Wearable Sensors for medical applications

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Outline

- Acknowledgement: working group
- Smart wearable sensors for improved Quality of Life
- Electrophysiological sensors
- Inertial MEMS sensors for human activity
- Biochemical sensor
- Sensors for gas and airborne particles
- Integrating electrode: Patch
- Micropump / Actuators
- Conclusions

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Global societal challenges relevant for smart systems

- Energy efficiency for a **smarter planet**
- Global challenges for **sustainable health care**

The Internet-of-Things calls for the deployment of up to a trillion tiny wireless devices!
(The Swarm, Guardian Angels for Smarter Life)

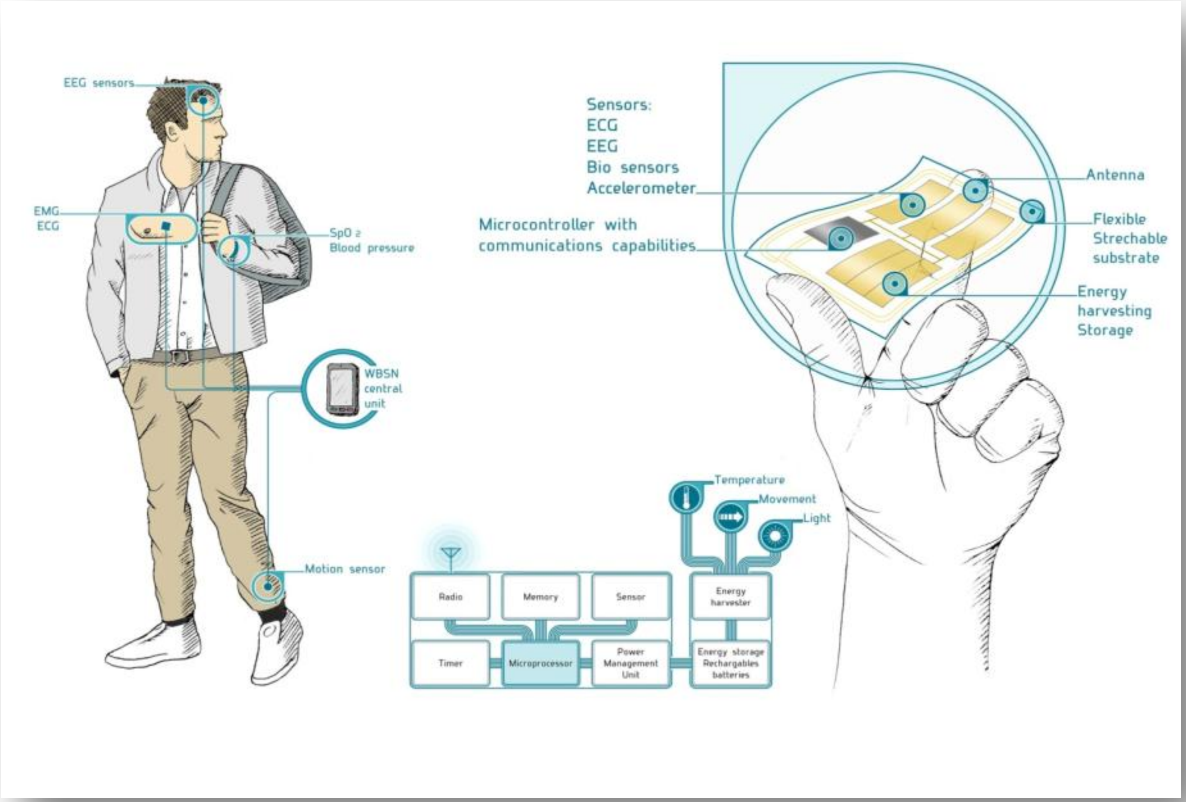
Global societal challenges for healthcare

- **Demographic evolution**
  - 2045: more people older than 60 than less than 15
- **Chronic illness**
  - Significant increase
    US: 157M (2020) from 118M (1995)
- **Unaffordable costs**
  - World wide health care spending: 15% of GDP in 2015
- **Ageing society and staffing shortage**
  - Huge increase of elderly &
    chronic patients demanding attention

Sources:
a) Philips Sustainability Report; b) Rand Corporation; c) Alonso-Zaldivar, Boston University, Los Angeles Times; d) World Health Organization News, The National Academies.

Smart wearable sensors for healthcare

- Zero-power Smart Body Area Network (BAN) of Sensors for medical applications
  - Ageing
  - Metabolic
  - Respiratory
  - Mental



Smart sensors: a technology platform for the advancement of medicine

Technology platform for the advancement of medicine:

- Inputs to engineers for new generation tools
- Long-term monitoring
- High portability (wearability) – no invasivity
- New software for data treatment
- High energy efficiency

Breathing

Pollution

Metabolism

Obesity

Nutrition

Heart

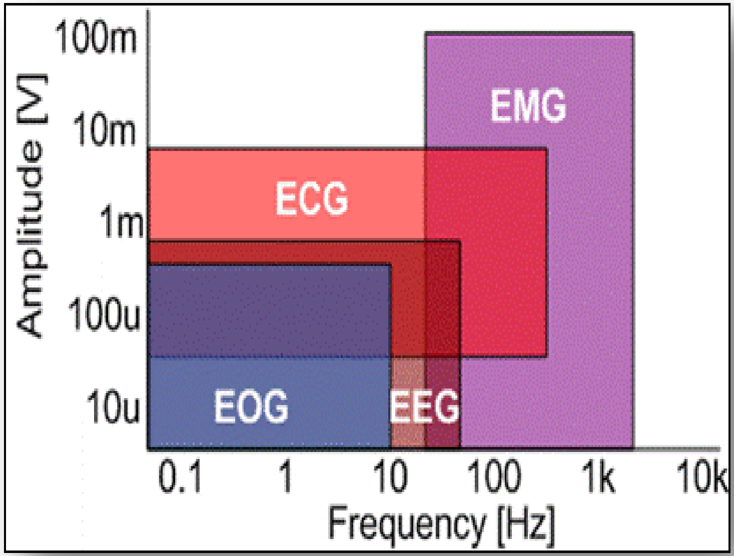
Categories of sensors & actuators

The chapter includes relevant emerging sensors for wearable & implantable smart systems, where the respective research is advanced in Europe and/or the potential economic and/or societal impact is large.

- **Electro-physiological sensors (ECG, EMG, EEG, EOG) and electrodes**
- **MEMS sensors for human physical activity: accelerometers and gyroscopes**
- **Bio-chemical sensors**
- **Sensors for gas and airborne particles**
- **Integration on patches**
- **Micro-pumps and actuators**

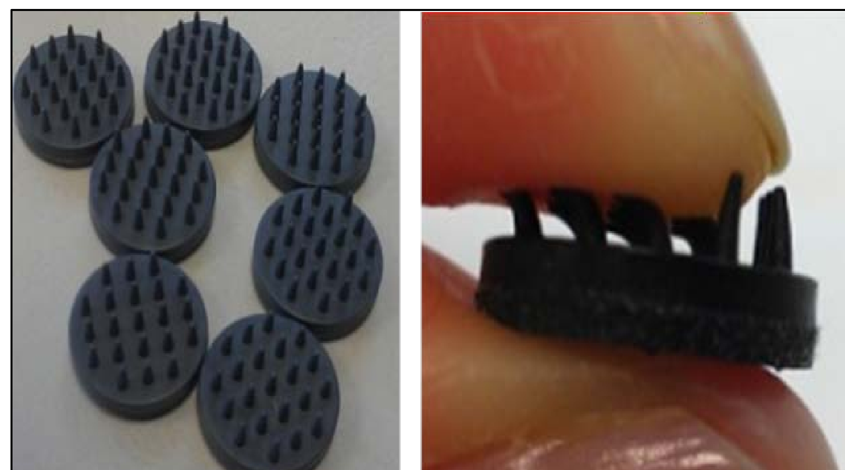
Electrophysiological sensors

- **Electrophysiological information = recording of weak electrical signals voltage generated by body organs**:
  - **Electrocardiogram (ECG):** electrical activity of the heart;
  - **Electroencephalogram (EEG):** measurement of electrical spontaneous or evoked brain activity
  - **Electromyogram (EMG)**: electrical activity of the skeletal muscles (characterizes the neuromuscular system)
  - **Electrooculogram (EOG):** measurement of the resting potential of the retina and eye movements



Wet versus dry electrodes

- Technical difficulty in measuring bioelectric signals from the body: establishing good & stable electrical contact to the skin
  - widely used of which are 'paste-on' (or wet) electrodes
  - dry electrodes: resistive & capacitive
  - conductive rubber

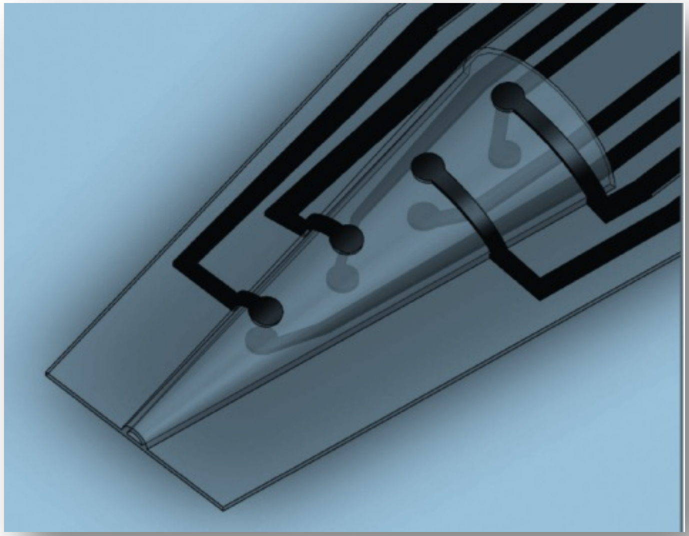


Challenges for biopotential measurement systems

- Further **development of the dry electrode based sensors**: higher user comfort and potential for independent home-use
- **Miniaturization** of the electrode and introducing **mechanical flexibility**
- Systems electronics: **motion artifact reduction and improved signal-to-noise ratio**
- Achieve a **low-cost unobtrusive and widely acceptable devices**:
  - conformable/flexible or stretchable features allowing direct epidermal electrical measurement
  - minimally invasive sensing, conformable to human body and easy to wear
  - innovation in term of textile is related to the use of functional yarns integrated in the fabric for sensing and acquisition of vital signs
  - Printed electronics (robust and flexible patch)
  - Electronic tattoos

Implantable systems and their challenges

- **Implantable applications**: treatment for spinal cord injury, cochlea implants, retinal prosthesis, epilepsy, Parkinson disease, depression, cardiac dysrhythmia, obesity, the drop foot stimulator, sensory deficit, etc.
- **Electrodes** = **critical element for establishing the electrical connection to measure the neural activity and to stimulate** the neurons the muscles for controlling the organs, the limbs or for overcoming the sensory deficits. Trend: to mix stimulation and recording → careful design of implantable micro-electrode and high performance ultra-low noise analog front end
- **Big challenge:** reliable and robust brain machine interfaces (BMI) that enable direct patient control of motor prosthetics.
- Research on **new materials for electrodes and packaging.**



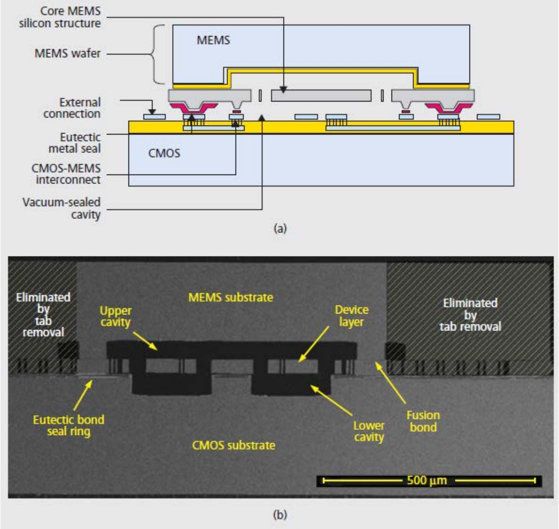
Parylene neural probe with 3D shealth

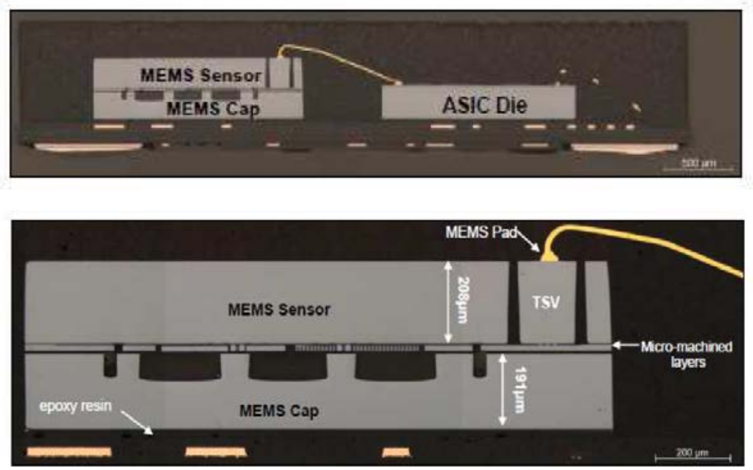
Inertial MEMS sensors for human activity (1)

- Engineering aspects:
  - **Different transduction mechanisms**: charge transduction, force transduction and electrostatic spring constant
  - Design optimization of inertial sensors aims at **high transduction gain, while rejecting the effects of parasitic forces on the mass**.
  - Inertial MEMS sensors require analog/mixed-signal circuitry to process and digitize the sensor output.
  - Important aspects for the wearability: **low power consumption and the small size**.
  - The energy efficiency of inertial sensors is currently evaluated by some **specific figures of merit such as a power ratio of peak SNR to energy per conversion**.

Inertial MEMS sensors for human activity (2)

- Status in MEMS for inertial measurement:
  - **major technology & package progress** made by ST Microelectronics, Texas Instruments and InvenSense pushed by mobile applications
  - **ST Microelectronics (2013)**:
    - 3 Billions MEMS units, with manufacturing capacity larger than 3 million units /day
    - include analog and digital accelerometer and gyroscope sensors with advanced power saving features for ultra-low-power applications.

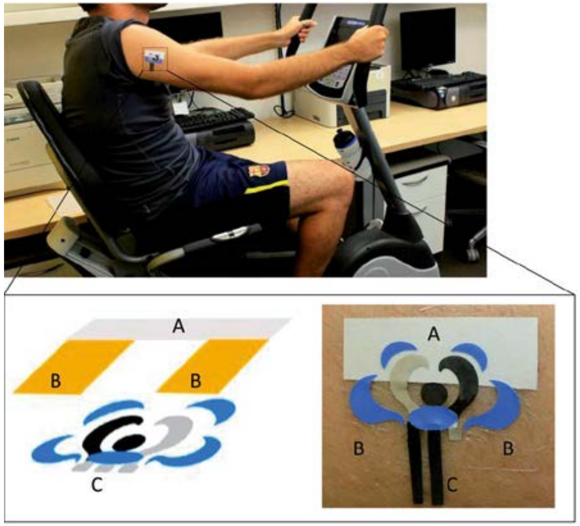




Bio-chemical sensors

- People are **familiar** with wearable heart rate monitors, pedometers for medical reasons or fitness.
  - respiratory activity, ECG, EMG, body posture
- Difficulties for **wearable chemical sensors**
  - bodily fluids such as tears, **sweat**, urine and blood
  - sample generation, collection and delivery, sensor calibration, wearability and safety issues
    - collect from skin, transport in a channel
    - Ionic Selective Electrode (ISE) on fabric
    - temporary-transfer tattoo paper
- Challenge: proper integration
  - polymer membrane, biochemical compound and micro-electrodes of the **biosensor**
  - **electronics circuits**
  - in a **robust** and **practical manner**

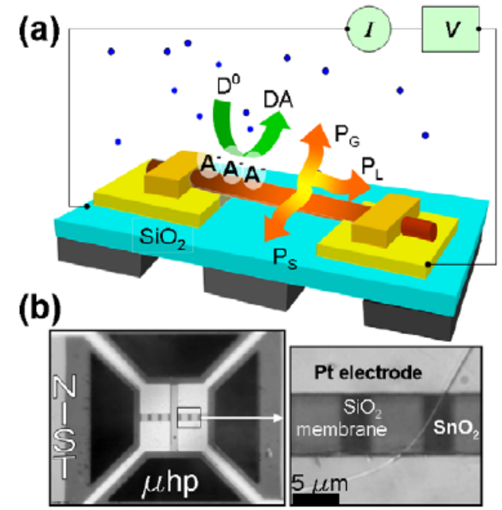
LifeShirt® by Vivometrics®



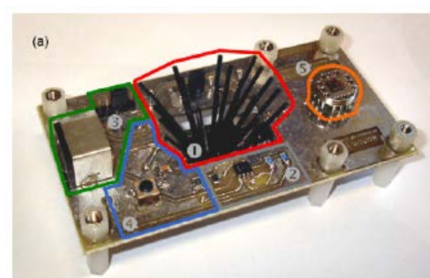
Guinovart et al. 2013

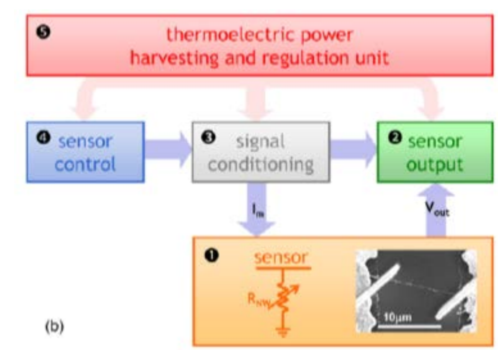
Sensors for gas and airborne particles

- Humans: **no biological senses** for industrial pollutants, microbes, viruses, etc.
  - **Need: sixth sense**
  - Chemiresistors, chemicapacitors, chemtransistors, MEMS and NEMS, etc.
  - ultimate miniaturisation heated gas sensors: **self-heated suspended nanowires**
- Challenge: for wearable sensors **zero-power**
  - Energy harvesters produce enough power (uW)



E. Strelcov et al., Nanotechnology, 2008, p. 355502.

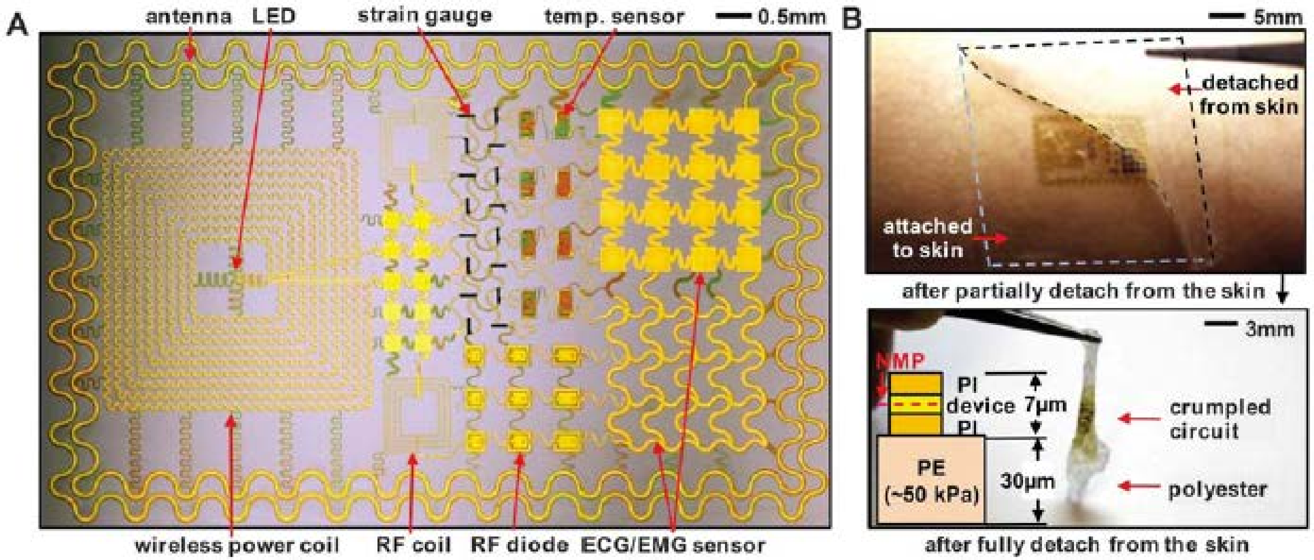




J.D.Prades et al., Sens. and Act. B: Chemical, vol. 144, 2010, p. 1–5.

Integrating electrode: Patch (1)

- Devices **dynamically** adapt to **body surfaces**
  - **Soft materials**, OLED, pressure touch transistors
  - MEMS technologies **on film substrates**: electrochemical sensors
  - **printed electronics** based on organic materials
  - **tattoo-like epidermal** electronic system

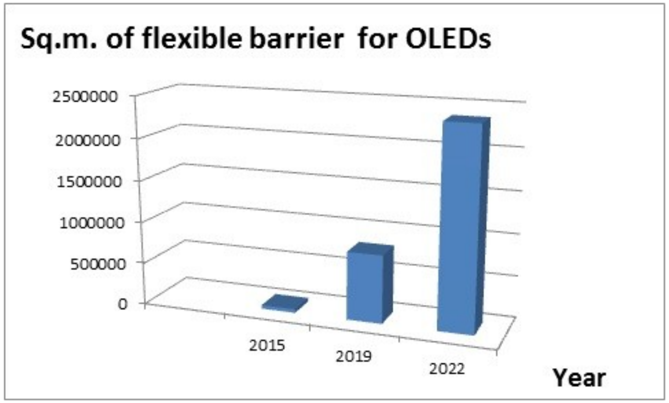


D.H Kim et al. 2011

Integrating electrode: Patch (2)

- Challenges: **boost in printed electronics** conformal or flexible (OLED smart phones)
  - Materials: supporting layer with mechanical properties close **natural skin**
  - **Densification** of sensors
  - **Wireless**: sensors connected to smart phones.
  - Energy harvesting/consumption
    - battery on the patch
  - **Wellness** and **safety** sensors
- Target: **light**, **flexible** (motion/harvest energy), **multifunctional** (collect, transport, analyze, deliver), **wireless**.
  Issue: packaging

Area of flexible barriers forecasted for utilization in OLED displays

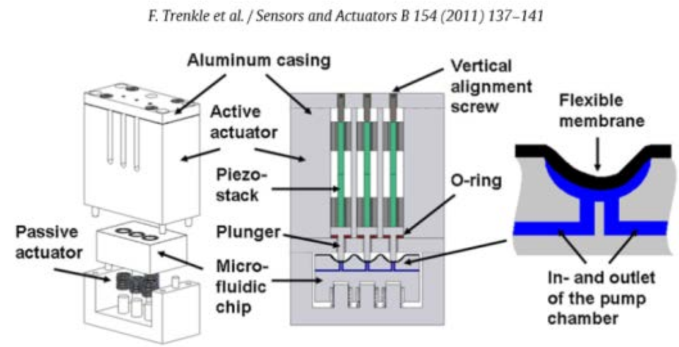


Source: IDTechEx report "Barrier Films for Flexible Electronics 2012-2022"
www.idtechex.com/barriers

D.H Kim et al. 2011

Micropump / Actuators

- **Drug Delivery,** autofocus eye-lenses, artificial sphincter
  - Piezoelectric
  - Electromechanical, etc.
- Material: **Si** and **polymers**
  - Silicon: biocompatible, mature, co-integration with sensors, higher cost.
  - Polymers: (PDMS) more cost-effective
- Future: integrate physical and physiological sensors with micropump
  - “**thinking global**”



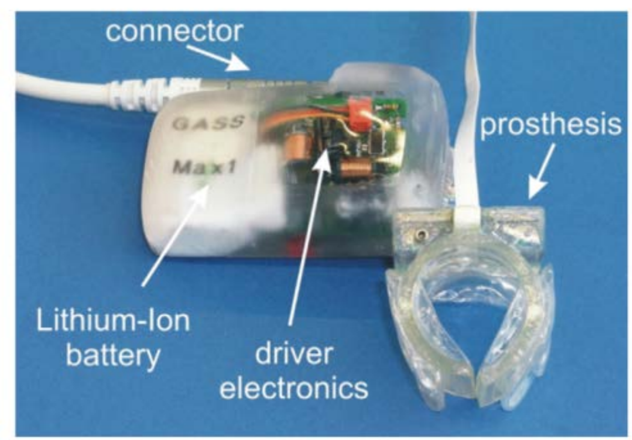


Fig. 1. The German Artificial Sphincter System: prosthesis and driver electronics.

Doll et al. 2007

Low power sensor roadmap (GA flagship)

- Power-constraint performance defines new challenges for autonomous smart systems

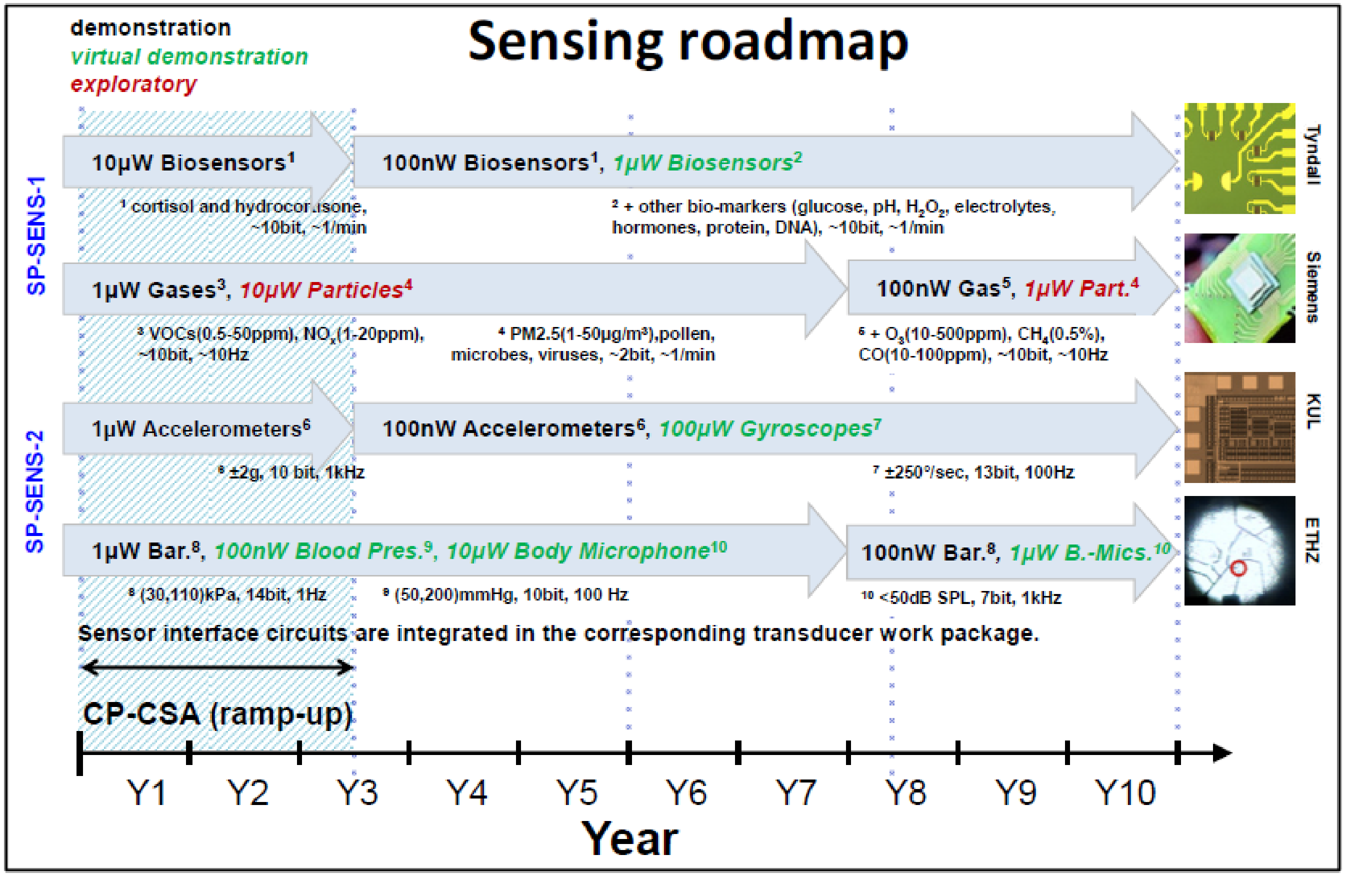
Emerging

Mature/ Emerging

Mature

Mature

Emerging



Conclusions

- **The sensors form the core technology of wearable smart systems:**
  - Different degree of maturity depending on the type of sensors
  - Different technologies and materials
  - The interface (electrodes, materials) with the human body strongly influences the sensing performance and the signal-to-noise ratio: big challenge
  - Strong need for low power sensing (system autonomy) for both wearable and implantable sensors
  - Need for adapted read-out scheme
  - Challenge: sensors on textiles & flexible substrates, printable, electronic tattoos.
  - Design and think about them at system level!