Guardian Angels for a Smarter Life

1 Billion Euros for Zero Power

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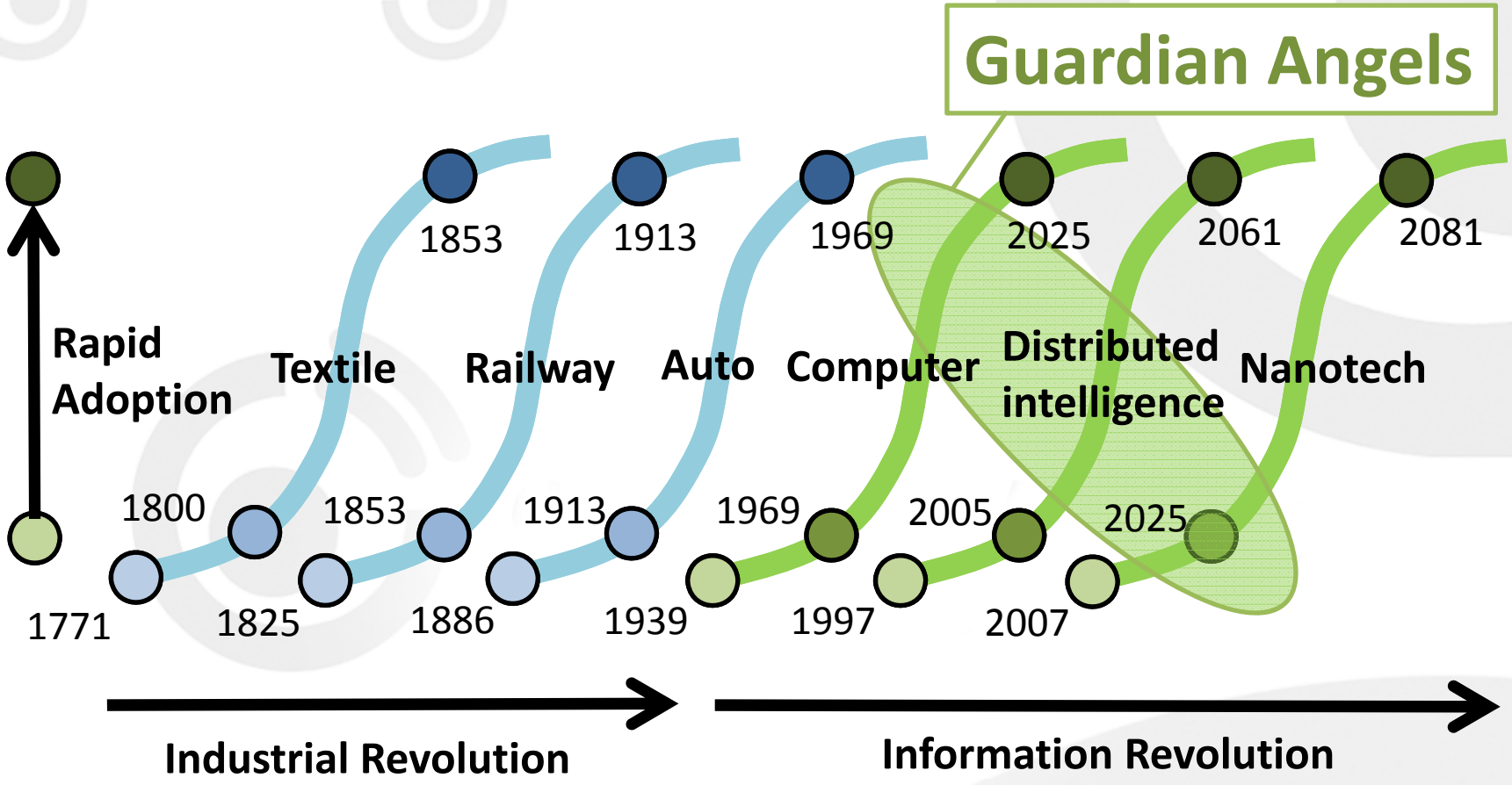
Outline

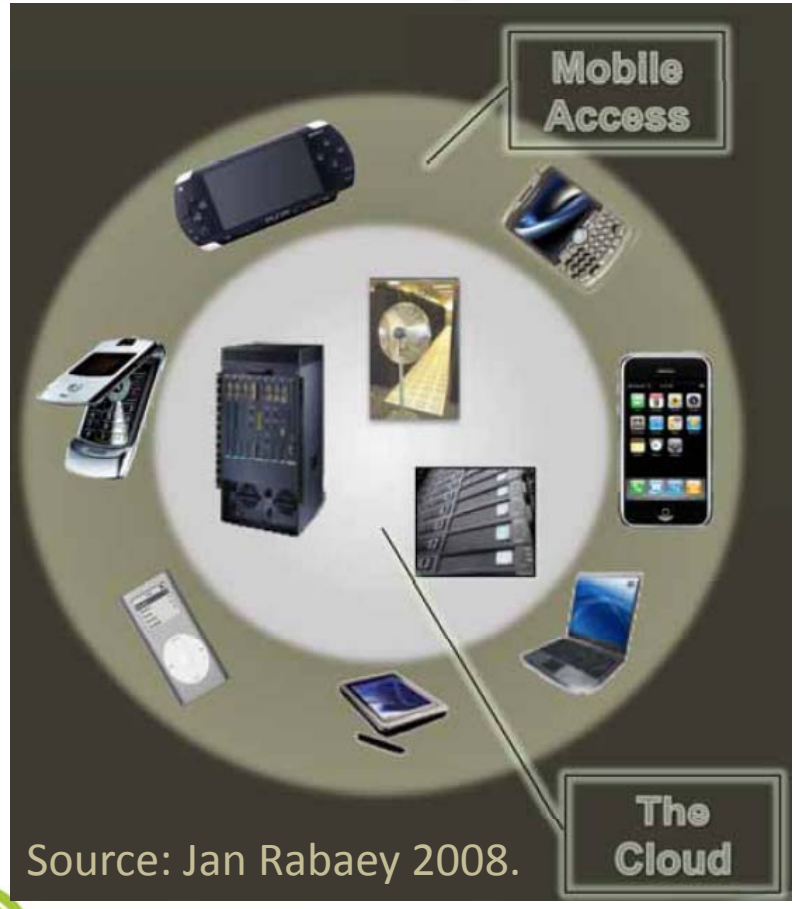
- **Introduction:**
  - the IT Platform of Today: at the edge of the cloud
- **Guardian Angels for a Smarter life:**
  - concept: enabled by Zero-Power
  - the next electronic switch
  - role of heterogenous integration:
    - Novel architectures and materials (silicon, carbon, III-V)
  - bridging reaserch and communities
  - enablig a revolution in academic curricula
- **Conclusion**

Innovation semantic waves



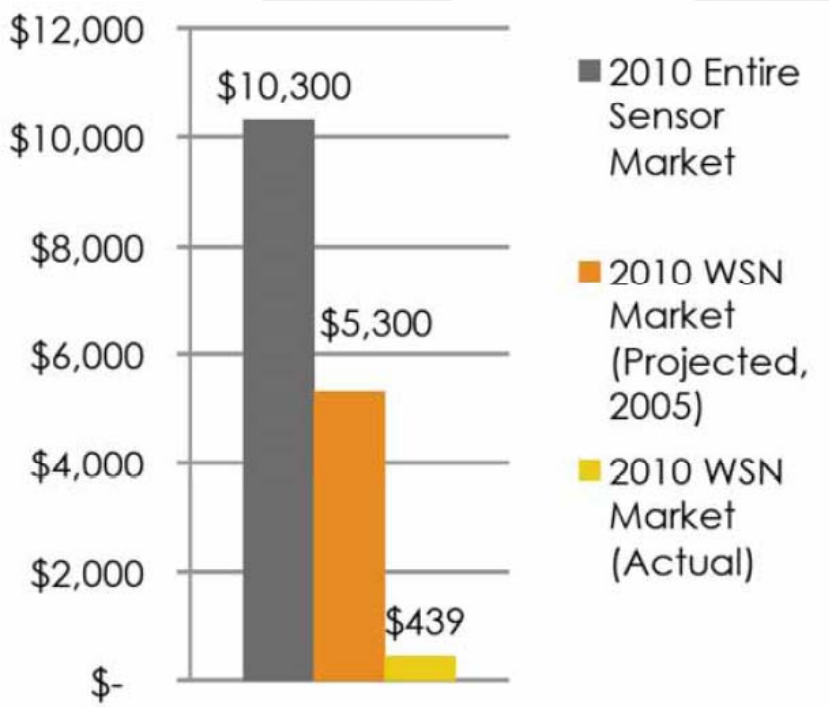
At the edge of the cloud

1. Today: **Mobiles at the Edge of the Cloud**



Source: Jan Rabaey 2008.

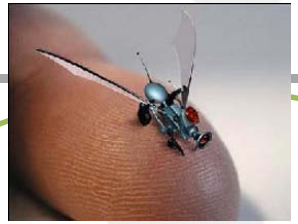
2. Today: **The unfulfilled promise of Wireless Sensor Nets**



WSN: the birth of the Swarm

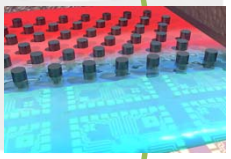
Challenges:

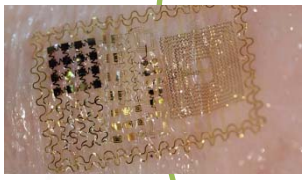
- economy of scale
- interoperability
- energy
- reliability
- cost & easy to use



The Gateway

The Swarm



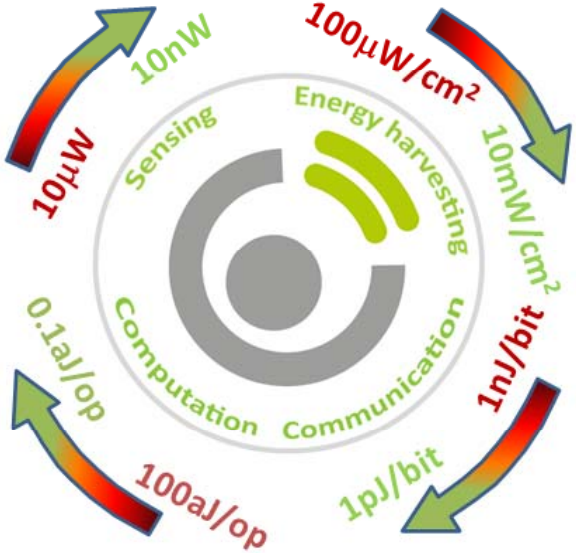


Interconnected smart objects enabled by energy efficient nanotechology : **the Guardian Angels.**

The Cloud

Concept: Guardian Angels

Guardian Angels are future **zero-power smart autonomous systems** featuring sensing, computation and communication beyond human aptitudes. They can harvest different kinds of energy.



Guardian Angels
for a smarter life

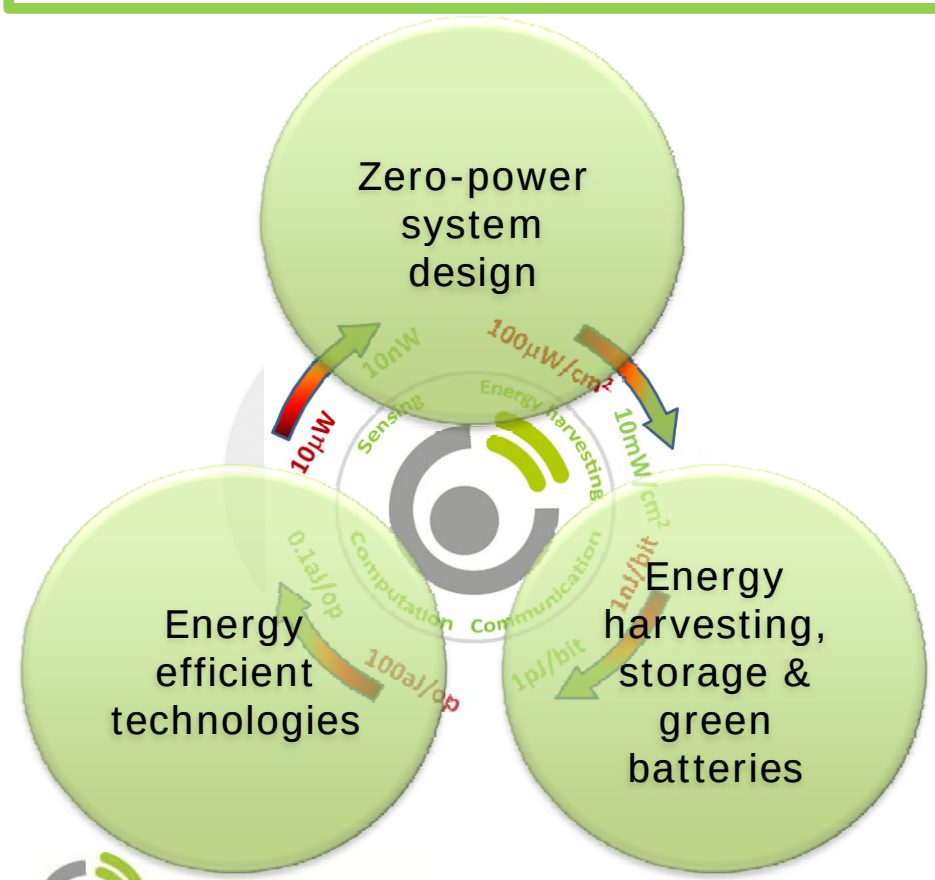
Enabled by zero-power

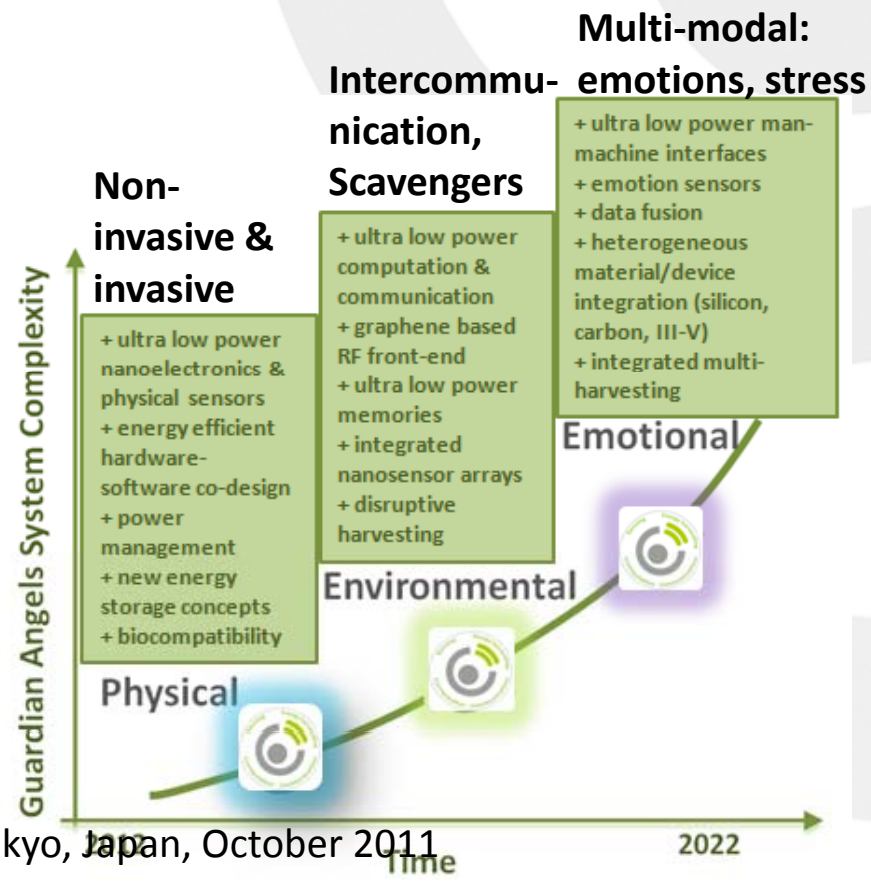
- **Zero-power is the system ability to harvest energy** existing in dynamic environments (solar, thermal, vibration, electromagnetic) and power-up the smart GA systems.
- **GA's are smart personal companions**
  - They will actively assist humans from infancy to old age in any life situation.
  - They are autonomous, straightforward and non-intrusive.
  - They are smart, controllable, secured and personalized.

The roadmap

Energy limits drive

the zero power technology platform ⟷ **3 generations of Guardian Angels**





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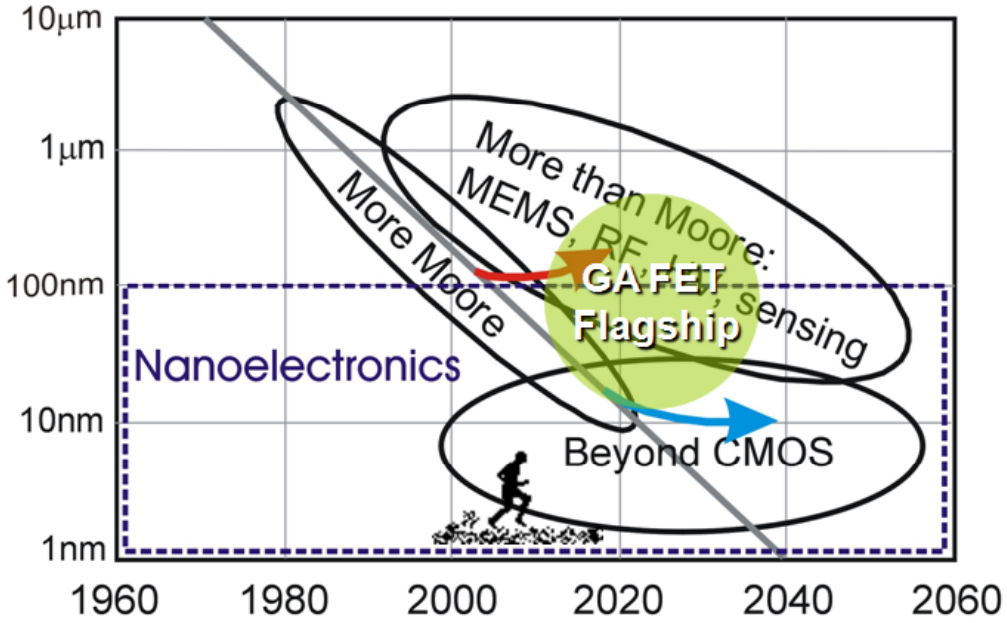
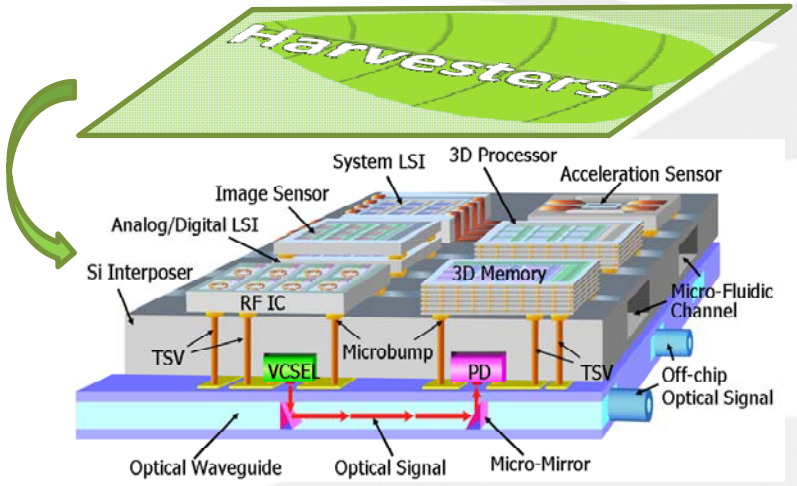
Heterogeneous integration

- **Heterogeneous integration at affordable cost**
- **Drivers: power consumption and novel functionality**



Guardian Angels zero power platform

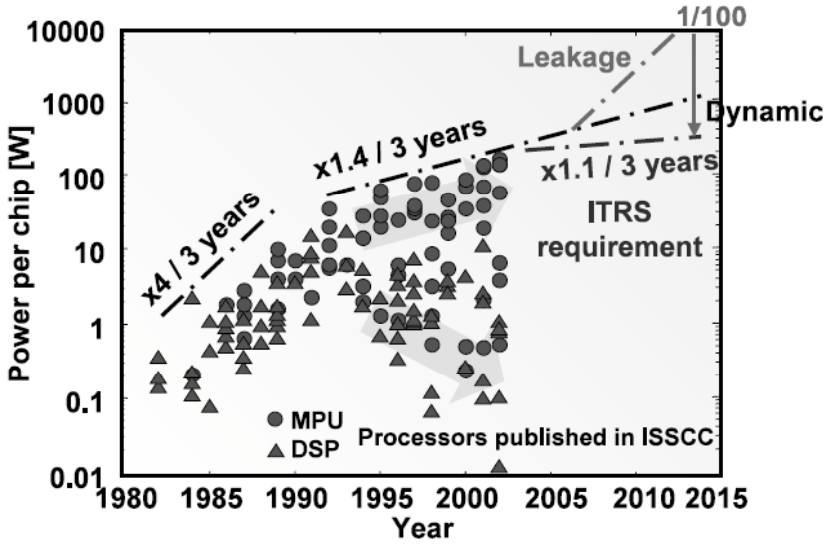


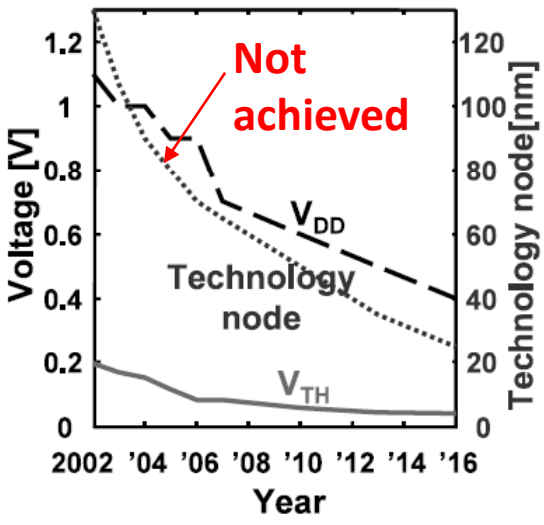
Guardian Angels
for a smarter life

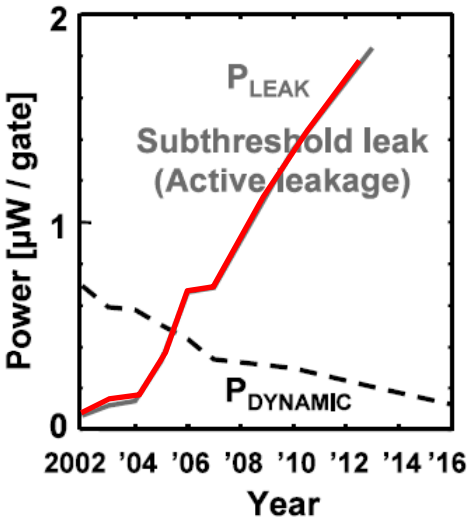
A.M. Ionescu, IS-AHND, Tokyo, Japan, October 2011

Power challenge

- Power per chip continues increasing.
- Leakage power dominates in advanced technology nodes.
- V_T scaling saturated by 60mV/dec physical limit.
- Voltage scaling slowed: 45nm=1V, 22nm=0.8V







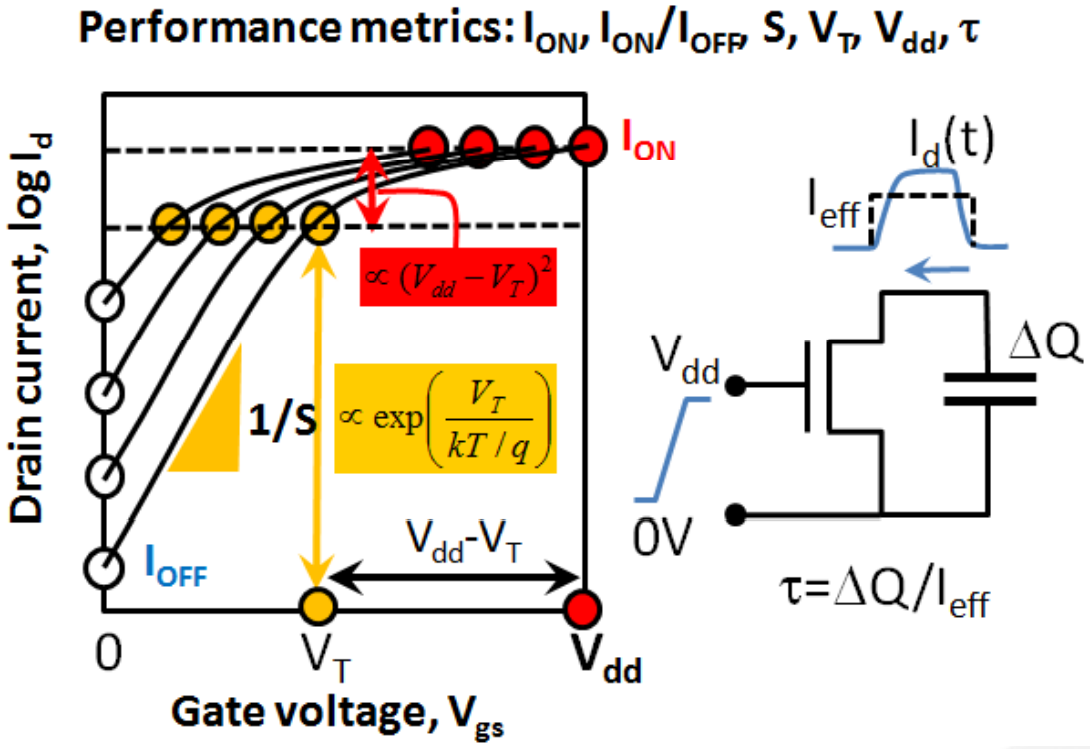
T. Sakurai, IEICE Trans. Electron., Vol.E87-C, April 2004, pp. 429-436.

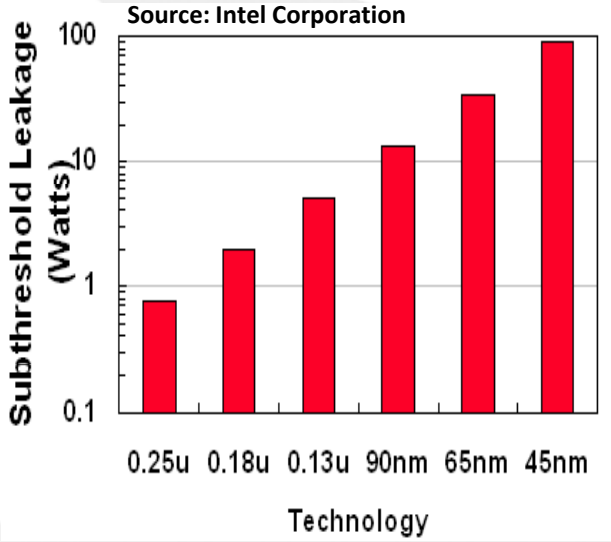
A.M. Ionescu, IS-AHND, Tokyo, Japan, October 2011

Guardian Angels
for a smarter life

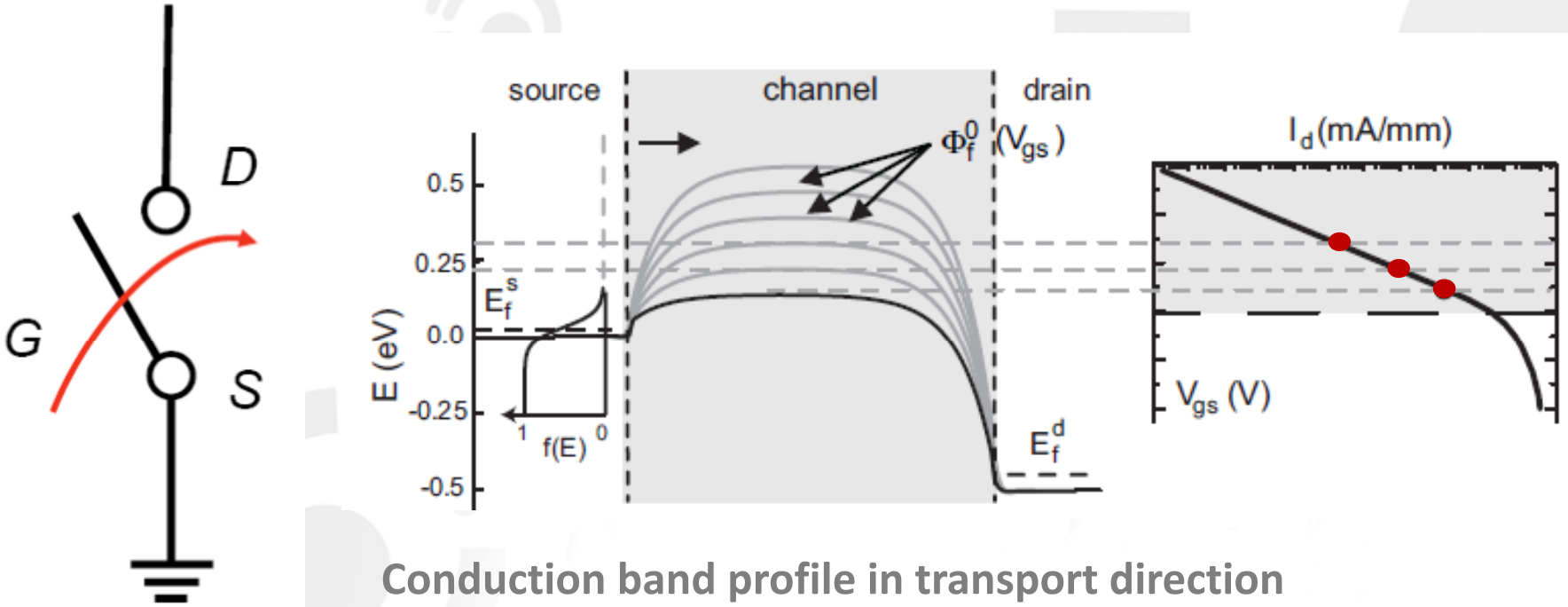
Leakage power & swing

Reducing threshold voltage **by 60mV**
increases the leakage current (power) **by ~10 times**





Physics of thermal swing



Conduction band profile in transport direction in a long channel MOSFET.

• The gate voltage moves the conduction band downwards, so that a larger fraction of the exponential tail of the source Fermi distribution can contribute to the current.

•This gives rise to the exponential increase of the current.

Energy limits and swing

$$E_{total} = E_{dynamic} + E_{leakage} = \alpha L_d C V_{dd}^2 + L_d I_{off} V_{dd} \tau_{delay} \approx$$

$$\approx \alpha L_d C V_{dd}^2 + L_d C V_{dd}^2 \frac{I_{off}}{I_{on}} =$$

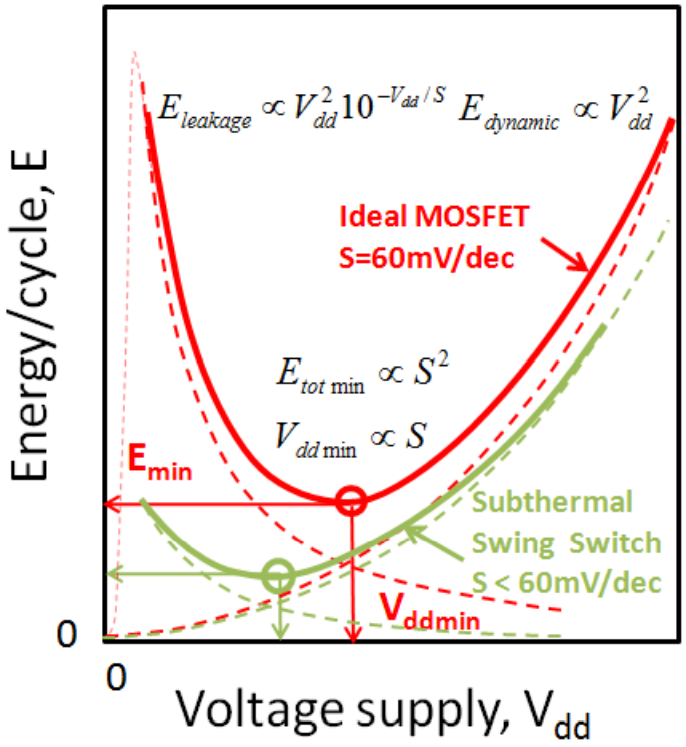
$$= L_d C V_{dd}^2 (\alpha + \frac{I_{off}}{I_{on}}) \approx L_d C V_{dd}^2 (\alpha + 10^{-V_{dd}/S})$$

$$P = \alpha L_D C V_{dd}^2 f + I_{off} V_{dd} \approx K C V_{dd}^3 + I_{off} V_{dd}$$

a technology that would enable a voltage scaling by a factor of 5 (from 1 V to 0.2 V) with a negligible leakage power (with ultra-low I_{off} due to a small S, as the TFET) **could offer a power dissipation reduction of 125x.**

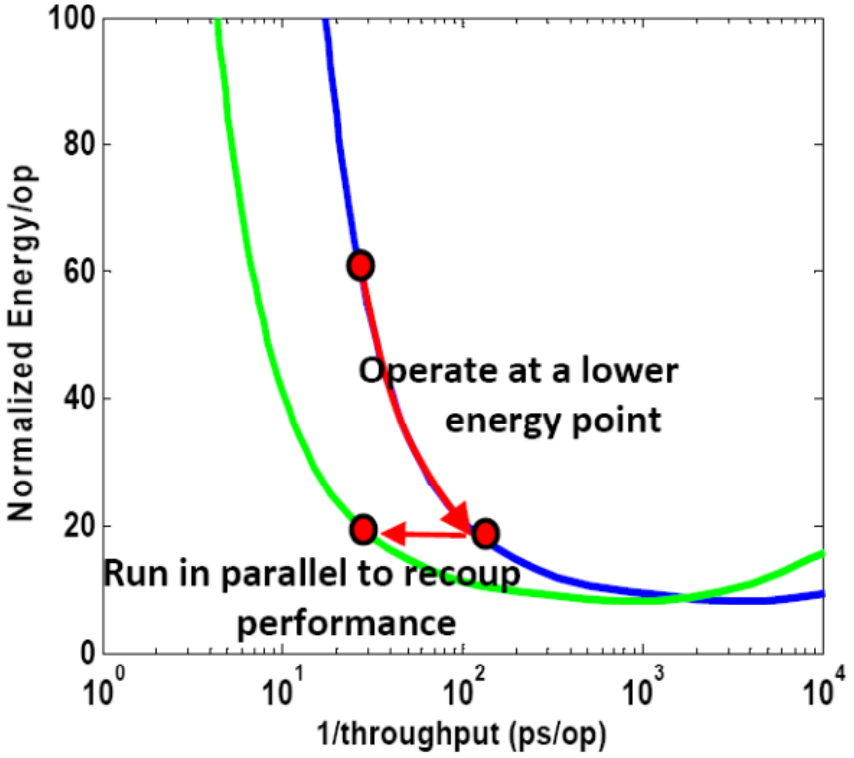
Device versus architecture

Lower CMOS fundamental limit in energy per operation by **subthermal S novel devices**



Source: A.M. Ionescu, H. Riel, to appear.

Parallelism (multi-core) is a key technique to improve system performance under a power budget



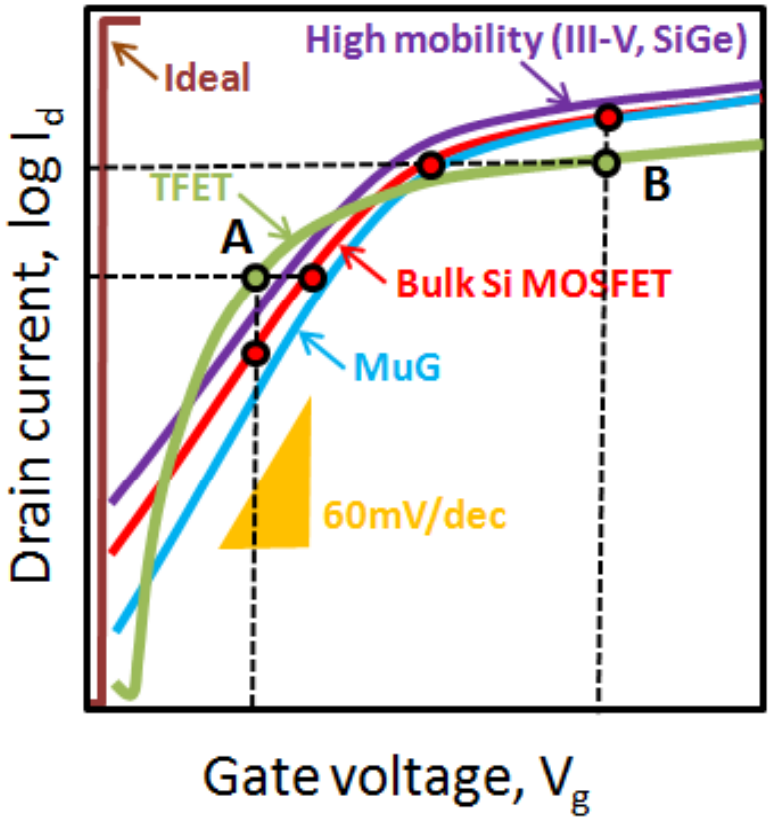
Source: T.J. King, UC Berkeley.

The next electronic switch

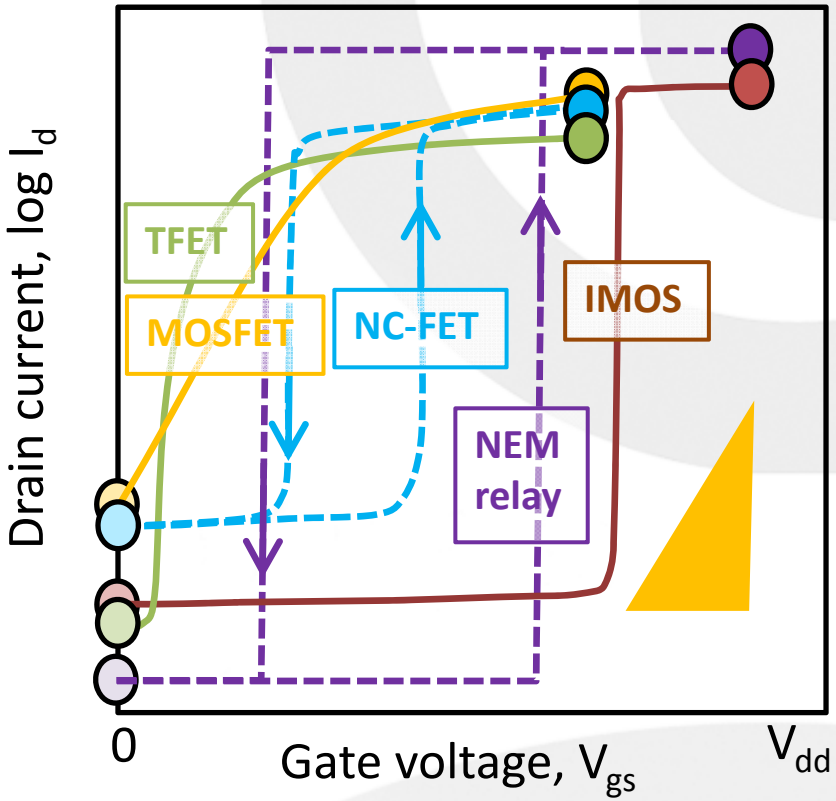
- **Improving the MOSFET switch:** evolutive, additive technology boosters.
  - Channel engineering to reduce the V_{dd}-V_t (Ge, III-V, graphene, etc).
  - Nanowire and nanotube FETs for improved electrostatic (subthreshold leakage) control.
- **Reduce the V_T and V_{dd} by a novel** small swing switch.

Subthermal swing switch

Tunnel FET vs. future FET

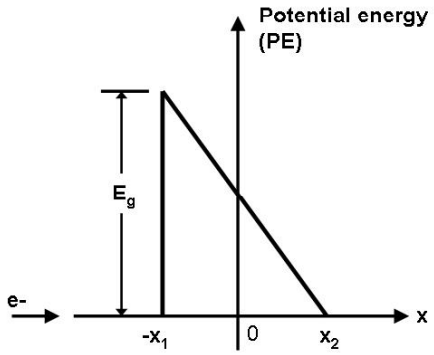


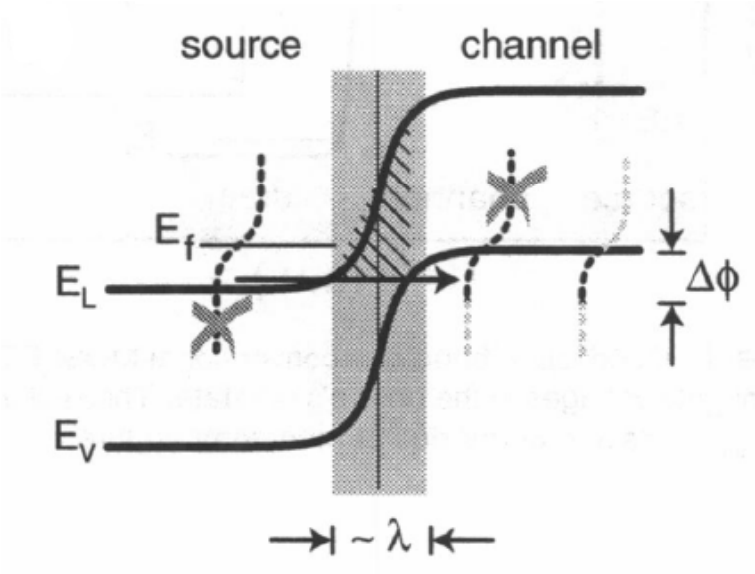
Small swing switches



Tunnel FET is the most promising small swing switch for V_{dd} scaling.

Quantum mechanical BTBT at the rescue



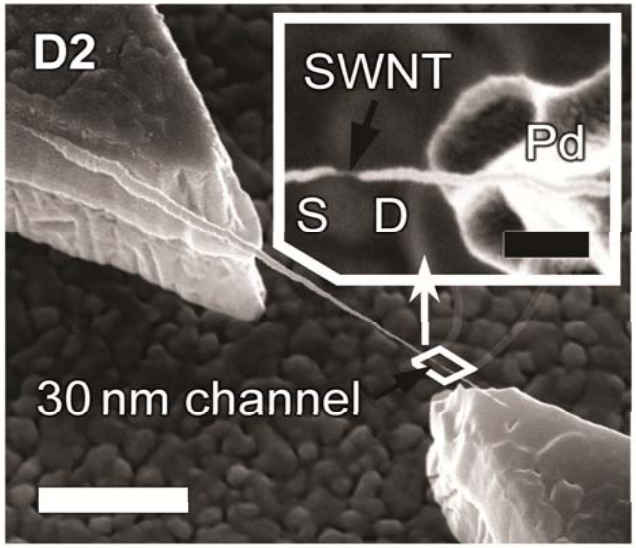


$$I_{BTB} \propto T_{WKB} \approx \exp\left(-\frac{4\lambda\sqrt{2m^*}E_g^{1.5}}{3\hbar(\Delta\Phi + E_g)}\right)$$

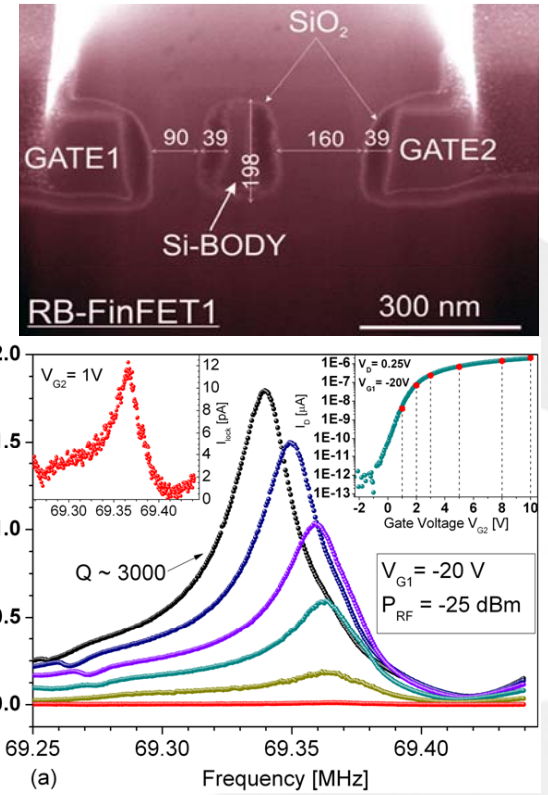
Parameter	Means of improvement
m^*	Small effective tunnel mass, SiGe, III-V, CNT
E_G	Source in SiGe, III-V heterostructures, strain CNT
λ	3D geometry (wrap gate), high-k gate dielectric, thin gate dielectric

Low power NEM sensors

Integration of a Field Effect Transistor (FET) into the suspended body of a silicon nanowire or carbon nanotube resonator results in integrated sensors with **mass-sensitivity below 10^{-19} grams and power consumption in the order of nW.**

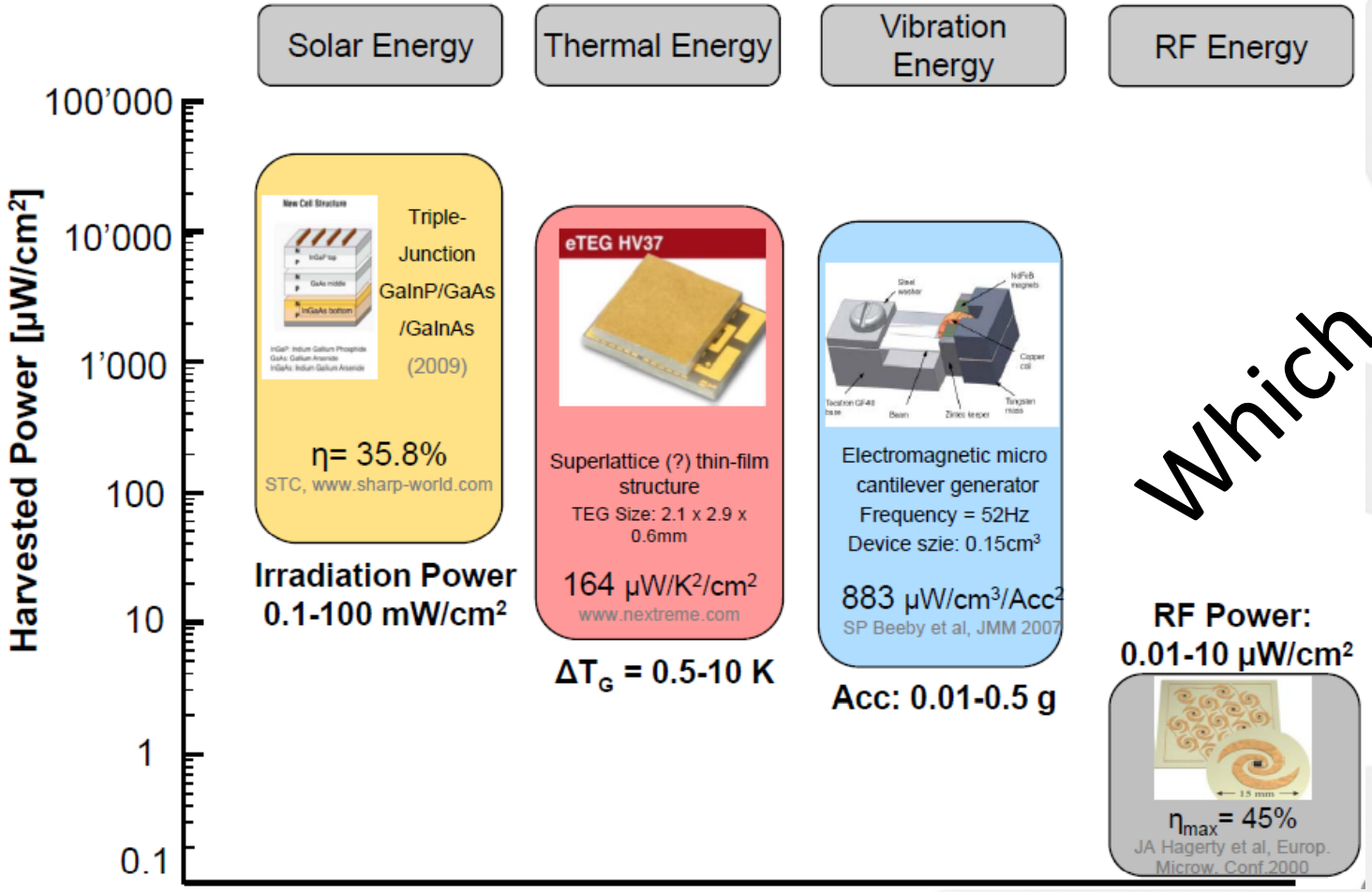


[Hierold lab]
Nanotera CABTURES (ETHZ)



[Ionescu lab/ Bartsch et al, IEDM 2010]

Energy harvesting systems



Source: Ch. Hierold, ETHZ.

Strategy for energy harvesting

The application of energy harvesters is driven by system requirements:

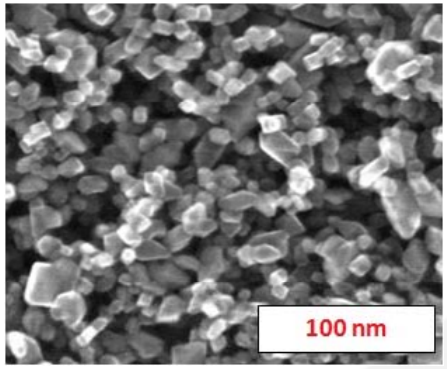
- **Energy efficiency** by recovery of dissipated energy, and renewable energy
  - solar energy, automotive and industrial systems
- **Autonomy to avoid battery replacement** and infrastructure costs
  - industrial automation, sensor networks for environmental monitoring and structural health, building automation
- **Autonomy for convenience** in wearable electronic devices
  - sport, health / home care, life style, short range communication

There is no winning concept:

The analysis of the system specification defines the right type of harvester or combination of harvesters

Disruptive harvesting ideas

Bio-inspired energy scavenging: **artificial photosynthesis**



- Environmentally friendly materials
- High efficiency in-door & out-door
- Low cost processing

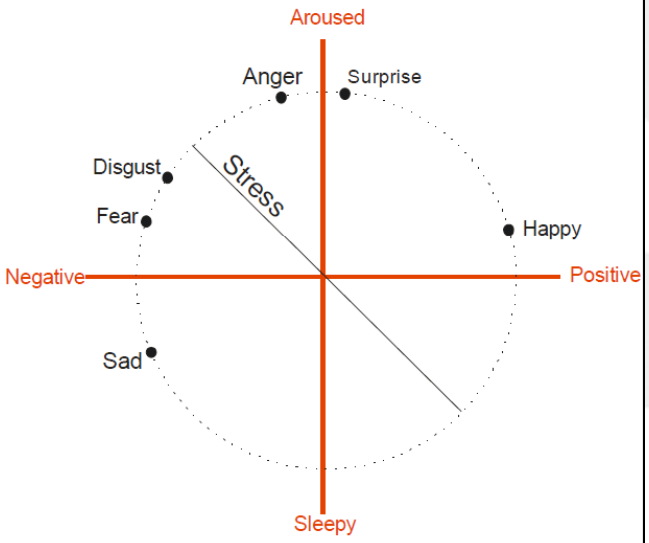
Guardian Angels
for a smarter life

A.M. Ionescu, IS-AHND, Tokyo, Japan, October 2011

Emotional interfaces

Tomorrow: comfortable, accurate, continuous emotion monitoring in real life situation

- Wearable and disappearing systems for real-time measurement of stress and emotion
- Multi-modal for improved accuracy: combine ANS, cognitive and bio-chemical information
  - ANS for physiological arousal
  - EEG for cognitive valence of emotion (positive – left hemisphere, negative – right hemisphere)
  - EMG of the trapezius muscle
  - Voice analysis
  - Chemical monitoring of sweat incl Cortisol
- Ultra-low-power for miniaturization and long term use (> 1 month) => zero energy: ultra low power, energy scavenging, micro batteries
- Smart, private and connected



Impact

- **Society and life**
  - as personal companions, GA's will preserve human health and improve the quality of life for all categories of ages, in an affordable way
  - GA's will make our environment more interconnected and smart, more energy efficient and safe
  - Disrutive technology focused on prevention based on augmented information for personal level decision
- **Leadership in science and technology**
  - leading role of Europe in zero-power novel technologies
  - enabling a stronger role of manufacturing in Europe
  - improving the competitiveness for leading communication and medical companies
- **Employment**
  - creation of new employment in Europe in ICT domain
  - new business opportunities

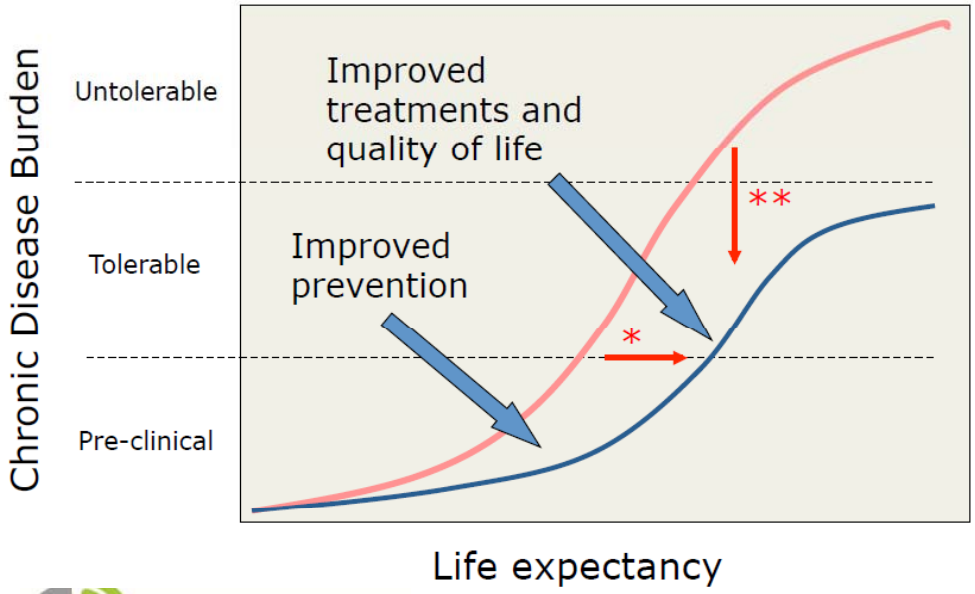
GA's care about you: prevention

Pharmaco-therapy

- **early detection** of treatment inefficiency or relapses.

Prevention/diagnostic

- **early signature** of disease, metabolic and cardiac disorders.



** Decrease severity

* Delay onset

Early detection of abnormalities by a Guardian Angel continuous monitoring

- **Homeostasis**
  - Hormonal
  - Metabolic
- **Compliance to treatments**
- **Biomarkers**
  - Cancer
  - Infectious diseases
- **Physical parameters**
  - **Activity**
  - **Circadian rhythm**
  - **ECG, EEG**

Guardian Angels
for a smarter life

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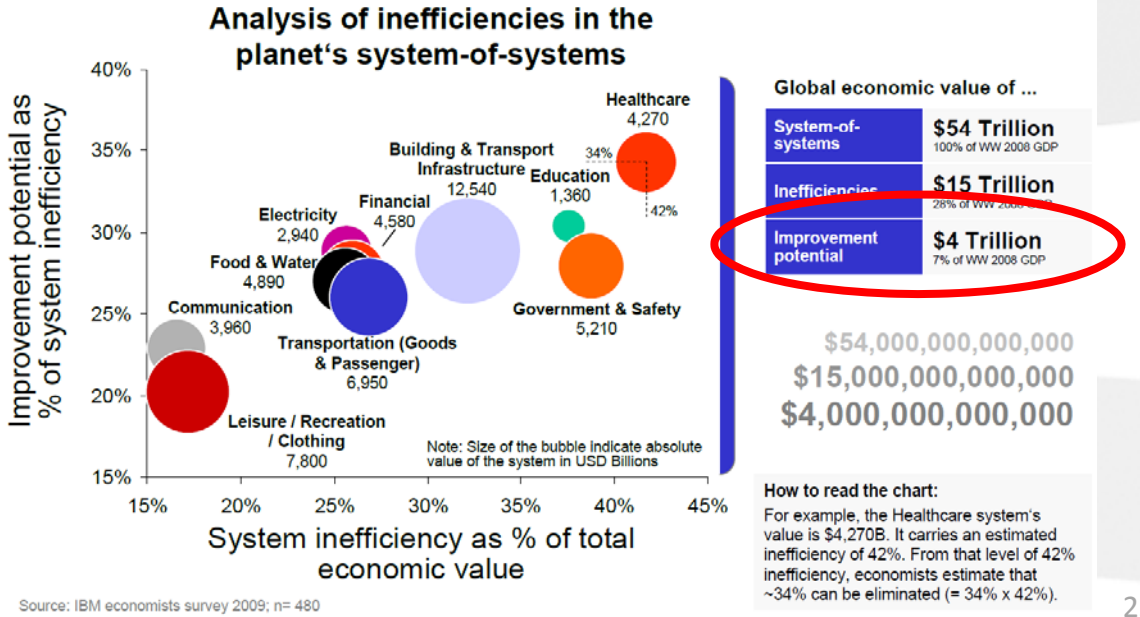
Energy efficiency: global

Energy Efficient Electronic Systems
June 11-12, 2009
Berkley

Gideon Varga, Industrial Technologies Program U.S. Department of Energy

Energy Consumption By Function		Technical Opportunity	Technological Energy Savings	Total Energy Savings	National Impact (in billion kWh)
			Estimated Maximum Potential Energy Savings		
			(% of IT energy)	(% of facility total energy)	(2006 baseline: 60 billion kWh)
Equipment and Software	50% of Energy Use (est.)	Chip-level and Automated Power Management	50%	50%	30
		Dynamic Energy Consumption Management in Network Devices	40%	40%	24
		Data Storage Technologies	10%	10%	6
		Hardened ICT Equipment	0%	25%	15
		Novel Computing Architectures	50%	50%	30
		Nanoelectronic Circuitry	75%	75%	45
		All-Optical Networks	75%	75%	45
		Superconductive Components	50%	50%	30

This chart shows 'systems' (not 'industries')



Source: IBM economists survey 2009; n= 480

Initiatives for improving the energy inefficiency of complex systems:

- IBM's **Smarter Planet**
- Intel's **Green** initiative

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for a smarter life

GA's in media

FINANCIAL TIMES

May 4th, 2011

Research projects vie for EU's €1bn funding prizes

'Grand challenge' finalists selected

Two to be chosen from shortlist of six

By Clive Cookson in Budapest

Europe has shortlisted six "grand challenges" as flagship research initiatives, including developing robots as personal companions and building a supercomputer simulation of the human brain.

Two winning projects will each receive €1bn ($1.5bn) in funding over 10 years.

Neelie Kroes, European Commission vice-president, announced the finalists on Wednesday at the Future and Emerging Technologies conference in Budapest. The aim was to produce "successes that will be remembered, not just for today, but for a lifetime," she said.

The contenders will each receive €1.5m from the Commission's Future and Emerging Technologies programme to work up their proposals before winners are chosen late next year.

The projects are expected to involve large networks of university and industry researchers across Europe and beyond.

"With the flagships it is not just about the excellence of the science," said Robert Madelin, Europe's director-general for information society and media. "Will it be possible on scientific grounds to tell the six projects apart in a year's time? I think not. The winners will have to be determined by non-scientific priorities."

Although Switzerland is not a member of the European Union, it is a full participant in EU research programmes and two of the shortlisted projects are led by the Ecole Polytechnique Fédérale de Lausanne.

Perhaps the most futuristic is EPFL's Guardian Angels, which will use computing and imaginative energy research to "create the ultimate smart device that will assist humans from infancy to old age".

The guardian angel will "scavenge for energy", for example by tapping the heat and movements of the human body.

Two projects concentrate on finding new ways to process vast amounts of data that are impenetrable using today's computers.

The most wide-ranging is the FuturICT Knowledge Accelerator, which would create a computer simulation of the whole planet, encompassing everything from climate to population movements and the economic system. Within this there would be several "crisis observatories" running gigantic data mining operations to warn of impending disasters such as financial crashes, emerging epidemics and environmental instabilities.

The other data-intensive project will apply IT to medicine to find better ways to apply all the health information gathered from the Human Genome Project and various biobanking projects to individual patients.

Perhaps the most futuristic is Guardian Angels which will use computing and imaginative energy research to create the ultimate smart device that will assist humans from infancy to old age

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Published online 8 March 2011 | Nature | doi:10.1038/news.2011.143

News

Stories by subject

European researchers chase billion-euro technology prize

From guardian angels to cuddly robots

As well as the Human Brain Project, the six shortlisted projects include Graphene, which will develop the thinnest conducting material known for data storage and processing platforms; and Guardian Angels, a project to develop nanoscale sensors and interfaces for detecting and responding to environmental danger.

The others are Robot Companions, which will develop soft-bodied 'perceptive' robots as companions for the lonely; FuturICT, for planetary-scale modelling of human activities and their impact on the environment; and ITFoM (IT Future of Medicine), which will develop ways to apply research data more efficiently in health care.

Those shortlisted were selected for the grandeur of their vision. "We can't even imagine today all the applications for Guardian Angel interfaces – they could even respond to changes in emotional states of people," says Adrian Ionescu of the EPFL, who leads the Guardian Angels project. The EPFL is one of the two sites of the Swiss Federal Institute of Technology (ETH).

GA's movie