Panel on Advances on Mini/Micro Materials and Technologies

ICQNM, Rome, 11th September 2017

Thierry Ferrus (moderator)

Hitachi Cambridge Laboratory

Hitachi Europe Ltd

HITACHI
Inspire the Next

Panel on Advances on Micro/Nano Materials and Technologies

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Panelists

Mario D'Acunto, CNR, Istituto di Biofisica, Italy
'NanoICT: nature - inspired sensing tools at small scales'

Brendan O'Flynn, Tyndall National Institute, Ireland
'System In Package Vs ASIC - More than Moore Challenges and opportunities'

Masato Inagi, Hiroshima City University, Japan
'Lithography Hotspot and Detection Methods'

Thierry Ferrus, Hitachi Cambridge Laboratory, UK
'From micro to nano: a long way down'

From micro to nano: a long way down

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New technologies and Moore’s law

- New requirements (solving complex problems…)

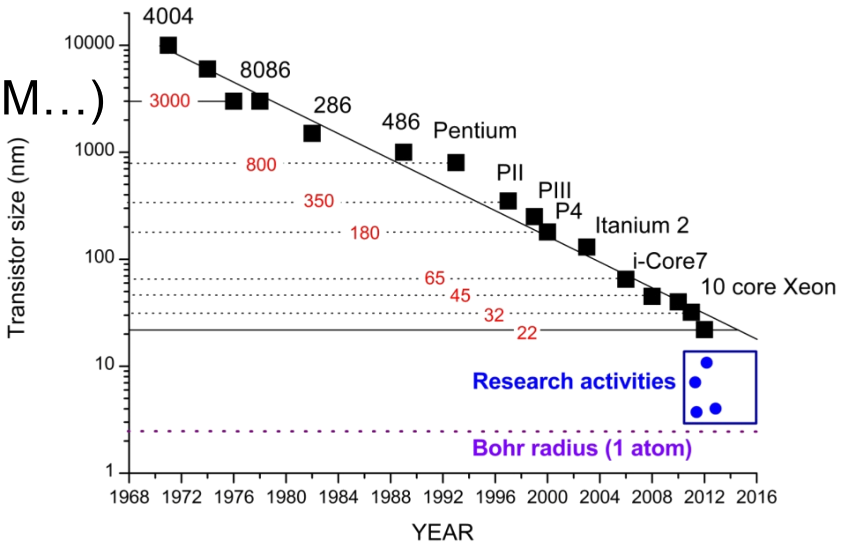
Motivation

Technical advances (lithography, SEM…)

Opportunities / Problems

New applications (QIP)

- Business not technology driven



New technologies and Moore’s law

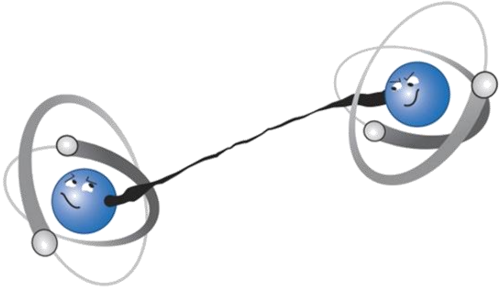
- Consequences of downscaling :

  - Provide new applications driven by technology → Thierry Ferrus …
    or inspired by nature → Mario D'Acunto

  - Create new challenges in processing → Masato Inagi
    in integration → Brendan O'Flynn
    in detection → Thierry Ferrus

New physics, new applications

- Quantum mechanics
  - Entanglement (security) :



    Cryptography (secure communication)

    Eavedropping

    Weak measurements

  - REAL parallel processing (speed increase)

    Limited bandwidth, speed of light / e-

‘From micro to nano: a long way down’

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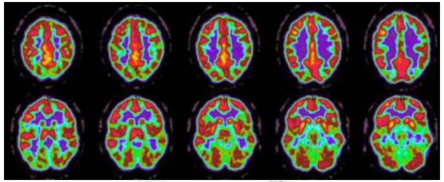
New physics, new applications

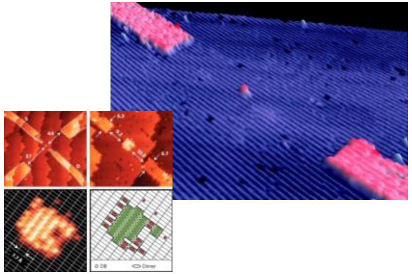


- Security : banking
  police (real time face recognition), military
- Medicine : faster, higher resolution scans,
  molecules sampling, drug testing
- Smart cities : intelligent cars
  real traffic management (car, plane)

- Space : star studies
  exoplanet search (resolution, sampling)

- Robotics : machine learning, artificial intelligence

New type of detection / access



- Gate access more difficult (complex design, number)

  Smaller objects (100 nm ➔ 3 nm), new physics

- Gate addressing and measurement

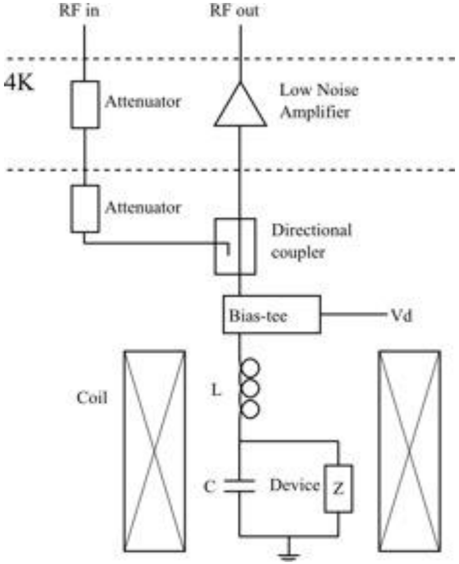
  Radio frequency (100 MHz-1 GHz)

  Microwave (1 GHz - 300 GHz)

  TeraHertz (300 GHz - 3 THz)

  Cable

  Optical



- Wireless communication to device

END

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Wireless Sensor Networks

More than Moore Research

"Enabling Smart Everything Everywhere"

-requires a Hardware Software Codesign Approach

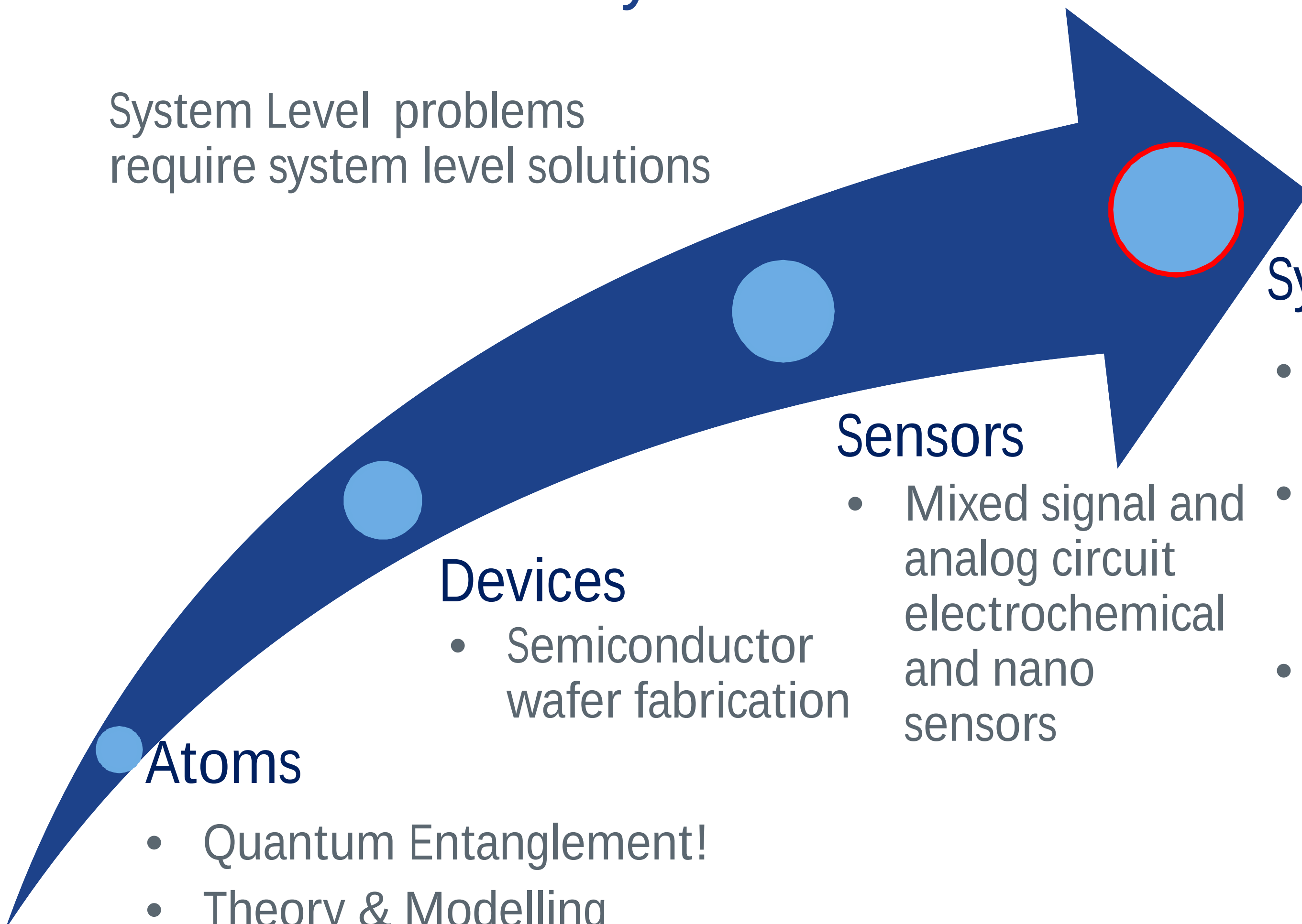
Dr. Brendan O'Flynn

2017

UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh
Ireland's European Structural and Investment Funds Programmes 2014-2020 Co-funded by the Irish Government and the European Union
European Union European Regional Development Fund

More than More than Moore
- from atoms to systems

System Level problems
require system level solutions



Atoms

- Quantum Entanglement!
- Theory & Modelling
- Nano materials and device processing

Devices

- Semiconductor wafer fabrication

Sensors

- Mixed signal and analog circuit electrochemical and nano sensors

Systems

- Smart sensors and systems
- Optical communication systems
- Microelectronic and photonic integration

Cyber Physical Systems for the Internet of Things
Creating Information from Data using a Systems approach

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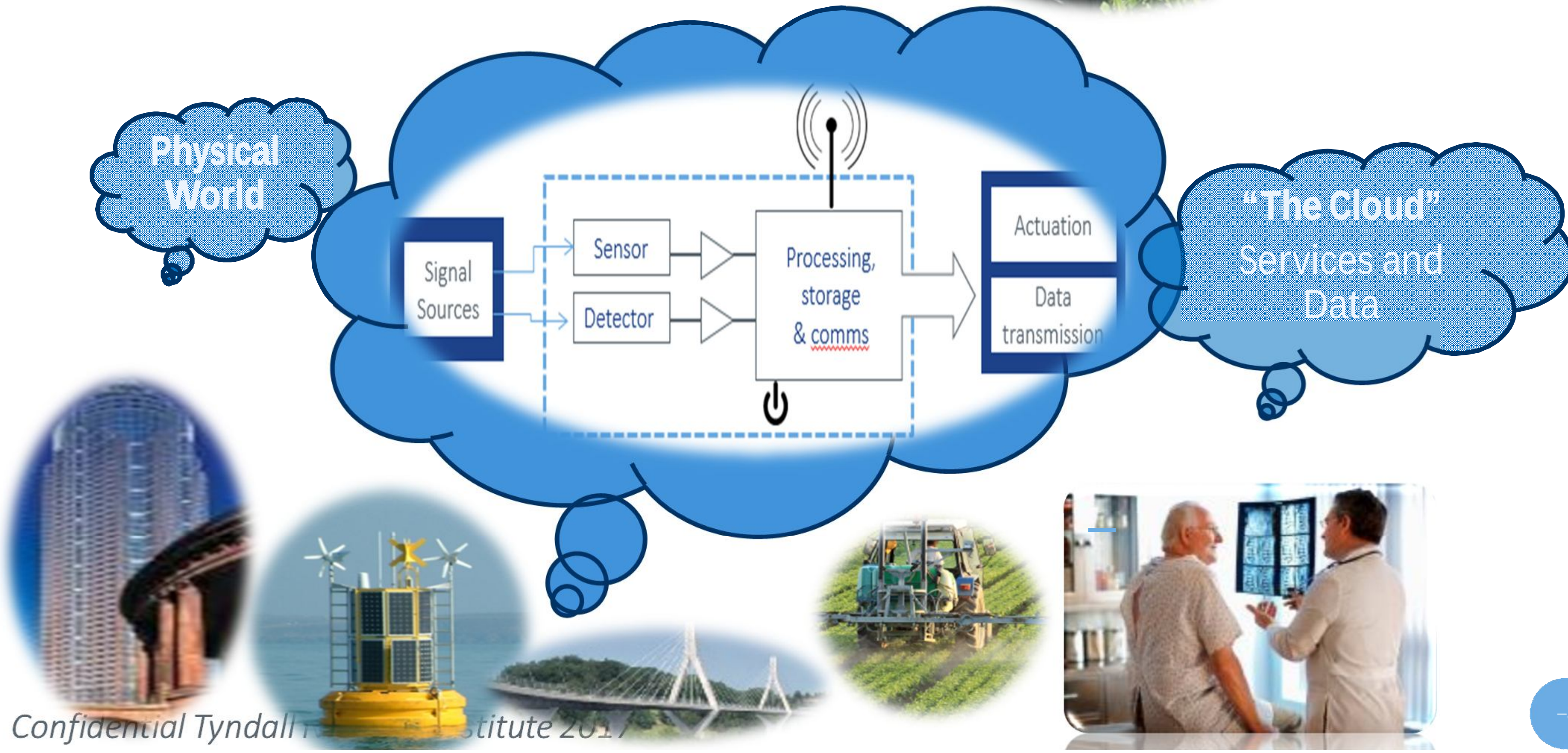
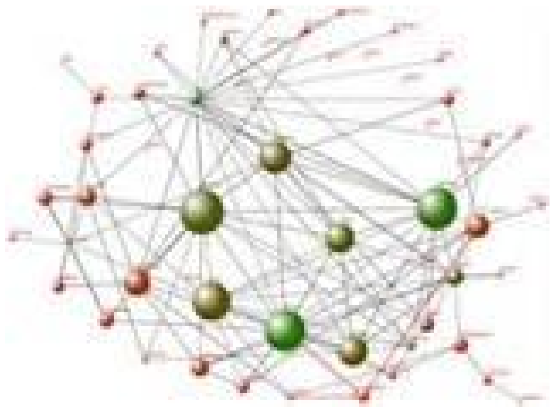
Interfaces to users, to the physical world and the cloud



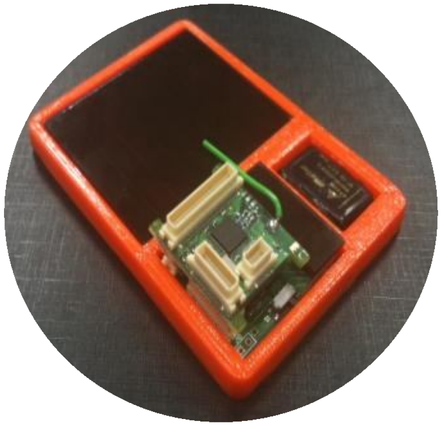
“Deploy & Forget”
Energy aware software & systems

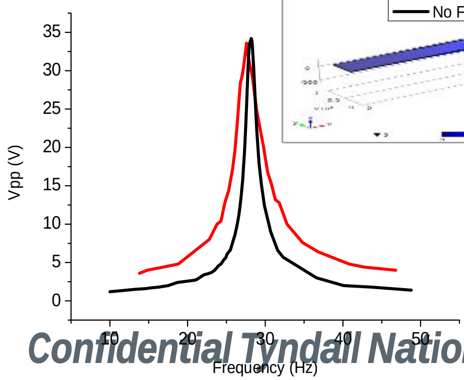
- **Key research challenge – indefinite lifetime deployment, low maintenance systems**

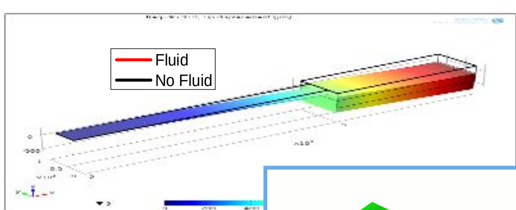


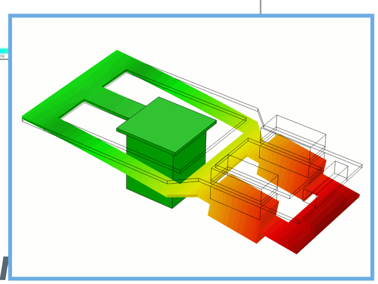
- Energy Aware Software and Systems

- **Energy Scavenging Systems**





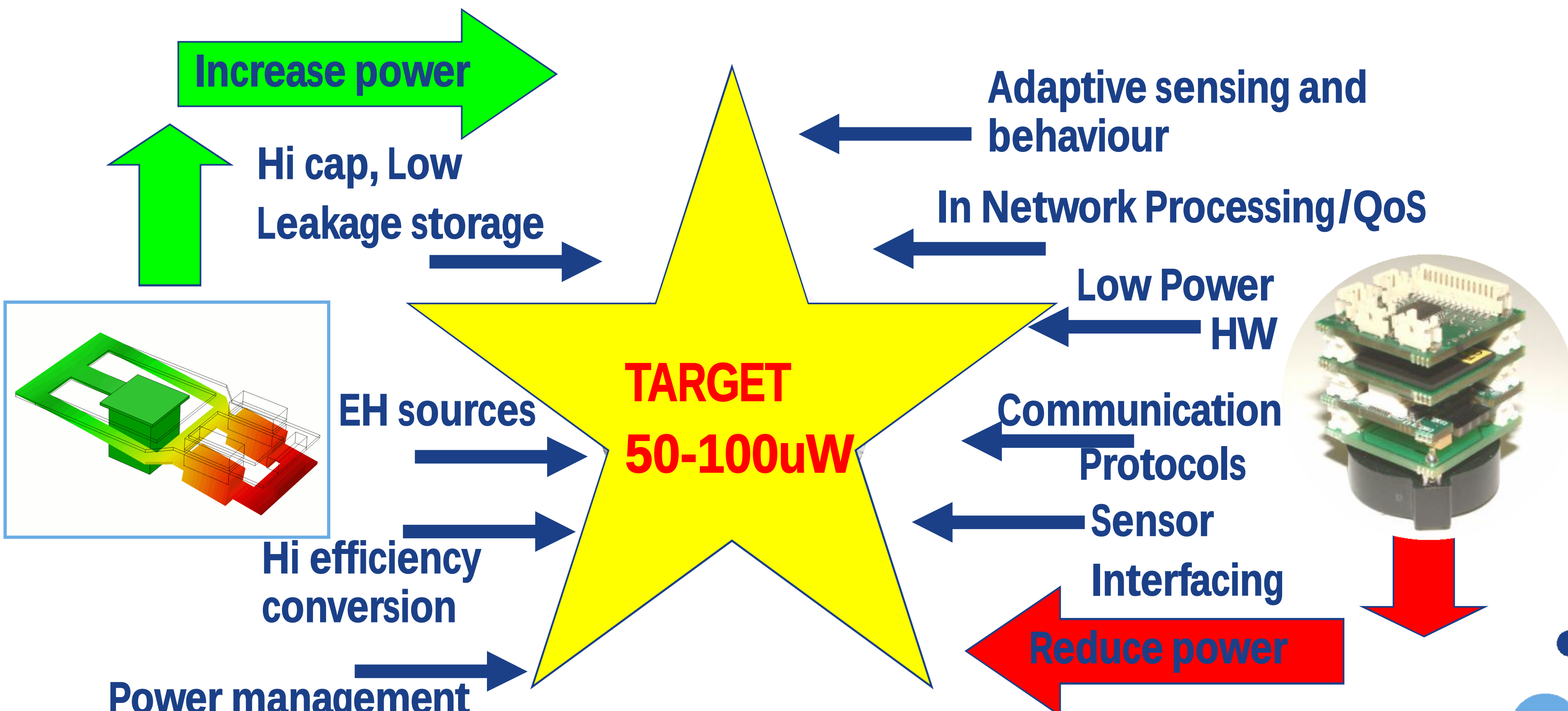




WSN: Energy aware software & systems

- **Bridging the gap…**

Needs a Hardware software co-design approach to maximise energy utilisation against energy available



Power management models
For Long Lifetime Wireless Sensor Networks

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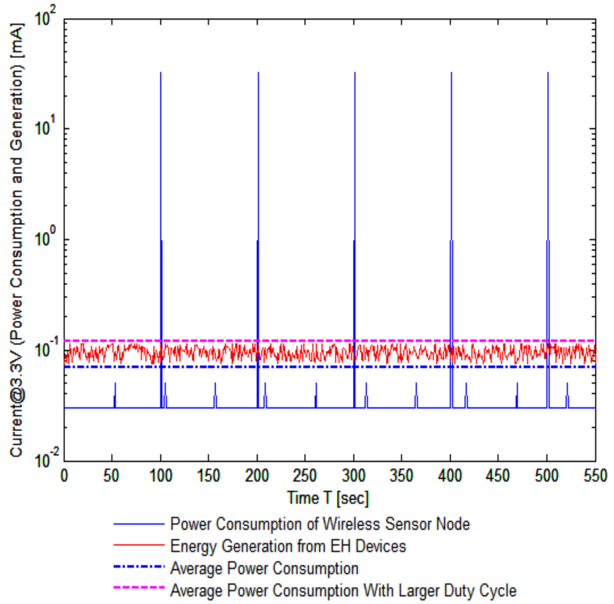
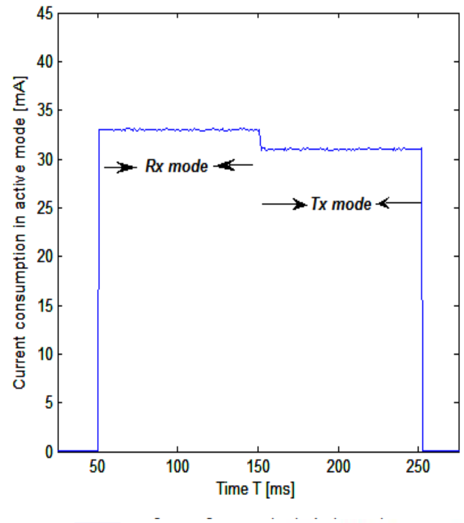
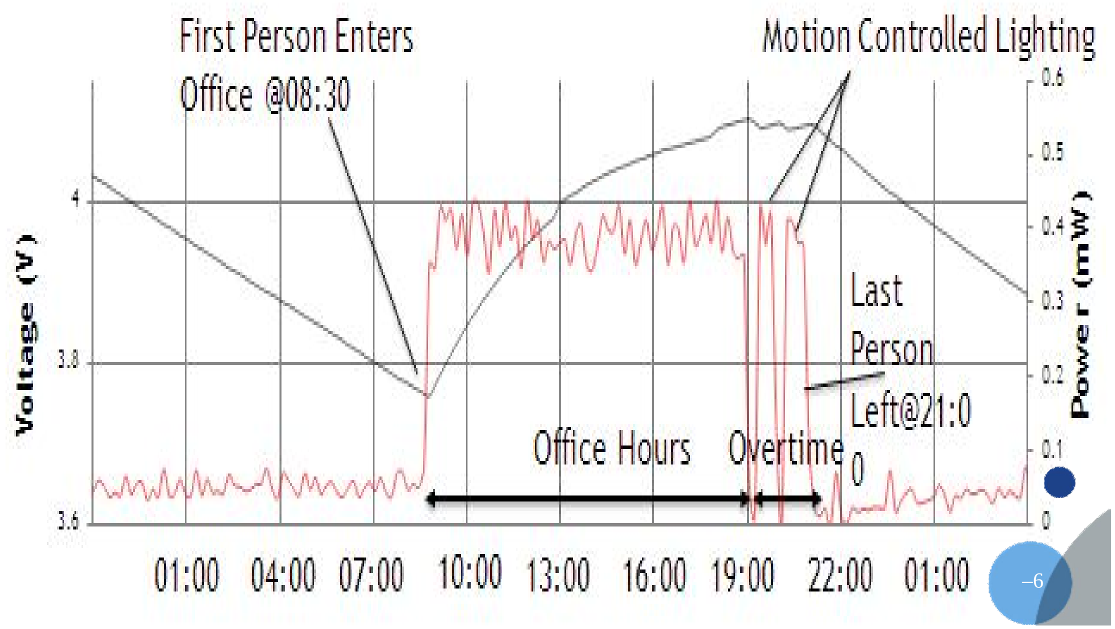


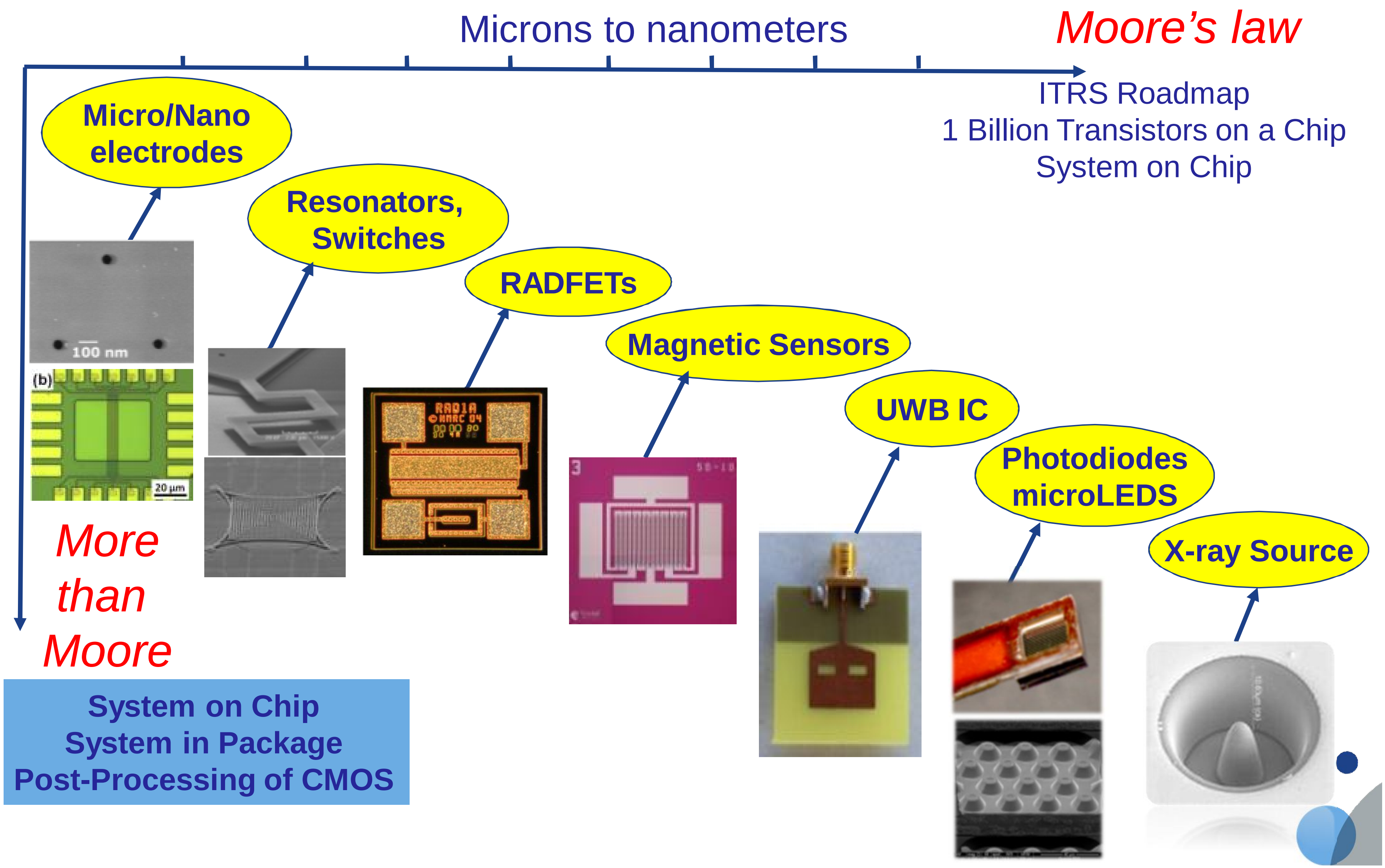


Energy Generated from Energy Harvester
Vs Power Consumption of Mote in Different Duty Cycle

Attempting to predict the behavior of networked wireless sensors, in terms of power consumption, in order to extend their lifetime.
Develop Smart systems that are adaptive in their behavior



Technology Platforms for More than Moore
Sensors and Actuators – Materials, Technology and Devices



Technology Platforms for More than Moore
Energy Harvesting & Storage – Materials, Technology and Devices

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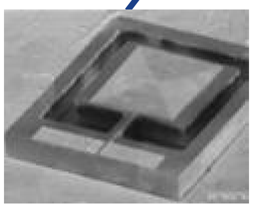
Microns to nanometers

Moore's law

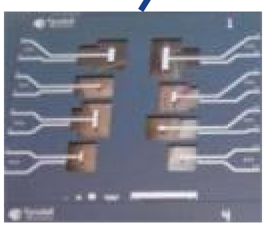
ITRS Roadmap
1 Billion Transistors on a Chip
System on Chip

More than Moore

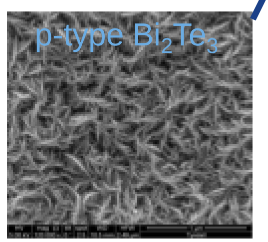
Energy Harvesting Electromagnetics

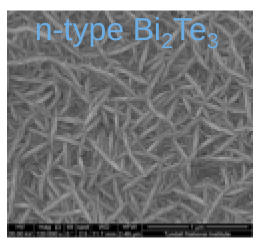


Energy Harvesting Piezoelectrics

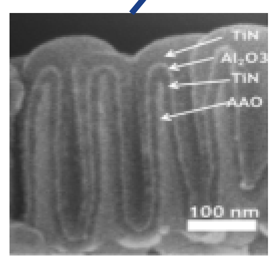


Thermoelectrics

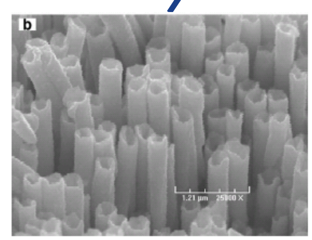




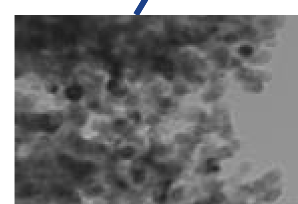
3D Supercapacitors



Microbatteries



Micro Fuel Cells



System on Chip
System in Package
Post-Processing of CMOS

A system level approach to Energy Provision

Tyndall National Institute

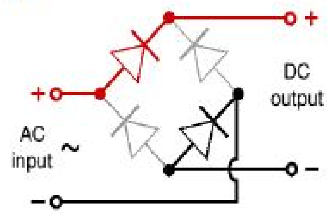
Control

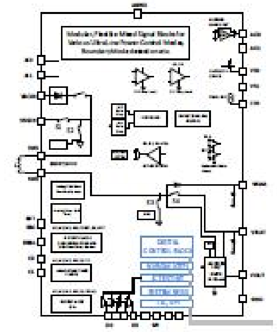
Power Management ICs & Circuits

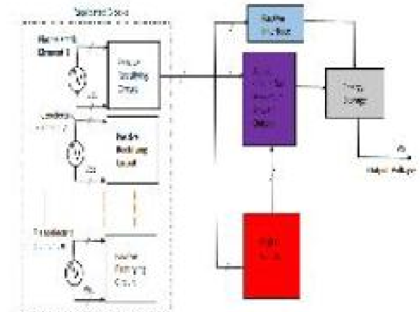
Multi-source

Self-start

High efficiency







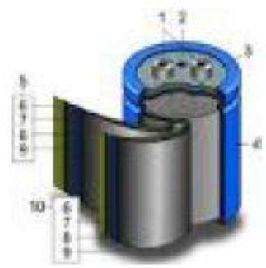
Storage

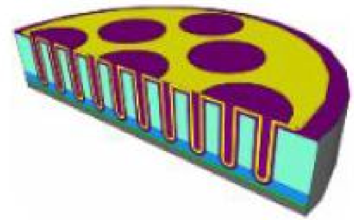
Supercaps on Silicon

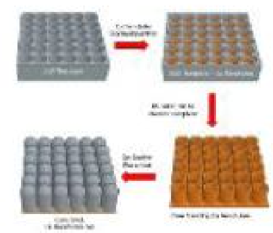
Flexible batteries

Micro-batteries

Nanotube high density







Generation

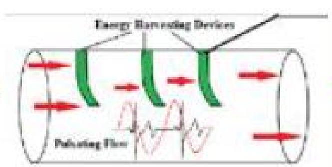
Generators on silicon

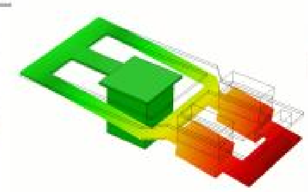
Wide bandwidth vibration

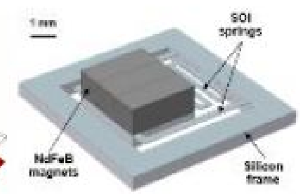
(Electromagnetic & piezo)

High density MEMS

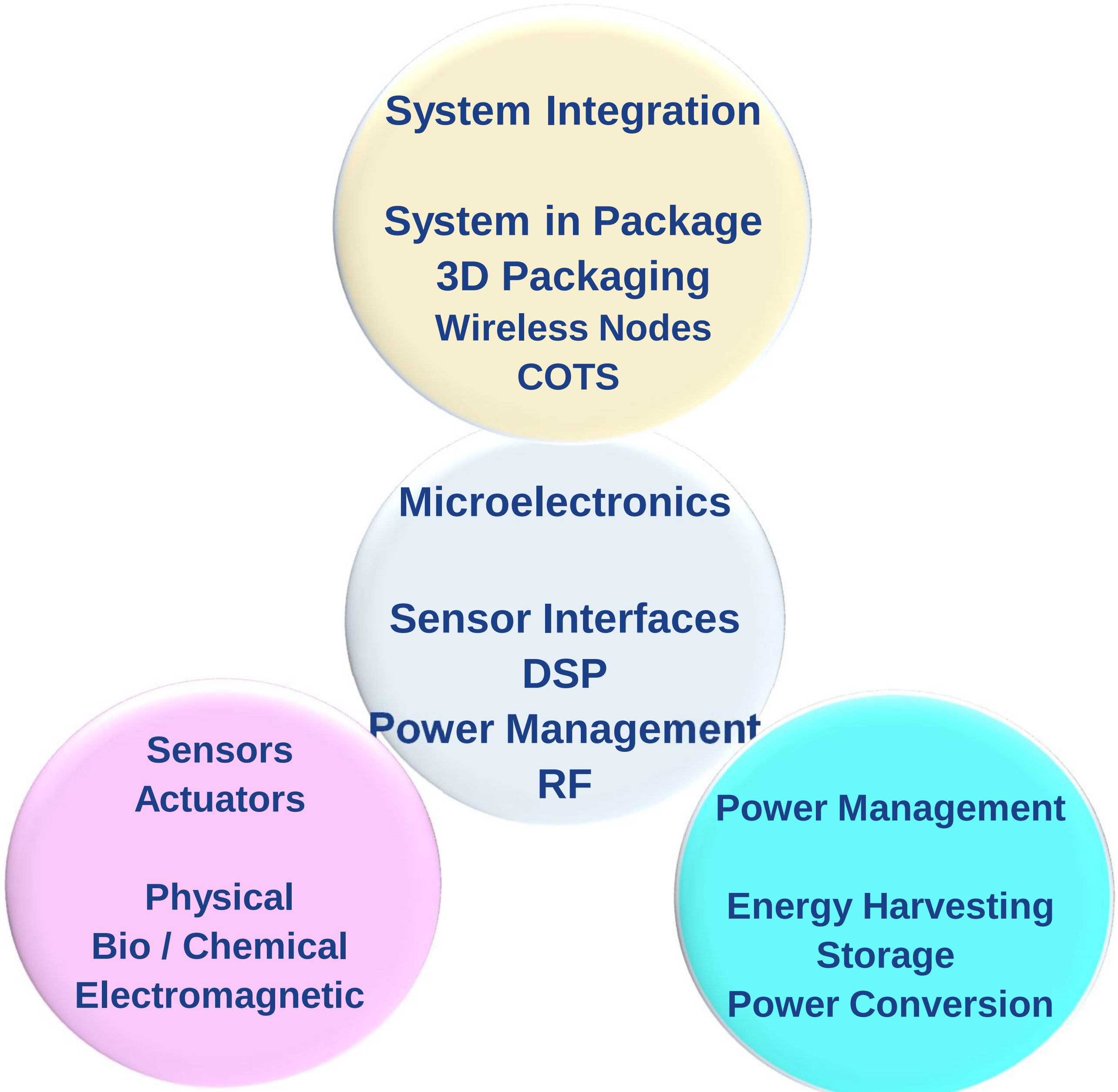
IC integrated highest efficiency TEG materials







Microelectronics Research Programme
System integration - More Moore – More than Moore



Smart everything everywhere
- Technology developments & Application Domains

Healthcare & Fitness:
Longer, healthy lives

Technologies for WSNs, Energy, Communications & Packaging:
Efficient, Reliable, Robust

Structures and Buildings:
Economic, Protected, safe

Environmental & marine monitoring:
Sustainable, secure

Acknowledgements

Tyndall
National Institute
Institiúid Náisiúnta

NDP National Development Plan Transforming Ireland

European Regional Development Fund

sfi Science Foundation Ireland

HEA Higher Education Authority An tÚdarás um Ard-Oideachas

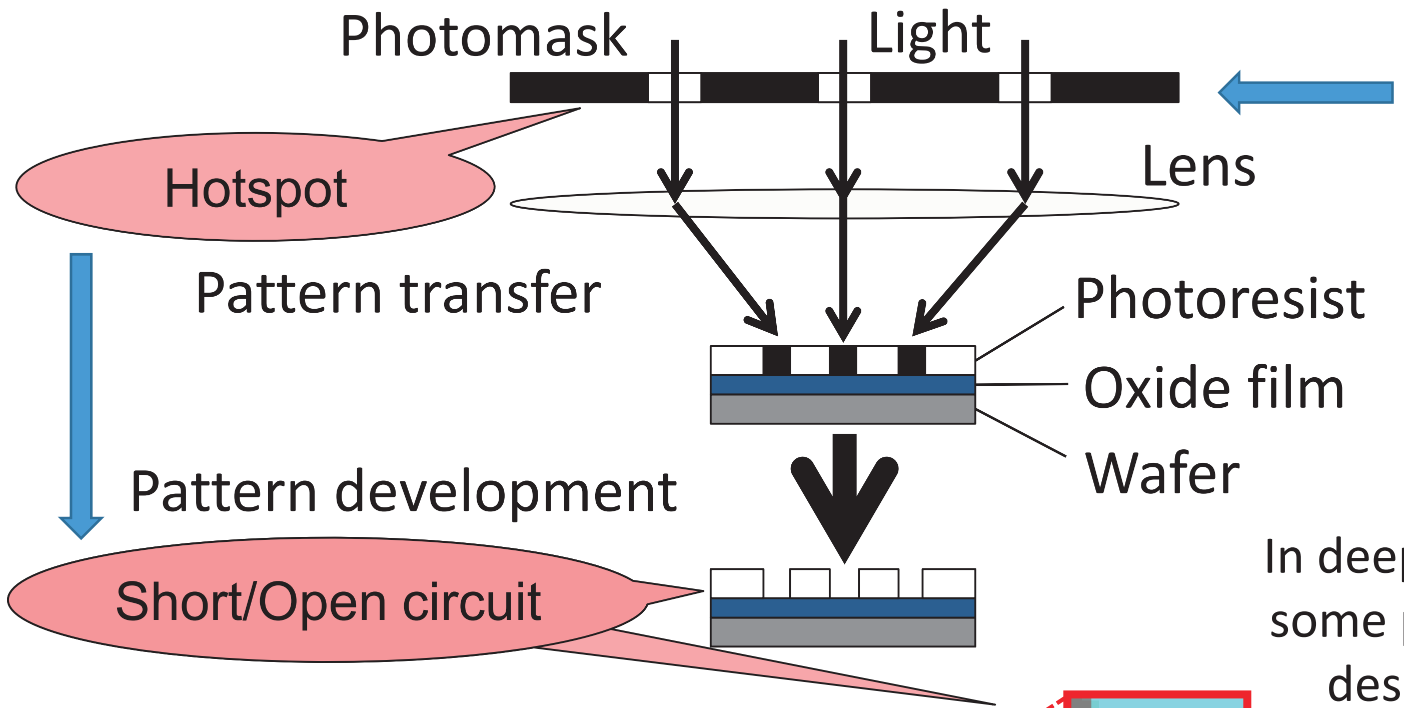
UCC University College Cork, Ireland

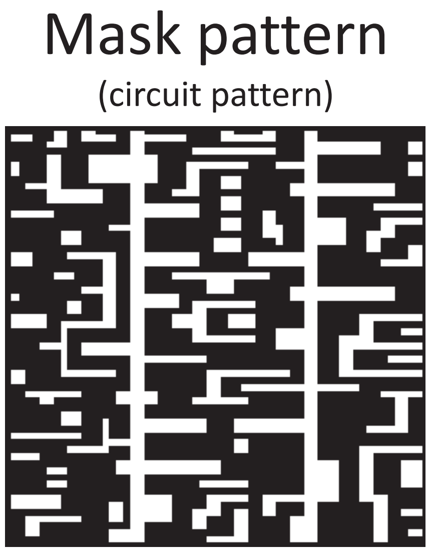
IRCSET Investing in People and Ideas

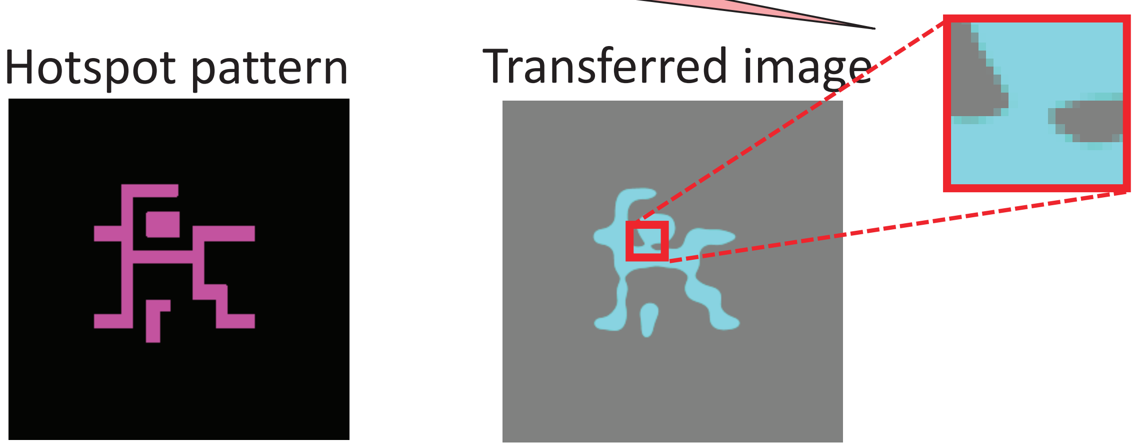
Enterprise Ireland

Lithography Hotspots and Detection Methods

Masato INAGI, Hiroshima City University





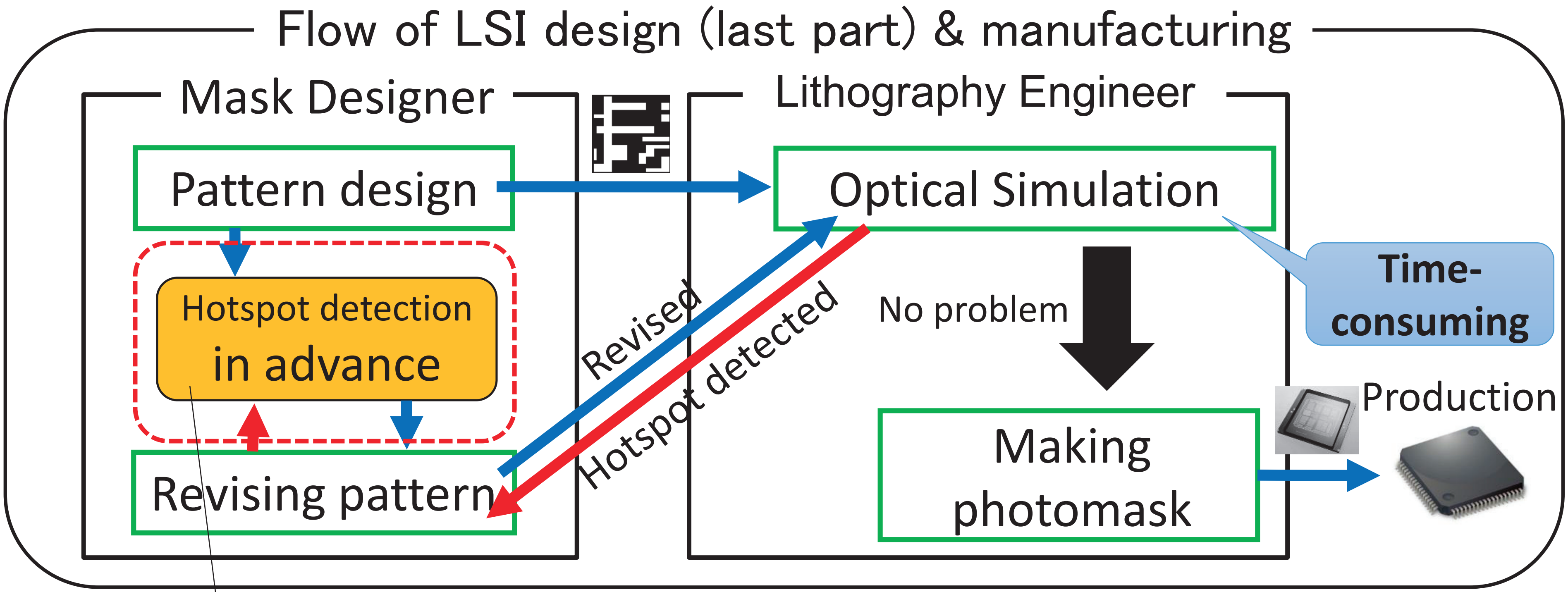


In deep submicron era, even some patterns which satisfy design rules cannot be transferred properly at a high rate. Such patterns are called hotspots.

Hotspots significantly reduce the yield rate.

Background: hotspot detection in LSI design flow

Hotspot removal before making photomask is necessary.



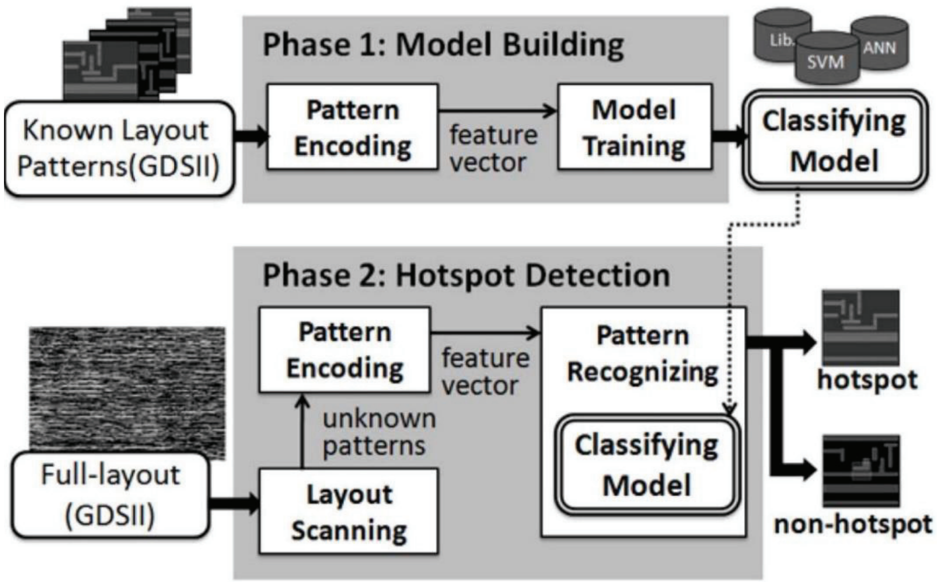
Hotspot removal before optical simulation is desirable.

Hotspot detection

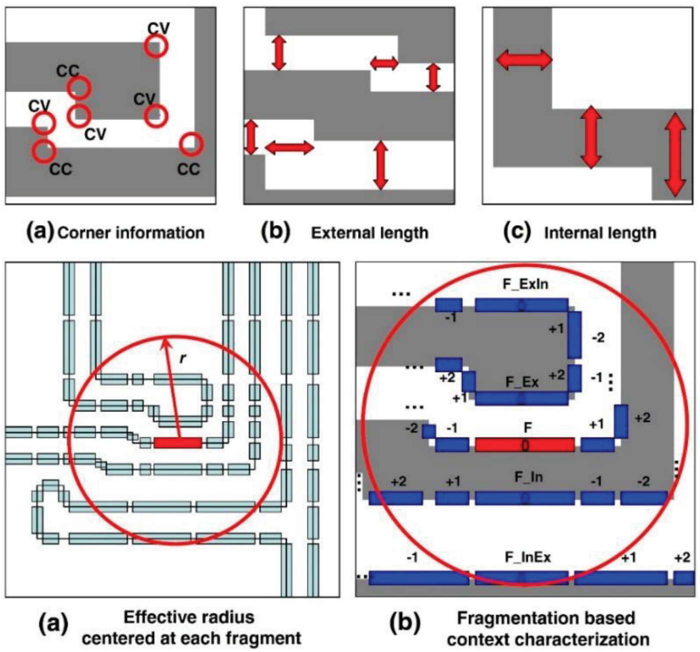
- Input:
  - Mask pattern
  - Known hotspot patterns (Hotspot library)
- Output:
  - Locations of hotspot candidates (on the mask pattern)

Existing studies (1)

- Machine learning based hotspot detection methods (e.g.,[1])
  (based on Artificial Neural Network (ANN), Support Vector Machine (SVM))



Outline of machine learning based methods
(This figure is cited from [3].)

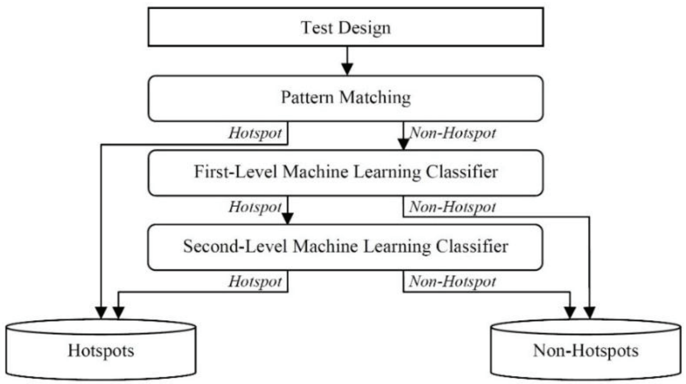


Features of patterns for accurate detection
(proposed in [1] / cited from [1])

[1] D.Ding, et al., “High Performance Lithographic Hotspot Detection using Hierarchically Refined Machine Learning,” ASP-DAC, 2011.
[2] Jen-Yi Wuu, et al., “Efficient Approach to Early Detection of Lithographic Hotspots Using Machine Learning Systems and Pattern Matching,” SPIE, 2011.
[3] W.Wen, et al., “A Fuzzy-Matching Model with Grid Reduction for Lithography Hotspot Detection,” IEEE Trans. CAD, 2014.

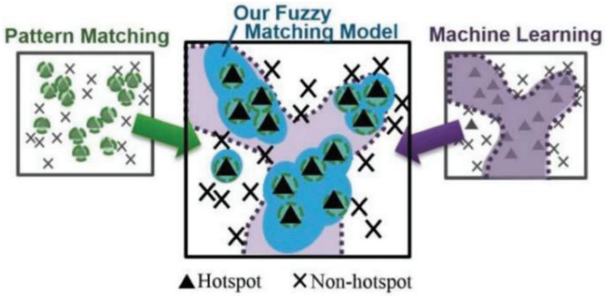
Existing studies (2)

- Hybrid detection method based on template matching and machine learning [2]
  - Composed of multiple stages
    - Template matching
    - Machine learning based matching
  - 1st-stage: Template matching contributes to accurate known hotspot detection.
  - 2nd-stage: 2-level machine learning classifier contributes to accurate unknown hotspot detection.



Outline of hybrid method [2]
(This figure is cited from [2].)

- Fuzzy matching based hotspot detection method [3]
  - Machine learning classifiers can divide a feature space into classes. But, each class must be joint.
  - Proposed fuzzy model can handle a disjoint/separate class, and thus contributes to accurate hotspot detection.



Key idea of [3]
(This figure is cited from [3].)

[1] D.Ding, et al., ASP-DAC, 2011.
[2] Jen-Yi Wuu, et al., SPIE, 2011.
[3] W.Wen, et al., IEEE Trans. CAD, 2014.

Challenges: Runtime and Accuracy

Further research is required for practical use.

NanoICT: Nature - inspired sensing tools at small scales

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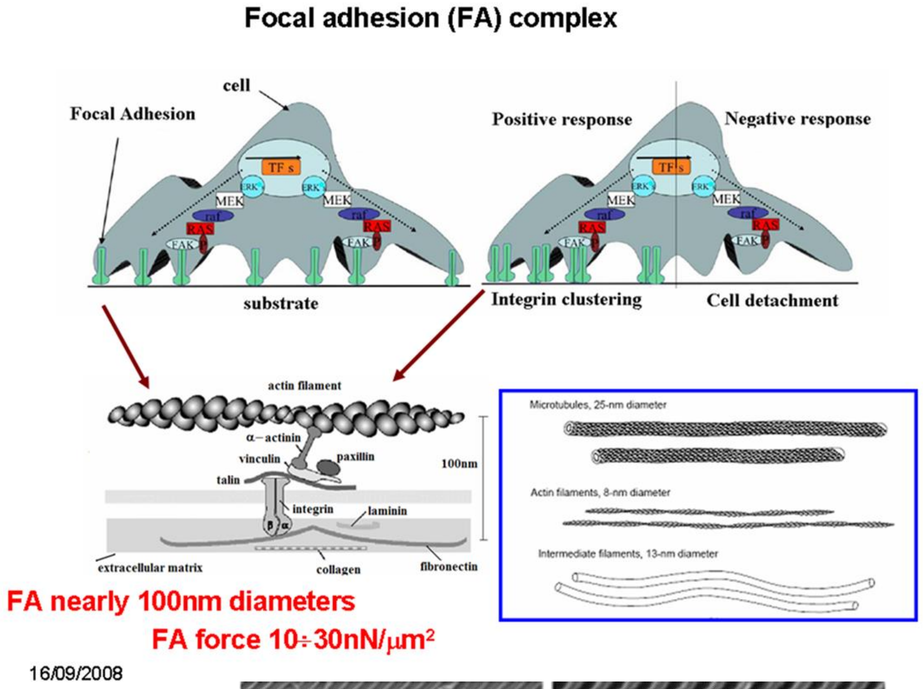
The Eighth International Conference on Sensor Device Technologies and Applications
SENSORDEVICES 2017 September 10 - 14, 2017 - Rome, Italy

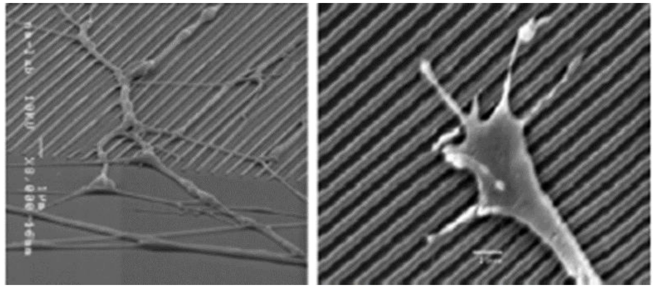
NanoICT: Nanotechnology will have a profound impact on the future development of many commercial sectors. The impact will likely be greatest in the strategic nanoelectronics (ICT nanoscale devices - nanoICT) sector, currently one of the key enabling technologies for sustainable and competitive growth in the World, where the demand for technologies permitting faster processing of data at lower costs will remain undiminished. very wide range of interdisciplinary areas of research and development, such as BioICT, NEMS, Graphene, Modelling, Nanophotonics, Nanophononics, etc. Certain ICT procedures, such as distributed calculus and smart processing can be considered suitable for the implementation of bottom-up nanotechnology procedures. The self-assembly of nanostructures is the clearest evidence of a bottom-up processing (as opposed to miniaturization that can be considered the basic top-down procedure).

Nature insipiring sensors: Smart sensors lie at the heart of modern technology – from inertial navigation systems in cell phones to object-detecting driver assistance systems. The Internet of Things, combined with creasing automation in vehicles and smart wearable systems for health monitoring, is ensuring robust growth in unit demand for sensors.

Single molecule sensing: to achieve single-molecule detection, the vast majority of approaches reduce the measurement space to very small volumes or areas. As a consequence, single-molecule measurements have thus far been a “nearfield” science.

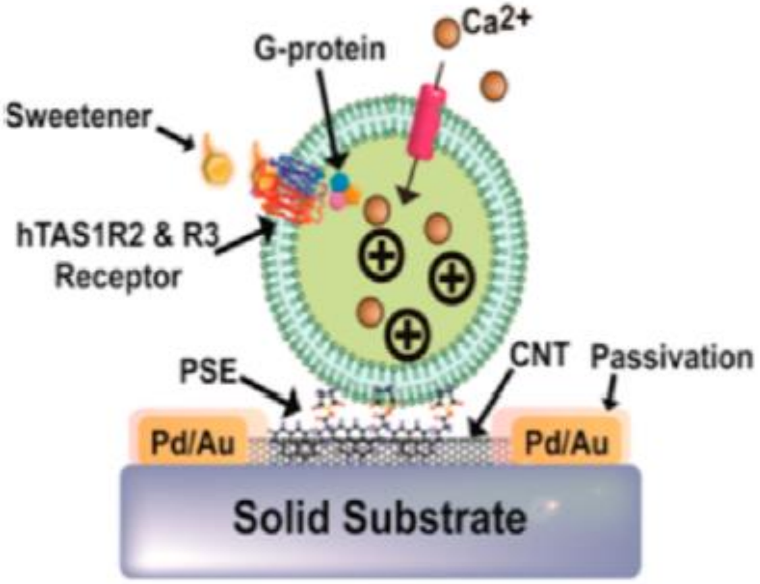
NanoICT:
combination of nanoscale features, surface/ volume ratio, bottom-up strategies with ICT paradigms, machine learning, smart optimization

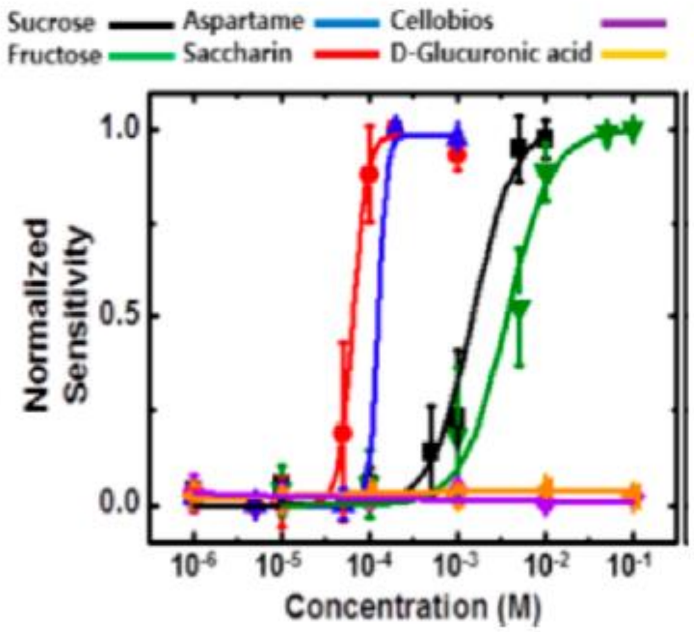




Nanosystems do it better!!

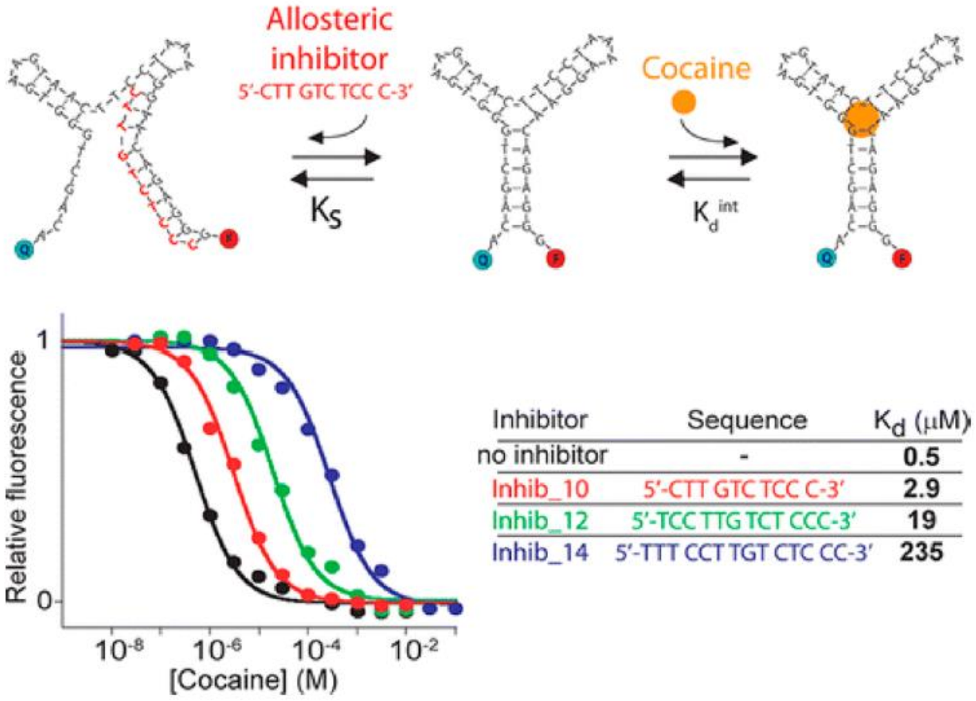
Nature insipiring sensors





Electronic tongue: nanovesicles with sweet taste receptors attached to a carbon nanotube field effect transistor. The electronic tongue specifically detects sweet tastants and shows no response to tasteless sugars. Source: **Song et al. ACS Nano 2014, 10.1021/nn502926x**

Nature insipiring sensors



Inhibitor	Sequence	K_d (μM)
no inhibitor	-	0.5
Inhib_10	5'-CTT GTC TCC C-3'	2.9
Inhib_12	5'-TCC TTG TCT CCC-3'	19
Inhib_14	5'-TTT CCT TGT CTC CC-3'	235

Aptamer sensor for the detection of cocaine. The binding affinity of the aptamer was altered by competition with short oligonucleotide strands operating as allosteric effectors. The binding affinity was altered over 3 orders of magnitude. Source: Porchetta et al. J. Am. Chem. Soc, 2012 134, 20601–20604.

Learning and inspiring from Nature

Neurons activity and Neural networks

Machine learning and Swarm intelligence

Swarm-inspired algorithms

- **Particle Swarm Optimization**
- **Ant algorithms**
- **Bee algorithms**
- **Firefly algorithms**
- **Bat algorithms**
- **Flower Pollination algorithms**

Nanostructures inspiring Computation

Nanoscale self-assembling Computation: the case of DNA

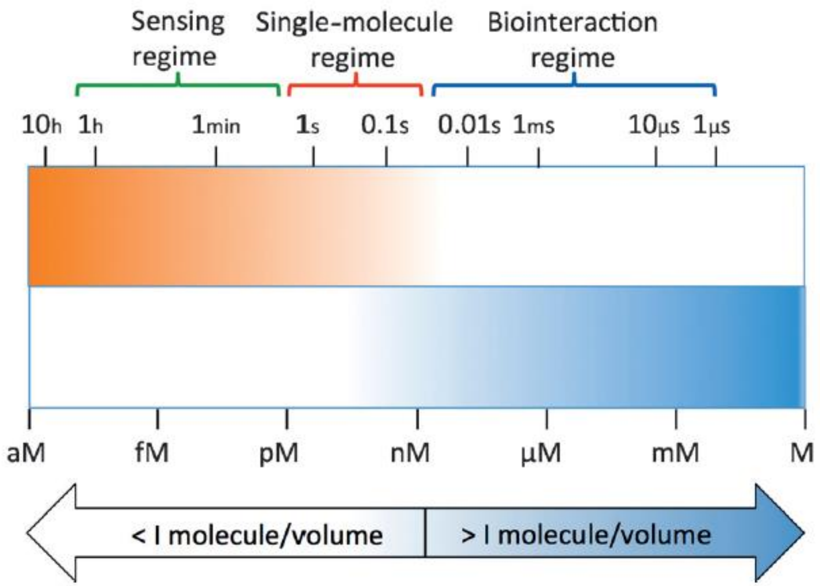
Self-assembled molecular circuits

Quantum dots networks and logic computation

Nano-optics and Nano-photonics Information:
computation inspired by light-matter interaction at nanoscale

Learning from Nature for Single molecule sensing

Today possible with Near-Field approach: Scanning Probe Microscopy, Optical Tweezers



Selectivity

In vivo measurements

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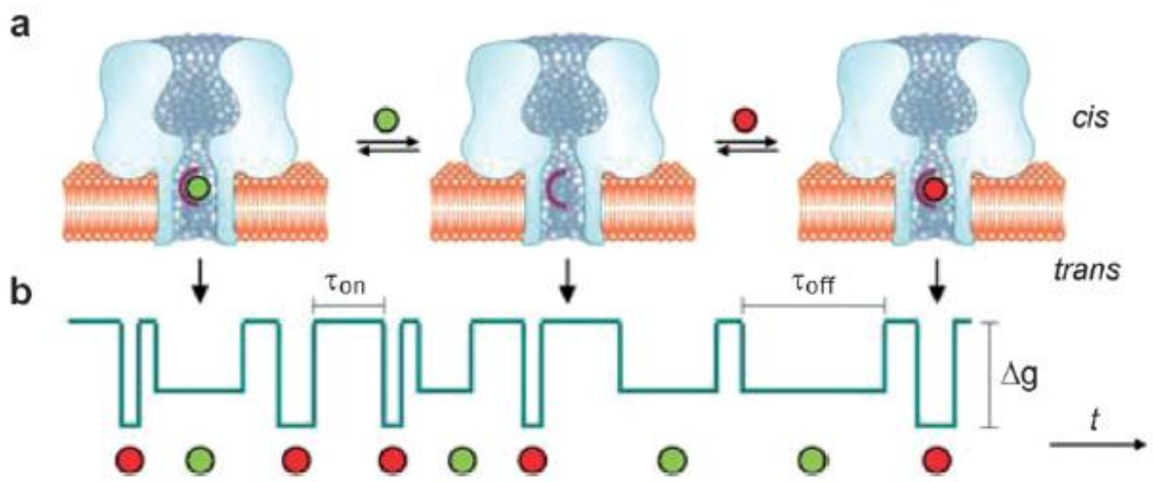

A single-molecule nanopore sensor. a) Reversible binding of different single analyte molecules (represented by red and green circles) with a receptor within the nanopore. b) The magnitude of the associated resistance pulses (indicated as a change in conductivity Δg) reflects the nature of the analyte, thus allowing differentiation between different analytes. Source: Gun and Shim, Analyst 2010, 135, 441.451.

Remarks Current and future challenges

Nanosystems work essentially confined at surfaces and use self-assembling strategies (Bottom-Up)
The combination of such characteristic with ICT functionalities could improve sensors, as well as many others technological areas

Learning from Nature: Nature uses time to find better solution: Natural systems evolved to handle broader concentration profiles either using multiplier recognition elements or changing binding-site functionality

Transition from a single-molecule detectors to single-molecule sensors

1) Getting enough signal from a single molecule
2) Measuring many single-molecule events to provide enough information for quantitative analysys