SCREEN PRINTED ORGANIC ELECTROCHEMICAL TRANSISTORS FOR RECORDING AND STIMULATION APPLICATIONS

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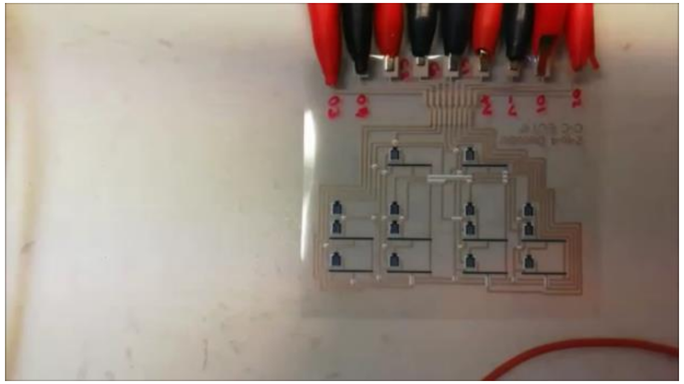
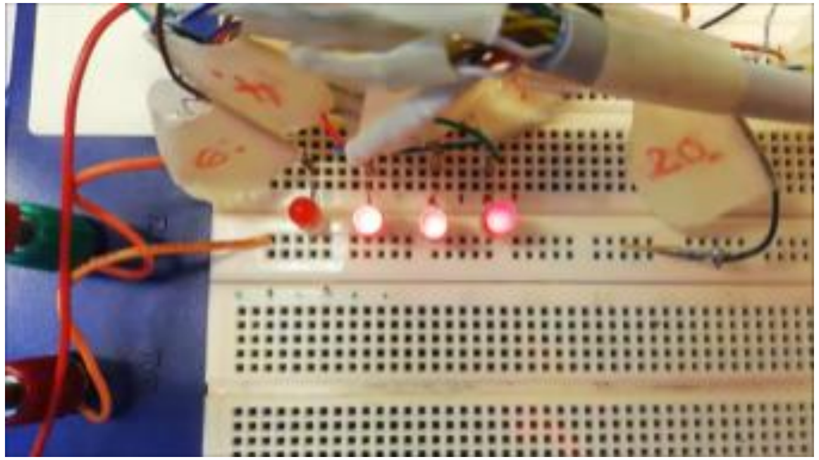
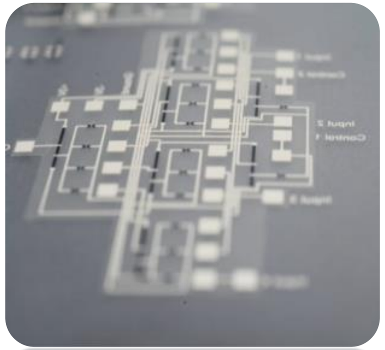




Development of printed electronic components

Transistors



PROPERTIES:
- Organic electrochemical transistors (OECT) and electrolyte-gated field-effect transistors (EGOFET)
- 0.5 – 1.5 V
- Switch time: 10^{-6} (EGOFET) to 10^{-2} s (OECT)

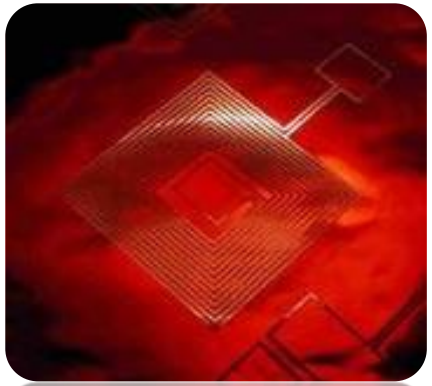
Sensors

PROPERTIES:
- Electrolyte sensor capacitors or transistors.
- Piezo and Pyroelectrical

Displays

PROPERTIES:
- Electrochromic
- Reflective
- 1-3 V
- Printed on flexible substrates

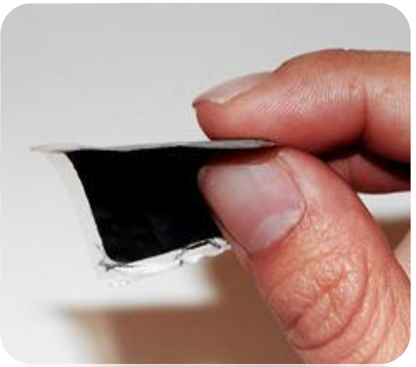
Antennas



PROPERTIES:
- Metal Al, Cu
- 1 kHz – 1 GHz
- Resolution: 100 μm
- Material thickness: 1-10 μm

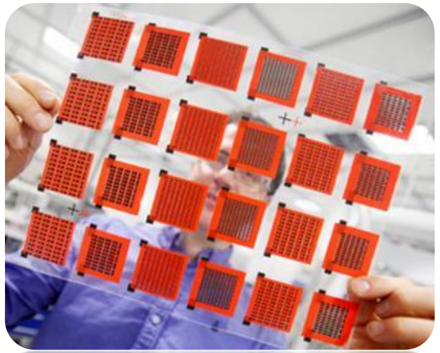
Development of printed components for powering

Batteries/ Super-capacitors



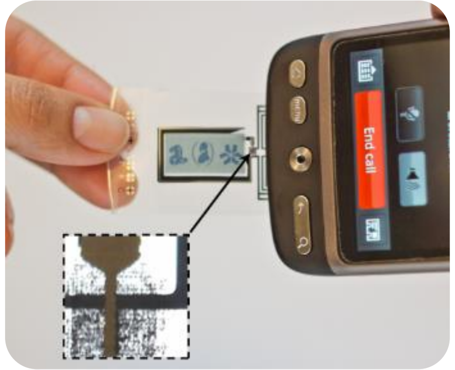
PROPERTIES:
1-10 mAh, 1.5 V
Energy Dense
Rechargeable
Lifetime comparable to Li-Ion
Thin, flexible

Piezo/Thermo electric generators



PROPERTIES:
All polymer
Screen printable

RF energy harvesting



PROPERTIES:
All-printed diodes + antennas
2 GHz
1V

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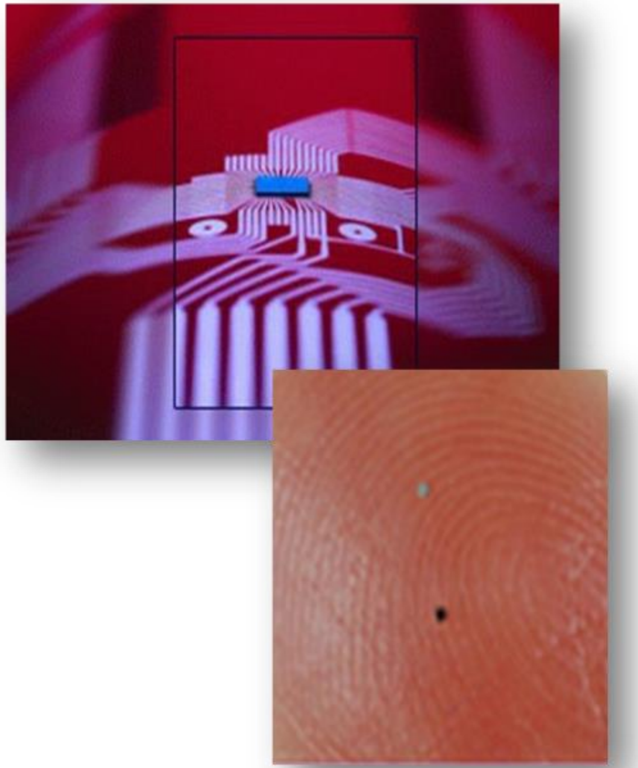
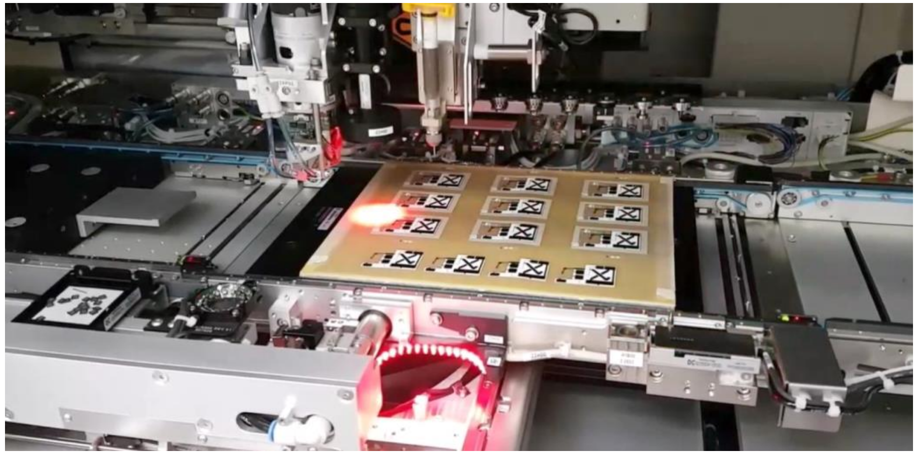
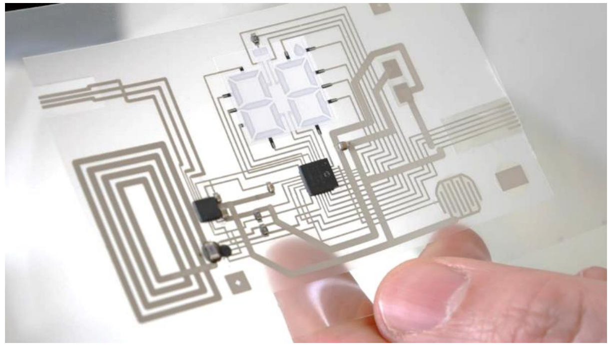
Development of hybrid electronic systems

- State of the art Si-chips have much higher density as compared to printed electronics
- Combine the high processing power and robustness of a Si-chip with the low cost and flexibility of Printed Electronics
- Hybrid electronic systems are assembled in a pick and place process

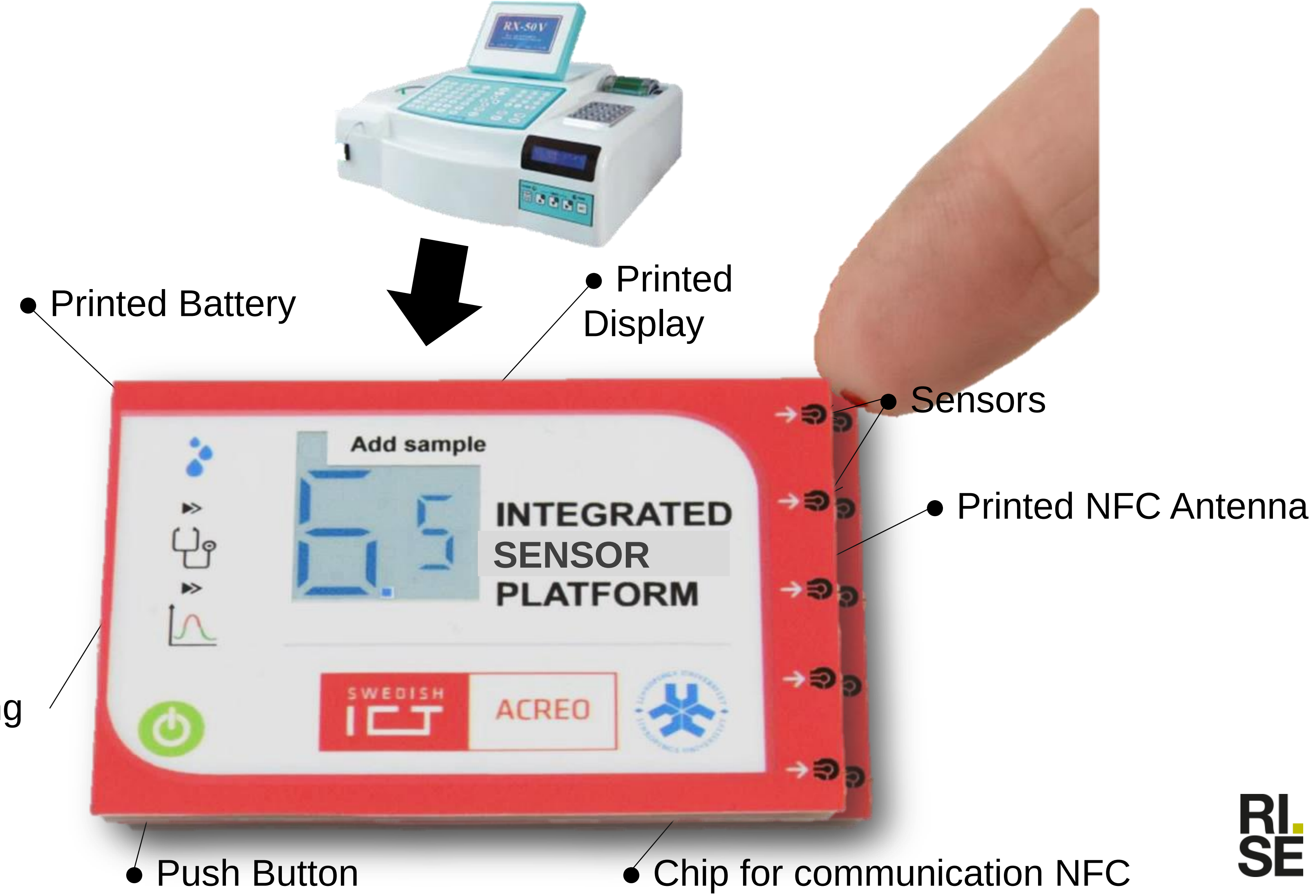




Printed (bio-)sensor platform

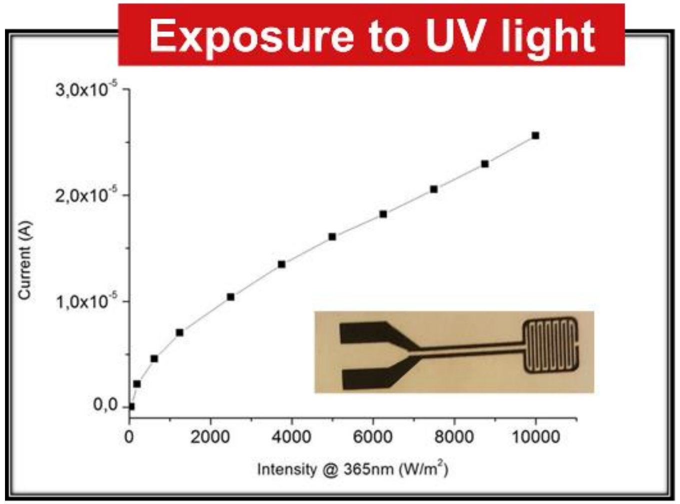


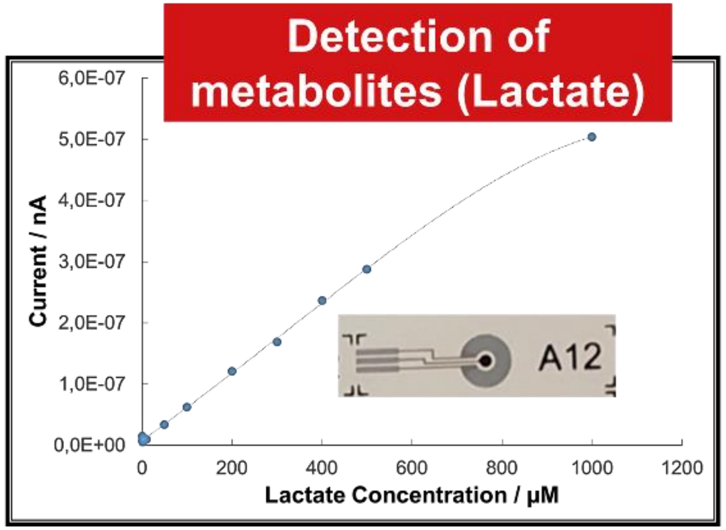
- "Printed instrument"
- Low cost
- Form factor
- Disposable
- Generic sensor technology platform
- Multiple sensors

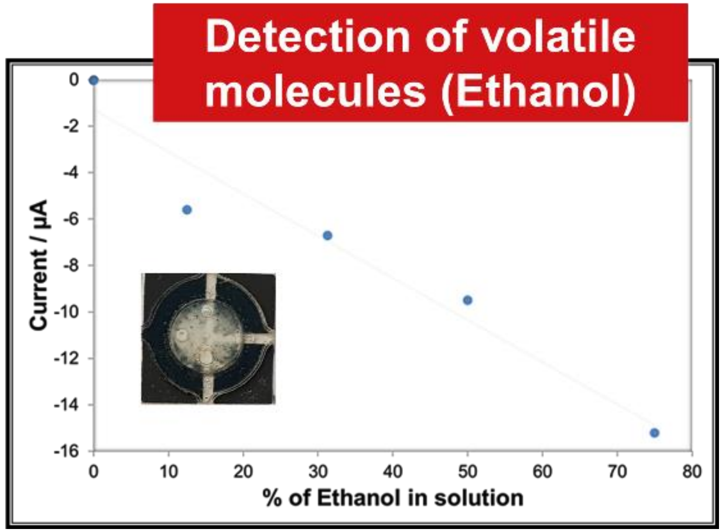


Sensors that have been/can be integrated with existing platform:

- Glucose (demonstrated)
- Lactate (in progress)
- Ethanol vapors (in progress, with commercial sensor)
- UV exposure sensor (demonstrated)
- Humidity sensor (demonstrated)







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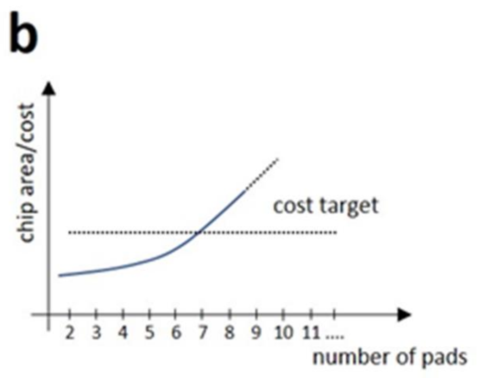
NFC-powered hybrid electronic systems

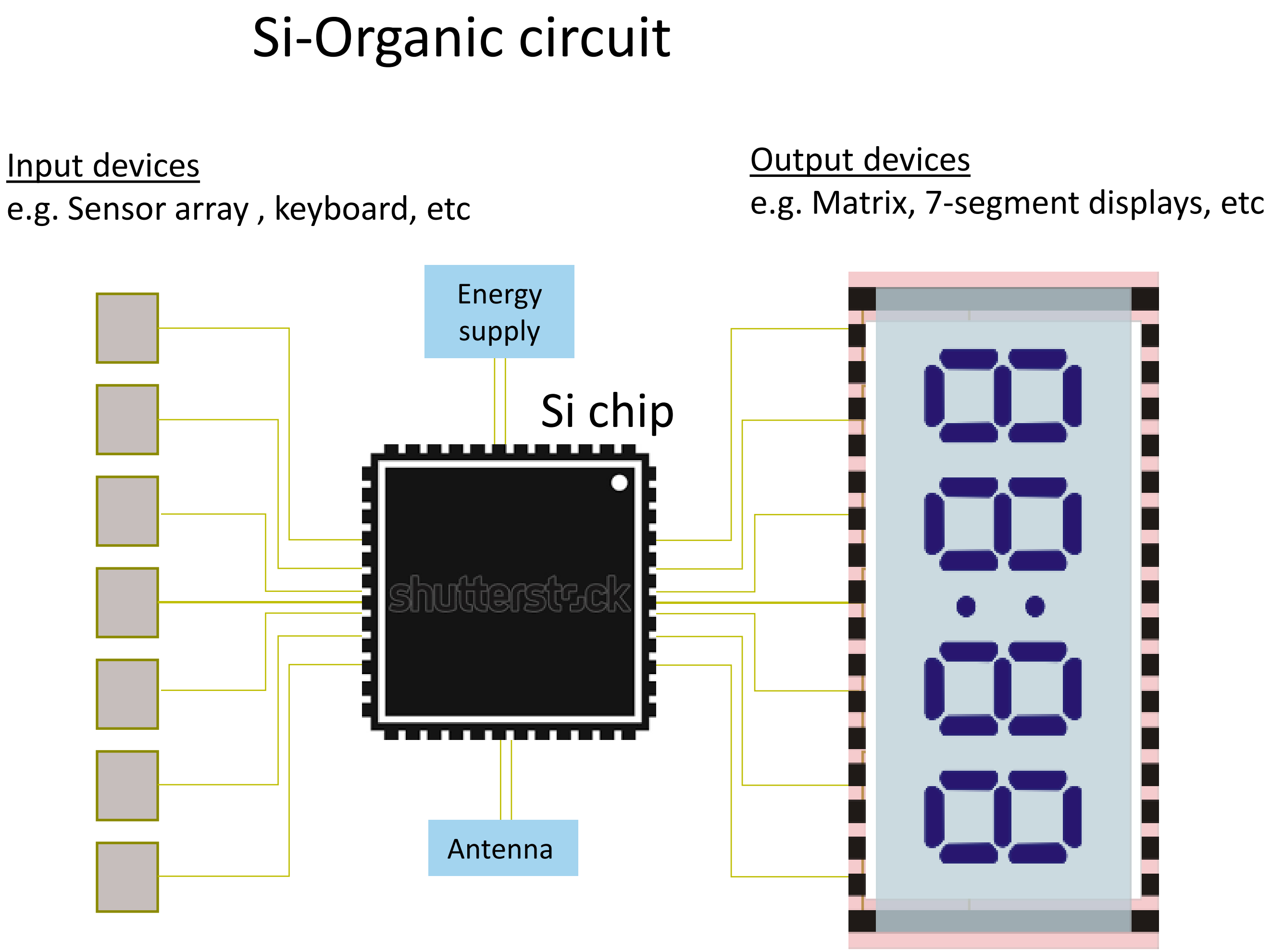
- An advantage of hybrid electronic systems is that Si-based electronics can be used for energy harvesting, e.g. from the NFC interface of a mobile phone
- Hence, no battery is needed in such system, the harvested energy is sufficient to power both Si-based electronics and printed electronics
- Especially beneficial in sensor platforms, where the harvested energy is used to monitor sensor status with a subsequent display update
- Can be used in a number of applications:
- Packaging
- Health
- Construction/buildings
- Industrial processes
- Logistics
- Food
- Branding
- Authentication

Next generation hybrid electronic systems:
To develop high resolution screen printed circuits to enable ultra low cost

Si-Organic circuits

- Cost of Si-chip dominates a hybrid solution
- Cost of Si-chip is driven by the area
- Area is driven by pad count





Si-Organic circuits

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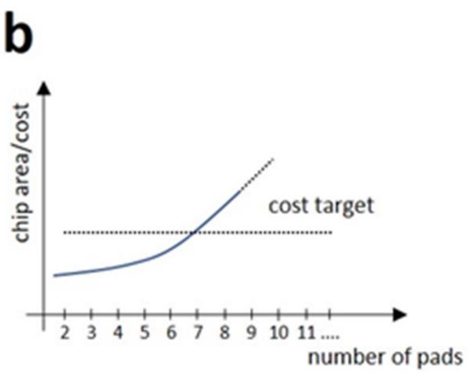
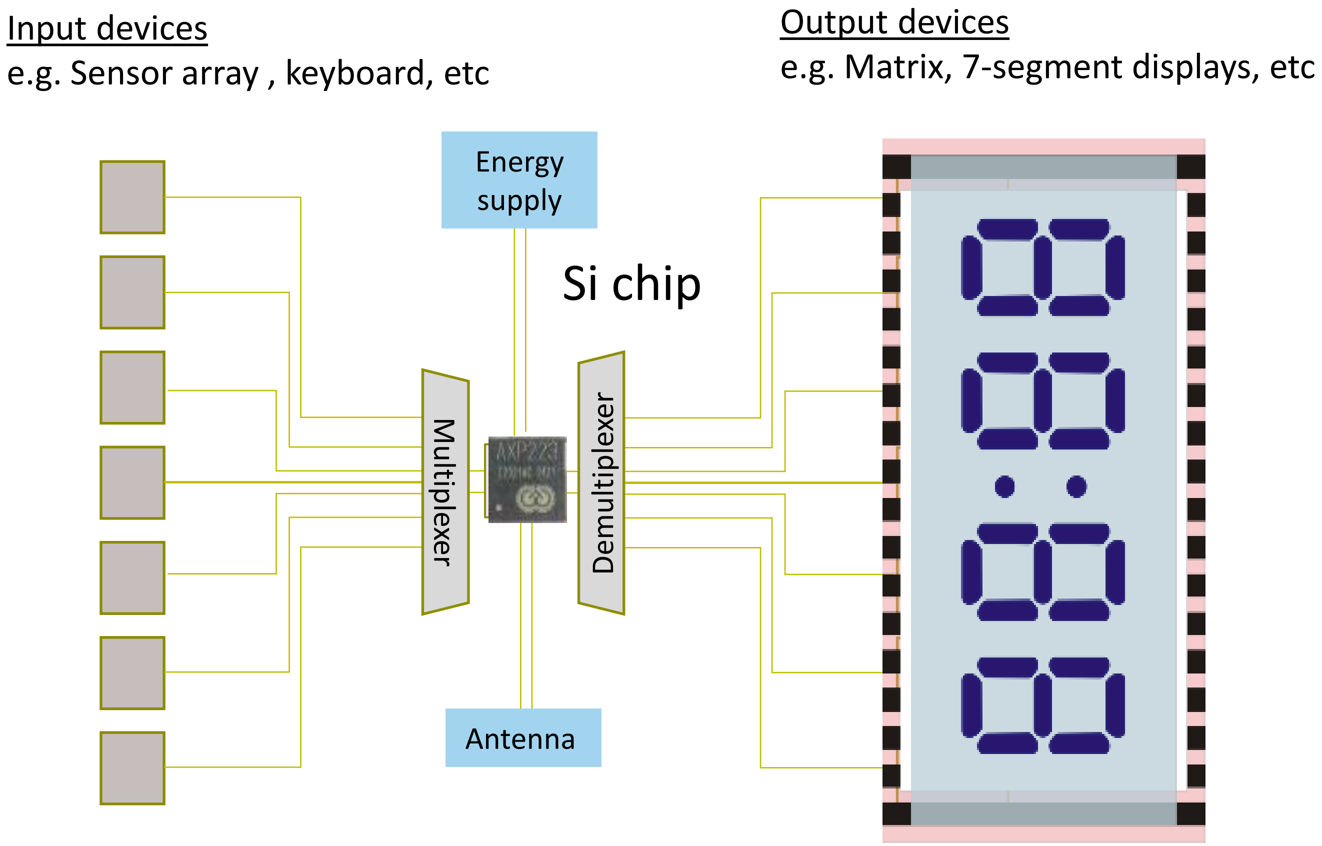
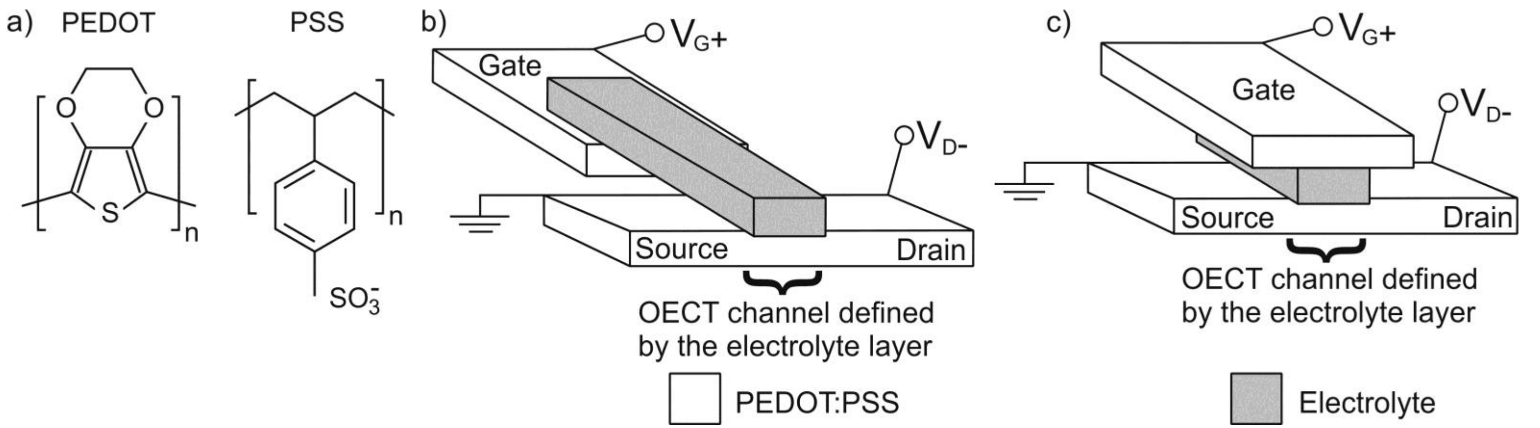


Si-Organic circuit



Solution: **Printed circuits** (e.g. multiplexer and demultiplexer) to minimize pad count, and thereby minimize both chip area and chip cost

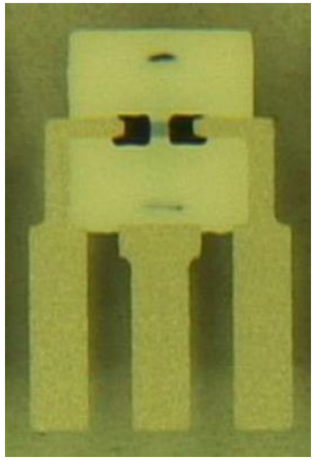
Screen printed organic electrochemical transistors (OECT)



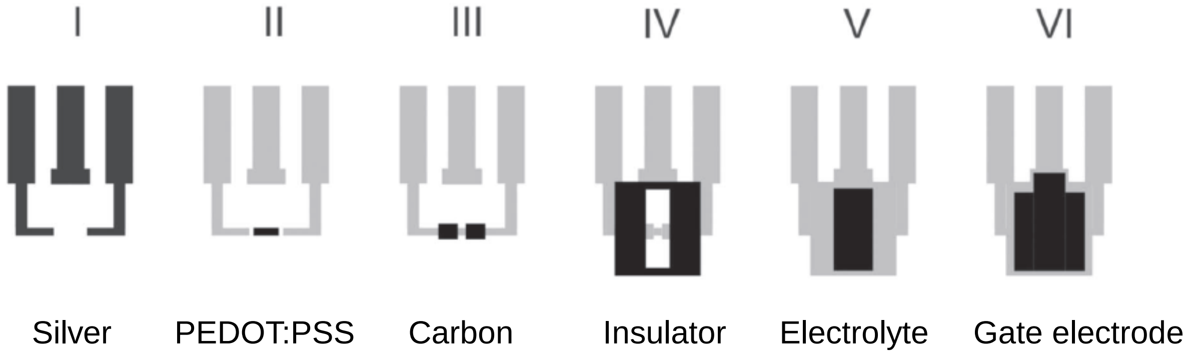
- PEDOT:PSS is commonly used in OECTs
- Lateral OECT devices are useful for sensor applications
- Vertical OECT devices are beneficial in printed circuits
- The electrolytic interface enables low voltage operation (approximately 1 V)
- Peter Andersson Ersman, et al., Screen printed digital circuits based on vertical organic electrochemical transistors, Flexible and Printed Electronics, 2, 045008 (2017)

Screen printed OECTs

- Approximately 1000 OECTs screen printed on plastic substrate (PET)

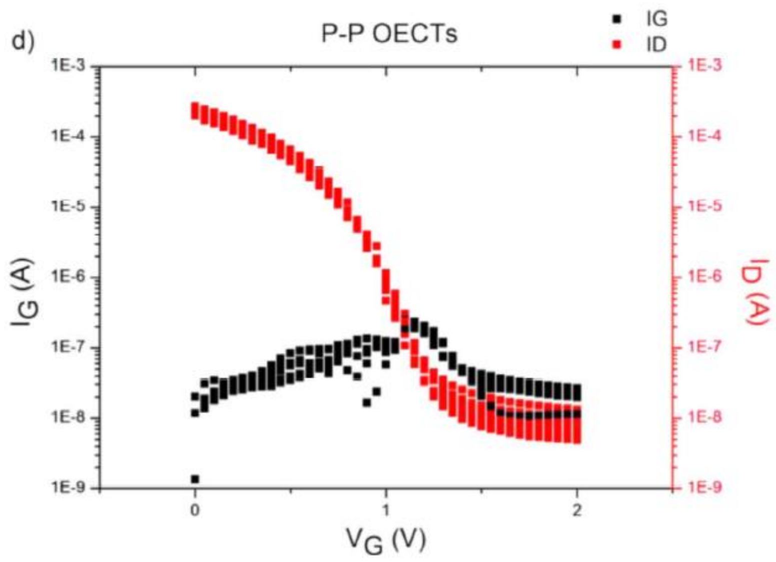


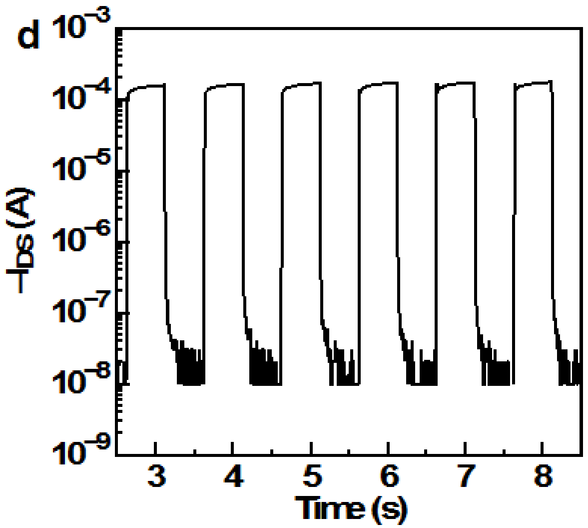
- Screen printing process



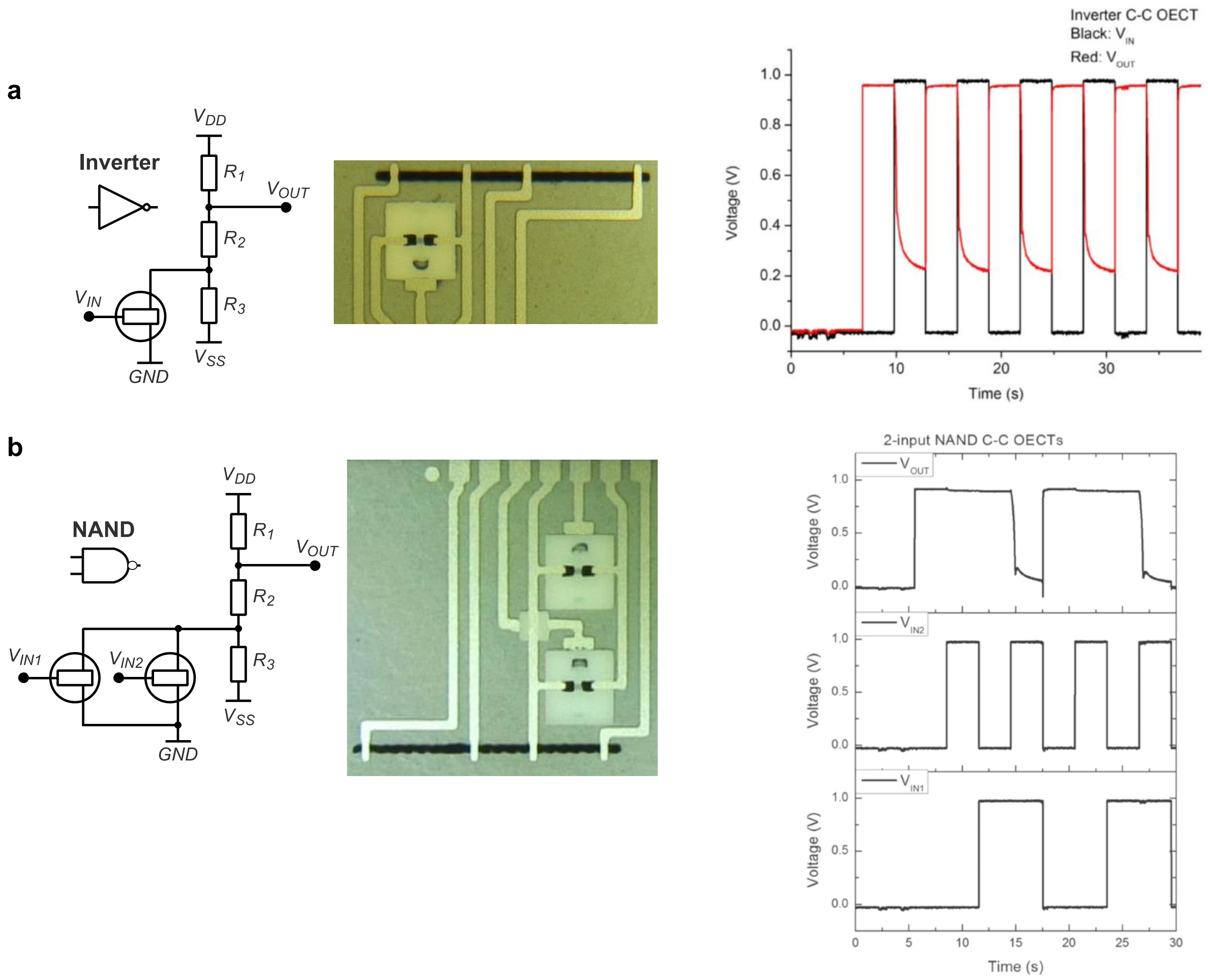
Screen printed OECTs

- OECT transfer and dynamic characteristics
- Reproducible switching performance
- Low voltage operation
- Relatively slow switching → tens of ms





Screen printed OECT-based circuits

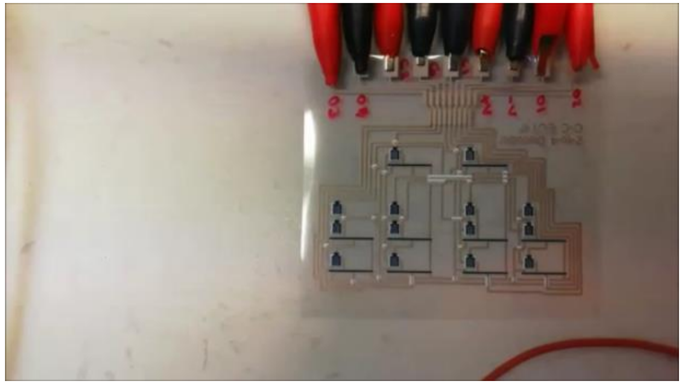


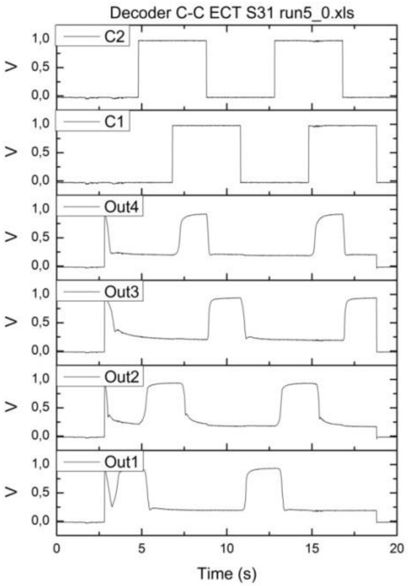
- NAND/NOT logic circuits are based on all-printed vertical OECTs
- The NAND/NOT logic implementation relies on a resistor ladder

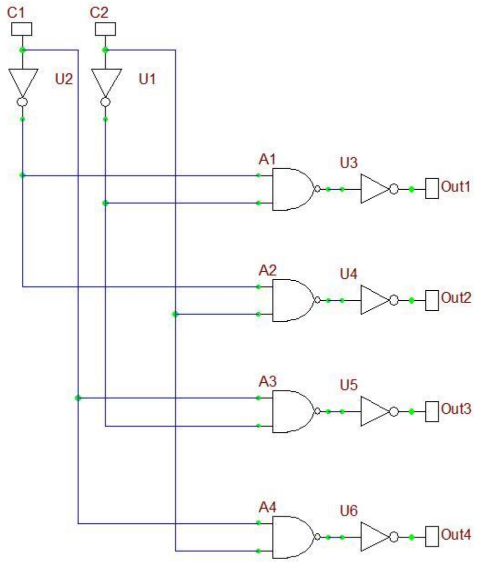
Vin1	Vin2	Vout
0	0	1
1	0	1
0	1	1
1	1	0

Screen printed OECT-based circuits

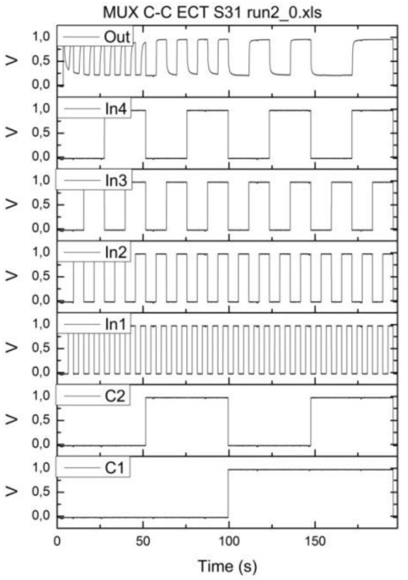
- 2-4 decoder

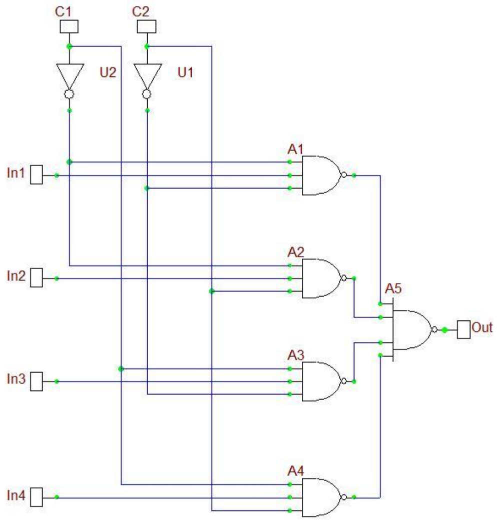




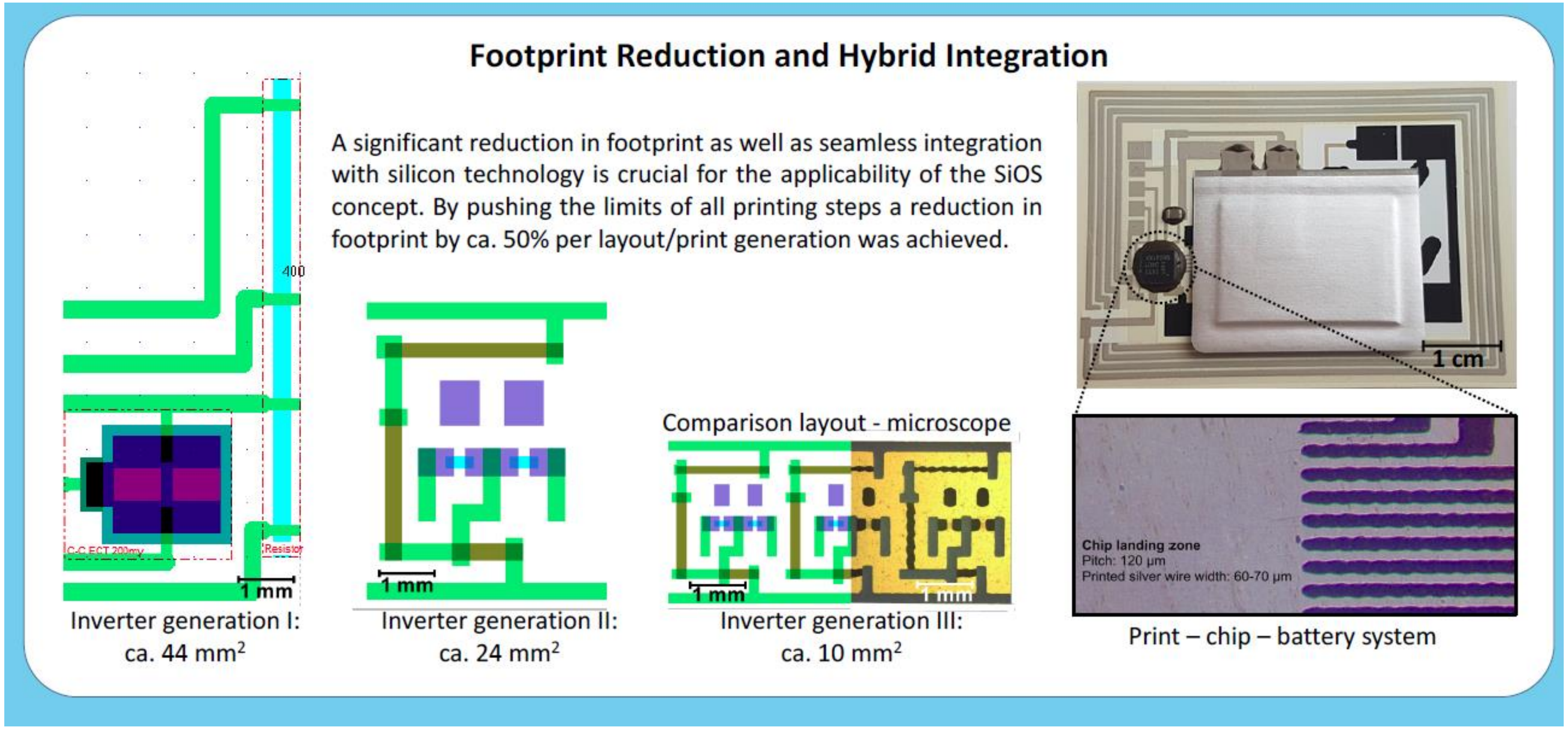


- 4-1 multiplexer (MUX)





Screen printed OECT-based circuits – Footprint reduction



- A significant reduction in footprint as well as seamless integration with silicon technology is crucial
- By pushing the limits of all printing steps, a footprint reduction of ~50 % has been achieved for each generation
- Silver wires have also been screen printed with high resolution, for further footprint reduction and to enable chip assembly

Screen printed OECT-based circuits with higher complexity

- Thanks to the high manufacturing yield and the development related to footprint reduction, OECT-based circuits with higher complexity have recently been achieved

- BCD decoders implemented with NAND-gates
- Reduces the required number of pads on the Si-chip
- Can be used for many applications, e.g. addressing of display segments

- Shift register circuits implemented with NAND-gates
- The shift register relies on flip-flop sub-circuits
- Can be used for many applications, e.g. addressing of display segments
- The input bits are shifted step by step by applying a clock signal
- Reduces the required number of pads on the Si-chip even further, since only one data signal and one clock signal are required on the input side

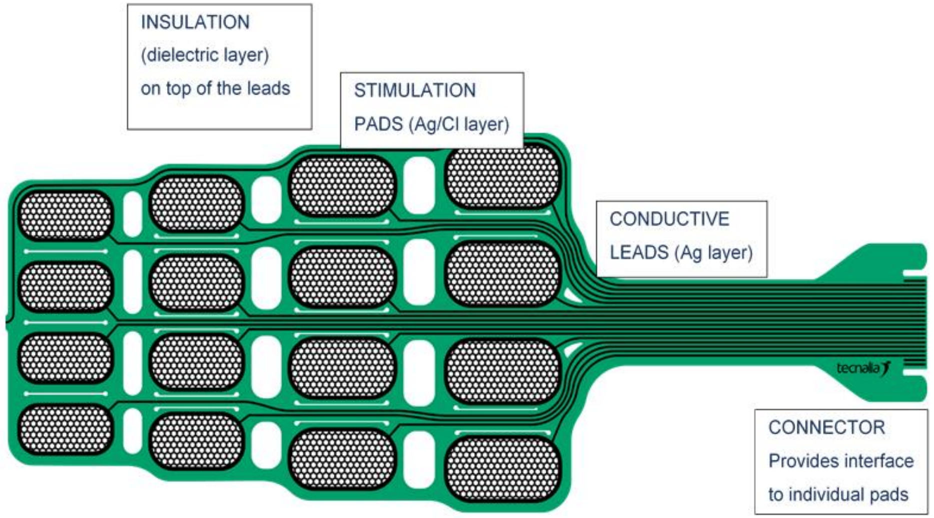
Monolithic printegration of circuits and displays

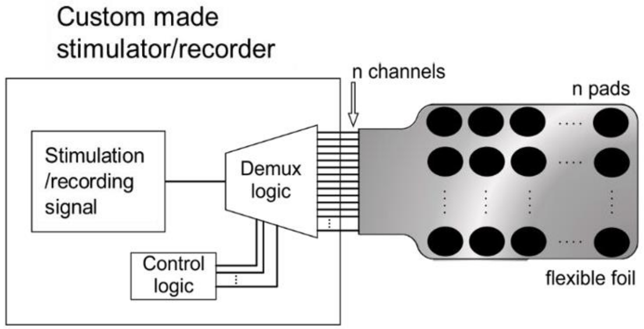
- The same materials are used in printed electrochromic displays and printed OECTs
- Hence, both devices can be monolithically printegrated by using the same screen printing process
- Printed OECT-based circuits contain a large number of OECTs, resistors and electronic vias
- Every sub-device has to be functional in order to provide proper propagation of the logic signals
- Hence, high manufacturing yield has been achieved

Link to the H2020 WEARPLEX project

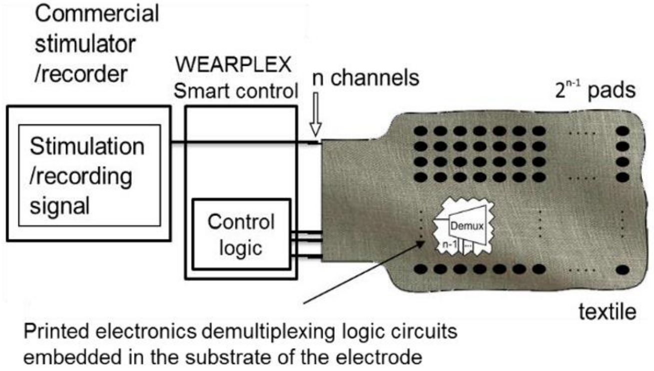
- Printed circuits embedded in multi-pad electrodes
- Minimizes the number of addressing lines from external electronics
- Can be used in both stimulation and recording applications, by using e.g. shift registers, demultiplexers or active-matrix addressing circuits

WEARPLEX concept of 'virtual' electrodes



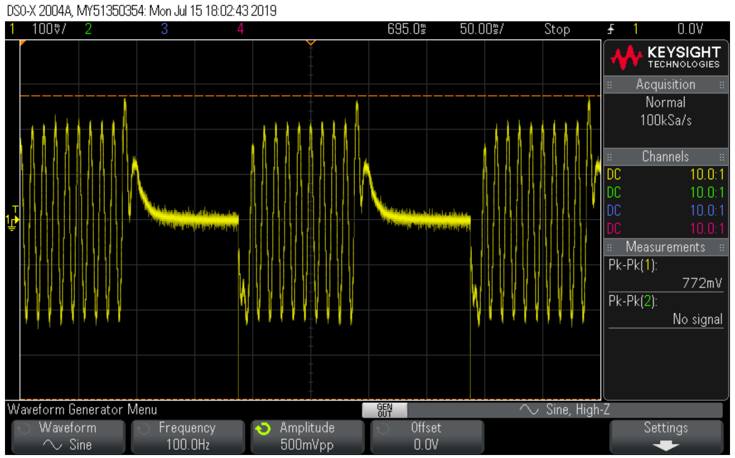


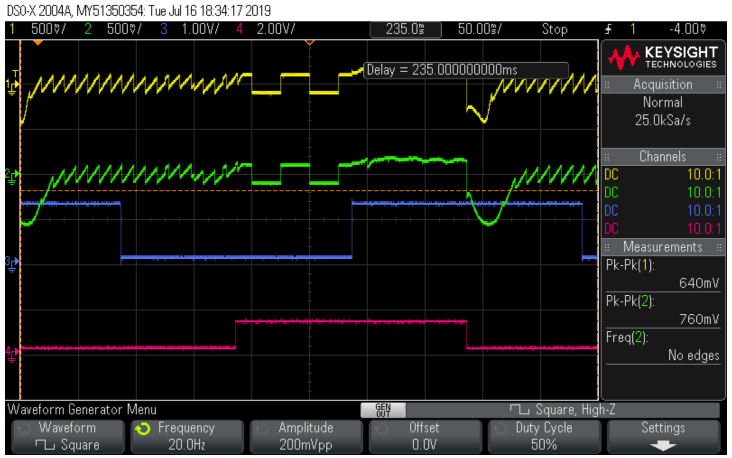
Current state of the art multi-electrode system



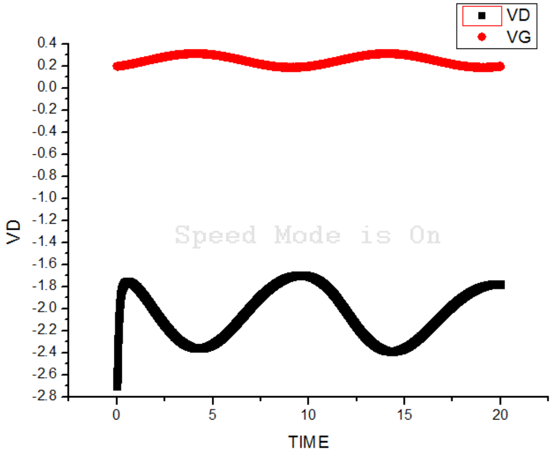
Proposed WEARPLEX solution

Link to the H2020 WEARPLEX project



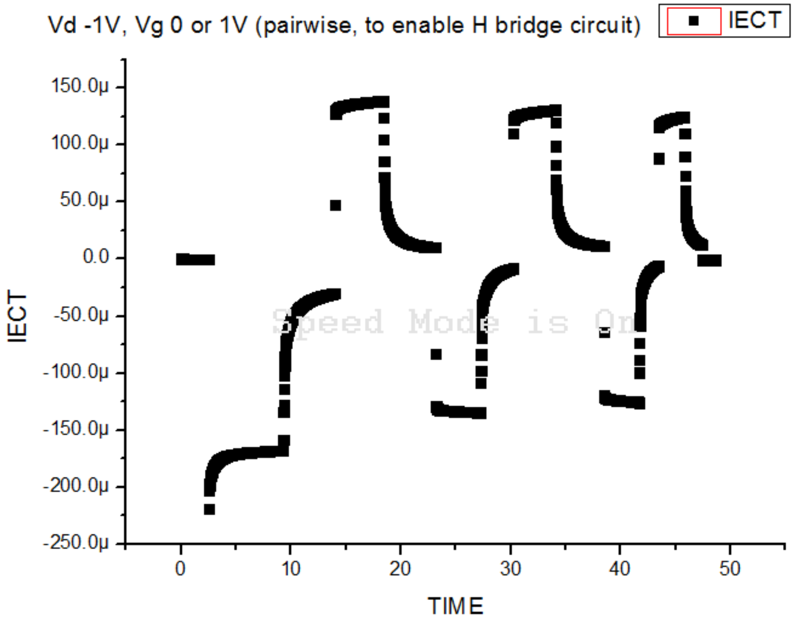


- OECT used to enable/disable propagation of electronic (stimulation) pulses
- Control of signal propagation has also been demonstrated by using an active-matrix addressing protocol



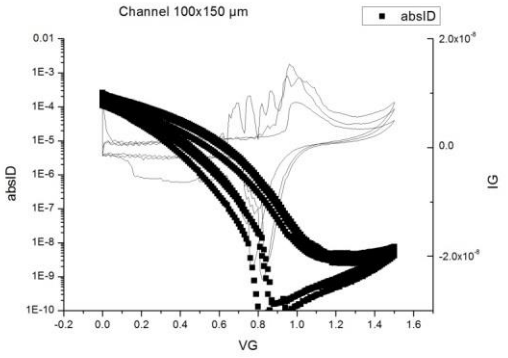
- OECT amplification can be used in recording applications

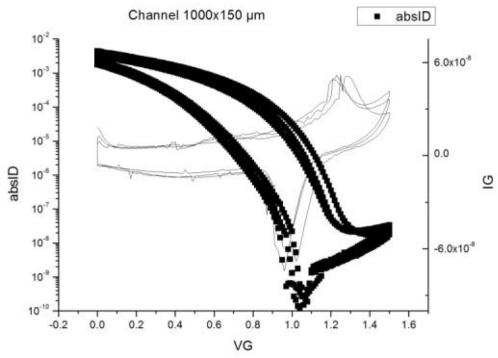
Link to the H2020 WEARPLEX project



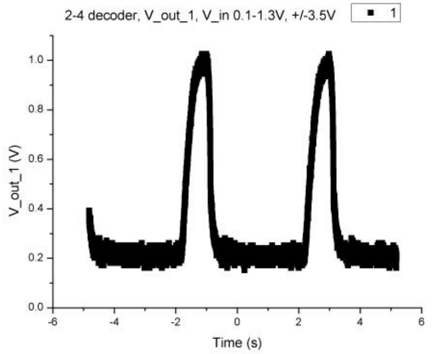
- H bridge circuits demonstrated with OECTs
- To allow current flow in both directions

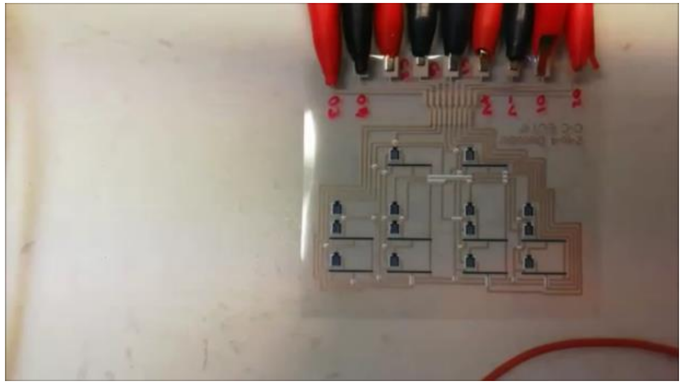
Link to the H2020 WEARPLEX project

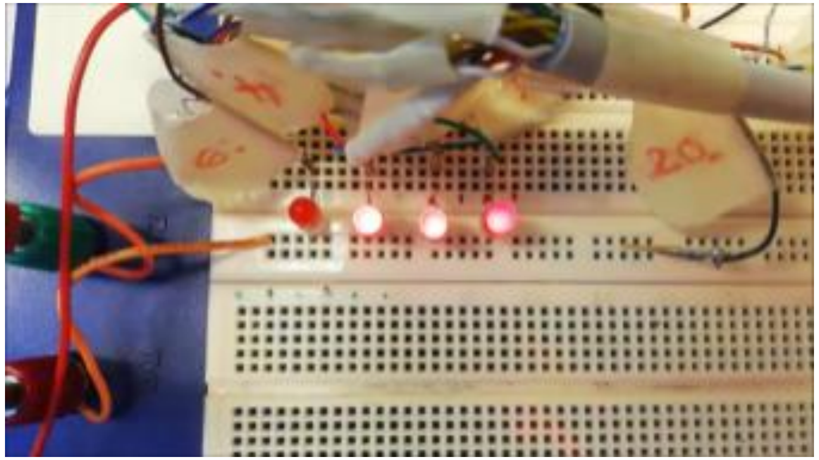




- Printed OECT-based decoder to enable LED addressing
- High current throughput in OECTs
- Demonstrated by capability of driving LEDs
- Each LED mimics a pad in the multi-pad electrode
- Trade-off between current throughput, switching response and footprint







Conclusions

- Hybrid electronic systems to demonstrate smart symbiosis between Si-based electronics and organic electronics that can enable smart electronic labels at low cost
- OECT – A transistor technology that can be manufactured by using screen printing as the only deposition technique
- The screen printing process has been taken to a new level - relatively complex OECT-based circuits have been printed with very high manufactured yield
- The objective within WEARPLEX is to manufacture embedded OECT-based circuits in multi-pad electrodes
- OECTs can be beneficial in both stimulation (high current throughput) and recording (signal amplification) applications

Acknowledgements

Funded by

Thanks for your attention!

Questions?

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