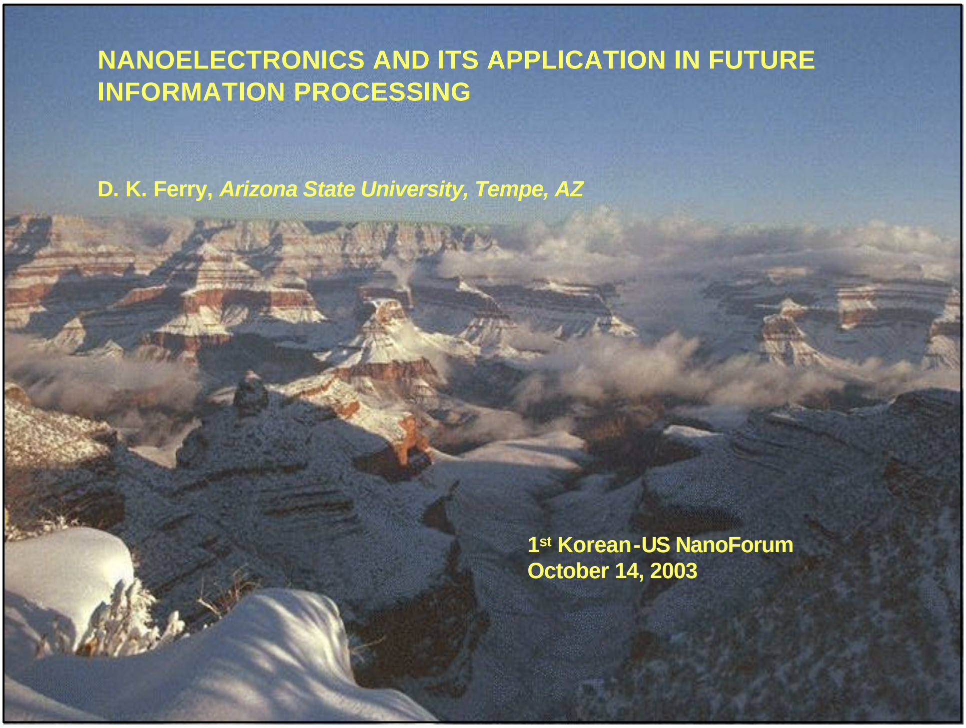

NANOELECTRONICS AND ITS APPLICATION IN FUTURE INFORMATION PROCESSING

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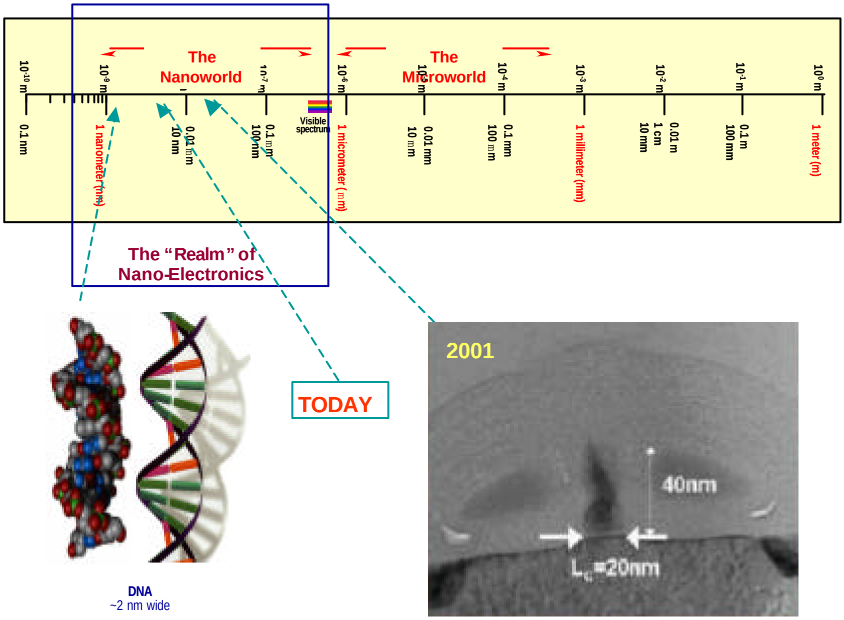
As is evident from the talk of Chau, and others, it is clear that semiconductor devices are becoming quite small—gate lengths of 5 nm or so have been made.

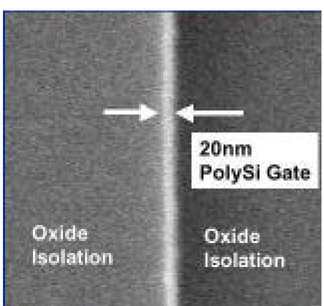
On the other hand, many suggestions have been made for novel structures, such as carbon nanotubes, to replace the CMOS transistor.

Here, we will talk about some limitations and barriers that will prevent this.

We then talk about the future for information processing. I will also give some simulation examples for the area.



Ultrasmall MOSFET
L_g ~ 20 nm



20nm polySi gate on oxide isolation *(Chau, Intel)*

20 nm critical sizes means that there are only about 80 atoms of the gate in the source-drain direction!

If Silicon is going to continue to this size scale, what limitations are there?

What options are there for novel new devices and/or quantum devices?

I will address this in the remainder of this talk.

What about some limitations?

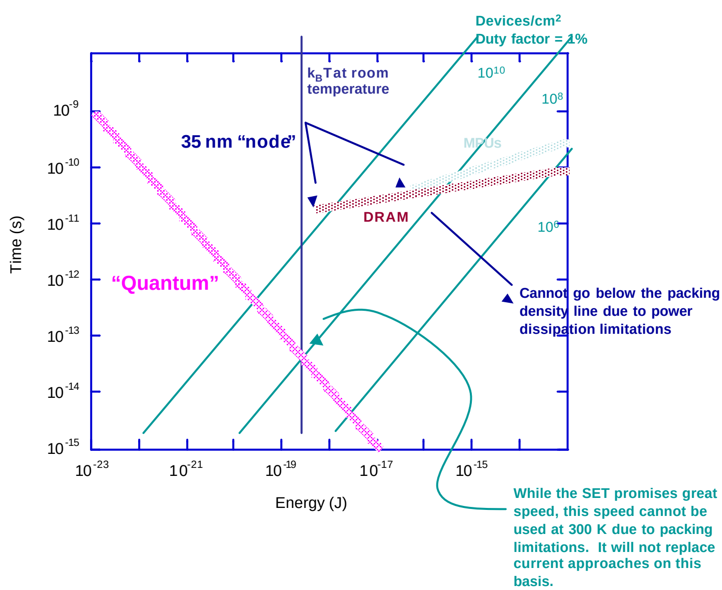
- There is a power limitation, in that Si can only dissipate on the order of 10 W/cm^2. If N is the number of devices per sq. cm., E is the energy required to switch, f is the frequency of the clock, and P is the probability that a switch occurs in each clock cycle, then

$$ENfP \leq 10$$

- The "quantum" limit, which also arises for SETs, comes from the Nyquist criteria

$$E / f \geq 100h$$

- Thermal limit of $E > k_B T$

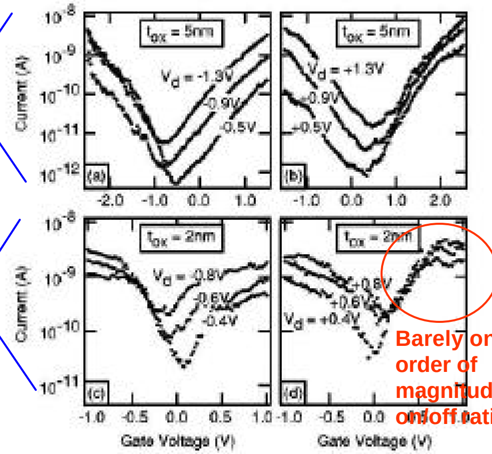


It is widely claimed that new, novel structures will replace Si transistors by doing the job of silicon better!

One such is the carbon nanotube (CNT). Consider one of the better versions, coming from a front-line research laboratory:

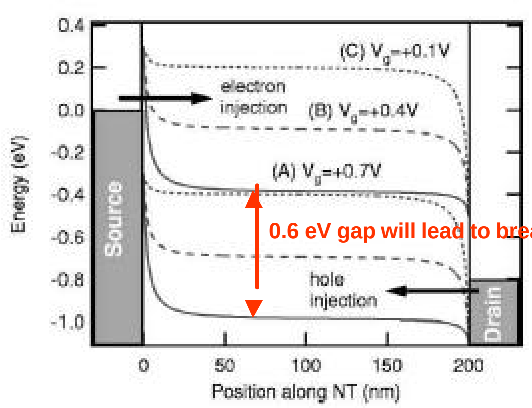
300 nm (S-D) tube

60 nm (S-D) tube



Barely one order of magnitude on/off ratio

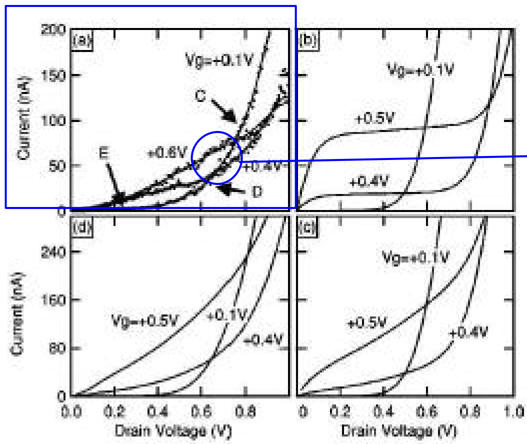
M. Radosavljevi? *et al.*, APL 83, 2435 (2003)



0.6 eV gap will lead to breakdown as well.

M. Radosavljevi? *et al.*, APL 83, 2435 (2003)

Experiment

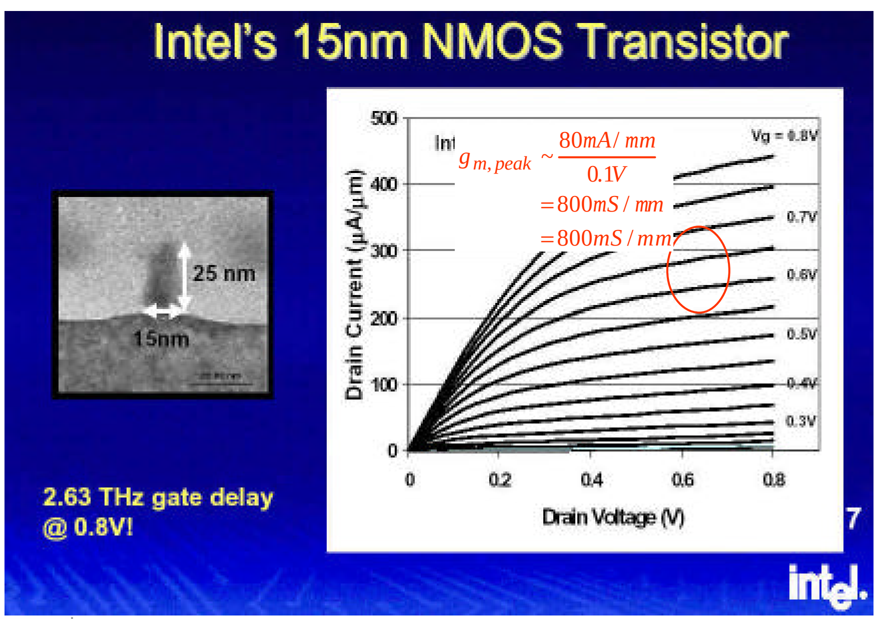


$$g_{m,peak} \sim \frac{30nA}{0.2V} = 150nA/V$$

A typical CNT has a diameter (or circumference) of say ~3nm:

$$g_{m,peak} \sim 50nS/nm$$
$$= 50mS/mm$$

M. Radosavljevi? *et al.*, APL 83, 2435 (2003)

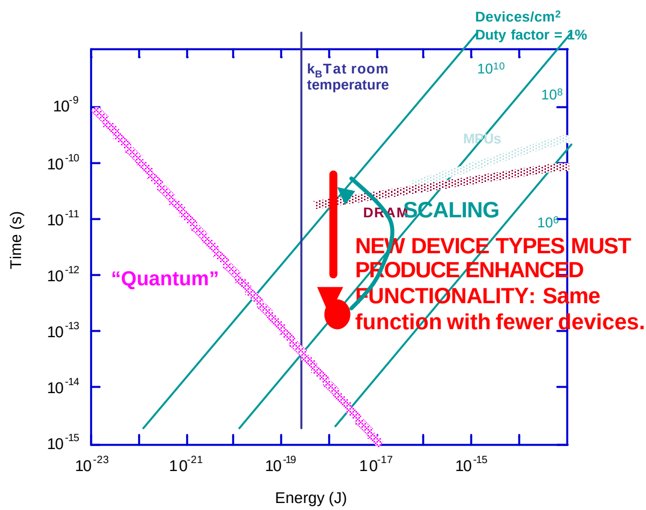


$$g_{m,peak} \sim \frac{80mA/mm}{0.1V}$$
$$= 800mS/mm$$
$$= 800mS/mm$$

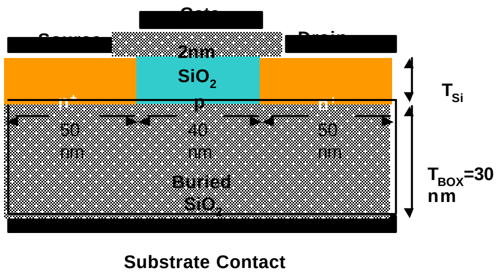
One does not give away transconductance!

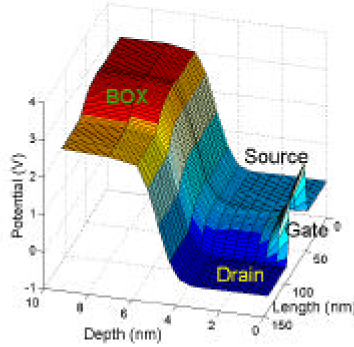
The ability to drive other gates is directly dependent upon the transconductance.

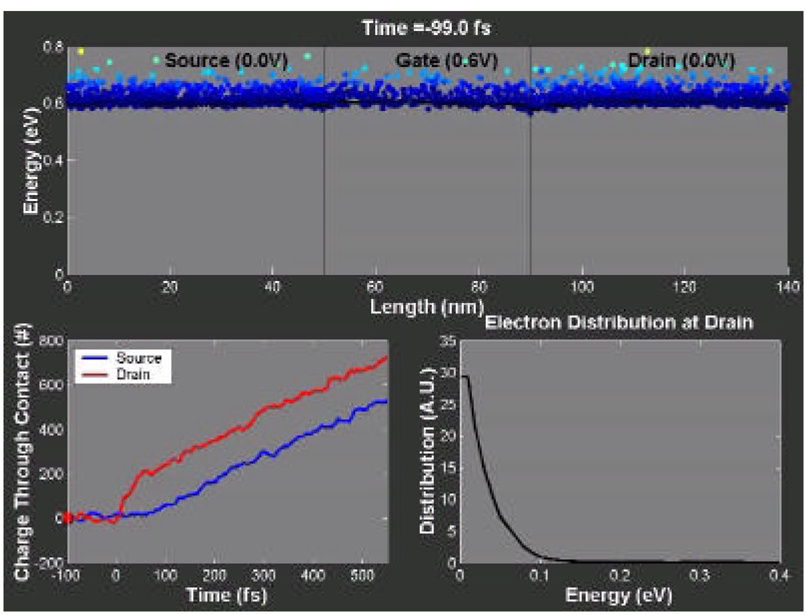
The MOSFET has more ~50 years of work in optimizing its performance. It performs excellently in its job, and is not likely to be replaced for this job!



SOI MOSFET Structure



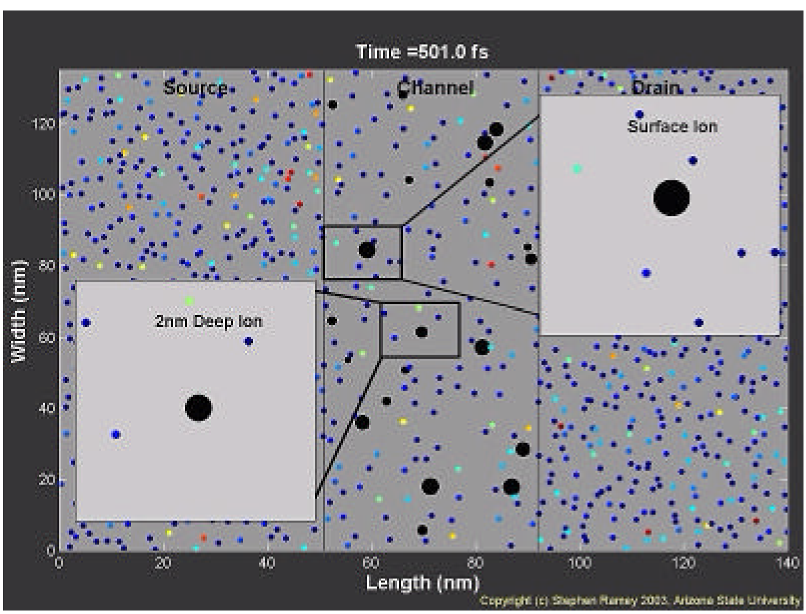




The discreteness of charge is now observable in these small devices:

We cannot use average densities any more, but must account for the exact position of impurities and individual atoms.

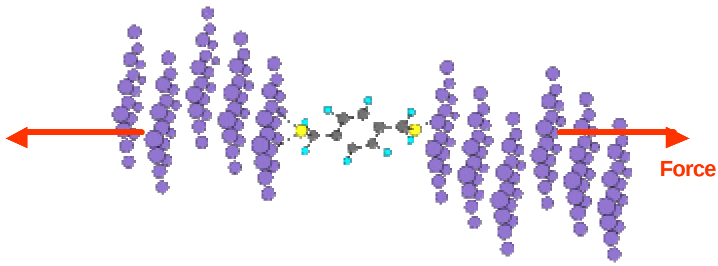
The inter-particle Coulomb interaction becomes extremely important in device operation and particle motion.

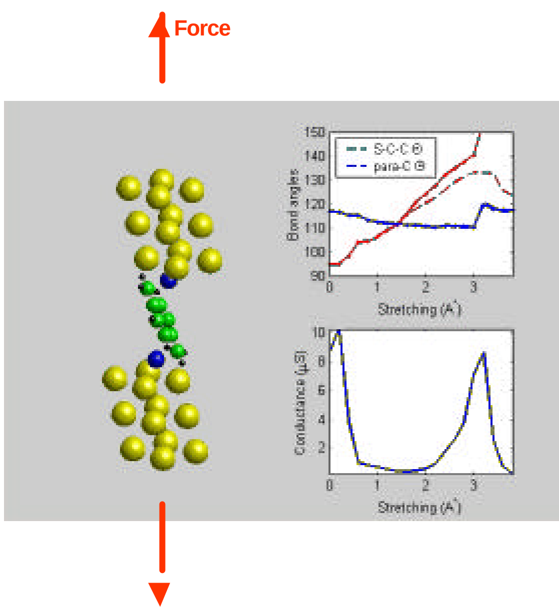


Nanostructures Research Group
CENTER FOR SOLID STATE ELECTRONICS RESEARCH

While it is not likely that MOSFETs will be replaced, for their applications, there nevertheless are many applications for which new structures, such as molecules, may provide new applications. One such is for organic LEDs, since the molecules are good at emitting in the blue end of the spectrum.

Here, we are studying transport through a metal-molecule -metal structure, using the techniques developed for semiconductor devices. The question we ask is how the conductance changes with stress on the molecule. The experiments are done by Tao *et al*. (ASU).





Conclusions:

It is unlikely that Si-based MOSFETs will be replaced in VLSI.

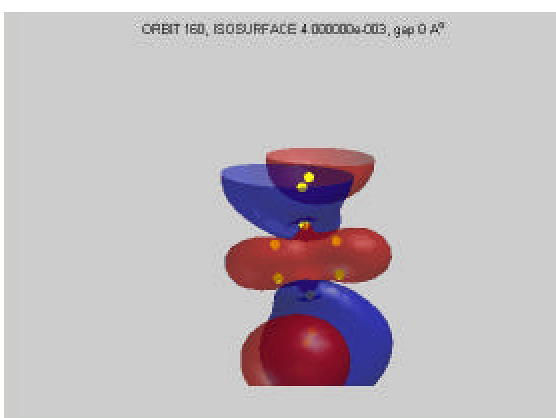
Novel transistors (CNTs, molecules, etc.) need to find new applications, for which the Si MOSFET is not a competitor.

While we have been focusing on trying to use simple molecules to make FETs, this is the wrong approach.

We need to enhance the functionality of each device.

We need to use the molecules to bridge the electronics —biology gap to make sensors for biological applications or for biological control.

HOMO Level



LUMO Level