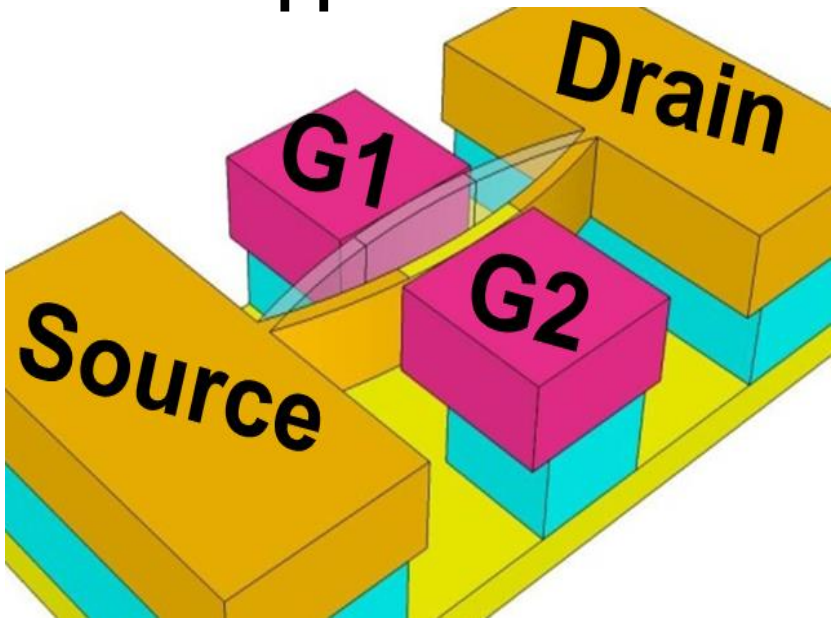


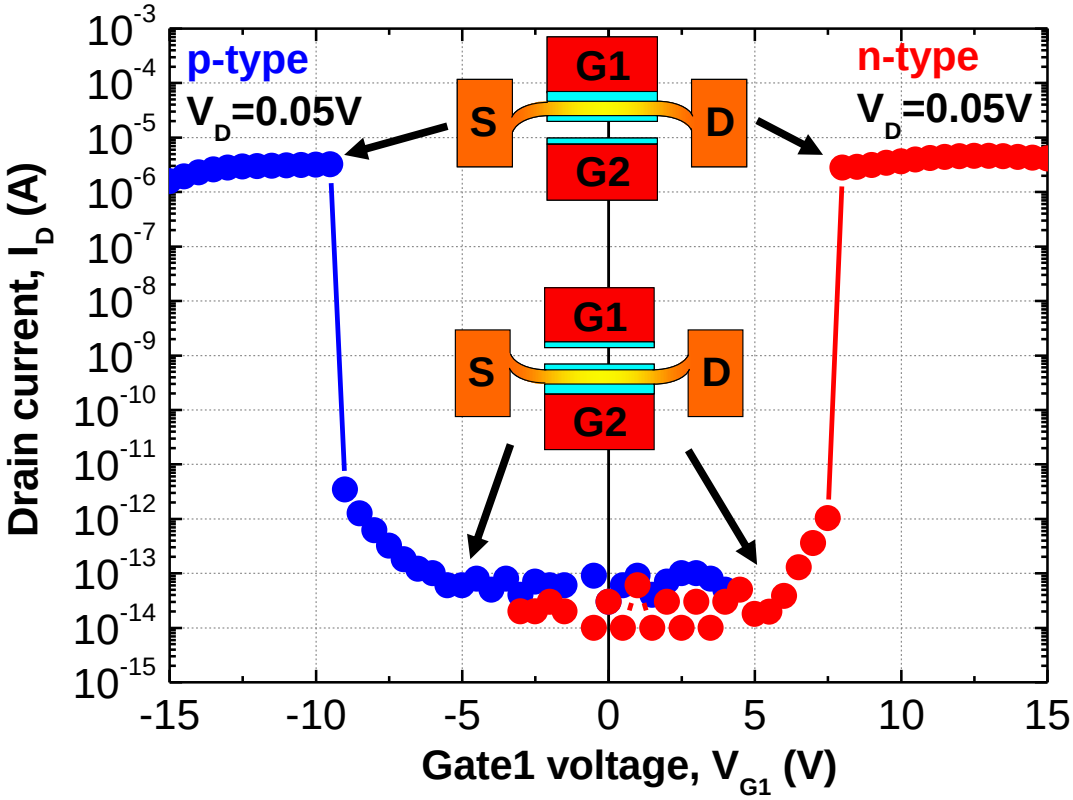
Back-gate factors of dV_T/dV_{G2} ~ 0.66 at W_{Fin} = 30nm

New NEM Switch – FinFACT*

(Fin Flip-flop Actuation Channel Transistor)

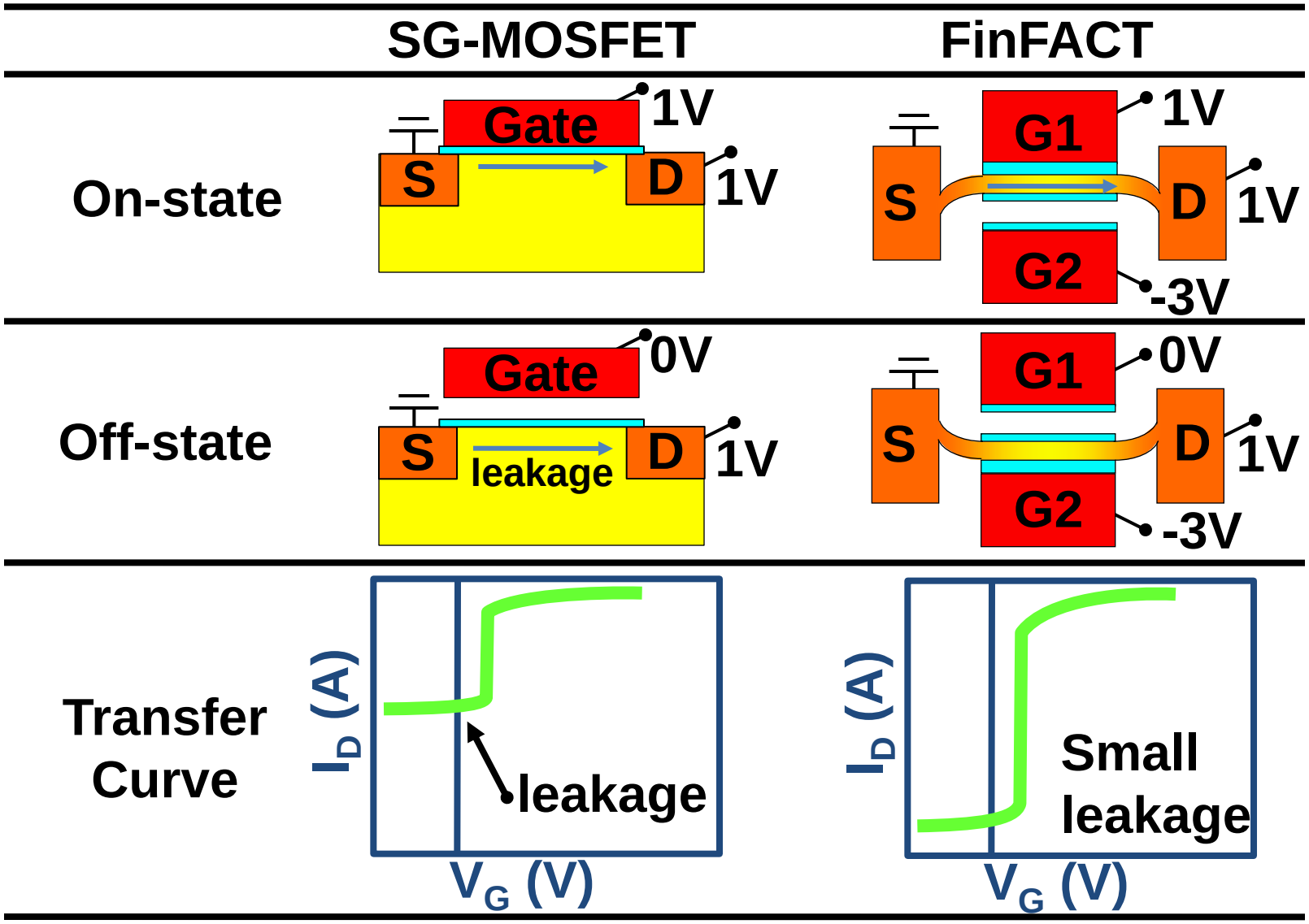
- **Fin : lateral flip-flop**
- **G1 : driving electrode**
- **G2 : supportive electrode**



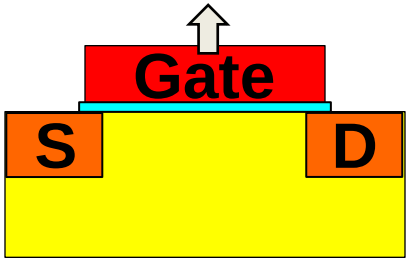
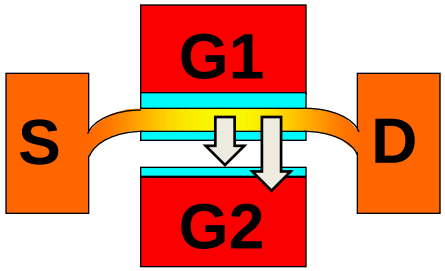


* J.-W. Han *et al.*, IEEE Electron Device Letters, Jul. 2010

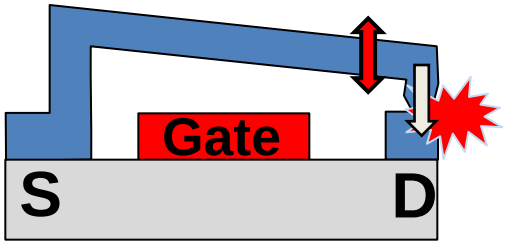
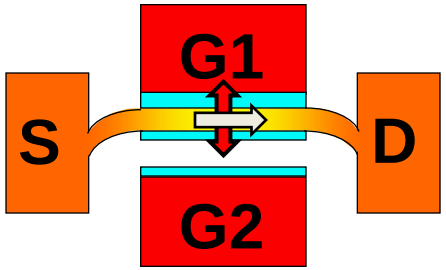
Comparison with SG MOS: Off-current



Comparison with SG MOS: Pull-off

	SG-MOSFET	FinFACT
On-state		
Restore (pull-off) source	Elastic force of gate	1) Elastic force of fin 2) Electrostatic force → Stiction immunity
Actuation	Out-of-plane (vertical)	In-plane (lateral)
Spring factor	Gate thickness (single k*)	Fin width (multiple k*)

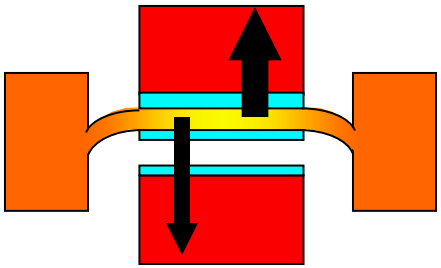
Comparison with Cantilever: Reliability

	Cantilever FET	FinFACT
On-state		
Actuation	↕	↕
Current flow	↓	→
Direction of actuation & current flow	Coupled	Decoupled
In-use stiction	Arc welding & Joule heating	Free of arc & Joule heating

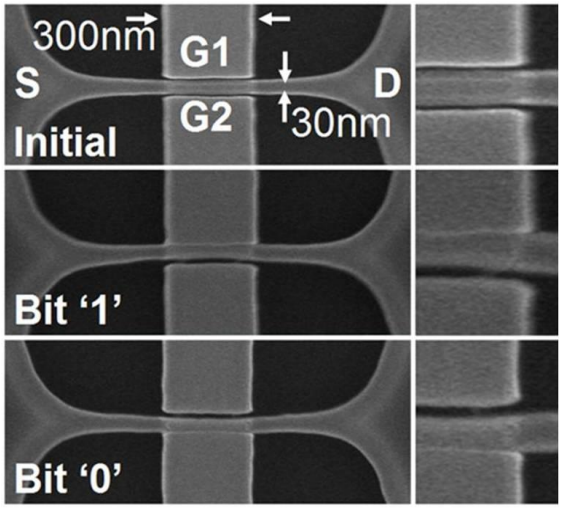
Ultra Low Power Nonvolatile Memory

Retention of Mechanical State

Surface Adhesion
: Van Der Walls



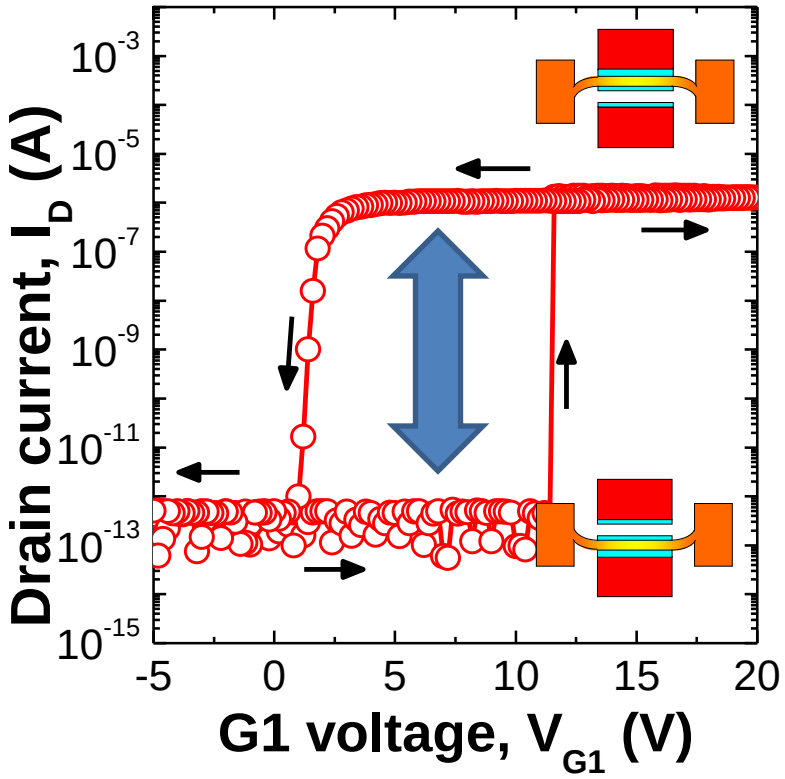
Restoration
: Elastic



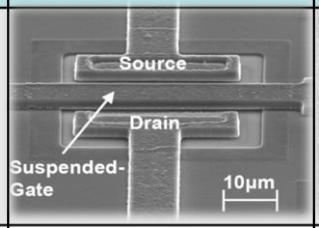
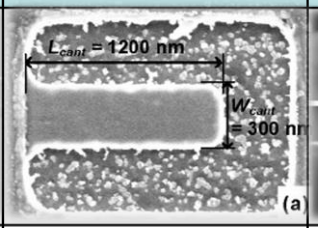
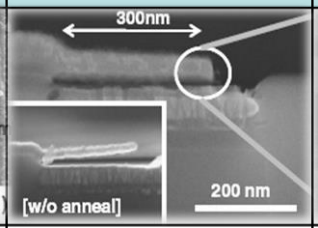
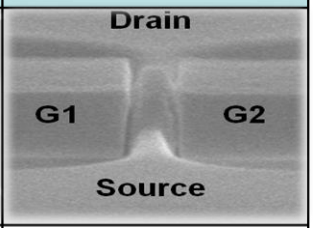
If, fin is narrow enough,
adhesion force > Elastic force

$$F_{Spring} = kx, \quad k = 16E_Y H_{Fin} (W_{Fin} / L_{Fin})^3$$

Hysteric I-V Curves



Comparison of NEMS Memory

	SG MOSFET (IEDM 2006) EPFL	NEMORY (IEDM 2007) Berkeley	Cantilever (APL 2008) KAIST	FinFACT (IEDM 2009)
Image				
Material	AlSi (1%)	Al	TiN	Si
Beam thickness (nm)	18000	100	35	30, 40, 50, 60
Dimension (nm X nm)	34000 X 6000	1200 X 300	200 X 300	100 X 300
Gap width (nm)	40	30	15	10
Sensing window(A/A)	$< 10^4$ (High off-leakage)	$<10^5$ (low on-current)	$<10^5$ (low on-current)	$>10^7$
Retention in air (sec)	~ 10^4	N. A.	10^3	~ 10^4
Endurance (#)	$>10^5$	< 10	10^5	10^4
Operation Voltage (V)	10	5	25	12
Issue	Pull-off	Welding	Welding	Mechanical Stability