CAM-I Meeting

Sunday, June 11, 2006

Business Management for High Technology Industries: Emerging Technology

Walt Trybula, Ph.D., MBA
Director & Senior Policy Fellow
w.trybula@tryb.org

Structure of Presentation

- **Background – the technologies**
- **Success and Failure**
  - Making hard decisions – terminating developmental efforts
- **Tale of Two Technologies – MEMS/NEMS**
- **Nano Technology**
- **Business Implications**

Background

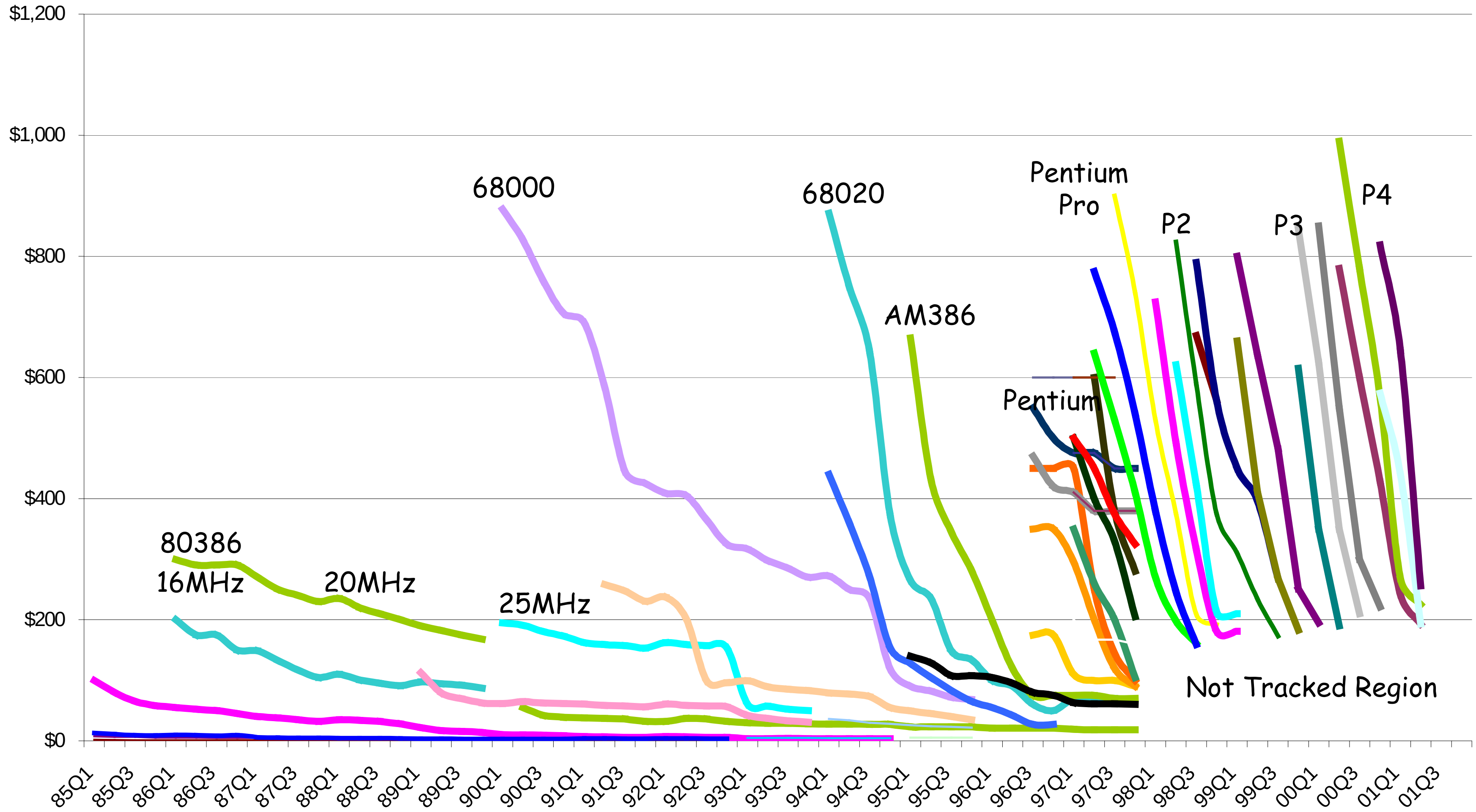
- **This is time of significant technology challenge**
  - The Semiconductor Industry has been on a phenomenal growth path for over 40 years.
  - MEMS/NEMS has been a promising industry for many years, but has not had the significant breakthrough application to make a mark with the business world.
  - Nano technology has acquired a mythical status of being able to be all things to all people, but apparently without substance.
- **The control of cost for the development of technologies into successful business opportunities will be the key.**
- **Technologies build on previous technologies. Nano will employ many tools from semiconductors just as MEMS does today.**
- **The ability to manage the technology development and the potential applications into successful products will be key to maintaining profitability for companies.**

Semiconductor Productivity

- **The semiconductor industry has invested at a uniquely prodigious rate the last 40 years to maintain a productivity improvement unprecedented in human history**
  – Doubling the number of transistors/bits available on a chip about every two years while reducing the cost of those transistors/bits ~30% annually

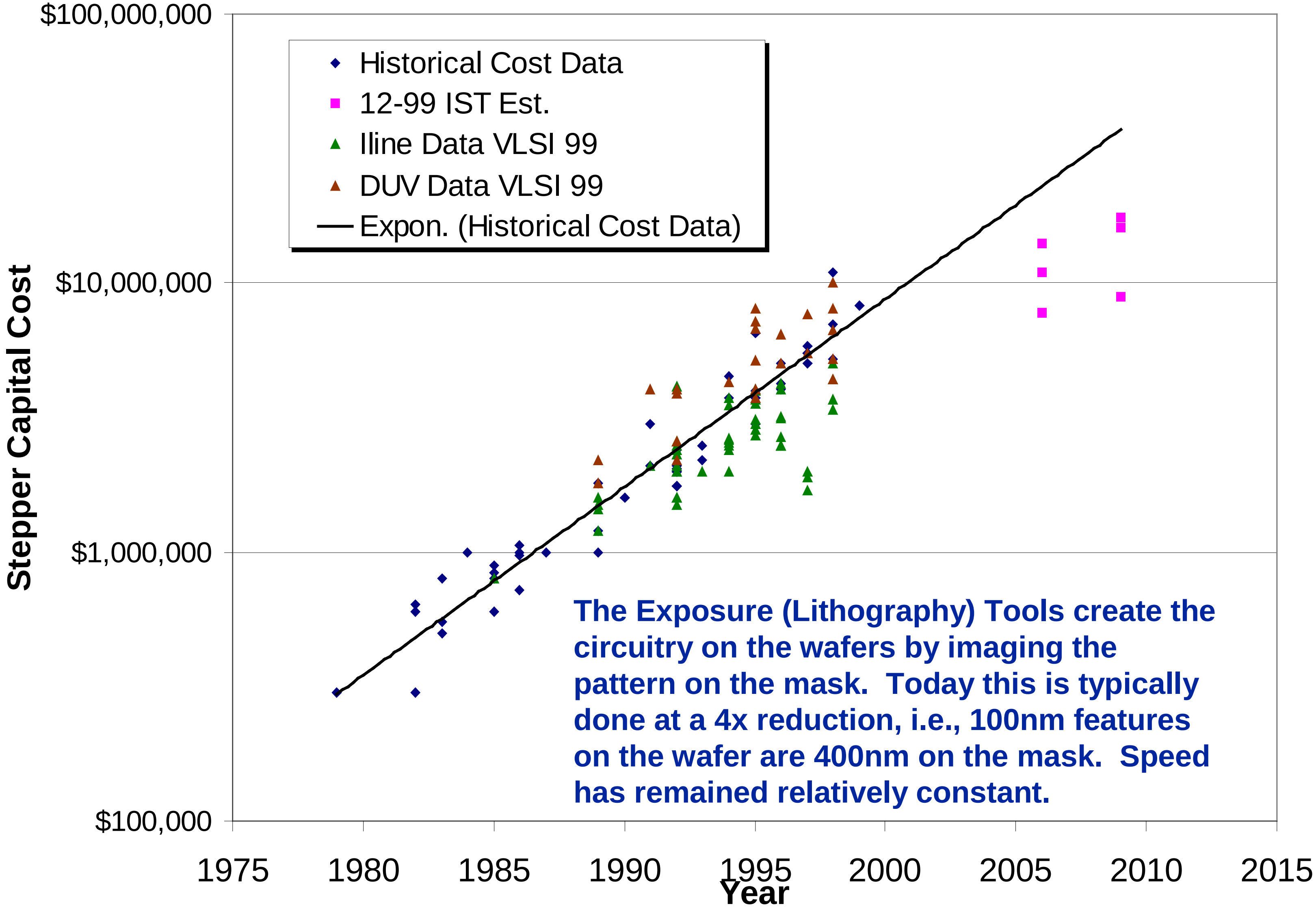
- **This amazing rate of productivity increase has enabled an improved standard of living in the US and the world in general**
  – Semiconductor improvements have also the basis for the continuous global superiority of the US military

Hyper-Competitive Industry
MPU Selling Price over Time



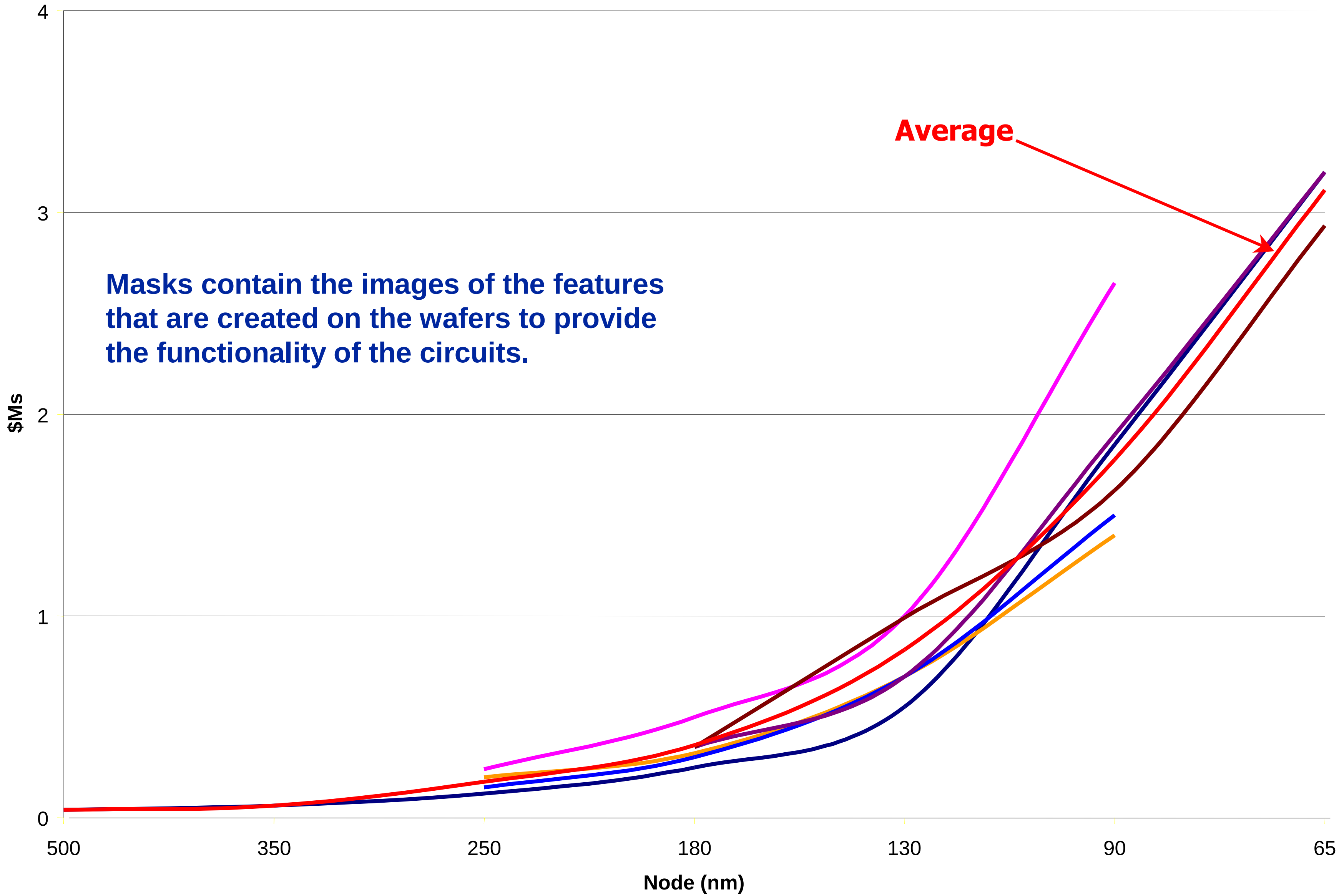
Based on information from DataQuest and MicroDesign Resources.

Exposure Tool Costs are Growing



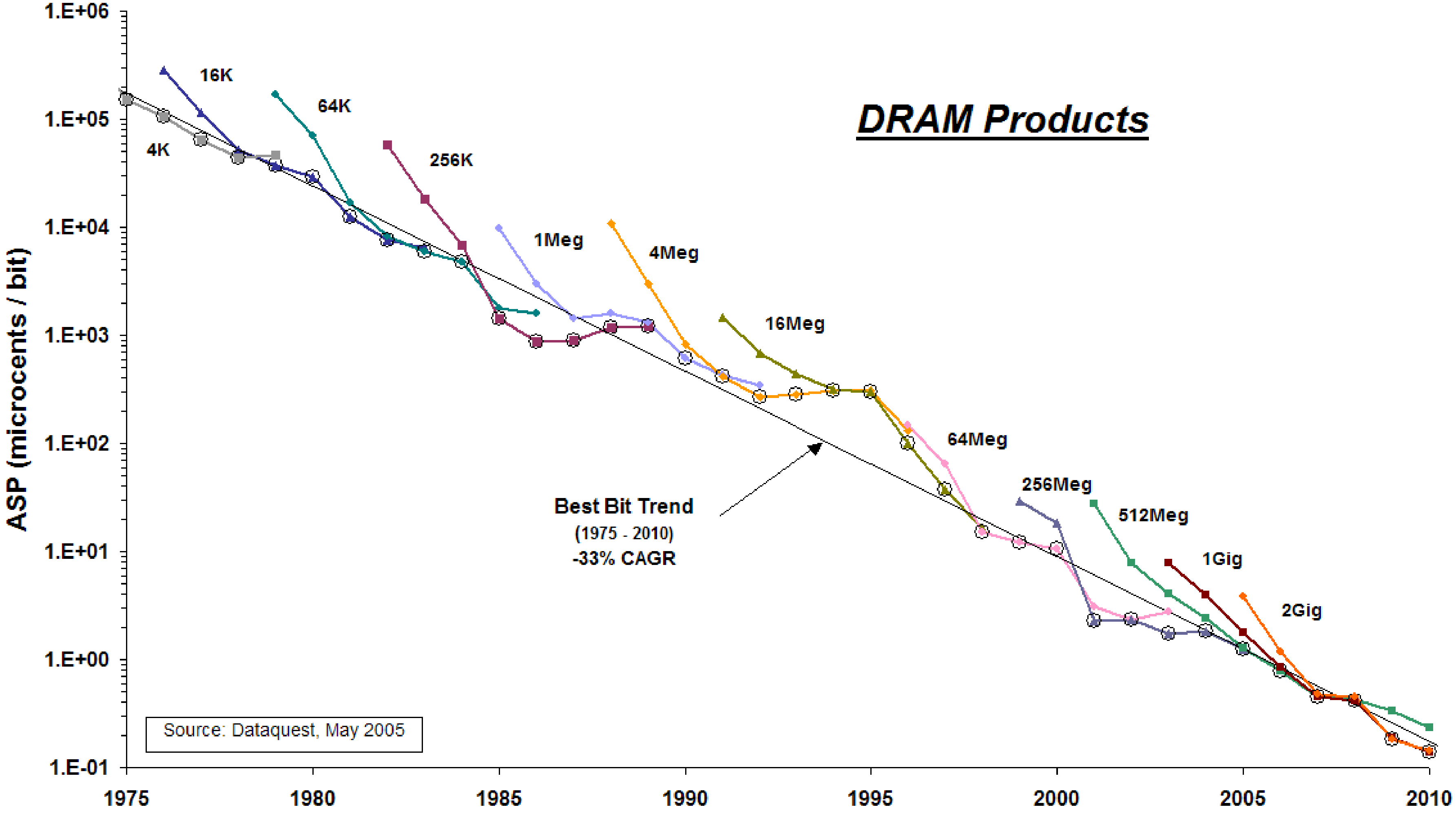
Based on Gene Fuller Data - ~2000

Mask Set Cost Projections – Also Upward



Productivity Sustains the Industry

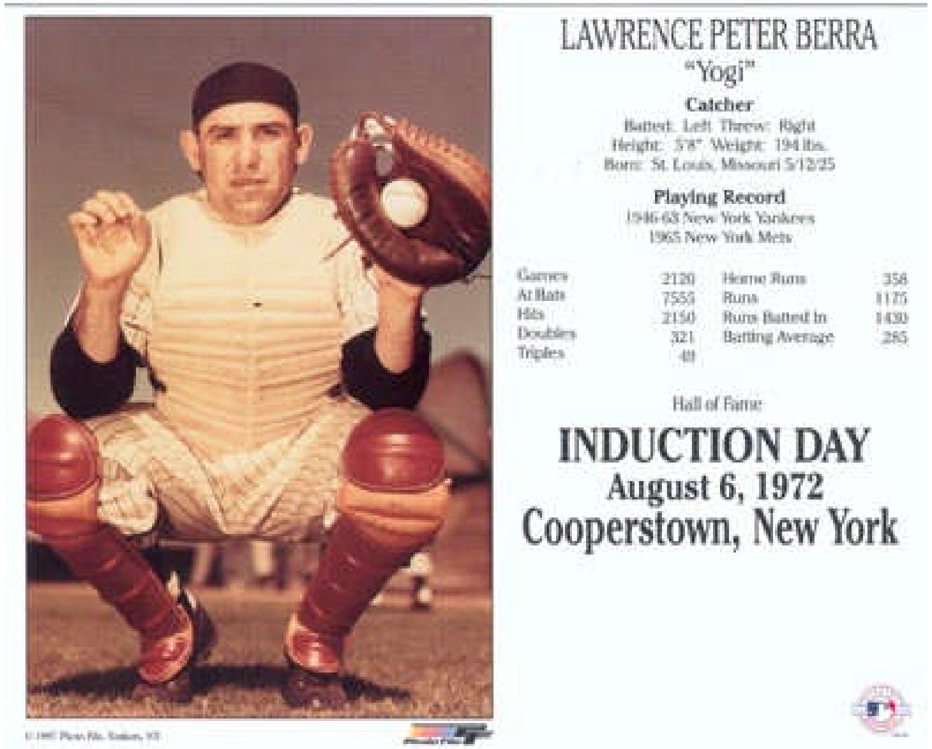
Example: DRAM Value Trends



←75-100mm 150mm 200mm 300mm 450mm→

Cost to process 1 cm^2 is about the same over this period (a few dollars)

The Semiconductor Industry has had 40 years of unprecedented growth, how long will it continue?



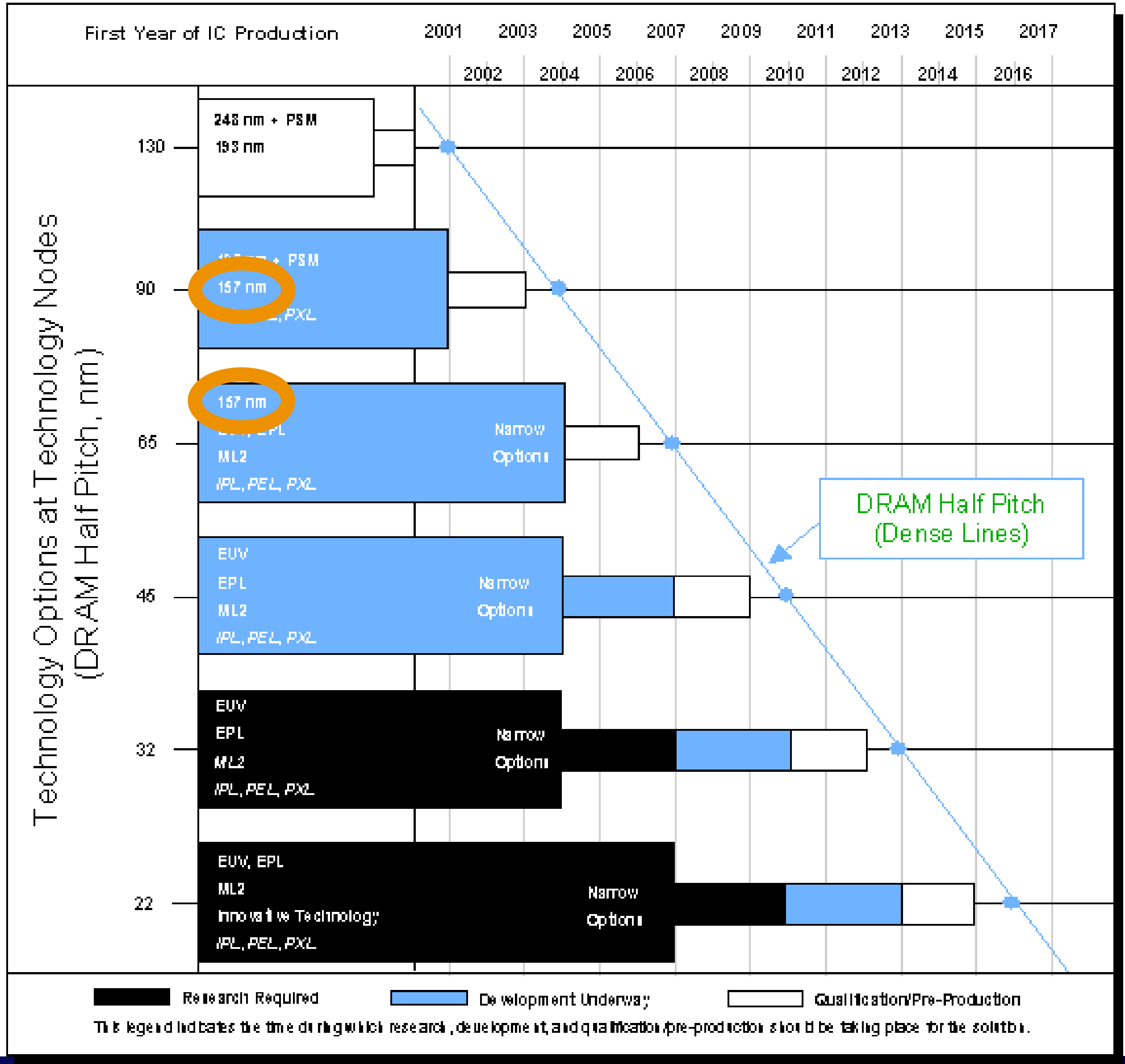
"It's hard to make predictions, especially about the future."

- Yogi Berra

Emerging Technologies provide opportunities with risk

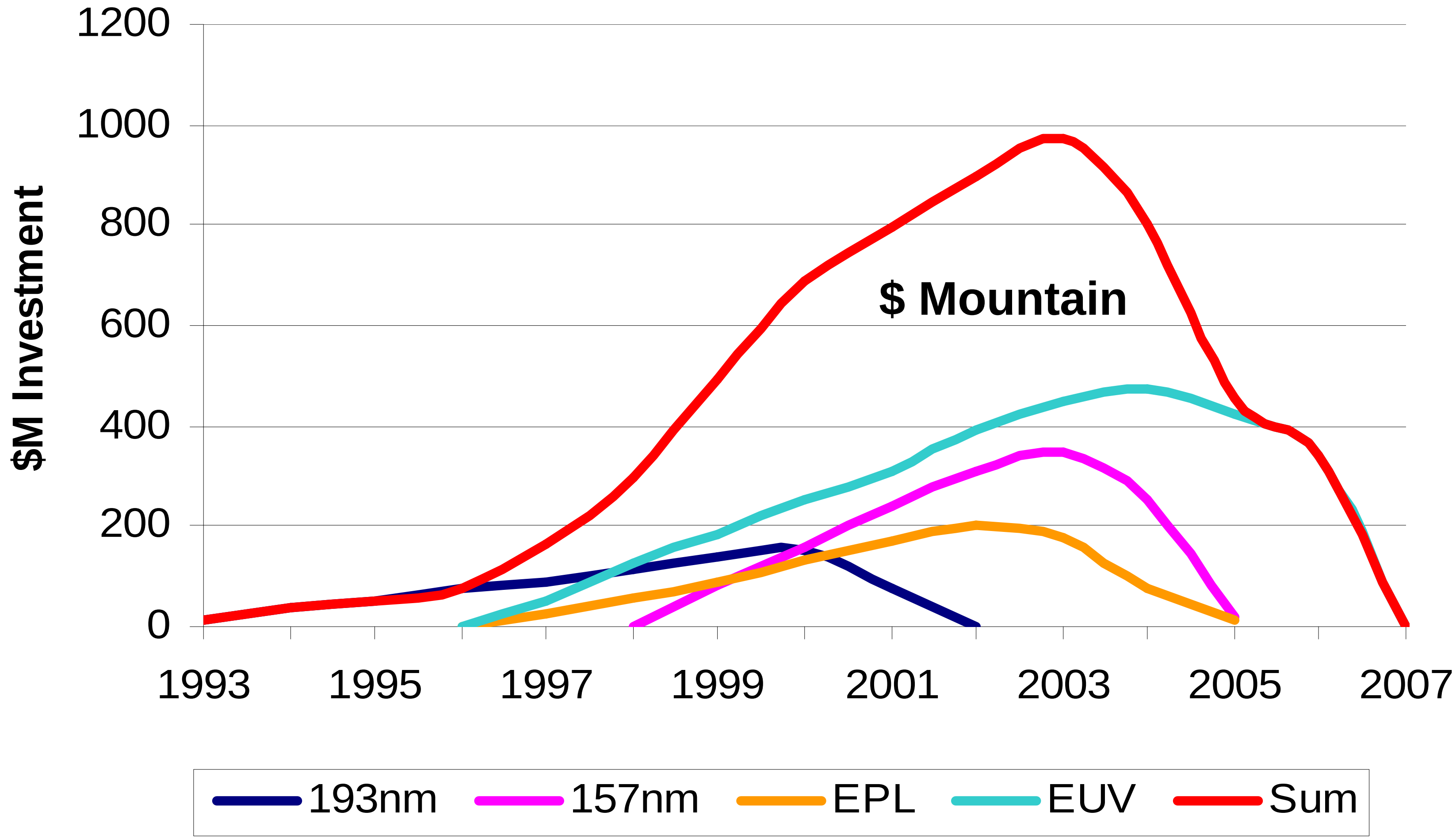
Example: Success and Failure in Semiconductor Technology

ITRS 2001 Version Predicting Litho



The Lithography R&D Mountain

Required World-wide Funding (1999 est.)



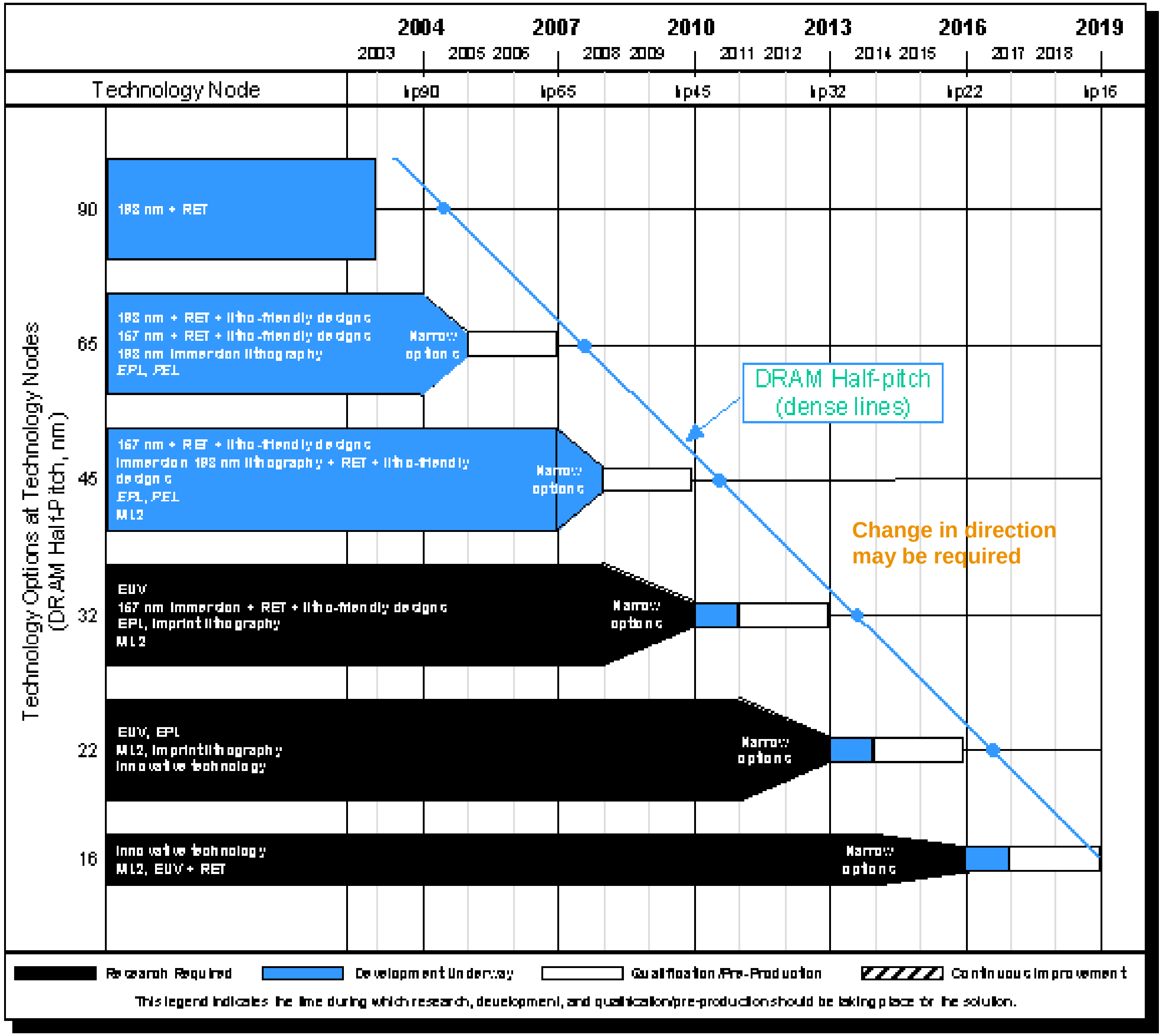
These numbers were revisited in 2002 and resulted in more than a 2X increase in total required funding!

A Problem Arose with 157nm!

- The CaF_2 has an issue with bi-refringence that needs to be compensated.
- The CaF_2 meeting the specifications for compensation was more difficult to produce than anticipated.
- Concern arose about having a sufficient supply of CaF_2 for industry needs.
- This raised sufficient concern that Immersion Lithography became interesting to the industry.

CaF_2 is the chemical representation of Calcium Fluoride.

ITRS 2003 Version Predicting Litho



Opportunities

"The Future Ain't What It Used to Be…"

- Yogi Berra

Tale of Two Technologies

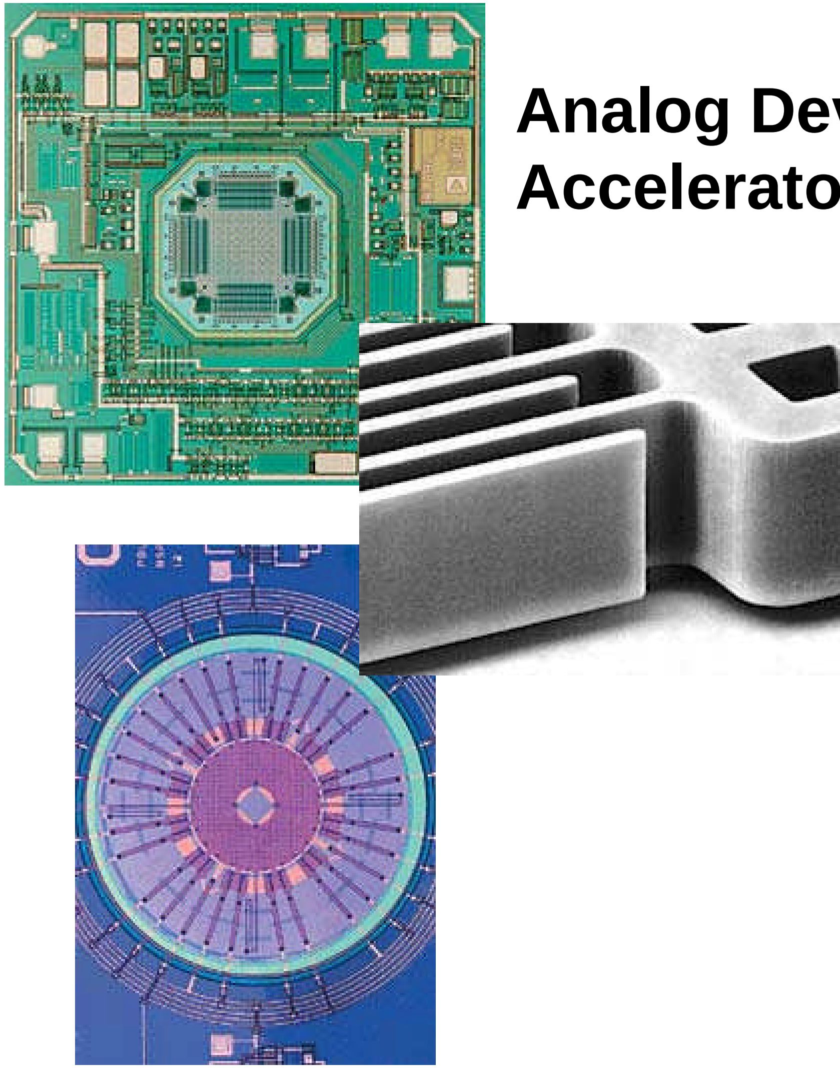
- **MEMS**
  - Micro Electro Mechanical Systems (MEMS) refers to a broad array of microfabricated devices that include both actuators and transducers in the realms of chemistry, biology, optics, fluidics, magnetics, mechanics, and electronics. Various MEMS technologies incorporate sensors, actuators, power sources, computation, and communication in a single system.

- **NEMS**
  - Although the terminology is similar, nano-electro-mechanical systems are vastly different from micro-electro-mechanical systems. Traditionally, micro becomes nano when the size reaches a prescribed limit, which is currently considered to be 100nm. In the true sense of nano technology, the change occurs when the construct employs properties available only at the nano scale

Examples of MEMS

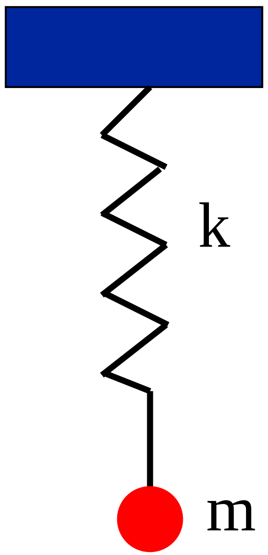
TI DLP

Analog Devices Accelerometer

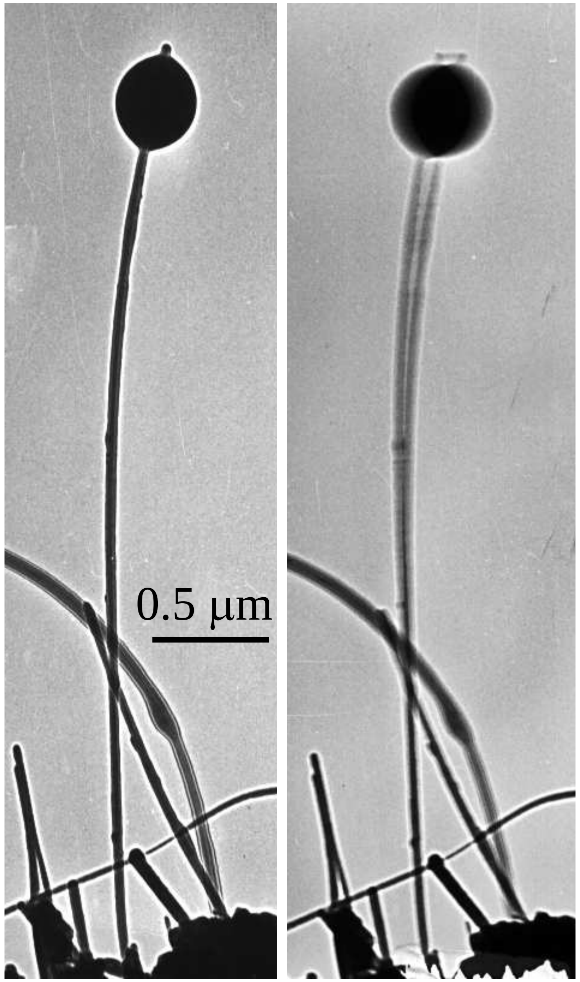


NEMS Femtogram Nanobalance

Smallest in the world



$f = (k/mg)^{1/2}$



$\nu = 0$ $\nu = 968$ kHz

Weighting individual nanoparticles, such as a virus

Bending modulus:

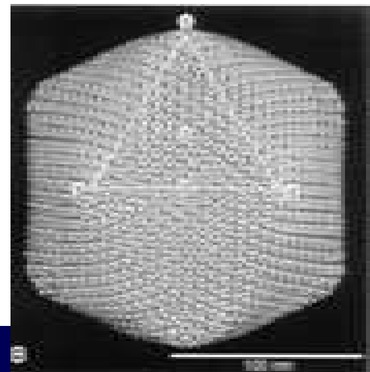
$E_b = 90$ GPa for D = 42 nm

Mass of the particle = 22 ± 6 fg

(1f = 10^{-15})

Calculated mass = 30 fg

Algal virus



Technology Challenges

"When you come to a fork in the road... take it ."

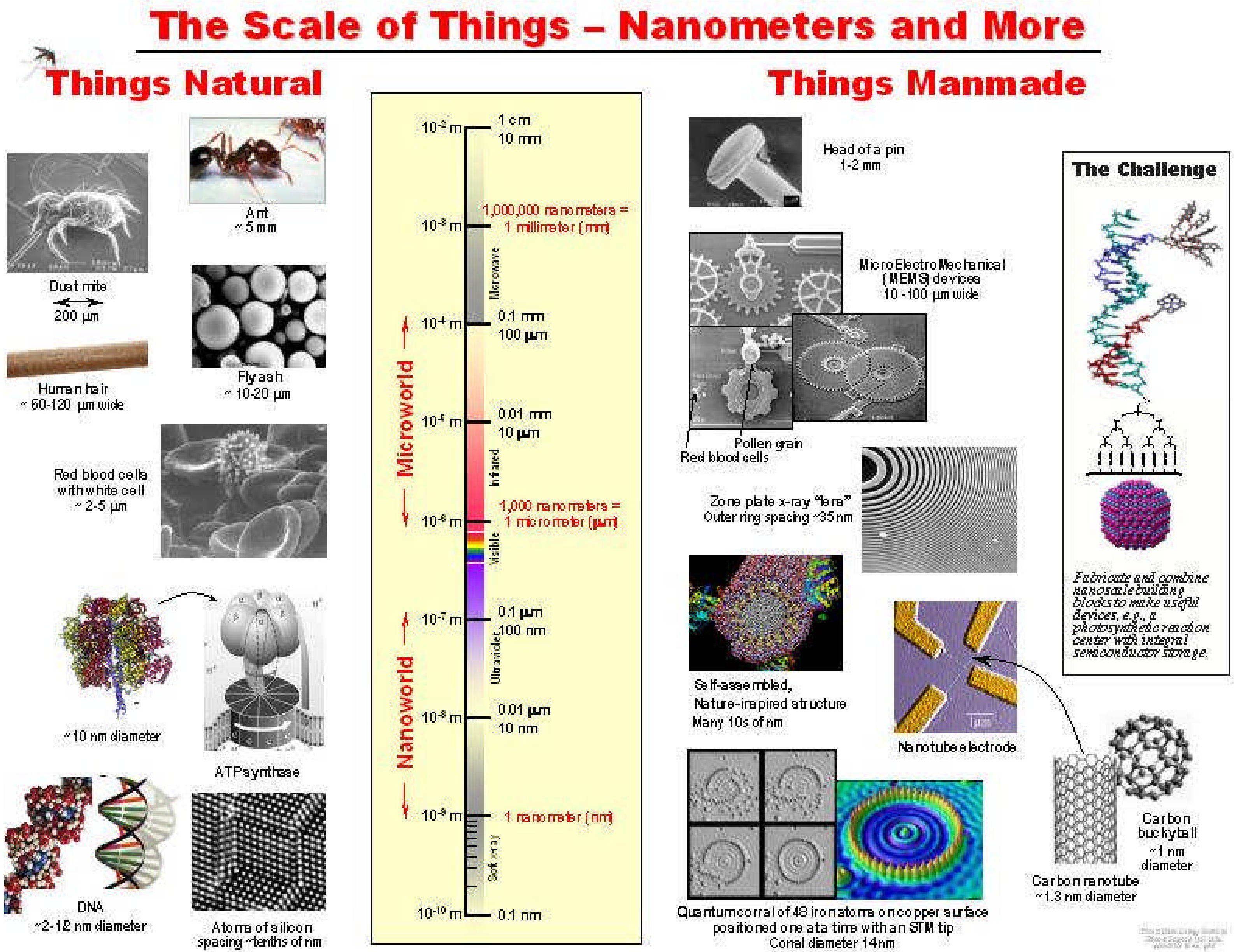
- Yogi Berra

Courtesy of Mike Polcari

Nano Technology

All promise but no substance?

or the “new” plastic?



Courtesy Office of Basic Energy Sciences,
Office of Science, U.S. Department of Energy

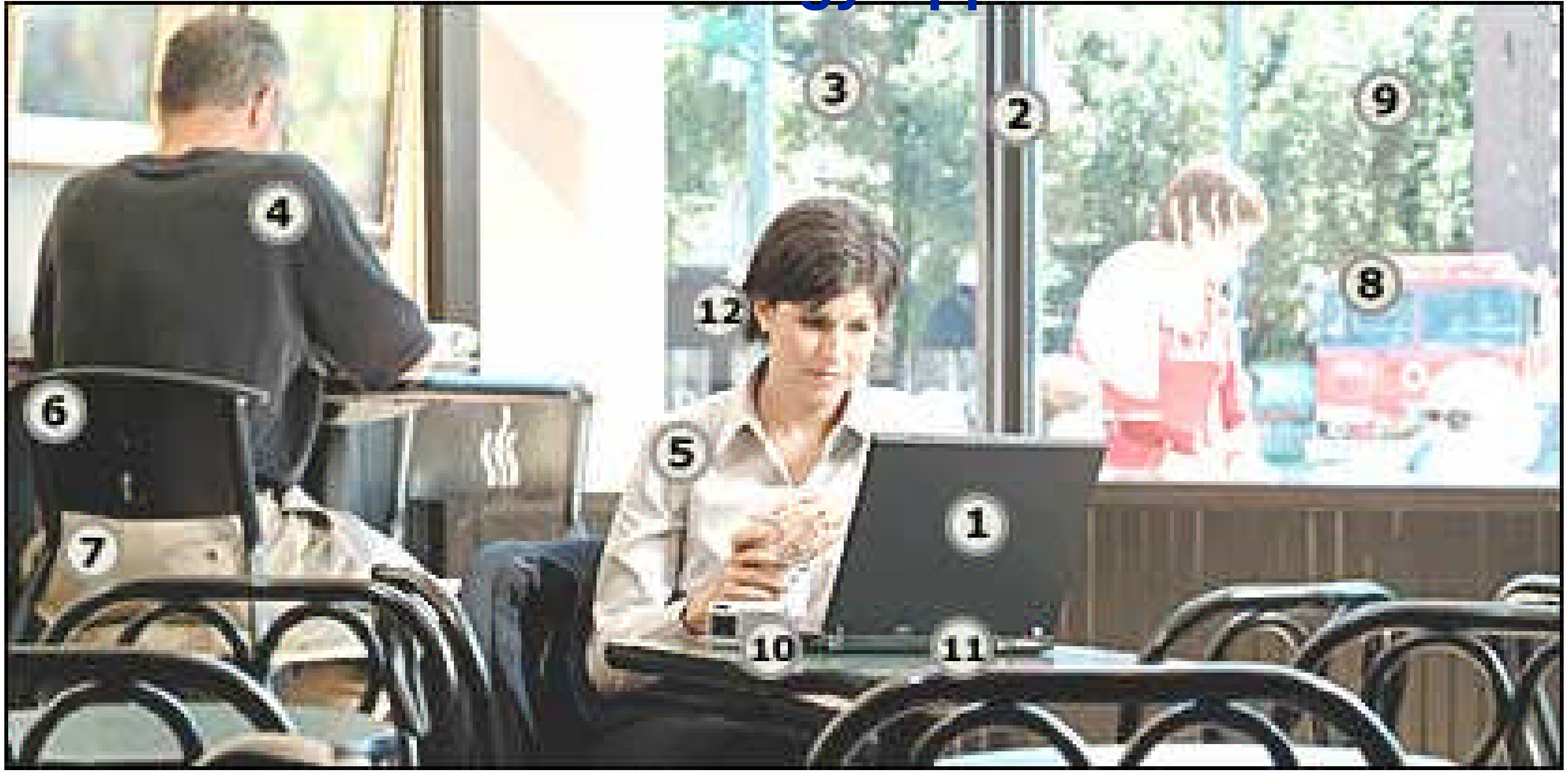
Nano Everywhere

- **There are hundreds of available consumer products being spawned as companies manipulate matter at the atomic level, according to The Project on Emerging Nanotechnologies, a Washington, D.C. initiative associated with the Woodrow Wilson International Center for Scholars.**

- **The group released a products inventory containing descriptions of more than 200 consumer goods purportedly made with some type of nanotech process or nanomaterial.**

- **Link to Nanotechnology Consumer Products Inventory - http://www.nanotechproject.org/index.php?id=44&action=view**

Nano Technology Applications



1 - Organic Light Emitting Diodes (OLEDs) for displays

2 - Photovoltaic film that converts light into electricity

3 - Scratch-proof coated windows that clean themselves with UV

4 - Fabrics coated to resist stains and control temperature

5 - Intelligent clothing measures pulse and respiration

6 - Bucky-tubeframe is light but very strong

7 - Hipjoint made from biocompatible materials

8 - Nano-particle paint to prevent corrosion

9 - Thermo-chromic glass to regulate light

10 - Magnetic layers for compact data memory

11 - Carbon nanotube fuel cells to power electronics and vehicles

12 - Nano-engineered cochlear implant

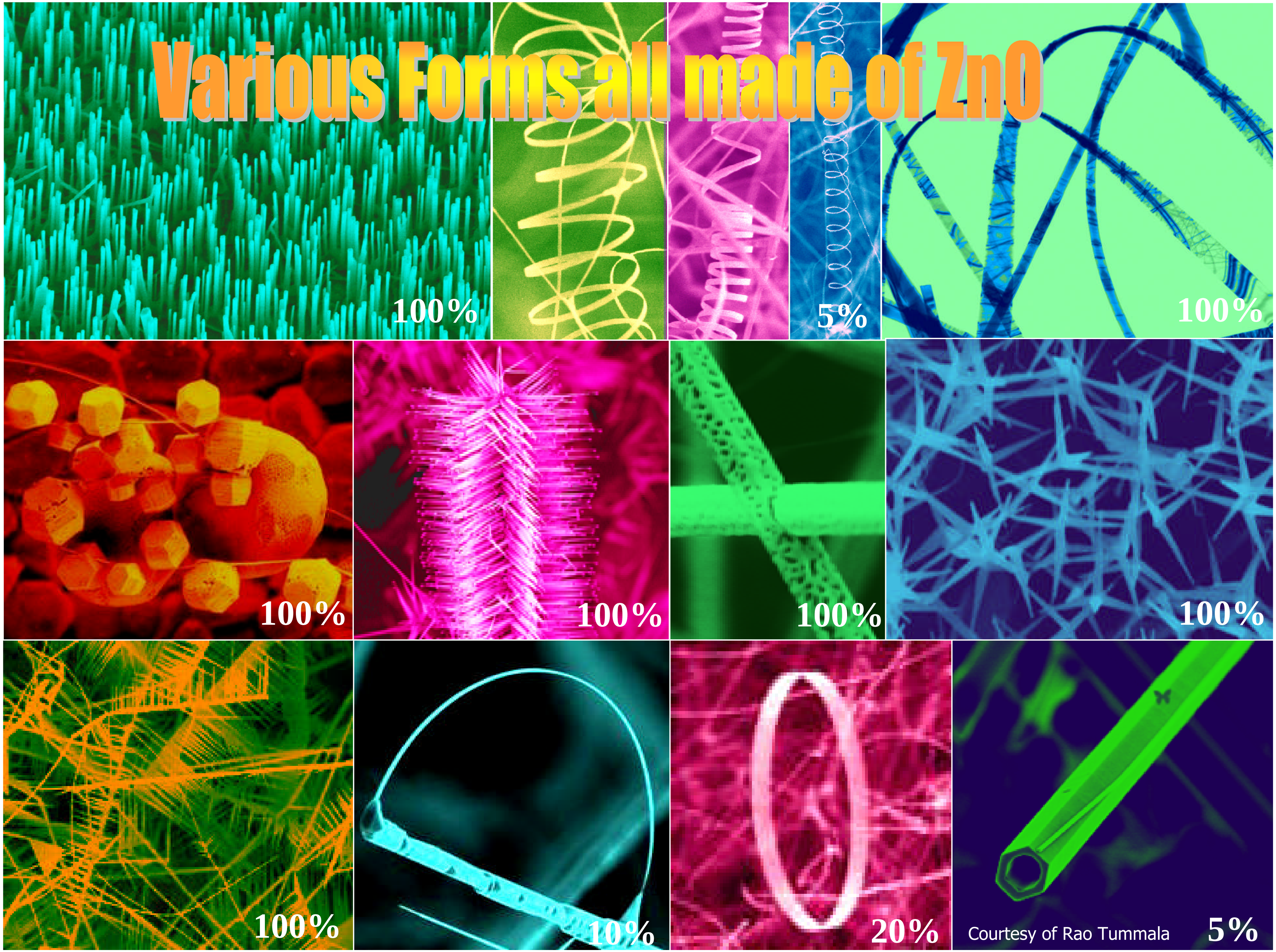
Compiled by Jo Twist, BBC News On-Line, July 28, 2004

Nano

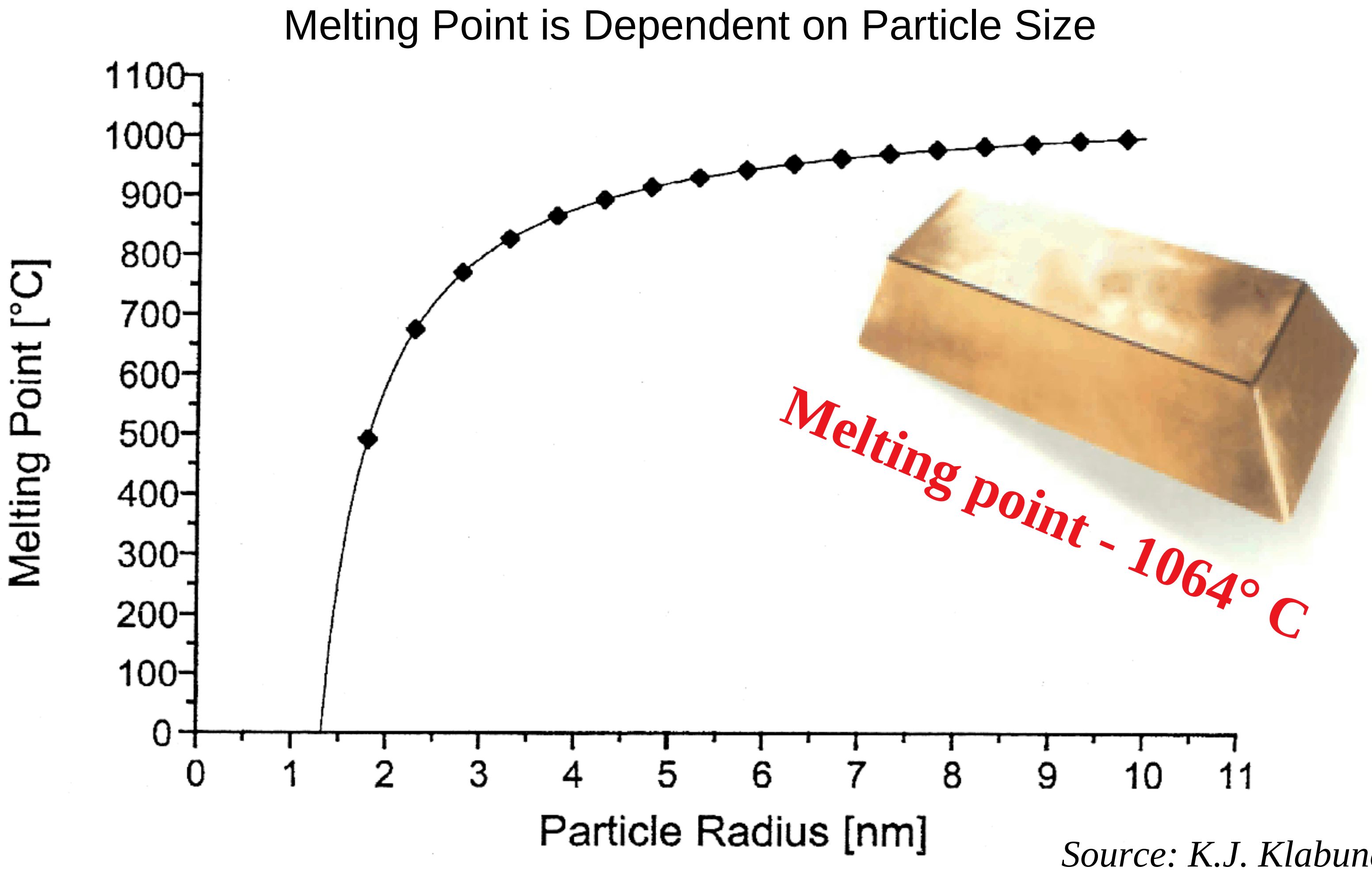
This is a new world

- **Some things will be familiar**
- **Others will be totally unknown or unexpected**
- **Caution will be required before proceeding rapidly forward**

Let's examine some examples


Various Forms all made of ZnO
100%
5%
100%
100%
100%
100%
100%
100%
10%
20%
Courtesy of Rao Tummala
5%

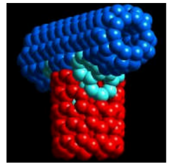
Melting Point is <u>not</u> Constant!

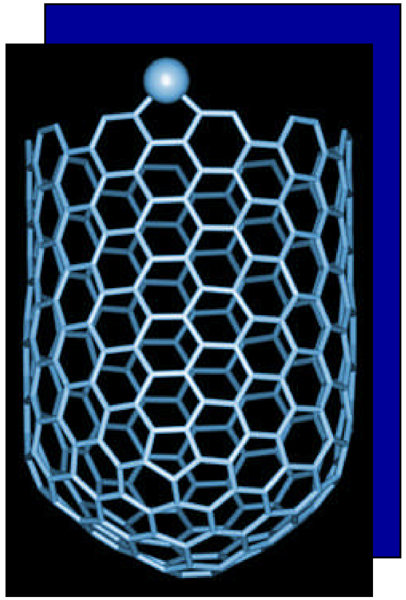


Source: K.J. Klabunde, 2001

NASA Ames

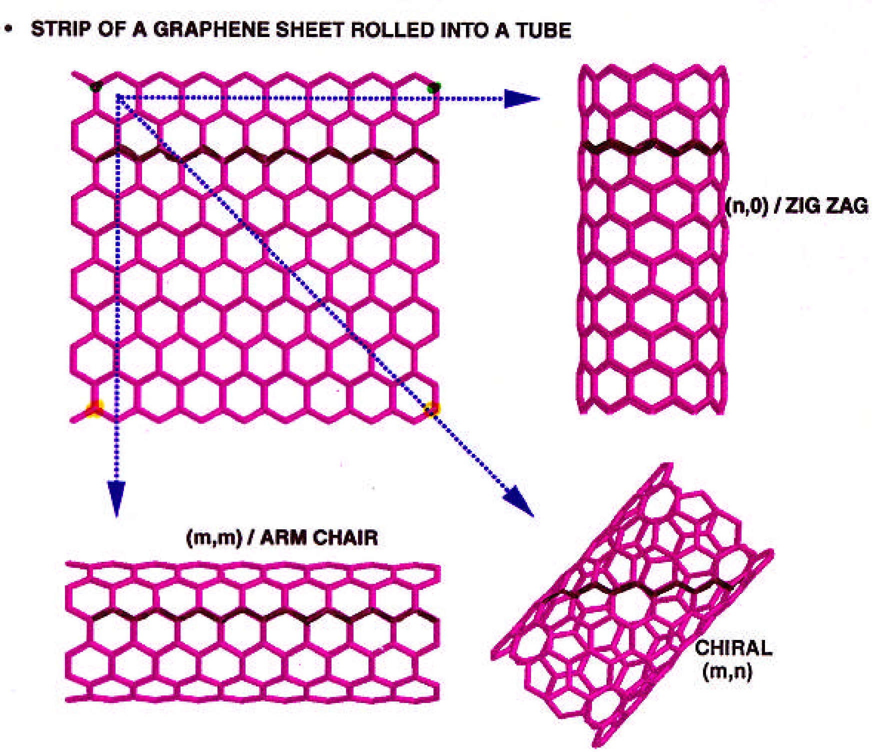
Carbon Nanotube





CNT is a tubular form of carbon with diameter as small as 1 nm.
Length: few nm to microns.

CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

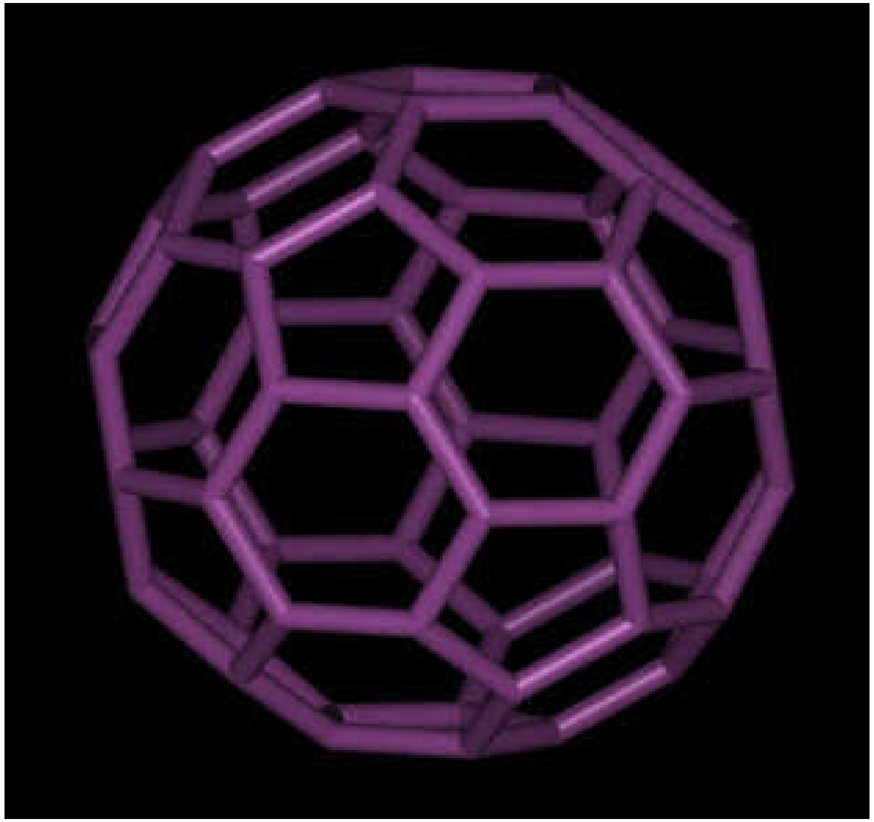


CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

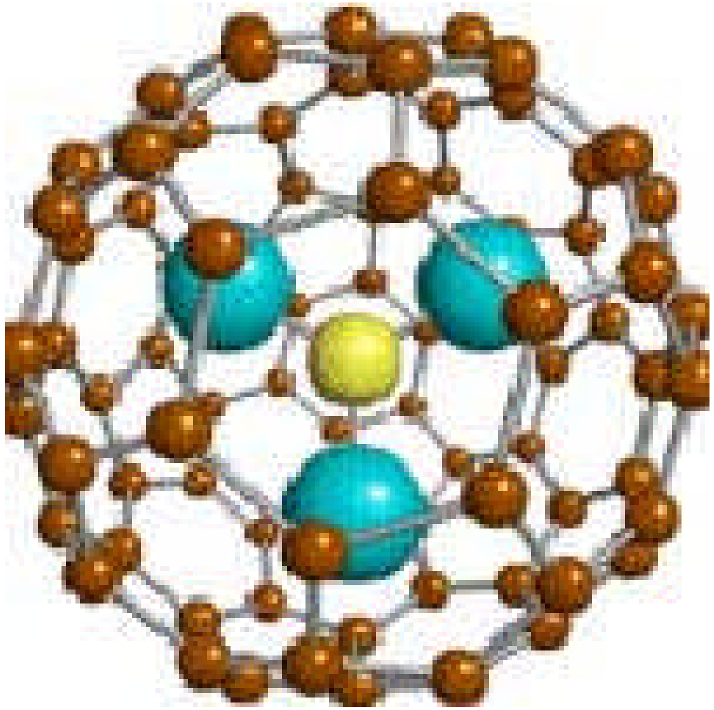
CNT can be metallic or semiconducting, depending on chirality.

Courtesy of M. Meyyappan

Novel Material Properties



A Carbon60 Buckyball (Courtesy CNI)



Luna's trimetasphere buckyball.

Small Times

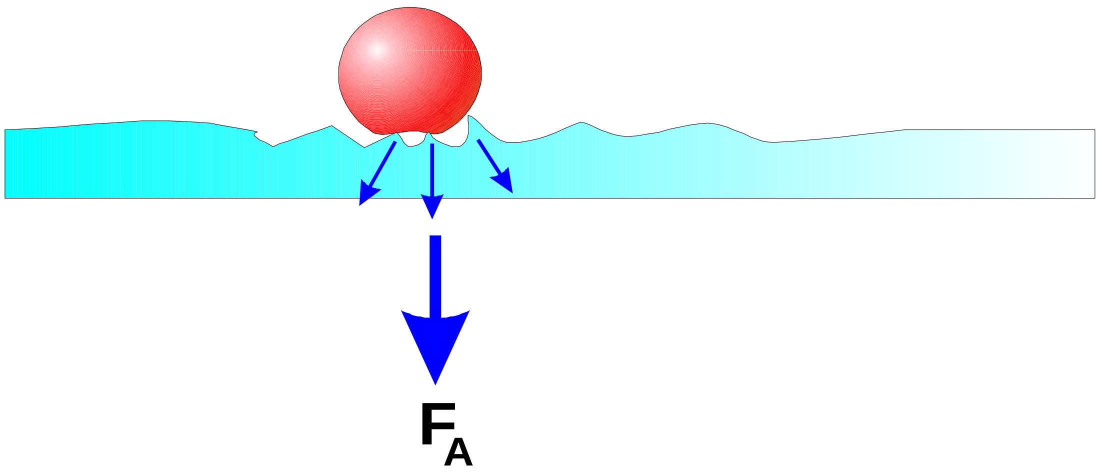
Quantum Dot Rainbow
Source: Andrey Rogach
References:

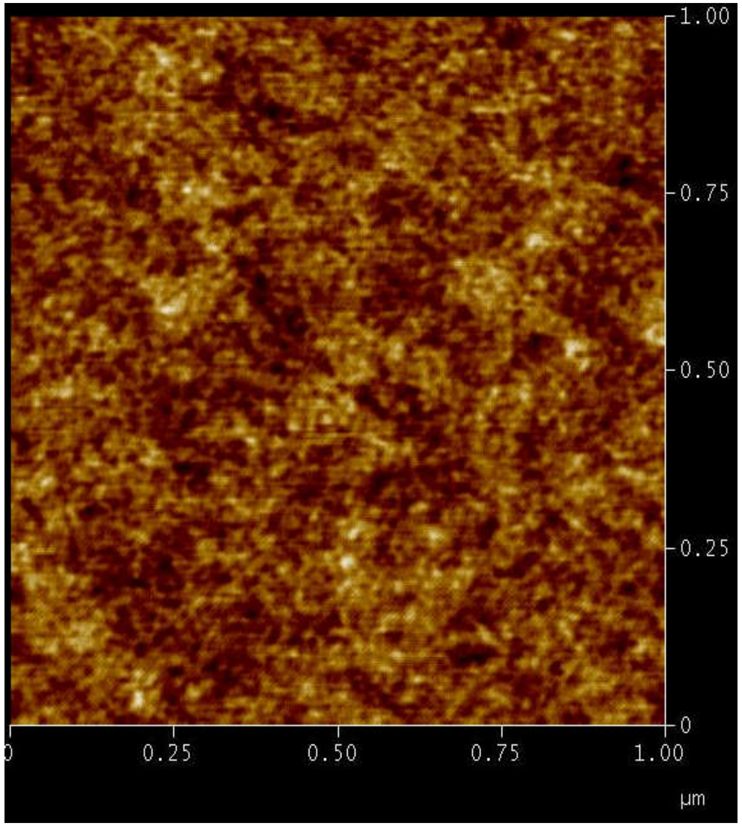
Yu. P. Rakovich, J. F. Donegan, S. A. Filonovich, M. J. M. Gomes, D. V. Talapin, A. L. Rogach, A. Eychmüller. "Up-Conversion Luminescence via a Below-gap State in CdSe/ZnS Quantum Dots." *Physica E* , 17, 99-100.2003

Description:
Semiconductor nanocrystals, also called colloidal quantum dots, typically have a size between ~1 and 10 nm and lie in the transition regime between bulk solids and molecules. They are fascinating objects for studying basic novel properties of matter, generally described by the term "size quantization effect". A famous demonstration of the size-dependent properties of semiconductor nanocrystals is the continuous change of their emission color. Shown is an example of the range of CdSe nanocrystal emission spectra.
Most nanocrystals are highly luminescent, and the emission is tunable through the whole visible and the near-IR spectral range by controlling the composition and size of quantum dots. Highly luminescent semiconductor nanocrystals are interesting for different applications, ranging from thin film optoelectronic devices to fluorescent labels. The incorporation of luminescent semiconductor nanocrystals into photonic crystals and microcavities has attracted considerable attention as a promising pathway to novel light sources with controllable spontaneous emission.

Cleaning Nano

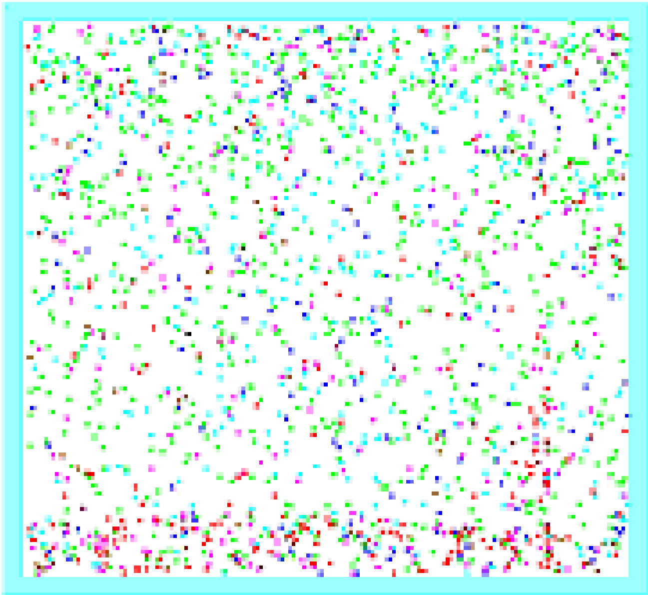
- **Multiple contact points**
- **Reduces the total adhesion forces**
- **Higher roughness leads to higher available surface**



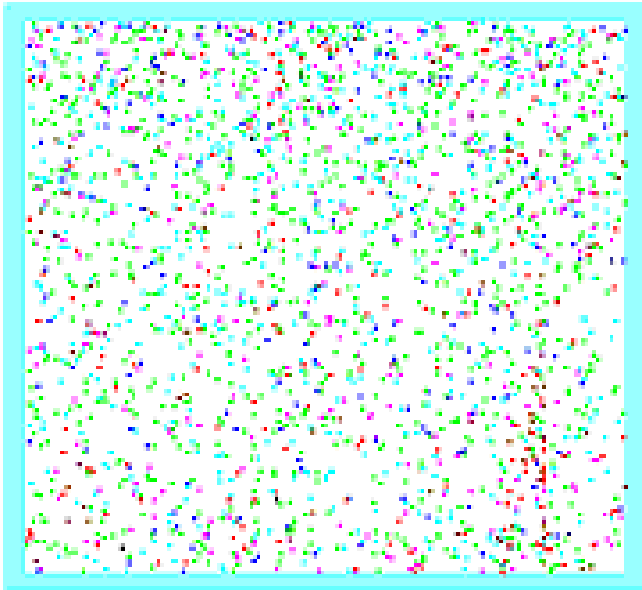


Cleaning Nano

The Challenge!



Before clean



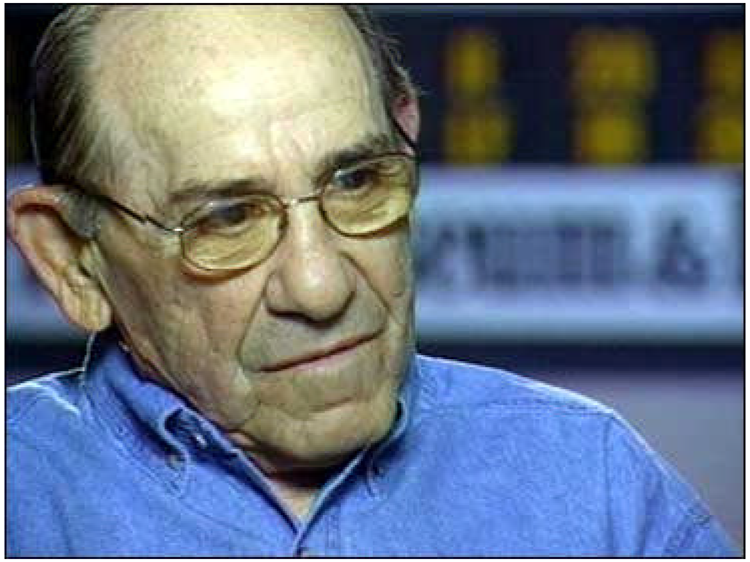
After clean

Redeposition is an issue
Problem with heating quartz

More Yogi Berra Thoughts

It’s not too far, it just seems like it is.

You can observe a lot by watching.



CBS picture, July 2003

Business Implications

- **There will be many new opportunities**
  - Some will be successful
  - And, some will not
- **Development in the “nano” region does not refer to the investment required**
- **Leveraging existing industry will facilitate the development of the nano community**

Semiconductors: First Nano Industry

- **Model of early nanotech adoption, foundation for other nano industries**
  - People, capital, technology, infrastructure, experience, and culture will enable the transformation of nano into the advanced technology economies of the future
- **Lessons learned that will apply to follow-on nano industries**
  - Meeting technical challenges
    - New requirements in nano region; issues do not just scale
    - Operating environment is critical
    - Complete infrastructure must be ready (development interdependency)
  - Meeting economic/business challenges
    - High barrier to entry
    - Each new generation costs more
    - Shorter and shorter life cycles
    - Development issues and technology acceleration can crash infrastructure
    - Greatest benefits come to earliest successful entries
      - Being late means losing leading edge capabilities

Development Interdependency

Every element of the "nano" manufacturing infrastructure must be ready for the "process" to succeed

248nm Exposure Tool

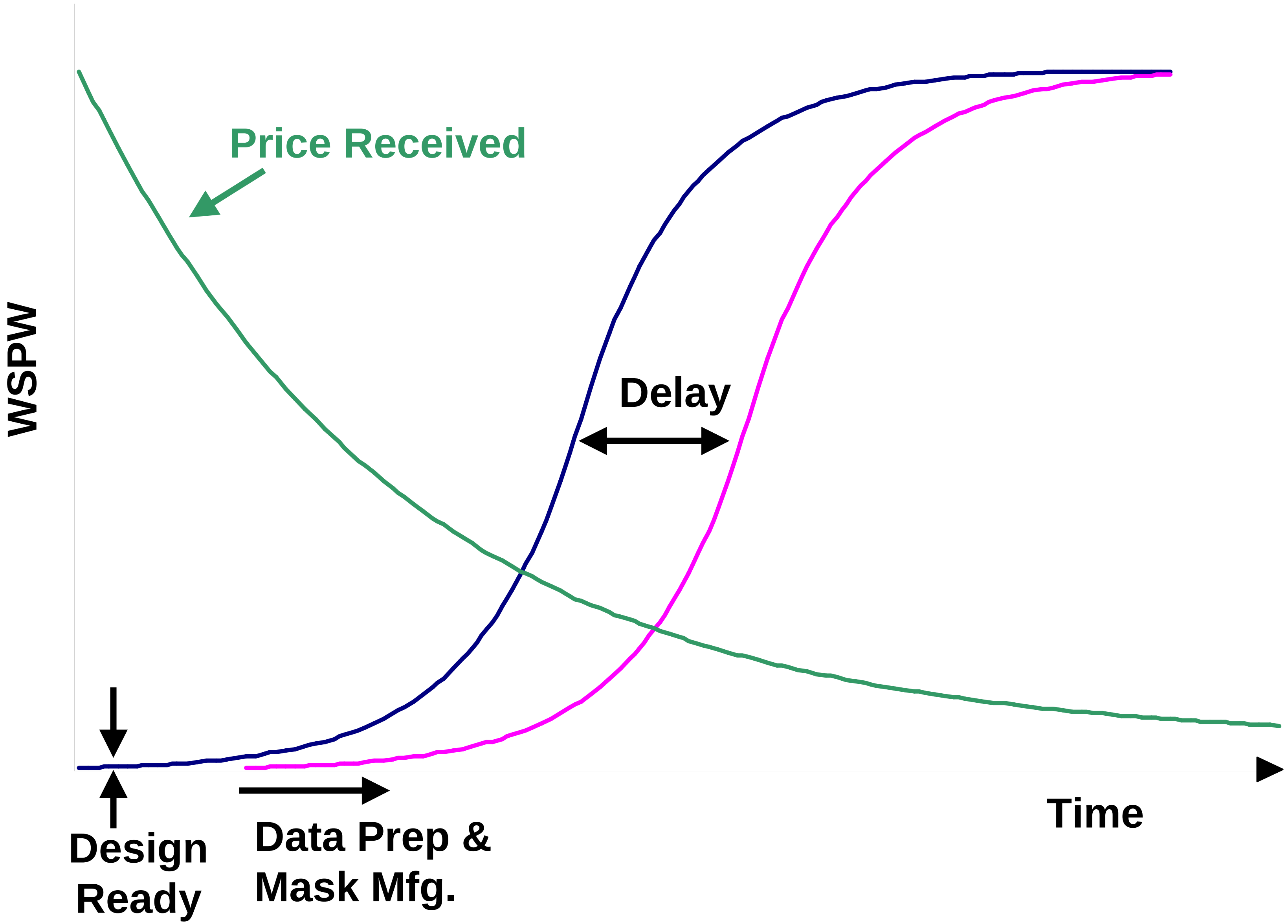
- Ready for production in 1991
- Only reached production in 1995

Why was there a 4 year delay?

- Resists were not production worthy
- Resulting in insufficient experience
- Resulting in lack of willingness to take risks

Learning: Complete infrastructure must be ready

Start Up Delay Impact



The Nanotech Challenge

- **Learnings from semiconductor industry can assist in coordinating industry, university, government, and infrastructure roles as nano industries develop**

- **In advanced technologies, companies and countries that want to control their own destiny must be at the leading edge**
  - Advanced technologies will drive the economy for the next 50 years
    US Dept. of Commerce
  - Enabler for national security and competitiveness
  - But competition is global and severe and already upon us

Key Points

Mis-applied technology costs businesses $Ms each year. Focused evaluation ensures compatibility and expedites time to market.

Businesses are good at what they do. Introducing a new technology can become a financial nightmare. Compatibility of business and technology does not magically happen.

Technology costs are easy to underestimate. Traditional tools may not Provide sufficiently accurate information.

Engineers love their technical developments and don't understand why business people can't see the value. Businesses what to see the return; engineers don't focus on the enumeration of the business, but on the beauty of the technology.

The semiconductor industry developed 248nm lithography tools in 1991, but these tools did not enter manufacturing until 1995!

Points are listed at http://www.tryb.org/entry-pg1.html

Key Points

The dot.com bust was driven by people, who did not understand technology, believing the developers, who loved the technology

The semiconductor industry investigated, evaluated, and committed to Immersion lithography after a 14 month industry R&D effort.

The semiconductor industry spent over $2B on developing 157nm lithography only to decide that it was not manufacturable in sufficient quantities.

Business people do not truly understand the engineering mindset. Engineers rarely understand the business implications of their efforts. Incompatibility Provides for an interesting relationship.

Points are listed at http://www.tryb.org/entry-pg1.html

Summary

- **Technology is interesting, but it is the application to products that generates jobs.**
- **Intelligent people can make incorrect decisions, but correcting these choice enables progress. "You have to know when to fold'em."**
- **Focusing on "your" expertise provides the ability to make correct decisions. Core competencies.**
- **There will be many technology "losers", but the successful will <u>understand</u> the technology and how to drive development to satisfy a consumer need.**