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SENSOR APPLICATIONS FOR ORGAN-ON-CHIP PLATFORMS

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INTEGRATED ELECTRO-CHEMICAL CHARGE SENSING IN ORGANS-ON-CHIP

Introduction

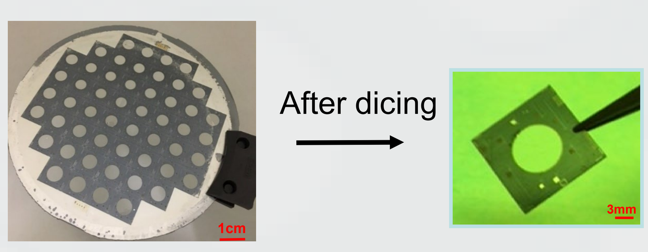
- Monitoring cell conditions and microenvironment in real time is crucial for Organ-on-Chip (OoC) functionality. In particular, biological cues such as **ions,** including metals and metabolites, play a critical role in physiology and homeostasis in the human body.
- Real-time monitoring of ions without optical systems is an unmet need for OOCs [1].
- Electrochemical sensors, such as organic electrochemical [2] and thin-film transistors [3], may address this need. Most of these sensors however rely on reference electrodes.

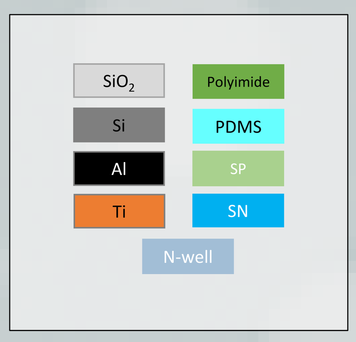
Ions present in the sensing region of the OoC → Modulation of the threshold voltage of the transistor → Effect can be tracked by measuring the drain current

- **We present an innovative and extremely compact electrochemical charge sensor for OoCs based on a floating gate field effect transistor (FGFET).** This sensor:
  - does not need a reference electrode
  - achieves label-free measurement of ion concentration in real time
  - can be seamlessly integrated into silicon/polymer-based OoCs
  - is compatible with wafer-scale CMOS-based microfabrication

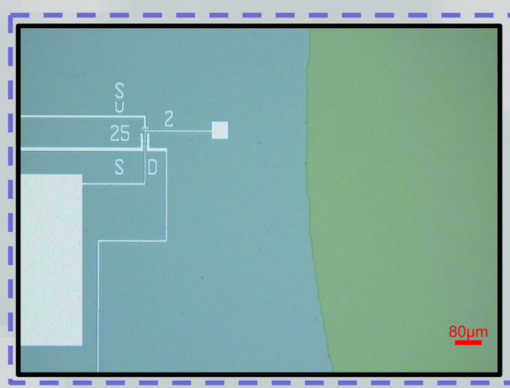
Wafer scale fabrication

- Each 4-inch Si wafer contains 52 OoC devices made of silicon and PDMS.
- After wafer-scale fabrication, the wafer is diced and the chips are electrically characterised.



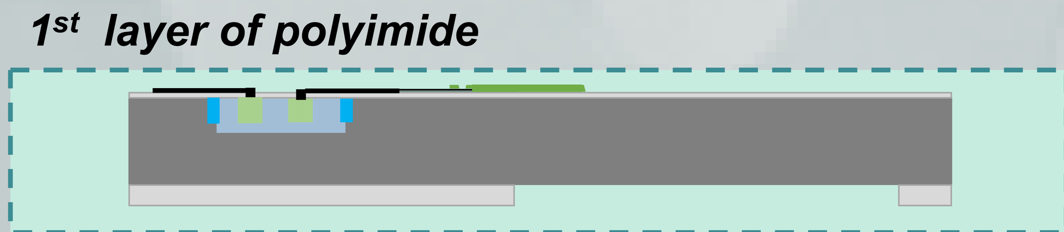


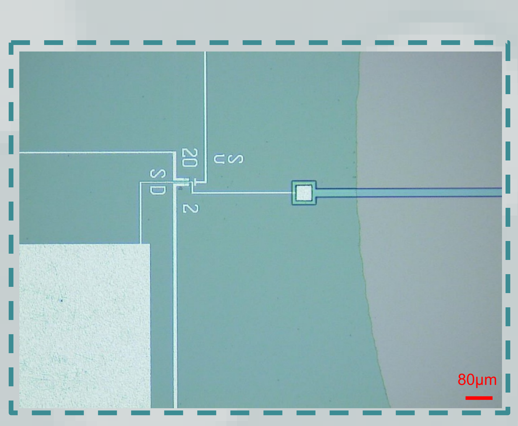
Fabrication of the transistor



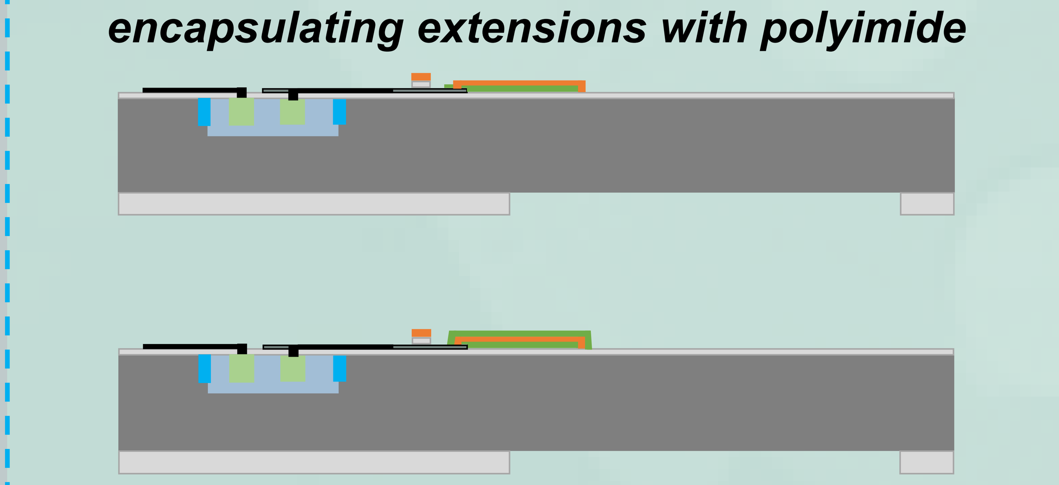
Encapsulation of gate extensions

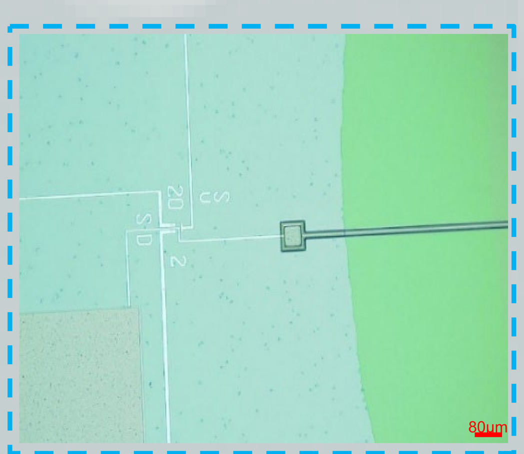
1st layer of polyimide



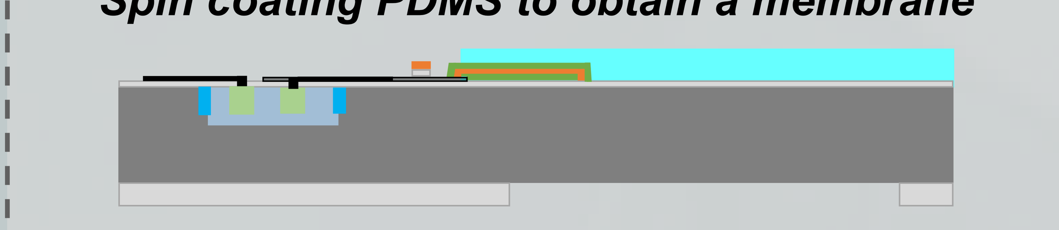


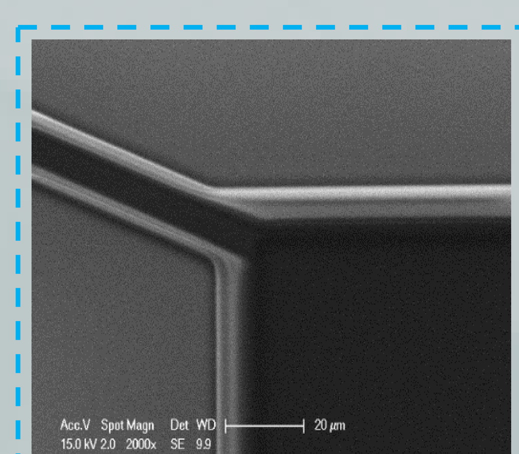
Fabrication of capacitive gate & gate extensions, encapsulating extensions with polyimide



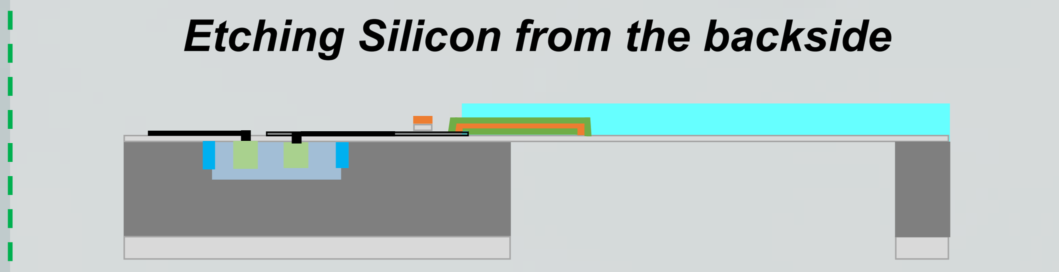


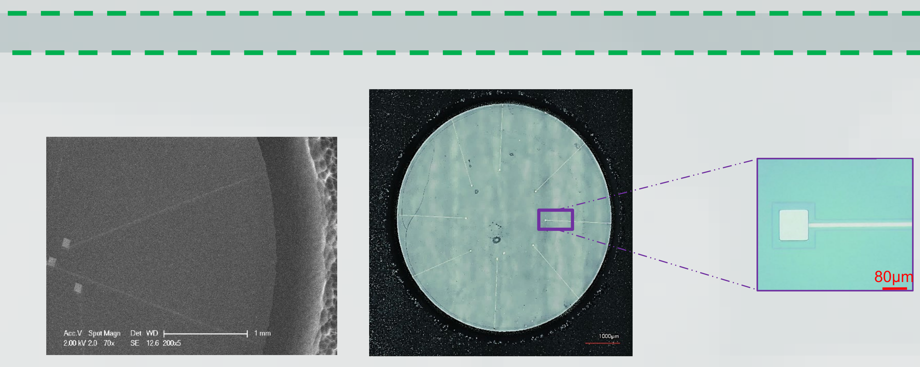
Spin coating PDMS to obtain a membrane





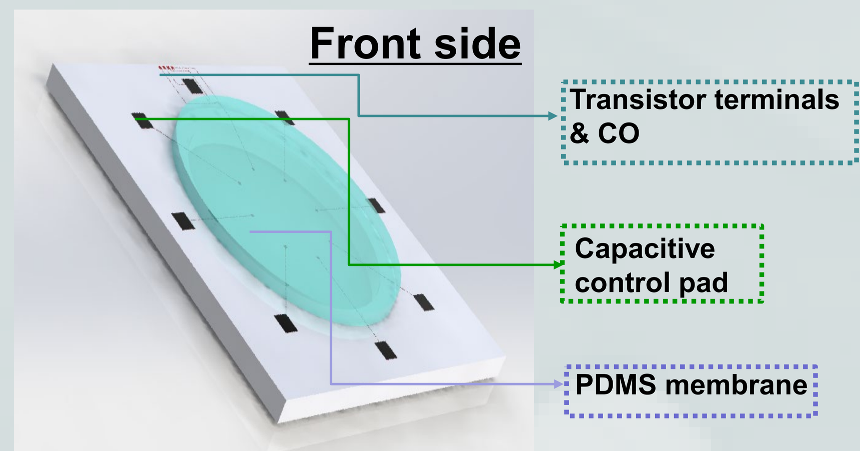
Etching Silicon from the backside

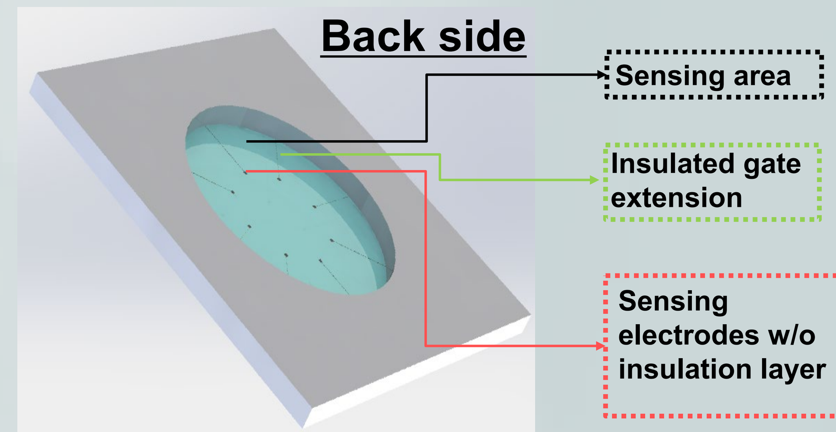




Back side of the chip after etching silicon and releasing the suspended PDMS membrane with insulated gate extensions.

Schematic of the device

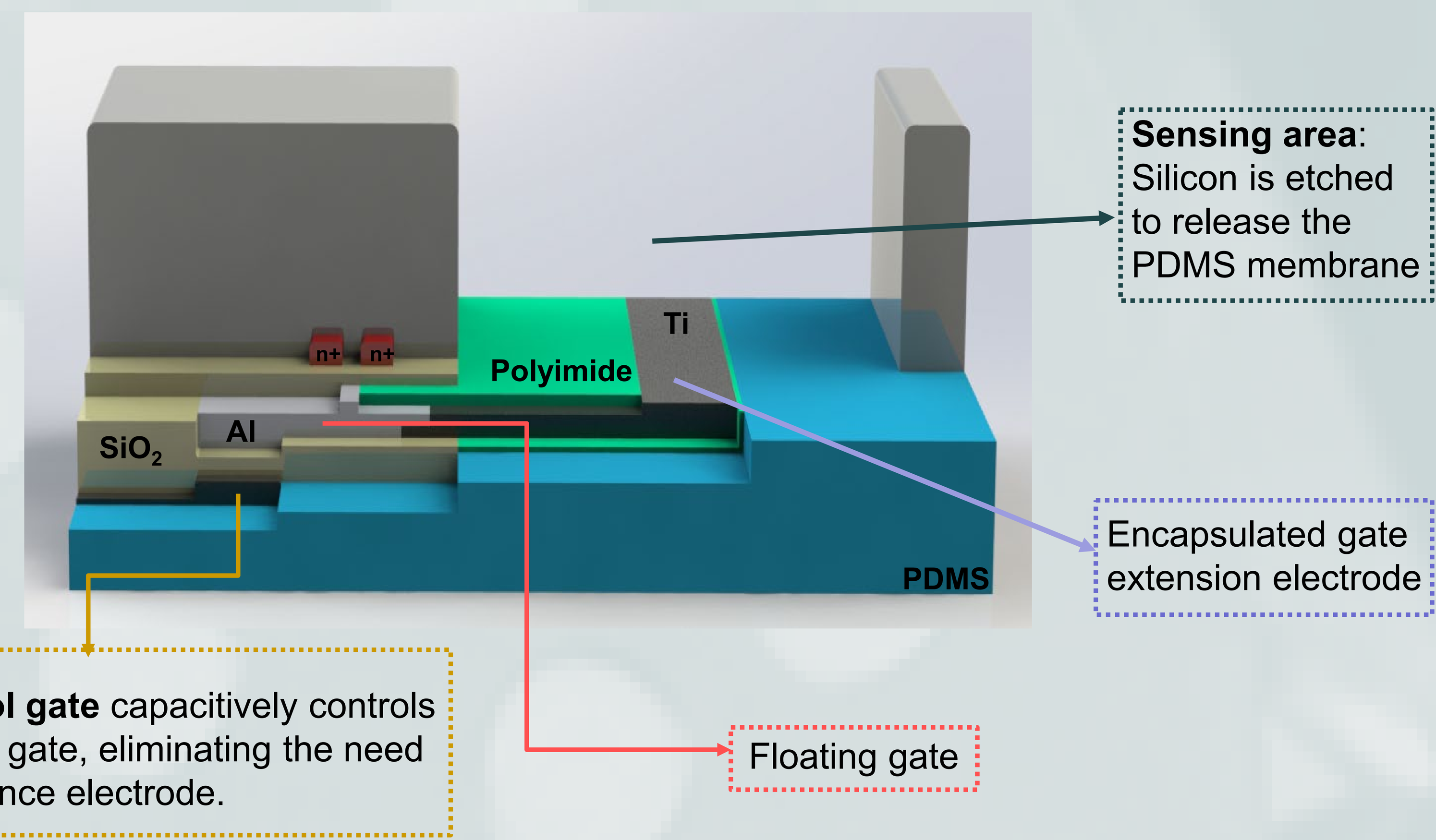




Front side: Electronic part, composed of 8 transistors.

Back side: Insulated gate extensions. Only sensing pads are in direct contact with the solution. Silicon is etched to suspend the PDMS membrane, which will be used as the sensing area.

Cross section of the device

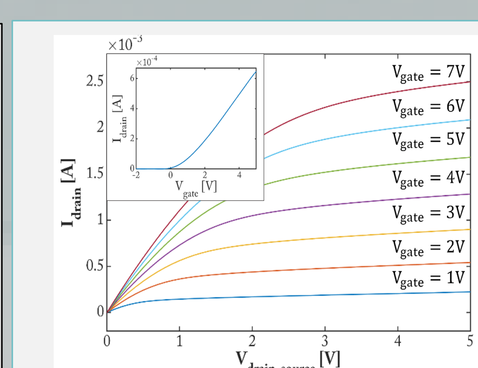


Preliminary Results & Discussion

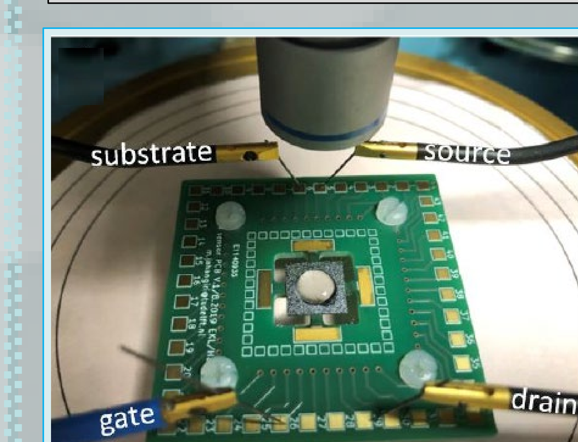
- We eliminate the need of a reference electrode by using a capacitive control gate to modulate the transistor threshold voltage.
- The output characteristics of transistors measured by biasing the control gate prove the functionality of the sensor both in dry and wet conditions.

Threshold Voltage (V)	NMOS	PMOS
Average	0.44	-3.69
Variance	0,000713	0,011257

Each die contains 4 NMOS and 4 PMOS transistors. Measurements were conducted across the whole wafer before dicing and mounting individual chips to a custom PCB. For all the transistors on the wafer, mean and variance of threshold voltages were calculated.

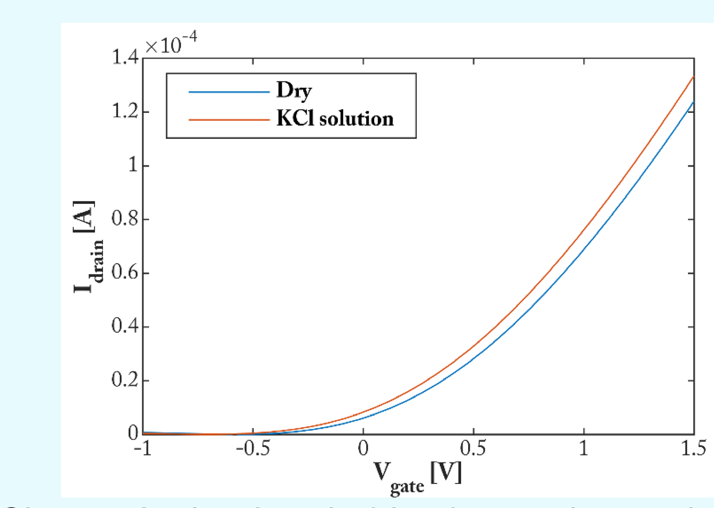


Characteristics of an n-MOS transistor. The extracted threshold voltage was 0.4 V.



A single die wire-bonded to a custom PCB.

4-needle probe station was used to bias the transistors and retrieve the drain current.



Change in the threshold voltage when a droplet of KCl solution is put on the sensing region.

Conclusions and Outlook

- Measurements prove the change in drain current by the ions present in the electrolyte.
- Our platform integrates CMOS-compatible fabrication with flexible polymer membrane, which forms the sensing region with transistor's gate extensions. It offers label-free and real-time sensing for biochemical cues in OoC applications.
- This platform could also be employed to monitor ionic displacement occurring at the cell membrane [4], and for disease modelling. For instance, abnormal changes in potassium channels of neurons can give information about Parkinson's disease [5].
- Future work includes selectivity and sensitivity studies for specific ions.

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