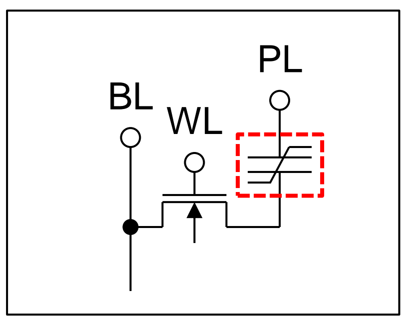
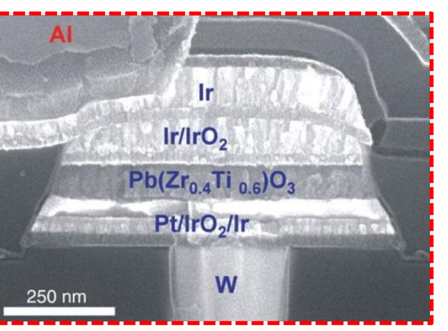
FeFET Memory: (e)NVM for Advanced Technology Nodes

Dr. Stefan Müller (Ferroelectric Memory Co.)

FeFET is not FRAM!

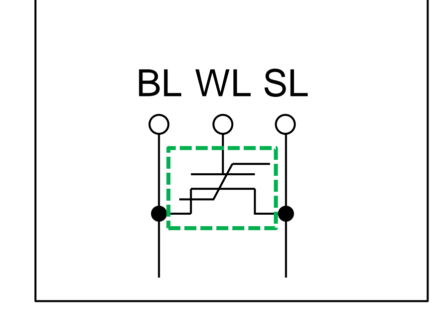
What I am **not** going to talk about:
Classical 1T-1C **FRAM**

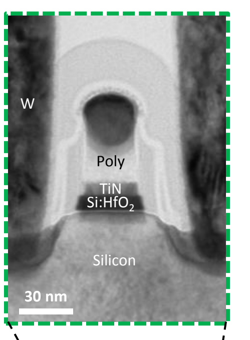




- 1T-1C memory cell
- Exotic ferroelectric materials (PZT)
- Stuck at 130 nm

What I **am** going to talk about:
Novel 1T **FeFET**





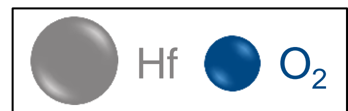
Source: S. Mueller, EMF, 2015.

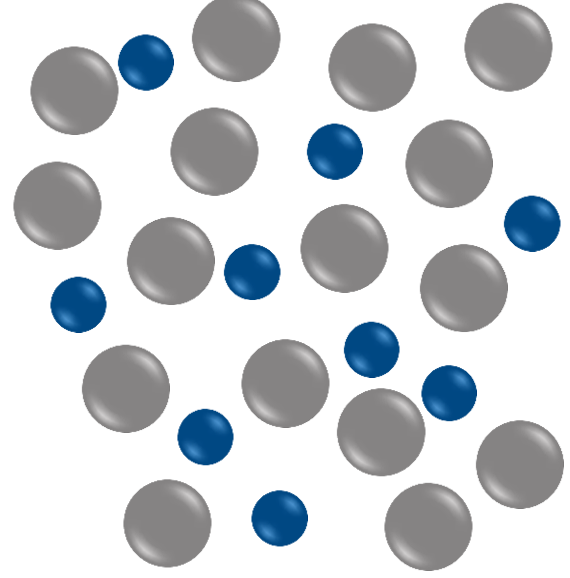
- 1T memory cell
- Ferroelectric HfO_2
- In dev. at 22 nm

to actual scale...

THE enabler for FeFET!

Ferroelectric HfO_2

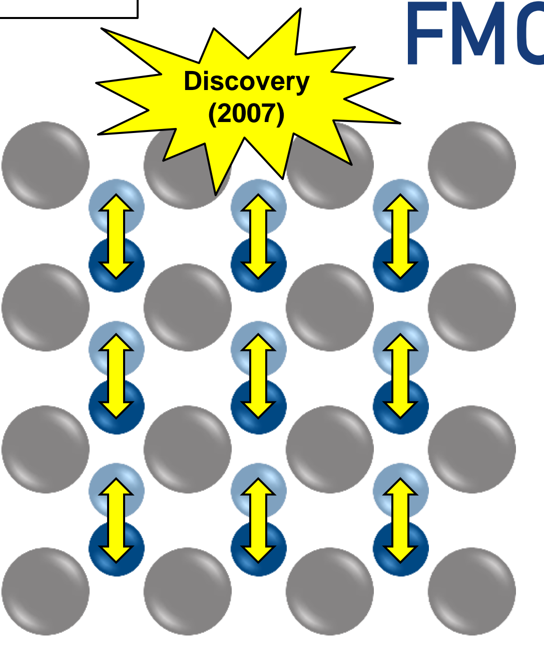




Amorphous (unordered) HfO_2
(used in **CMOS** gate stack)

Crystalline (ordered) HfO_2
(used in **DRAM** capacitor)

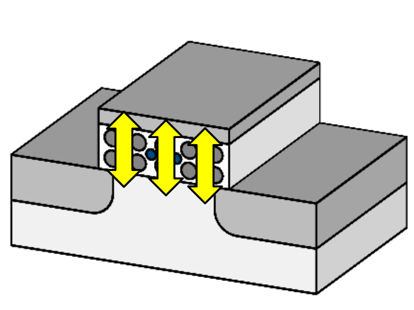
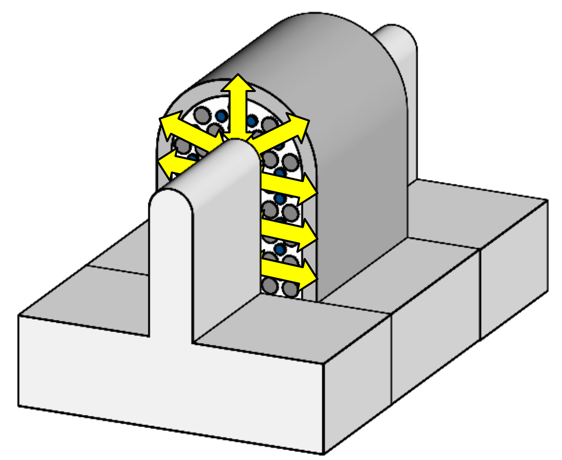
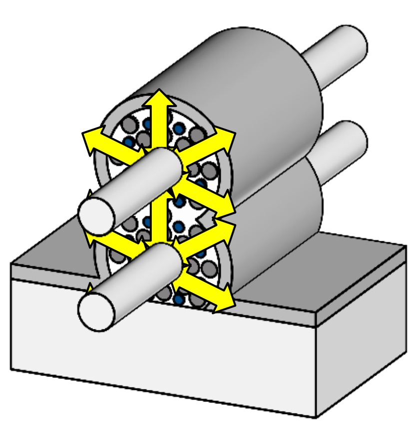
*Actually ZrO_2 but chemically almost identical



Ferroelectric HfO_2

2 atom positions = 1 Bit!
(Patented)

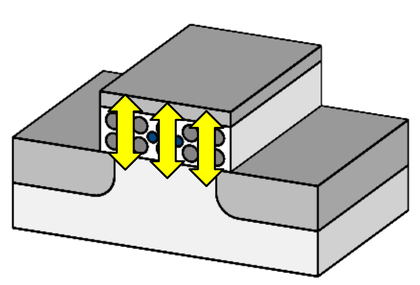
Why it matters

Planar transistor (> 20 nm)	Fin-transistor (20 nm – 7 nm, today)	Nanowire-transistor (< 7 nm, future)
		

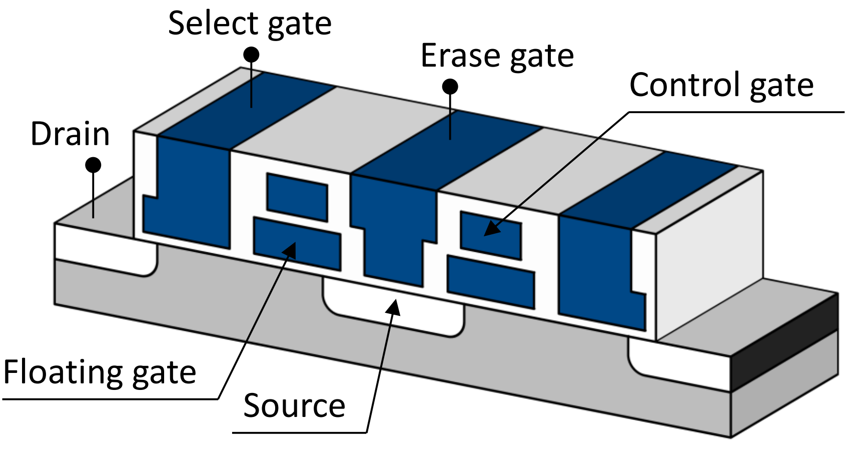
We transform any logic transistor into a memory cell! (2 threshold voltage states)

FeFET vs. eFlash

FeFET:



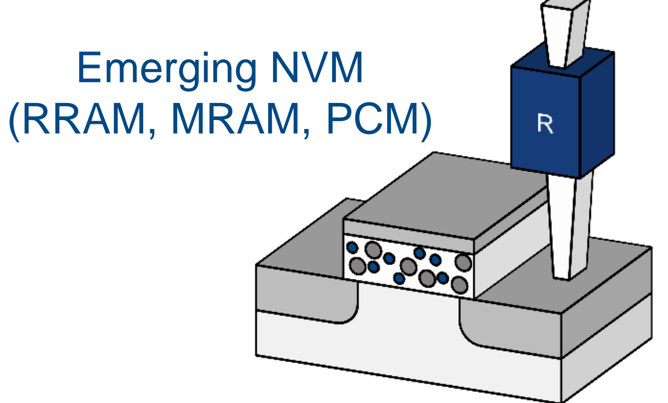
eFlash (2 bit):



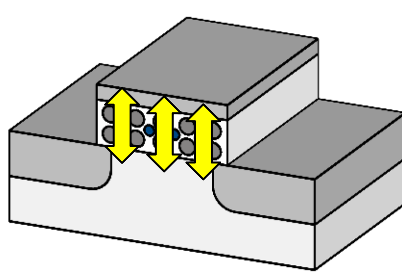
- 2 additional masks
- Write voltage 2V … 4V
- Write by gate voltage only

- 15+ additional masks
- Write voltage > 10V
- Write by channel current flow (HCI)

FeFET vs. emerging NVM



The FeFET solution



Challenges:

- **Additional memory element R adds cost!**
- Higher power consumption
- Questionable scalability

FeFET benefits:

- Reduces manufacturing cost significantly
- Lowers power consumption by 1000x
- Inherently scalable alongside CMOS

Technology status

	FeFET array (IEDM ‘16 & ‘17)	Lab capacitor	Theory
Cell size	$44F^2$ (0.035 μm^2) planar AND-type	> 10.000 μm^2	< $4F^2$ (3D)
Write speed	10 ns	10 ns	< 1 ns
Read speed	20 ns (limited by design)	10 ns	< 1 ns (architecture)
Endurance	10^5 cycles	> 10^{10} cycles	Unlimited
Retention	250° C / 7 days (0.28 μm^2 cell)	10y at 125° C extr.	10y at > 175° C
V_{write}	4 V	1.5 V	~ 1V
Write energy	< 1fJ (per bit)	< 1fJ (per bit)	Below fJ
Mask set adder	2	NA	1
Tool capex	**No**	**No**	**To be discussed**
Solder reflow	Yes	Yes	Yes

Impact on memory landscape

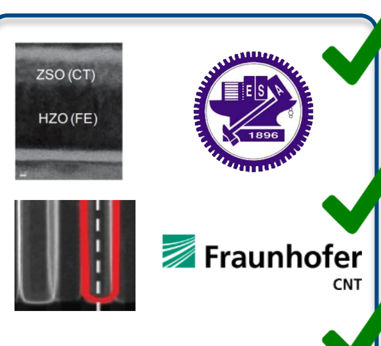
FE-HfO_2-based: | Proof-of-concept | Arrays / circuits | Qualification | Product

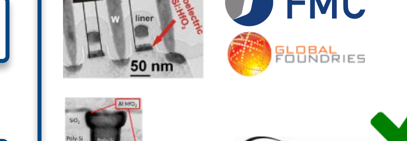
SRAM/DRAM

FRAM

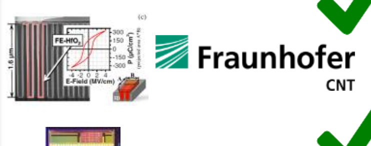
eNVM

SSD / SCM

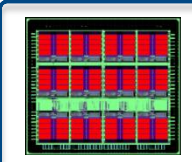




DRAM vendors / foundries / IDMs



DRAM vendors



3D NAND vendors

Thank you!

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