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Intel's High-k/Metal Gate Announcement
November 4th, 2003

What are we announcing?

- Intel has made significant progress in future transistor materials
- Two key parts of this new transistor are:
  - The gate dielectric consists of a “high-k” material
  - The gate electrode is made of metal
- Intel has succeeded in integrating these innovations and creating transistors with *record-setting performance*, and with dramatically reduced current leakage
- Intel believes that high-k/metal gate can be implemented in the 45nm manufacturing process, to be in production in 2007

Continuation of Moore's Law

Process Name	P856	P858	Px60	P1262	P1264	P1266	P1268	P1270
1st Production	1997	1999	2001	2003	2005	2007	2009	2011
Process Generation	0.25µm	0.18µm	0.13µm	90 nm	65 nm	45 nm	32 nm	22 nm
Wafer Size (mm)	200	200	200/300	300	300	300	300	300
Inter-connect	Al	Al	Cu	Cu	Cu	Cu	Cu	?
Channel	Si	Si	Si	Strained Si	Strained Si	Strained Si	Strained Si	Strained Si
Gate dielectric	SiO_2	SiO_2	SiO_2	SiO_2	SiO_2	High-k	High-k	High-k
Gate electrode	Poly-silicon	Poly-silicon	Poly-silicon	Poly-silicon	Poly-silicon	Metal	Metal	Metal

Introduction targeted at this time

Subject to change

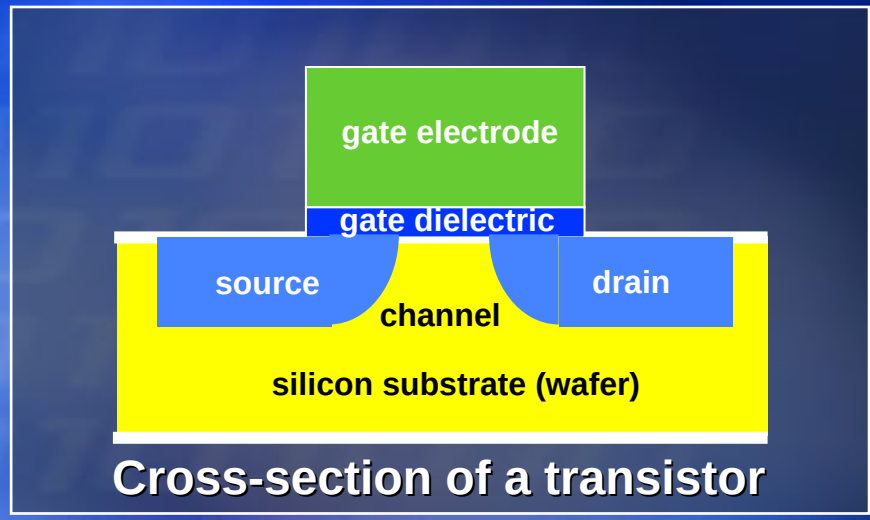
Intel found a solution for High-k and metal gate

Why is this important?

- These steps are necessary if transistors are to continue shrinking and delivering better performance, while containing power consumption
- Many others have been working on the same problem for some time, but no company is as far along as Intel
- These steps will enable the continuation of Moore's Law, ultimately leading to vast, lower cost computing power and enabling applications that cannot even be imagined today

What is a transistor?

- A simple switch
  - Current flows from source to drain when gate is at certain voltage; otherwise, it doesn't flow (the gate's voltage is analogous to the position of a light switch)



Cross-section of a transistor

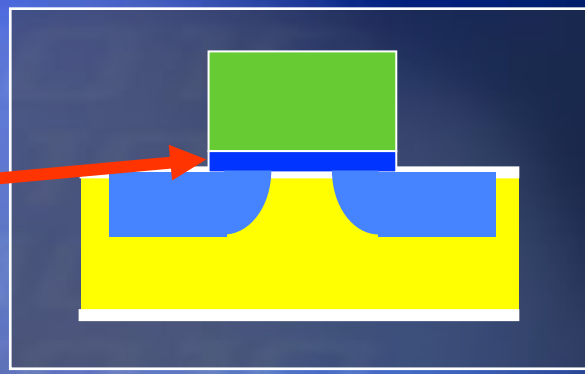
- NMOS* transistors are *on* when gate is at high voltage; PMOS transistors are *on* when gate is at low voltage
- Objective in transistor design: Make them smaller, faster, cheaper and less power-hungry

*CMOS (Complementary Metal Oxide Semiconductor) consists of NMOS (negative) and PMOS (positive) transistors

Fundamental component of all logic chips

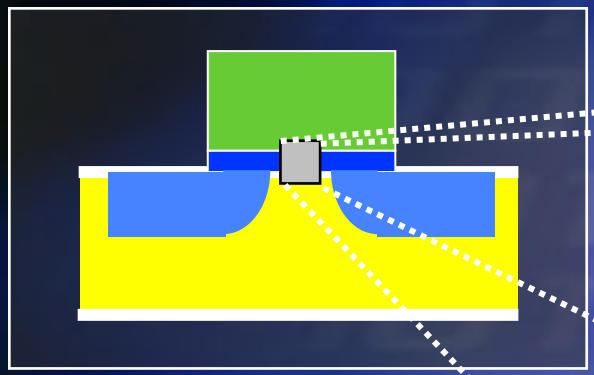
What's the problem as transistors are made smaller?

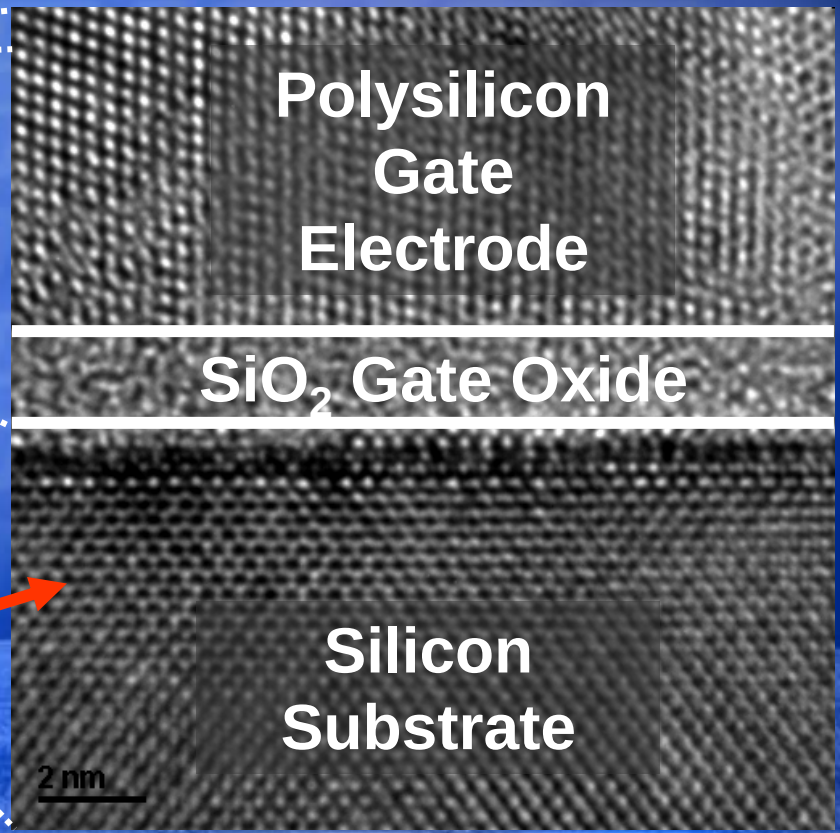
- **Smaller transistors are faster and cheaper, but …**
  - **Gate dielectrics, traditionally made with Silicon Dioxide (SiO_2), are only a few atomic layers thick**
- **SiO_2 is ideally an insulator, but at this thinness, current leaks through**
  - ***Think of a faucet that drips when it should be off***



A new material is needed to reduce leakage

Gate dielectric today is only a few molecular layers thick





Individual Atoms

Seeking new materials to drive Moore's Law

"SiO_2 is at the very heart of the transistor, and replacing it is like performing a heart transplant," said Robin Degraeve, a researcher at the Interuniversity Microelectronics Center (IMEC) based in Leuven, Belgium.
EE Times. 4/8/03, "High-k insulators line up at the gate"

"**Failure to address leakage current could make the problem the big stumbling block to Moore's Law**. Today's approaches to the problem are only getting the industry half way home, and the solutions to handle the rest of the job haven't been invented yet," University of Tokyo professor Takayasu Sakurai told the International Solid-State Circuits Conference in a keynote address.
EE Times. 2/10/2003, "Leakage current called obstacle to chip complexity"

"As the scaling of classical bulk Si CMOS transistors approaches its fundamental limits, **innovative device structures and new materials must be considered** to continue the historic progress in information processing and transmission."
IEEE Electron Device Letters, Vol. 23, No. 8, August 2002: "Germanium MOs Capacitors Incorporating Ultrathin High-k Gate Dielectric"

"**High-k is a very tough problem**," he [Bijan Davari, vice president of tech development at IBM Microelectronics] said. "People have started working on it, but not enough attention has been paid to it. Silicon dioxide is this amazing material, the interface with silicon is so good, it will take more time to develop alternatives."
EE Times, 6/11/02, "Technologist sketches IBM's silicon road map"

Power issue is huge - industry recognizes that high-k is needed

What is High-k?

- The industry is searching for an SiO_2 replacement
  - Intel has led SiO_2 gate oxide scaling for over a decade
- This material should be thicker (to reduce leakage) but should have a high "k" value
  - "k", the dielectric constant of a material, relates directly to the transistor's performance
  - *When the faucet is turned on, water should gush out*

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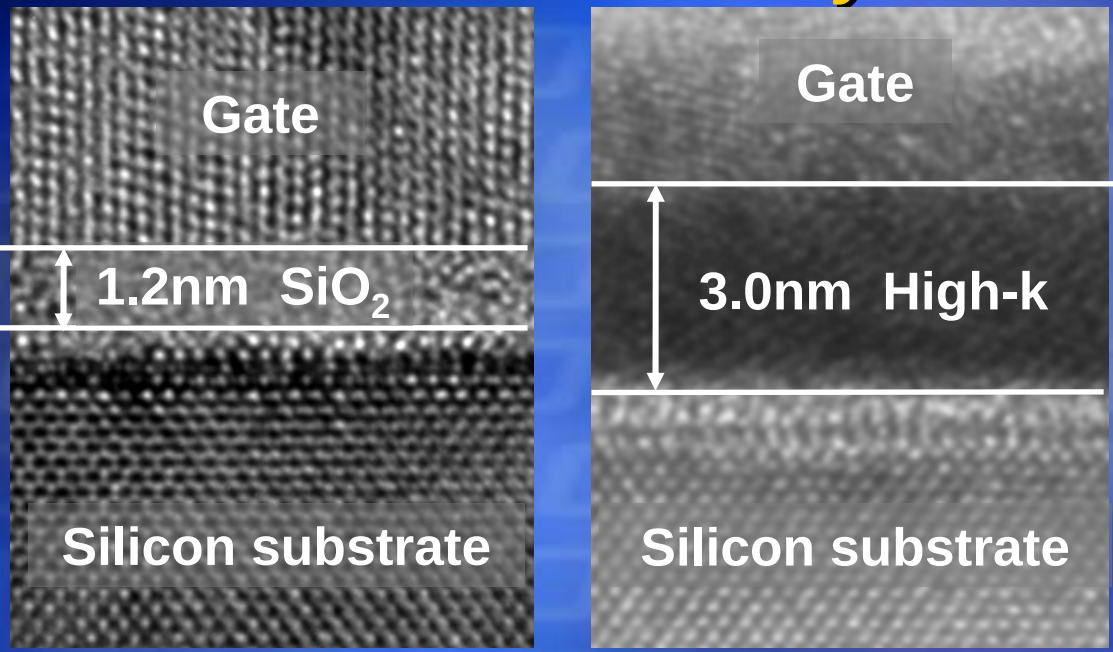
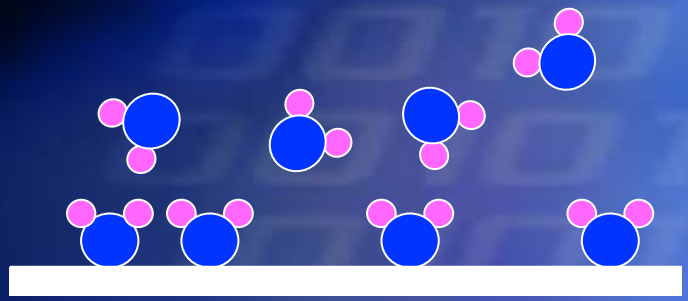
High-k Dielectric reduces leakage substantially



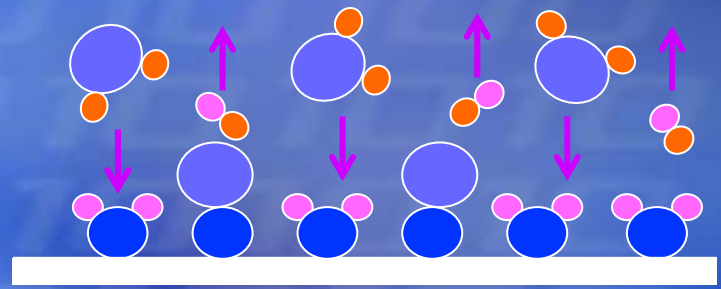
Benefits compared to current process technologies

	High-k vs. SiO_2	Benefit
Capacitance	60% greater	*Much faster transistors*
Gate dielectric leakage	> 100x reduction	*Far cooler*

High-k Materials Require New Manufacturing Techniques



Step 1



Step 3

Step 2

Step 4

High-k Materials Are Deposited One Molecular Layer at a Time

What's so hard about using high-k?

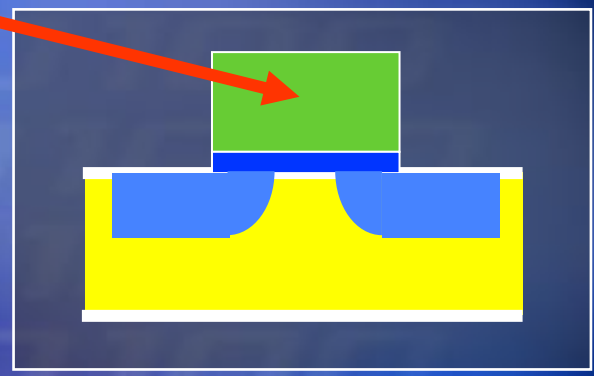
Replacing SiO_2 with high-k materials leads to two problems due to interaction with the polysilicon gate electrode:

1. **Threshold voltage pinning – defects that arise at the gate dielectric / gate electrode boundary cause the voltage at which the transistor switches to be too high**
2. **Phonon scattering – electrons are made less mobile (they slow down)**

Both of these problems limit the transistor's switching speed

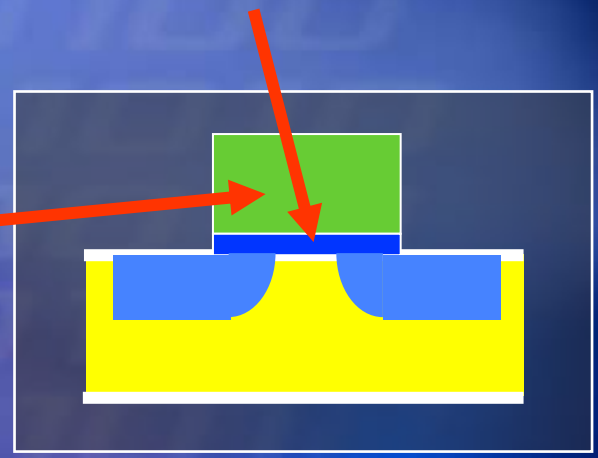
Solution: Use Metal Gates

- Conventional gate electrode is polycrystalline silicon
- By using a specific metal for NMOS transistors, and a different one with PMOS transistors, and combining with a specific process recipe, the two problems go away
- With this combination, Intel has achieved record performance with a transistor design that can scale according to Moore's Law



Intel's Announcement

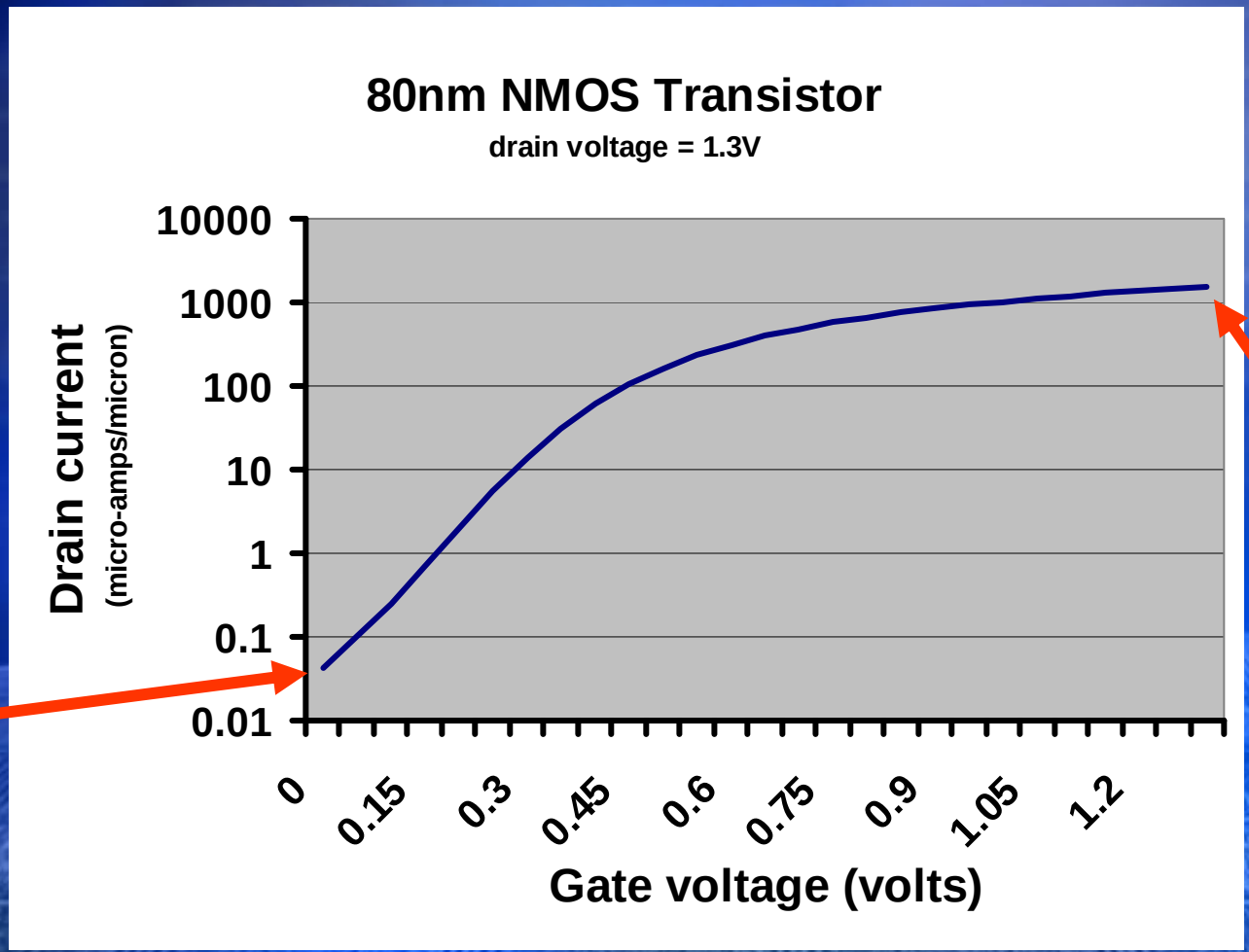
- Intel is announcing that after 5 years of research, it has found the right high-k material
- Intel has also identified compatible gate electrode materials for both NMOS and PMOS



- Intel has succeeded in integrating these and has achieved record transistor performance

Moore's Law continues

High-K + metal gates = Transistors with Excellent Characteristics



Very low leakage when OFF

Very high drive current when ON

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Summary

- Intel researchers have removed the industry's most challenging roadblock to ensuring Moore's Law spans into the next decade, ultimately leading to vast, lower-cost computing power and enabling applications that cannot be imagined today
- The power and heat issue is huge and industry has been searching for solutions for a long time. Intel has solved a major part of the problem by integrating new materials into transistors.
- Intel has achieved world record performance at dramatically reduced leakage with its new transistor
- Intel is on track to put this new transistor design into production in 2007

Moore's Law continues

Additional details on Intel's high-K/metal-gate transistors were presented at the International Workshop on Gate Insulator 2003 in Tokyo, Japan on Nov 6, 2003 by Robert Chau, Intel Fellow

For further information on Intel's silicon technology, please visit the Silicon Showcase at www.intel.com/research/silicon