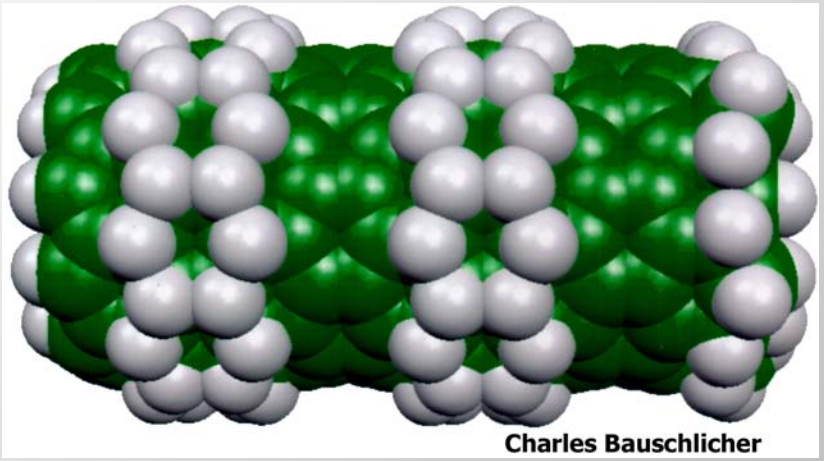

NANOTECHNOLOGY

What is Nanotechnology?

Nanotechnology is the creation of **USEFUL/FUNCTIONAL** materials, devices and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and properties (physical, chemical, biological) at that length scale



"If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering."

-Neal Lane
Former Assistant to the President for Science And Technology

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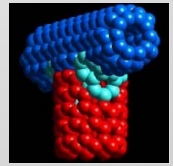
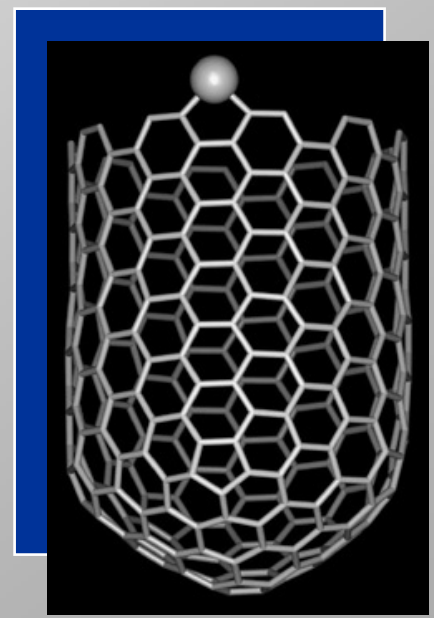


- Ability to synthesize nanoscale building blocks with control on size, composition etc. → further assembling into larger structures with designed properties will revolutionize materials manufacturing
  - Manufacturing metals, ceramics, polymers, etc. at exact shapes without machining
  - Lighter, stronger and programmable materials
  - Lower failure rates and reduced life-cycle costs
  - Bio-inspired materials
  - Multifunctional, adaptive materials
  - Self-healing materials



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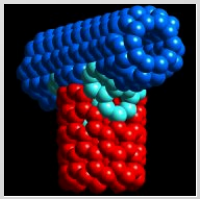
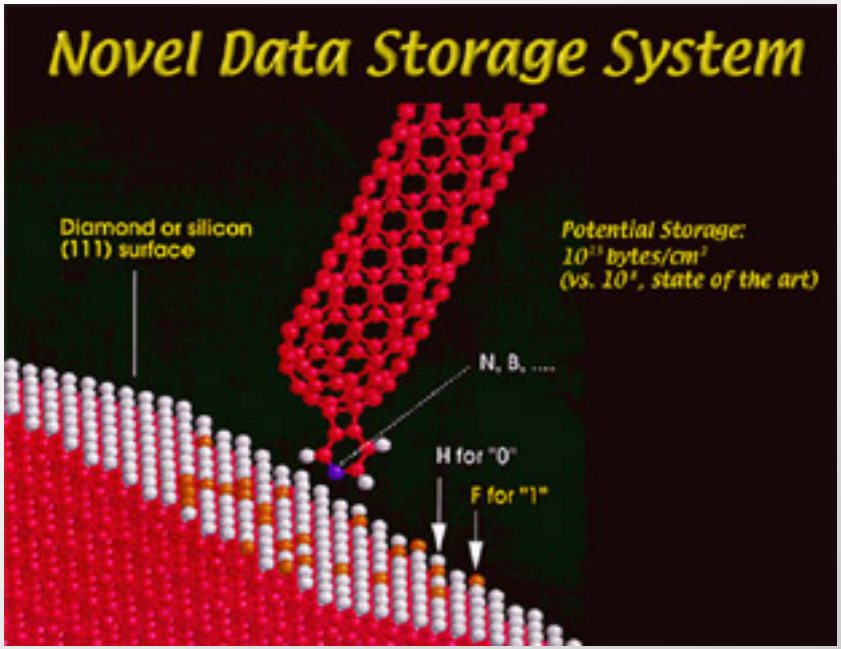
Impact of Nanotechnology





Nanotechnology is an enabling technology

- Computing and Data Storage
- Materials and Manufacturing
- Health and Medicine
- Energy and Environment
- Transportation
- National Security
- Space exploration

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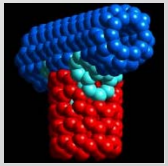
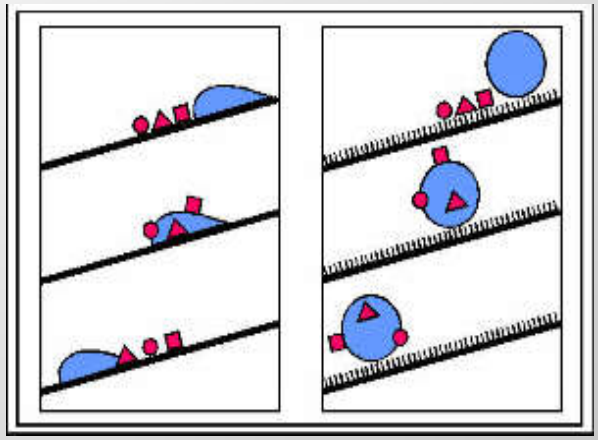
Self-Cleaning Surfaces: Lotus Effect

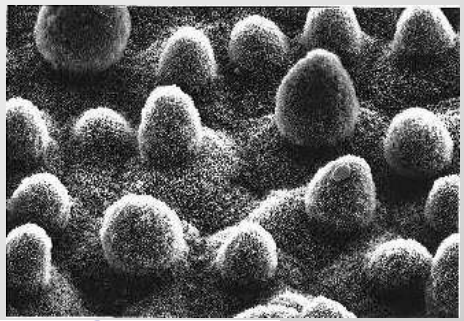


10 μm

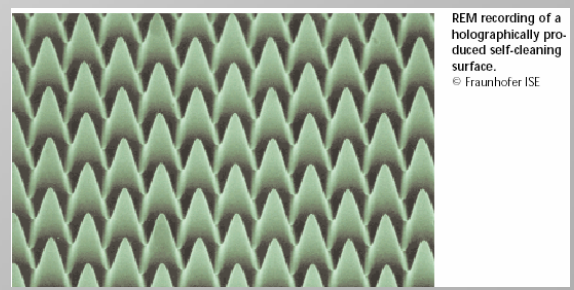


W. Barthlott, Univ. of Hamburg

On a smooth surface the contaminating particles are only moved by the water droplet (left). In contrast to that, on a rough surface they stick to the droplet rolling off the leaf thus being washed off (right).



Epicuticular wax



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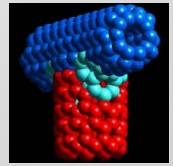
Source: Metin Sitti, CMU

Energy and Environment



- Energy Production
  - Clean, less expensive sources enabled by novel nanomaterials and processes
- Energy Utilization
  - High efficiency and durable home and industrial lighting
  - Solid state lighting can reduce total electricity consumption by 10% and cut carbon emission by the equivalent of 28 million tons/year (Source: Al Romig, Sandia Lab)

- Materials of construction sensing changing conditions and in response, altering their inner structure

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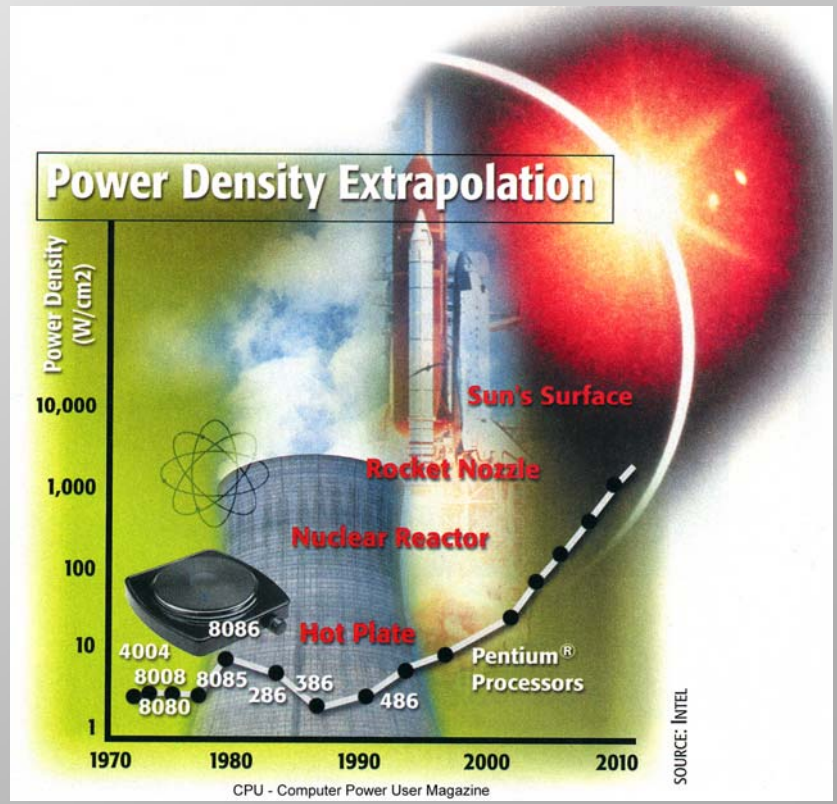
Expected Nanotechnology Benefits in Electronics and Computing

- Processors with declining energy use and cost per gate, thus increasing efficiency of computer by 10^6
- Small mass storage devices: multi-tera bit levels
- Integrated nanosensors: collecting, processing and communicating massive amounts of data with minimal size, weight, and power consumption
- Higher transmission frequencies and more efficient utilization of optical spectrum to provide at least 10 times the bandwidth now
- Display technologies
- Quantum computing



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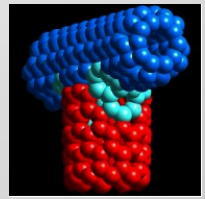
Benefits of Nanotechnology in Transportation



- Thermal barrier and wear resistant coatings
- High strength, light weight composites for increasing fuel efficiency
- High temperature sensors for ‘under the hood’
- Improved displays
- Battery technology
- Wear-resistant tires
- Automated highways

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Nanoelectronics: What is Expected from Alternative Technologies?

(Beyond the SIA Roadmap for Silicon)

- Must be easier and cheaper to manufacture than CMOS
- Need high current drive; should be able to drive capacitances of interconnects of any length
- High level of integration (>10^{10} transistors/circuit)
- High reproducibility (better than ± 5%)
- Reliability (operating time > 10 years)
- Very low cost (< 1 µcent/transistor)
- Better heat dissipation characteristics and amenable solutions
- Everything about the new technology must be compelling and simultaneously further CMOS scaling must become difficult and not cost-effective. Until these two happen together, the enormous infrastructure built around silicon will keep the silicon engine humming….

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Nanowires and nanowalls

Motivations for selecting Single Crystalline Nanowires & Nanowalls (in Nano-scale Electronics)

- ❖ High single crystallinity ⇒ Low defect density, grain boundary free
- ❖ Well-defined surface structural properties ⇒ Enhanced interfacial engineering
- ❖ Predictable electron transport properties ⇒ Predictable device performance
- ❖ Unique physical properties due to quantum confinement effects ⇒ Enhancement in device characteristics
- ❖ Tunable electronic properties by doping ⇒ Enhancement in device characteristics
- ❖ Truly bottom-up integration approach ⇒ Innovative fabrication schemes
- ❖ Potential to revolutionize nano-scale science and technology

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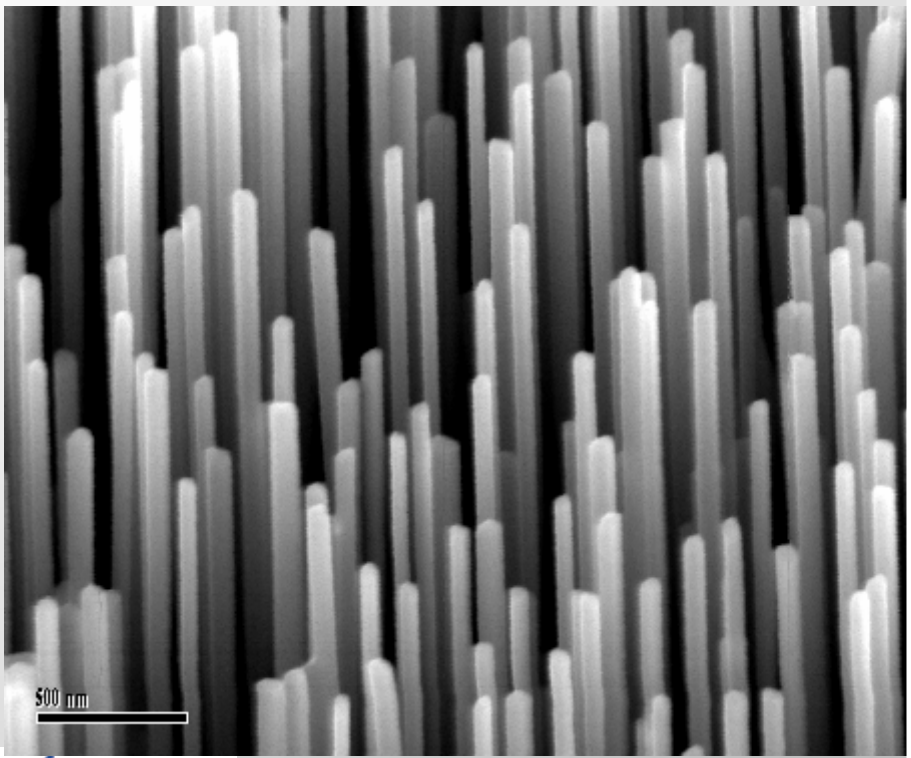
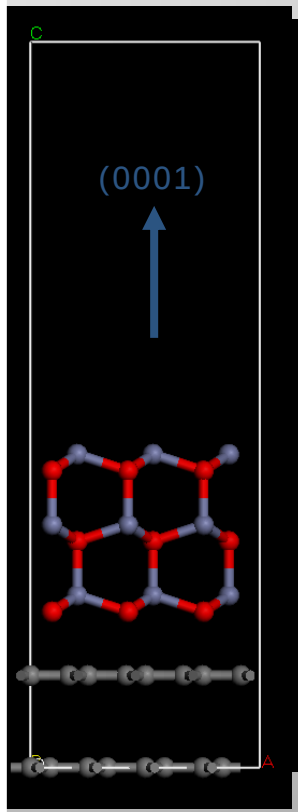
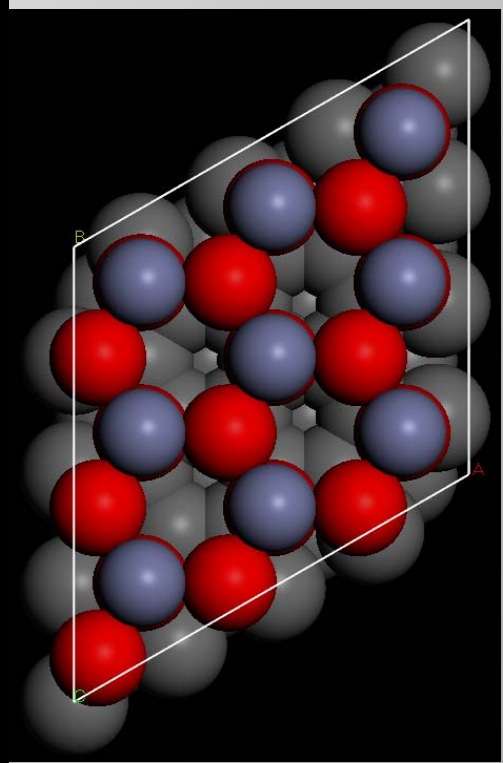
Challenges in Nanowire Growth

- Uni-directional nanowire growth; ⇔ substrate engineering
  vertical or horizontal ⇔ electric field directed

Understanding of the interfacial epitaxial relationship between potential substrates and nanowire structures ⇔ modeling and simulations ⇔ experiments ⇔ combinatorial approach







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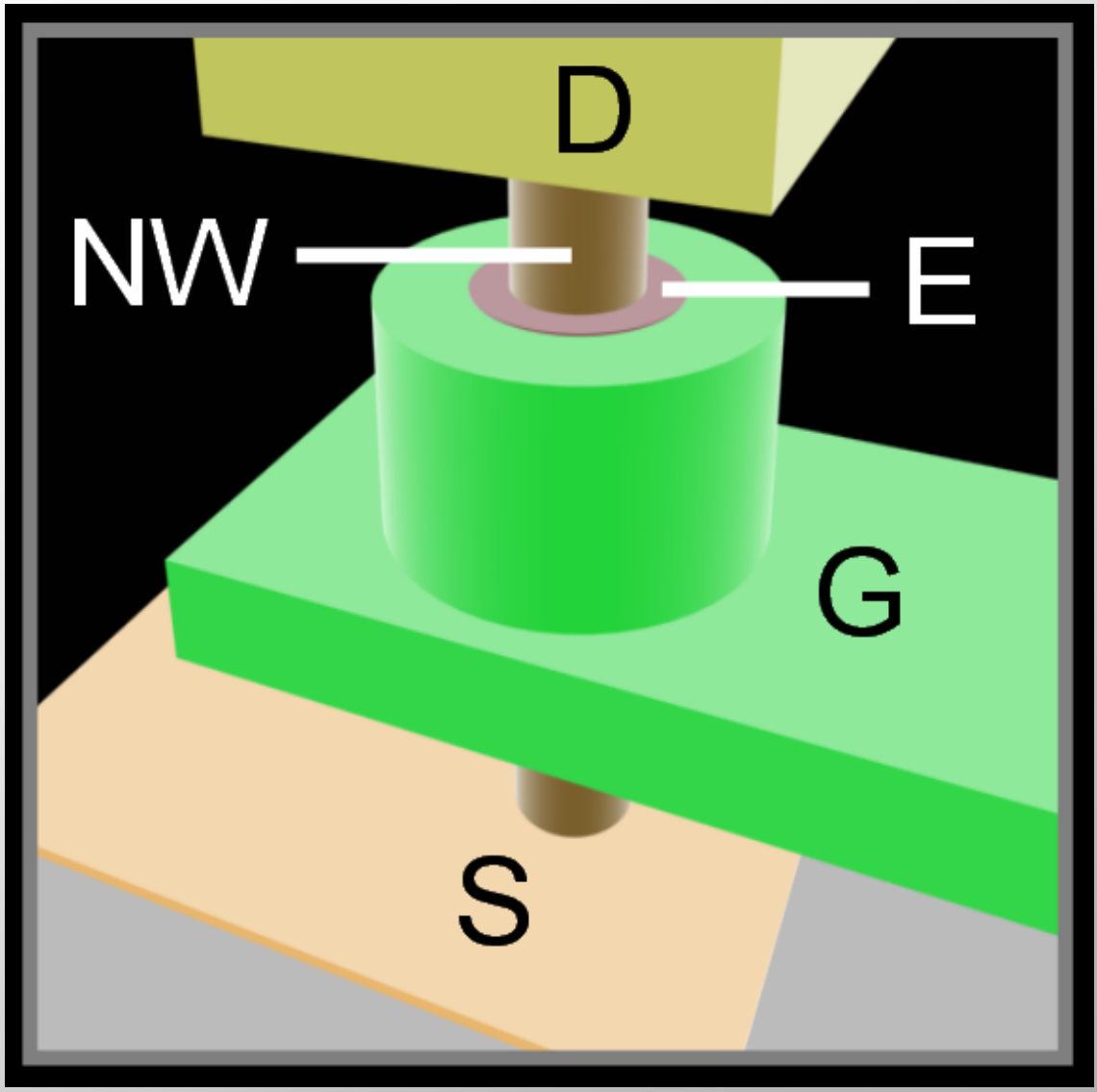
Nanowire-based Vertical Surround Gate FET



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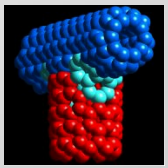
Nanotechnology at NASA



- Advanced miniaturization, a key thrust area to enable new science and exploration missions
  - Ultrasmall sensors, power sources, communication, navigation, and propulsion systems with very low mass, volume and power consumption are needed
- Revolutions in electronics and computing will allow reconfigurable, autonomous, “thinking” spacecraft
- Nanotechnology presents a whole new spectrum of opportunities to build device components and systems for entirely new space architectures
  - Networks of ultrasmall probes on planetary surfaces
  - Micro-rovers that drive, hop, fly, and burrow
  - Collection of microspacecraft making a variety of measurements

Europa Submarine

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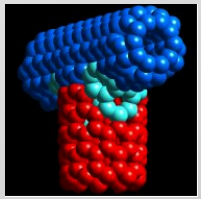
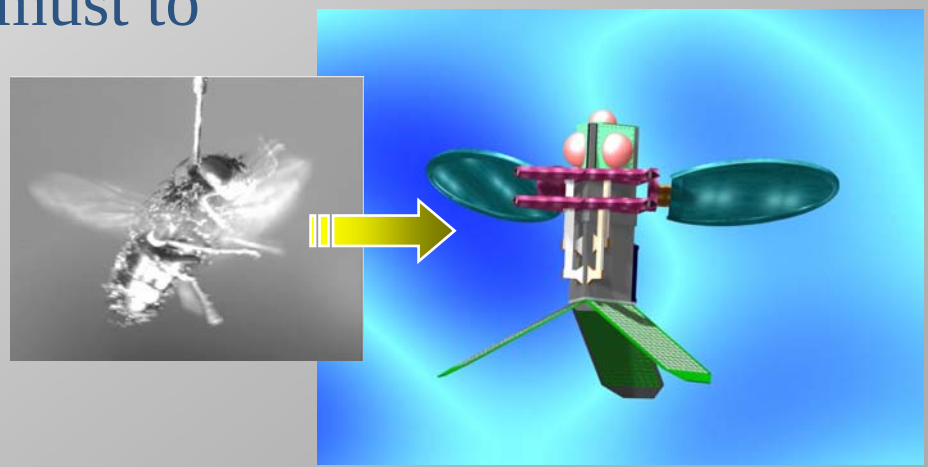
Challenges facing Nanotechnology



- Lots of nanoscience now, some nice nanotechnology; more emphasis on technology development and participation from engineering communities are needed

- People do not buy technology; they buy products
  - Robust product development is critical to realize the potential
  - Early and periodic wins, a must to keep investor confidence high
- Recognition of nano-micro-macro hierarchy in product development

Source: UC Berkeley



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