ITC 2025

19th International TFT Conference

March 24 ~ 26, 2025 / Nara, Japan

IMM Istituto per la Microelettronica e Microsistemi

Consiglio Nazionale delle Ricerche

Next-Gen Neuromorphic Circuits: Fabrication of Flexible Full Organic Systems with CMOS Technology

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Mattia Scagliotti

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Outline

- *Introduction: Neuromorphic Circuits*
- *Organic Electronics in Neuromorphic Circuits*
- *The FirstBorns project*
- *Circuits design*
- *Fabrication process*
- *Preliminary results*

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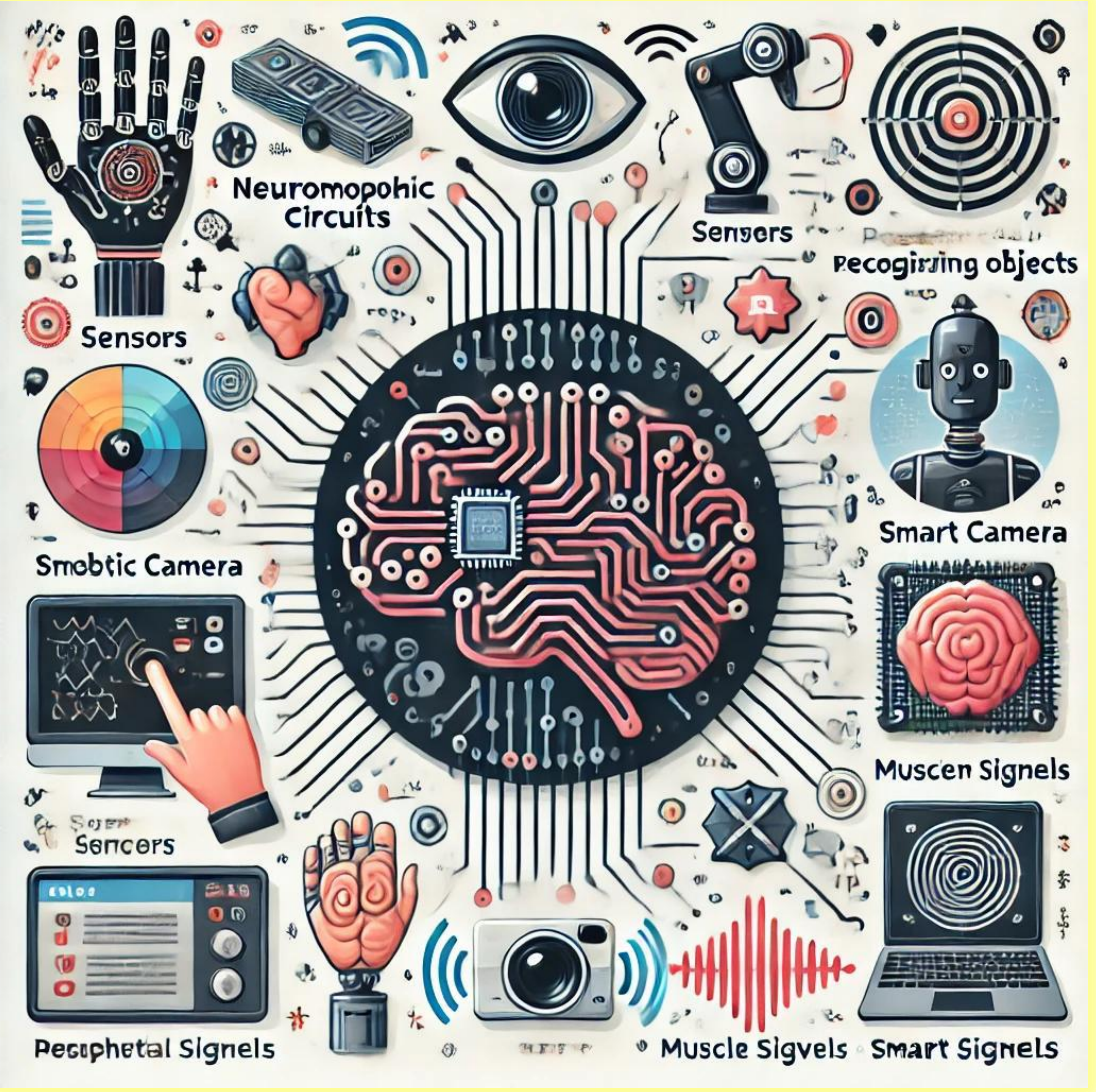
Consiglio Nazionale delle Ricerche

[2] iit EDPR ISTITUTO ITALIANO DI TECNOLOGIA
EVENT-DRIVEN PERCEPTION FOR ROBOTICS

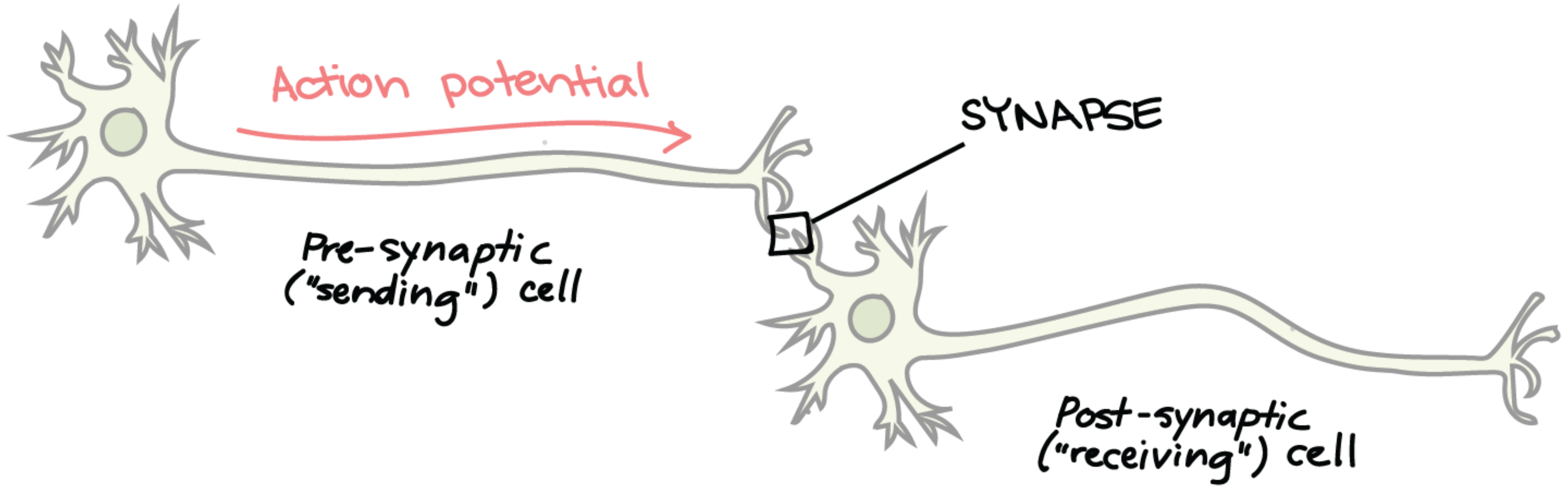
What is a Neuromorphic Circuit?

Generated by AI: see any problems?

electronic system designed to mimic the behavior of the human brain



It uses analog or digital components to simulate neurons and **synapses**, the building blocks of *neural networks*



Unlike traditional computers, neuromorphic systems *process data in parallel and in real time*, just like our brain

What can a neuromorphic circuit do?

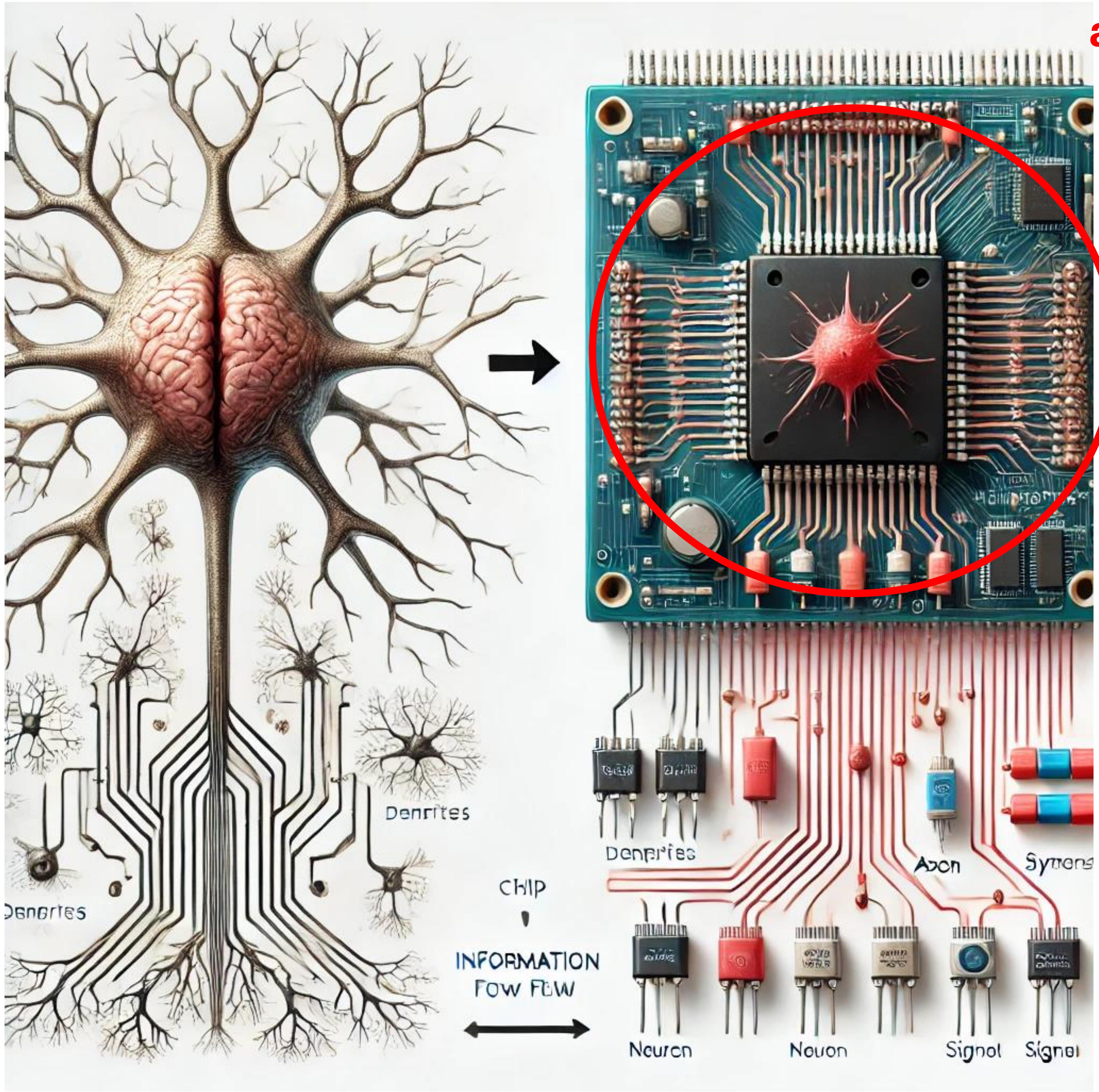
1. Real-time processing
It is highly efficient at processing information in real time, such as sounds, images, or sensory signals.

2. Low power consumption
It imitates how biological neurons communicate (only when needed), so it consumes much less energy compared to traditional computers.

3. Learning and adaptation
It can "learn" from new data or experiences, much like a brain does, using mechanisms similar to synaptic plasticity.

4. Pattern recognition
It is very good at recognizing patterns, for example in computer vision, speech recognition, or sensory data analysis.

5. Massive parallel processing
It can process a large amount of information simultaneously, just like neurons in the brain.



Rigid materials and devices

Limitation!

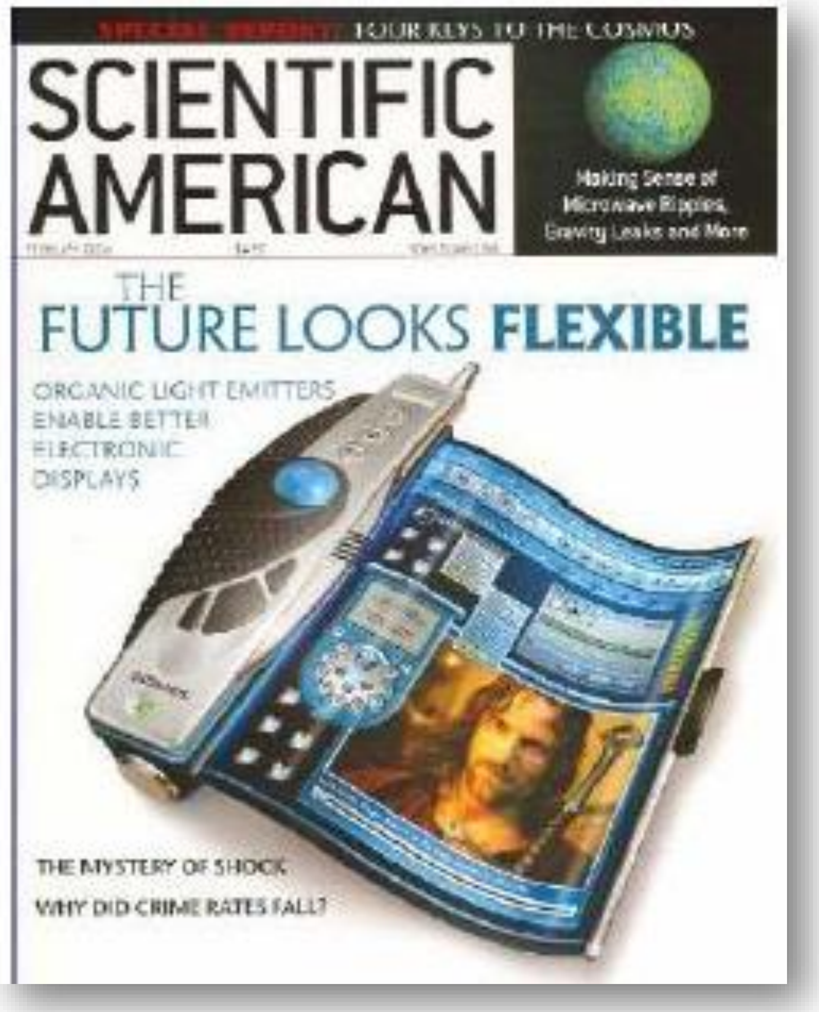
Soft Robotics

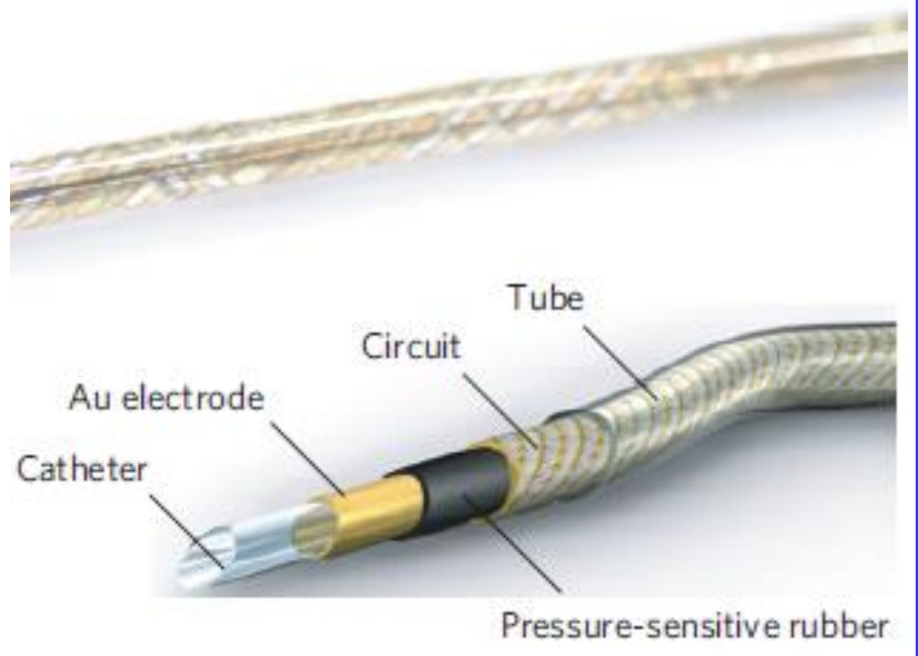
Our world consists of ***soft materials*** *and objects, where* ***interactions*** *with them are* ***flexible*** *and not rigid.*

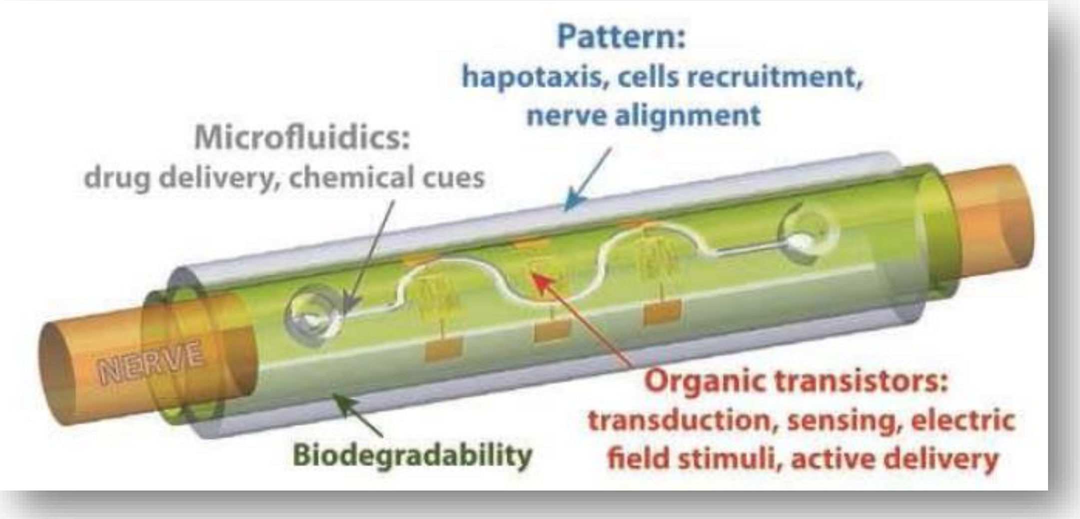
Soft robotics focuses on creating **flexible, adaptable robots** made of soft materials like silicone or fabrics. Inspired by nature, these robots can bend, stretch, and safely interact with humans.

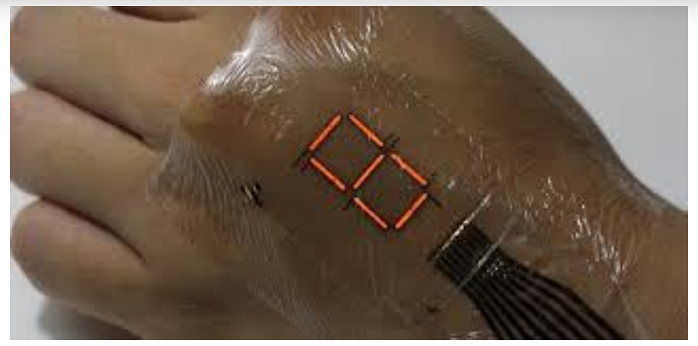
They're used in **medicine**, **rehabilitation**, **search and rescue**, **underwater exploration**, and **bioinspired design**—especially where traditional rigid robots can't operate effectively.

Organic Electronics in Neuromorphic Circuits









what kind of materials?

Semiconductor
Dielectric materials
Conductor materials

"format"?

Small molecules
Polymers

Which kind of devices?

Big three of electronics:
- Transistors (OTFT)
- Light Emitting Diode (OLED)
- Photovoltaic devices (OPV)

Why? advantages?

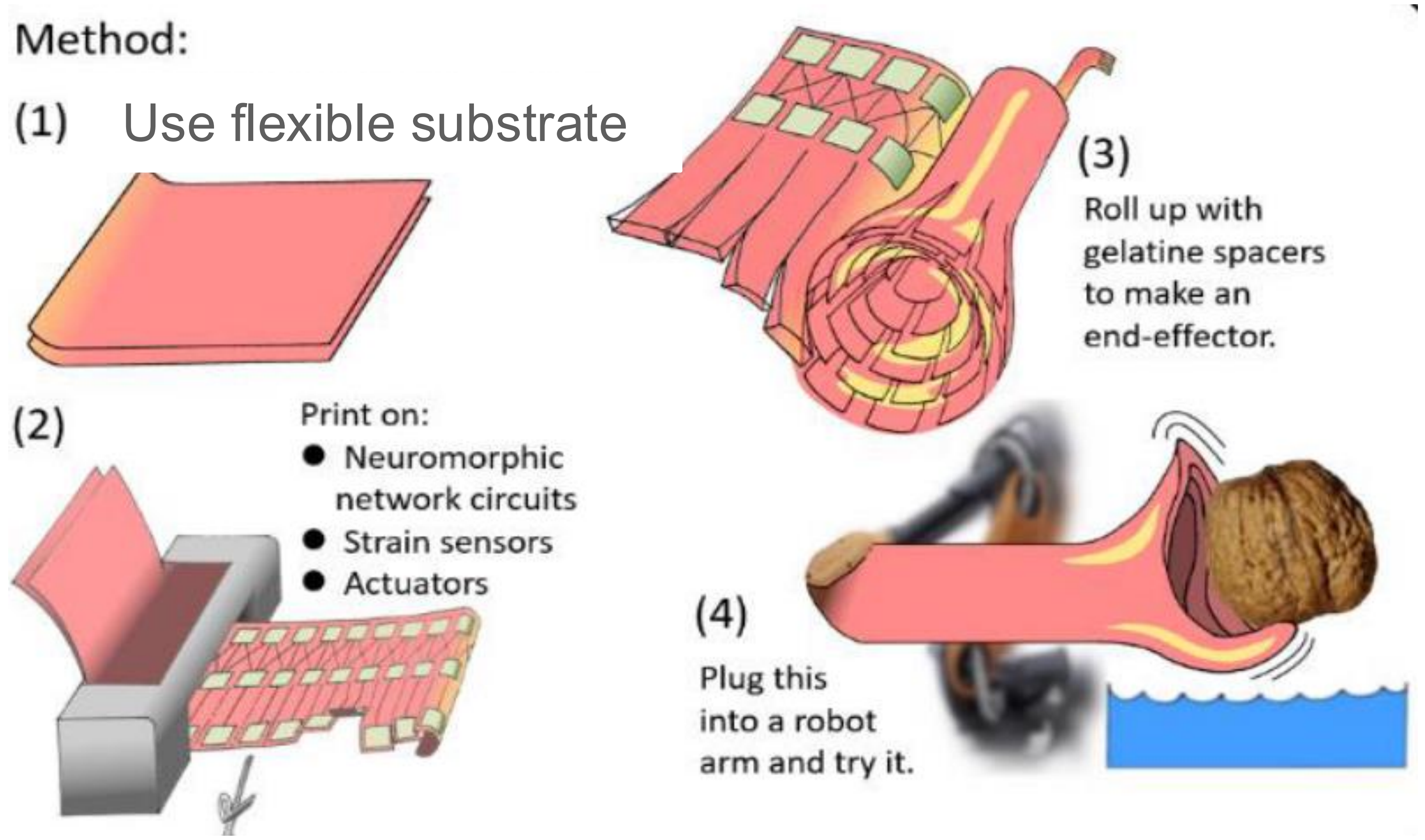
- Flexible
- Bio-compatible
- Bio-compostable
- Stretchable
- Light
- Green fabrication
- Low temperatures required
- Solvent free fabrication
- Printable
- Roll-to-roll
- Low Cost
- Low Power
- …

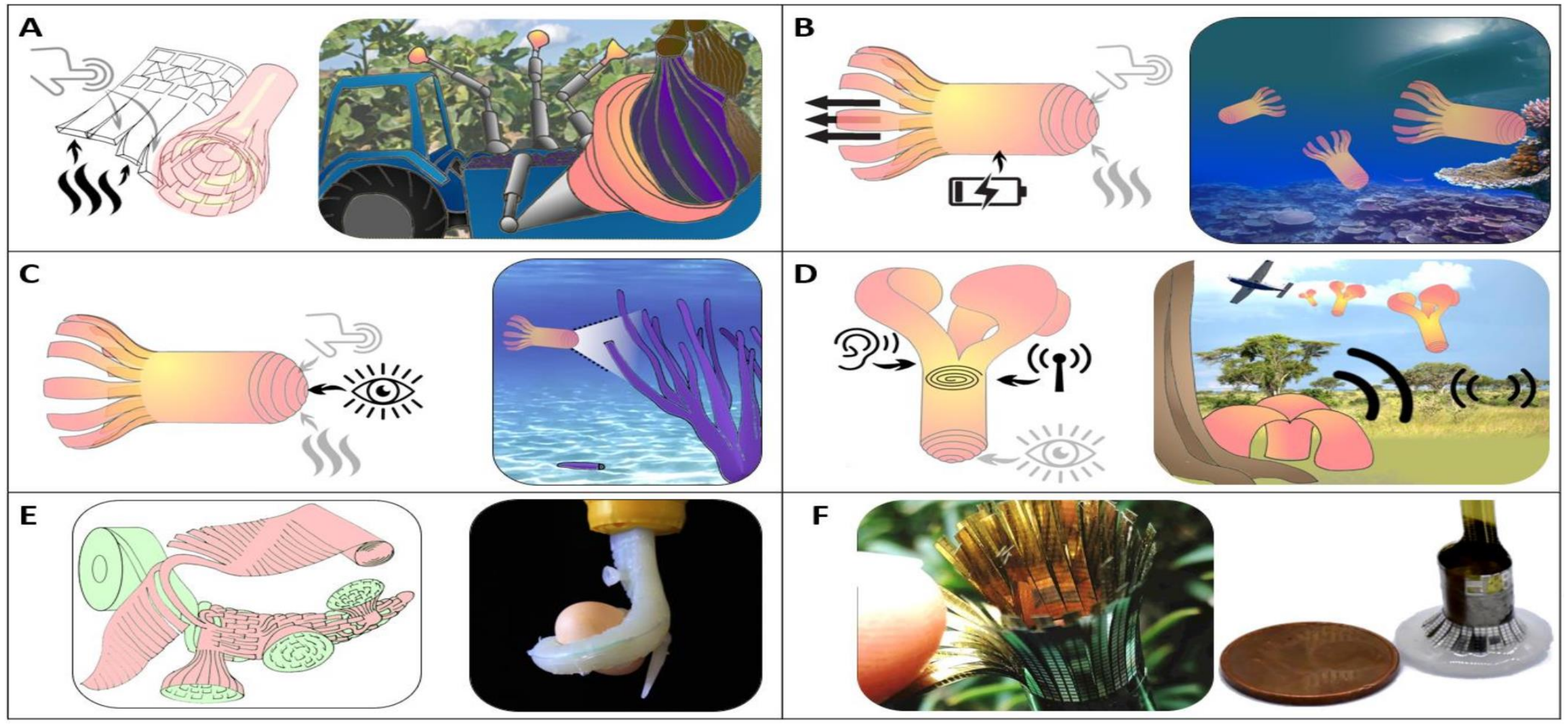
FirstBorns Project: Organic Electronics for Neuromorphic Circuits

Flexible Inked Rolled Sensing acTuating Biodegradable Organic Robotic Nervous Systems

Objective

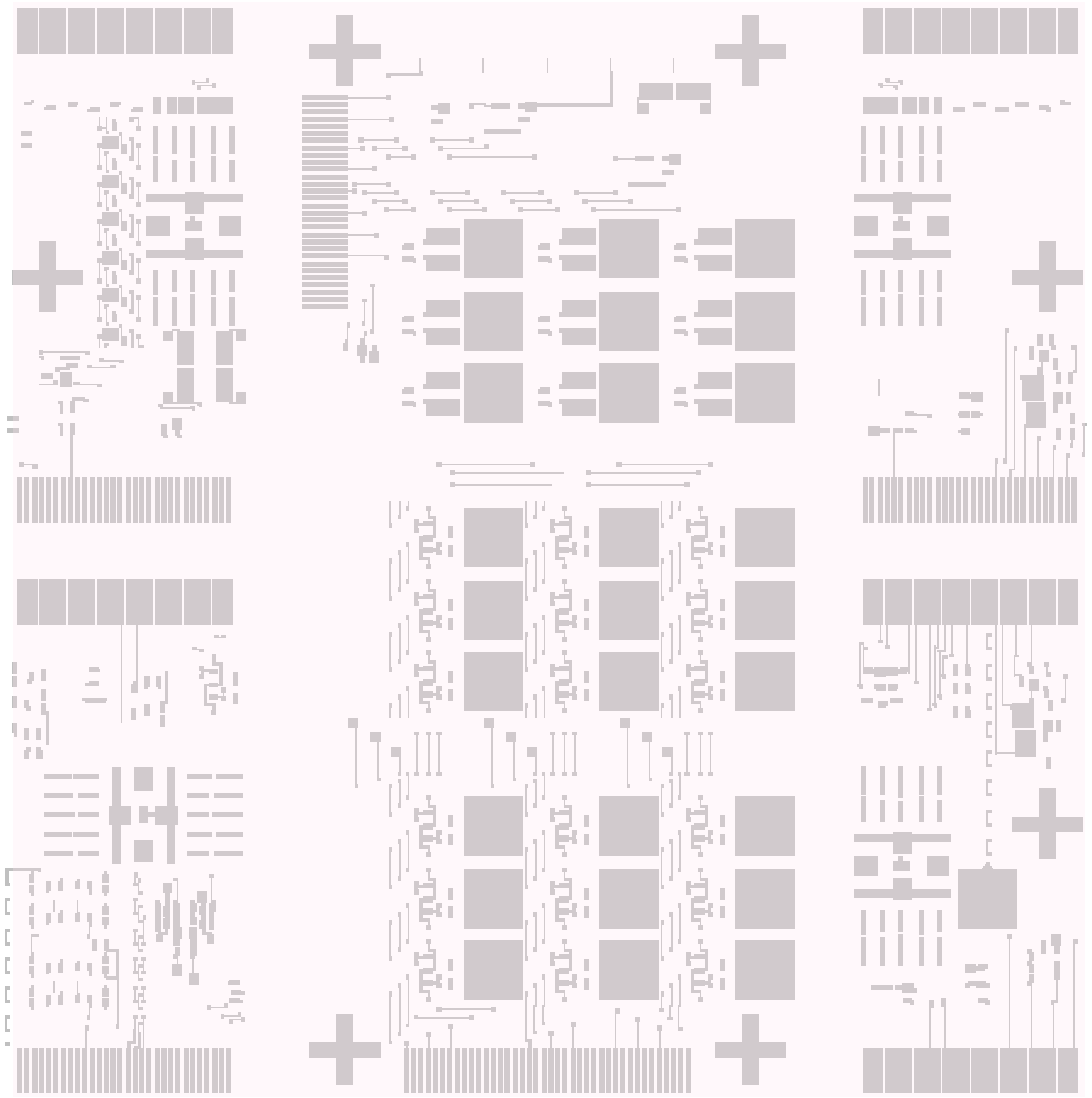
- **Soft robotics** takes cues from nature to create compliant robots for gentler tactile interactions. They depend on sensors and actuators, developed through **flexible thin-film electronics** integrated with soft materials.
- A key challenge is creating interfaces between these soft elements and rigid Si.
- We use a **neuromorphic approach:** flexible, OTFT electronics for sensing, computation, and actuation in soft robots, like how neural systems effectively manage decision-making with varied computing elements.

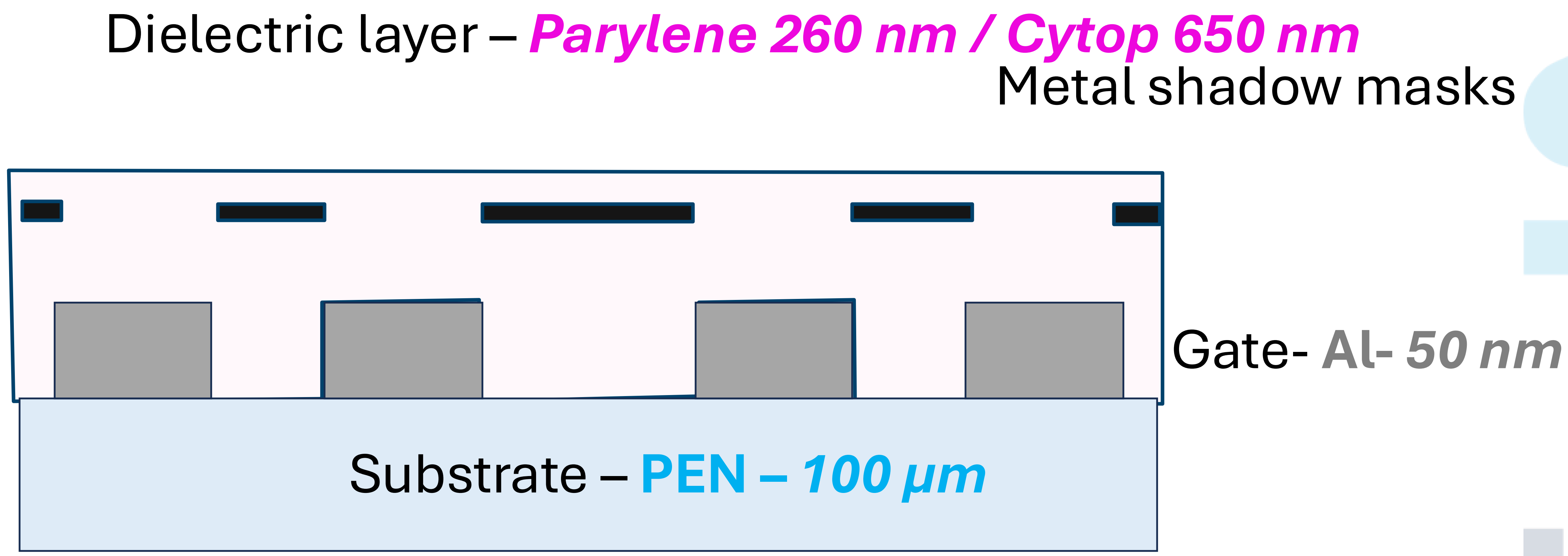




Circuits Design and Fabrication

Bottom Gate Top Contact (BGTC) device CMOS structures





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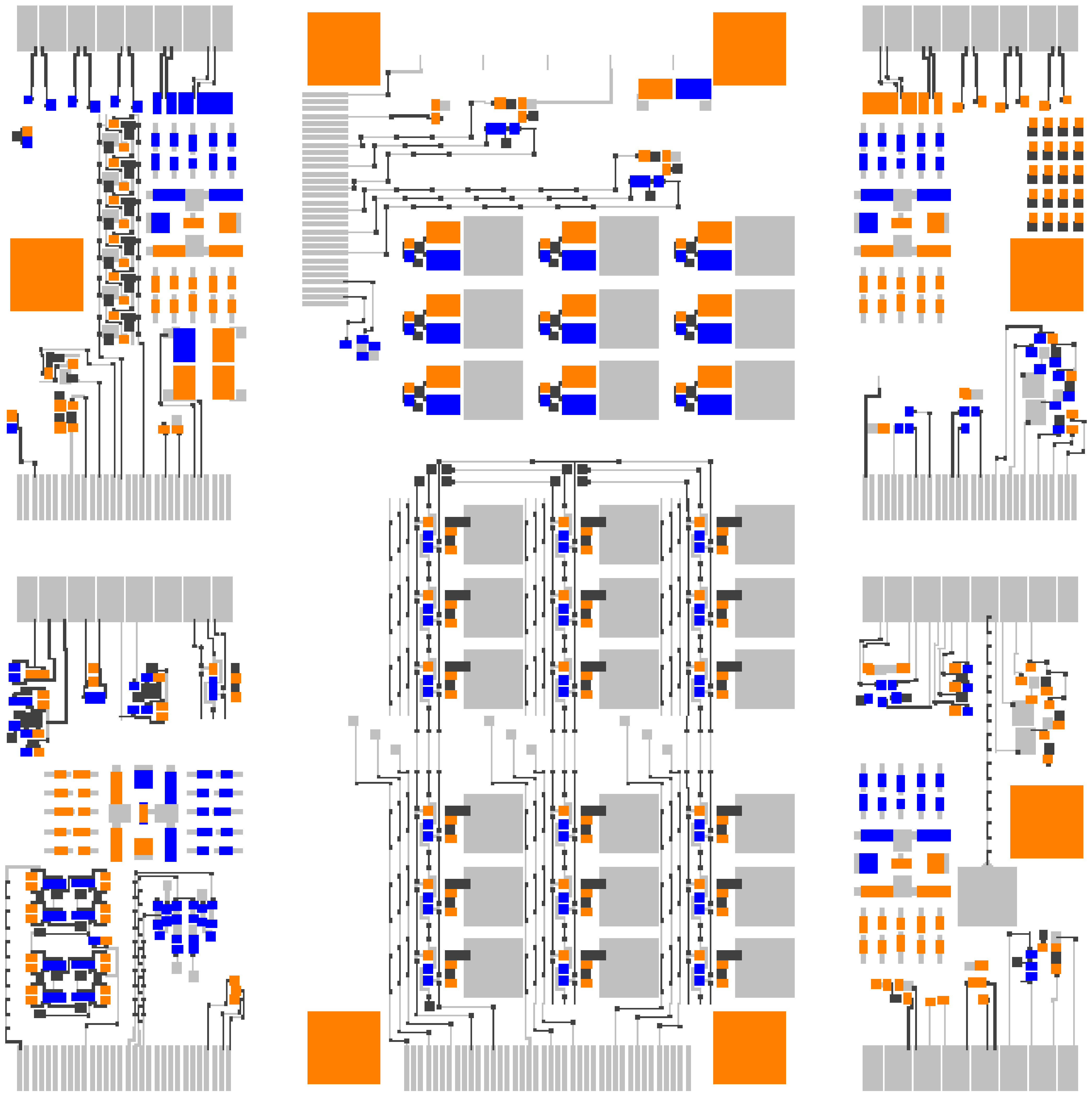

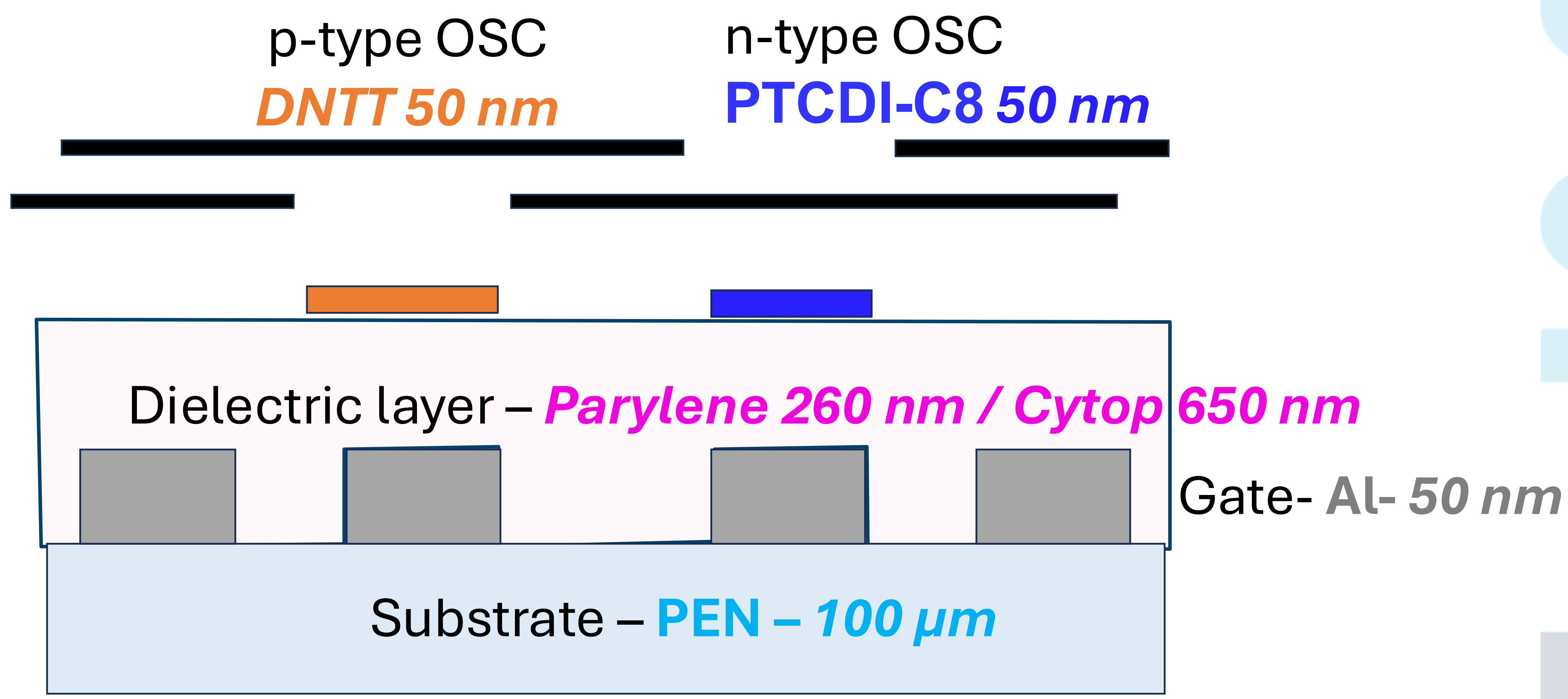

Circuits Design and Fabrication

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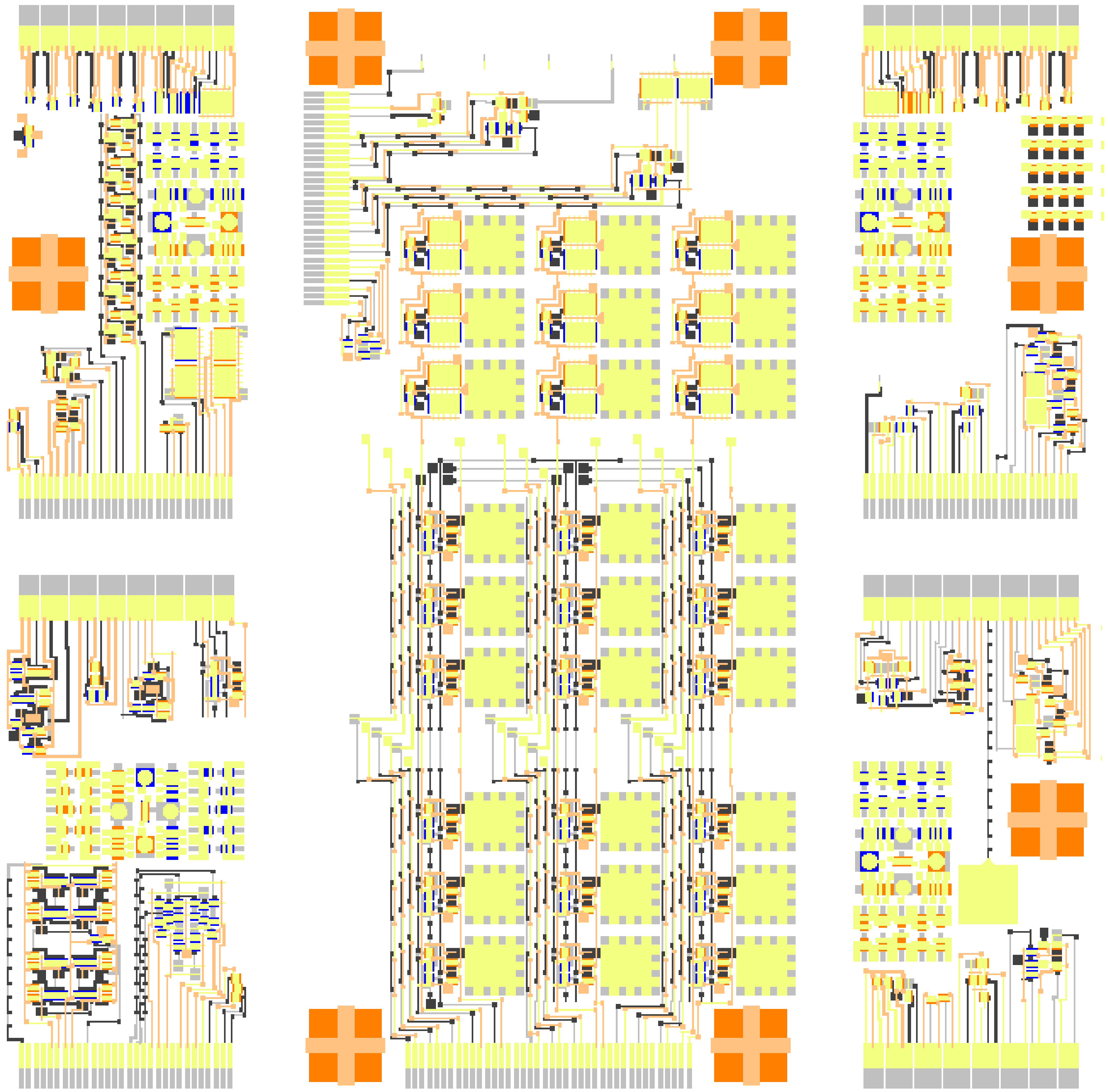

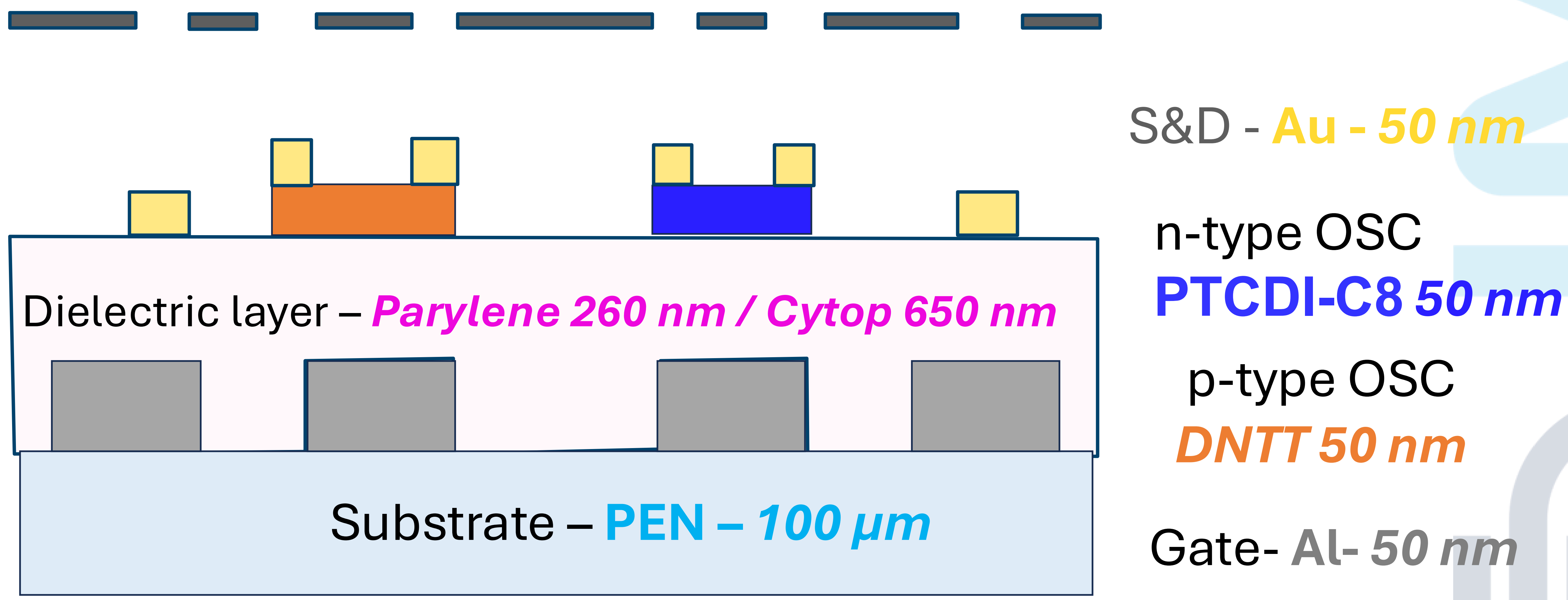

Circuits Design and Fabrication

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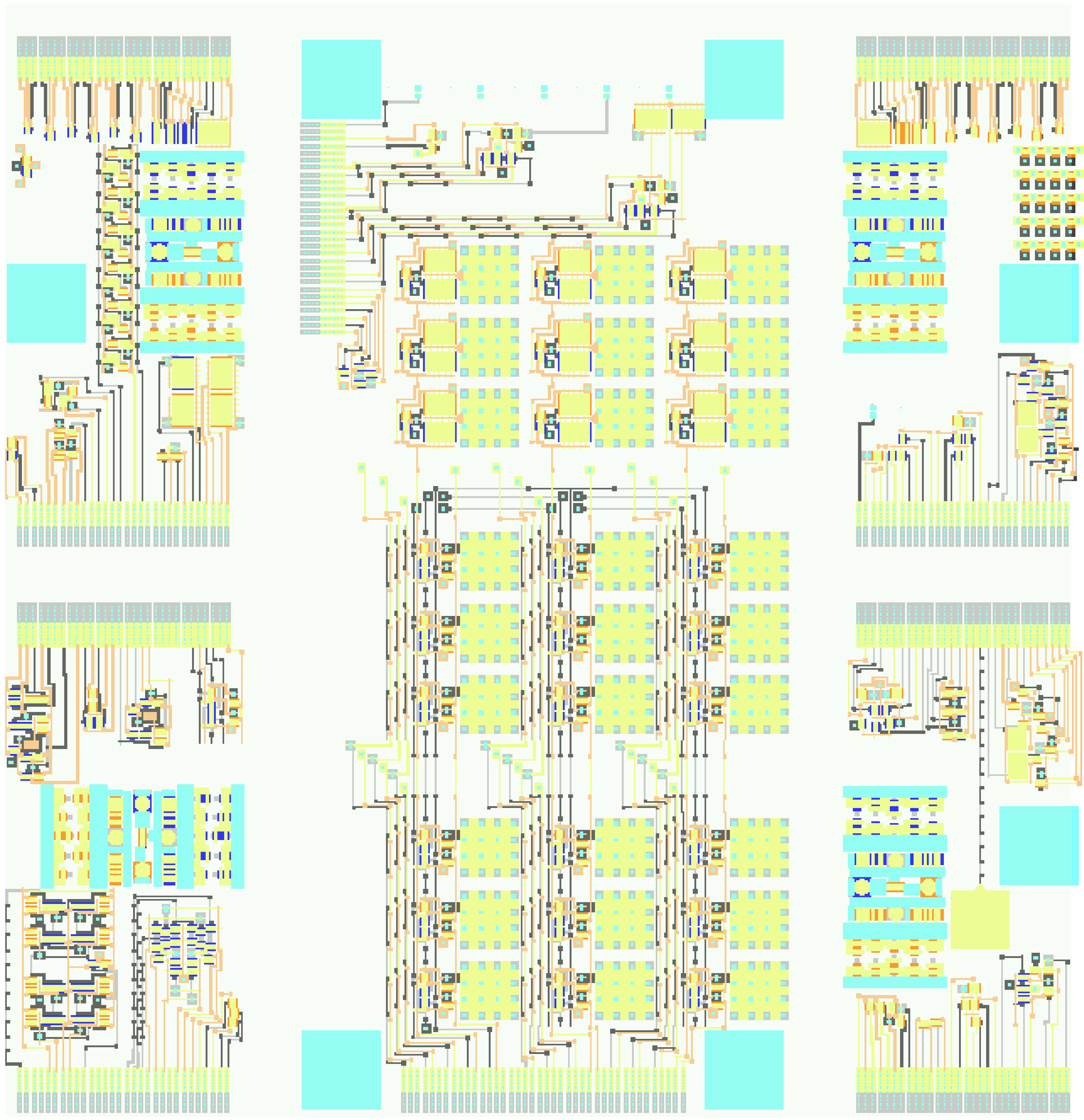
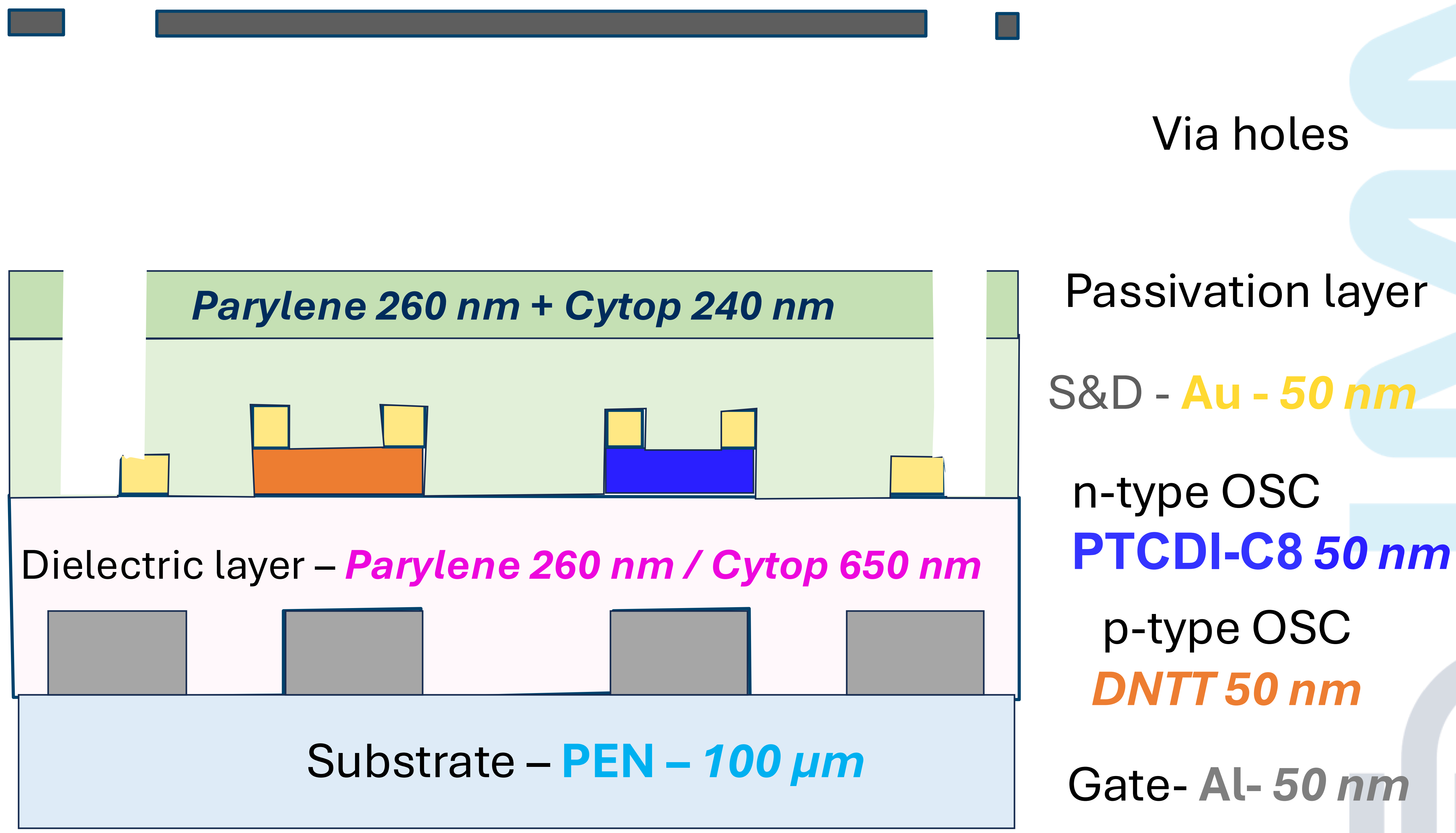
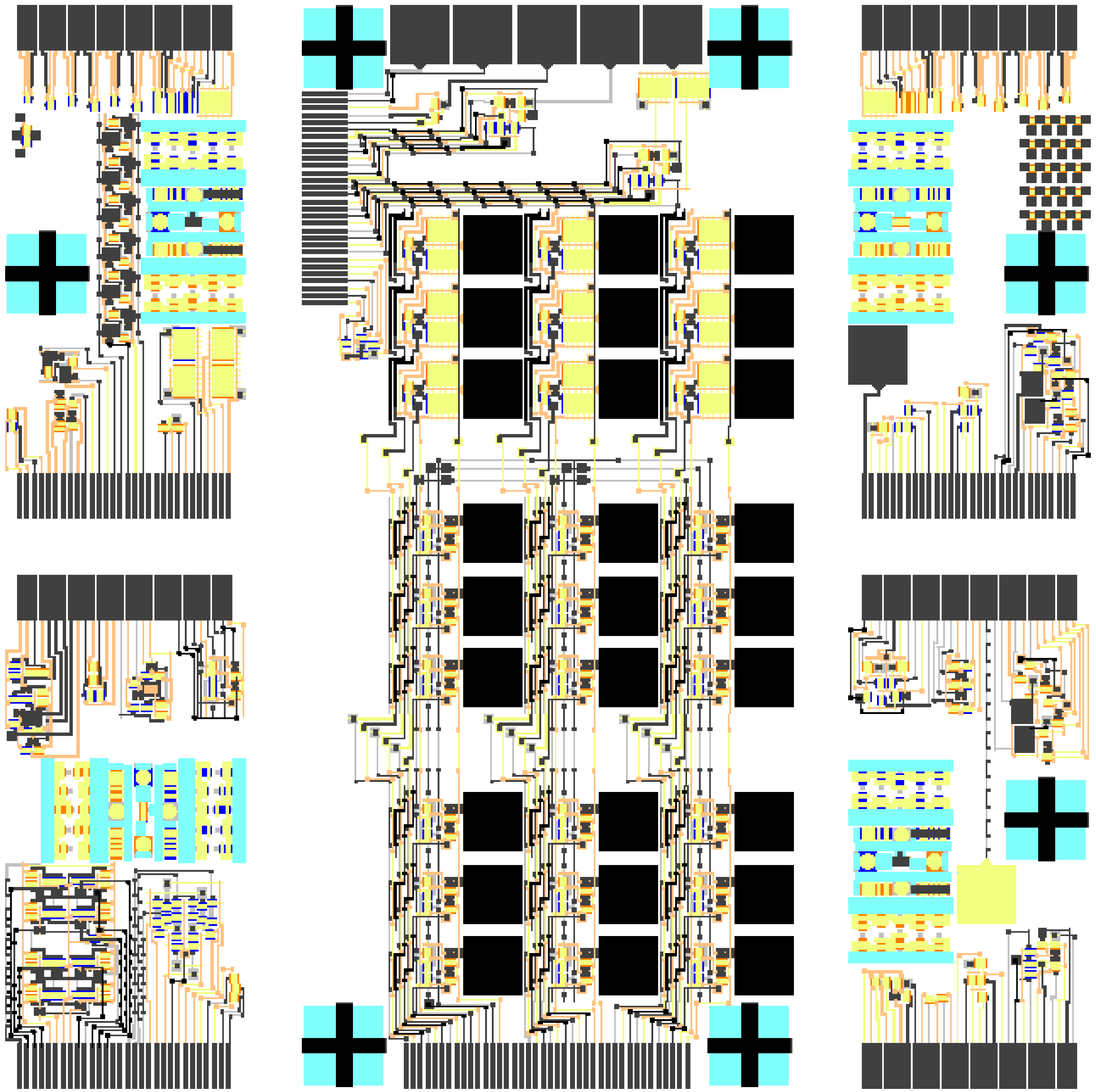
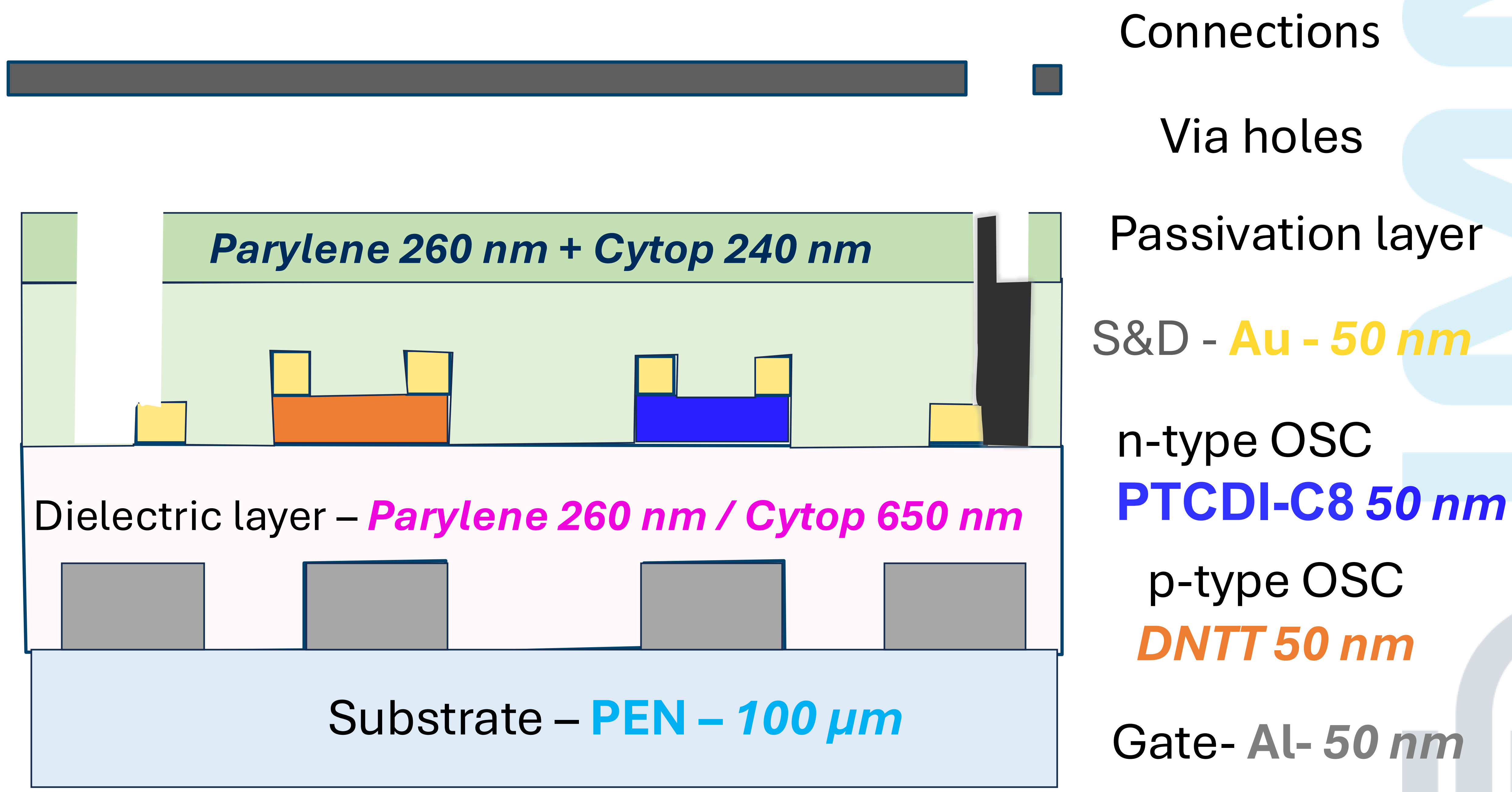




Circuits Design and Fabrication

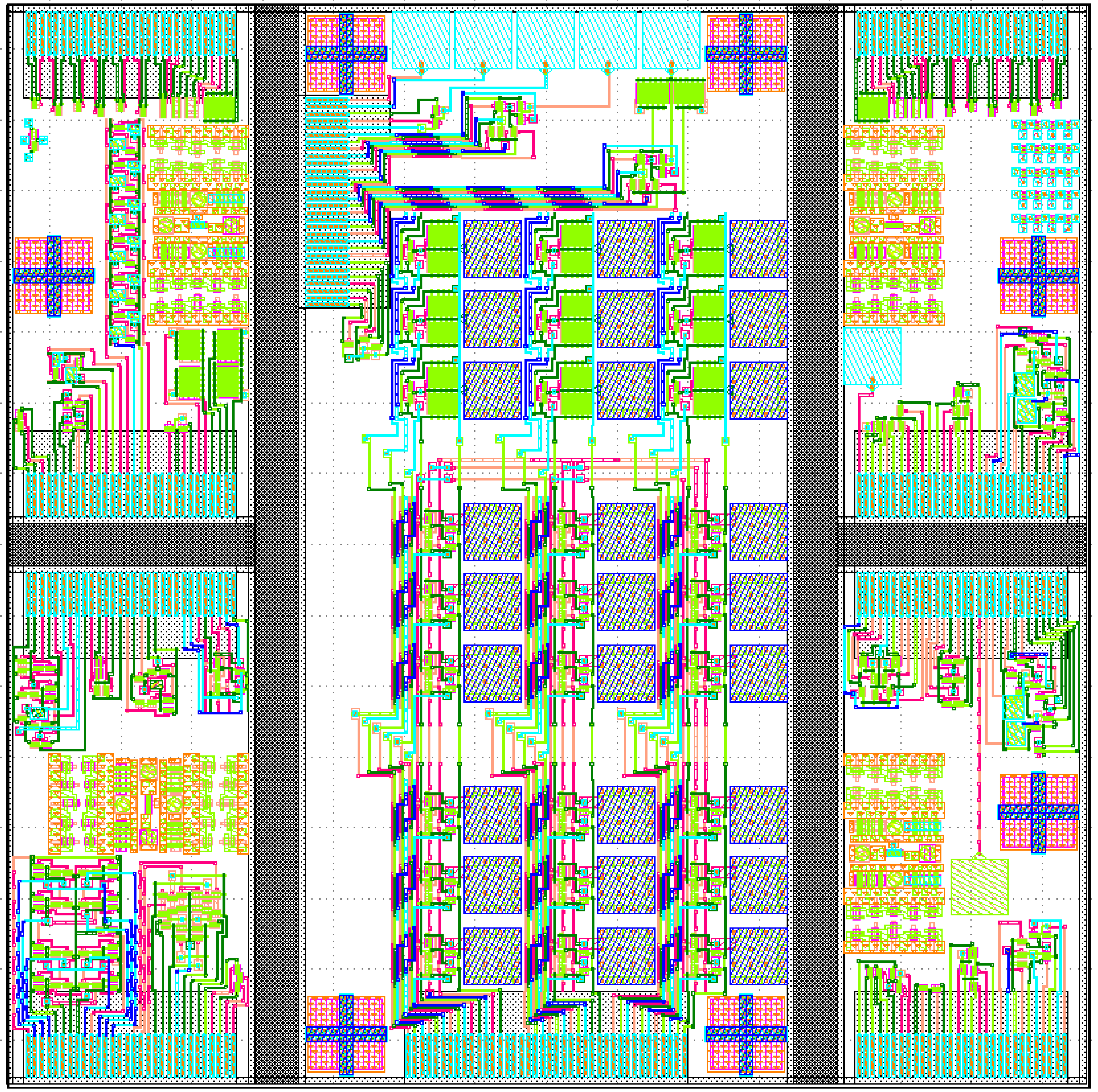
Bottom Gate Top Contact (BGTC) device CMOS structures



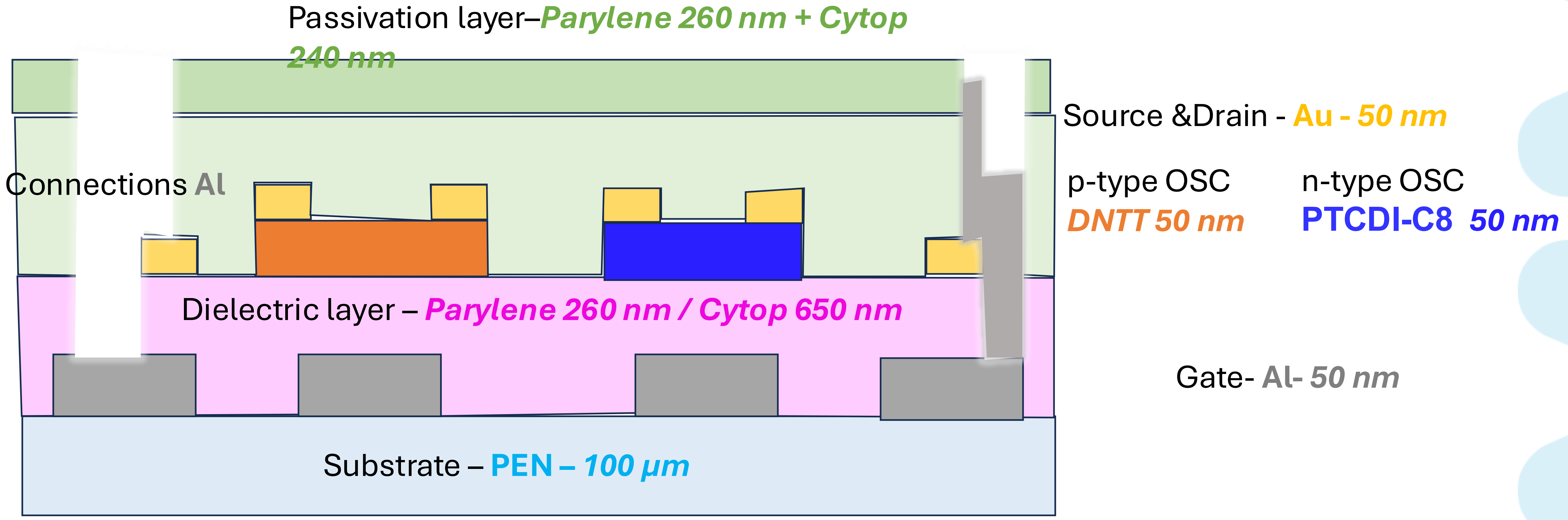


Circuits Design and Fabrication

The design consists of a series of components, from individual transistors through small 2-3 transistor circuits, through to larger circuit designs.



Bottom Gate Top Contact (BGTC) device CMOS structures



12 design levels:

- 2 organic semiconductors
- 3 metal layers
- 2 organic dielectric films
- via holes by O_2 plasma

Solvent free

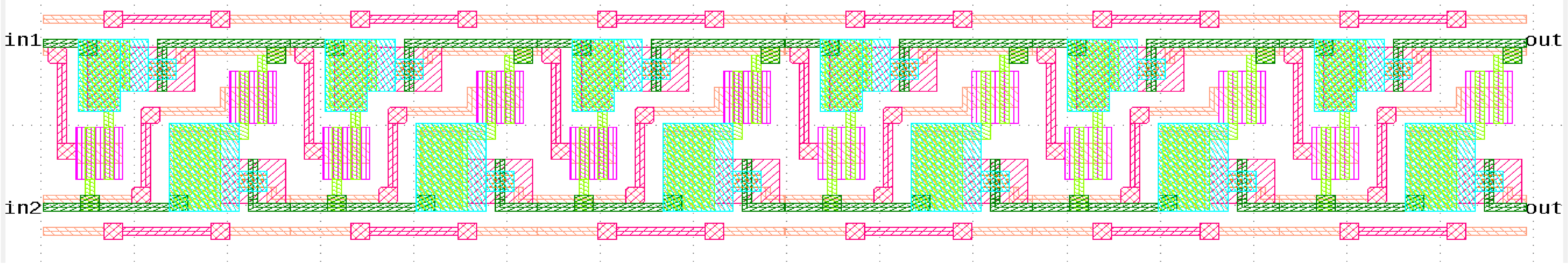
Minimum features 20-50 µm

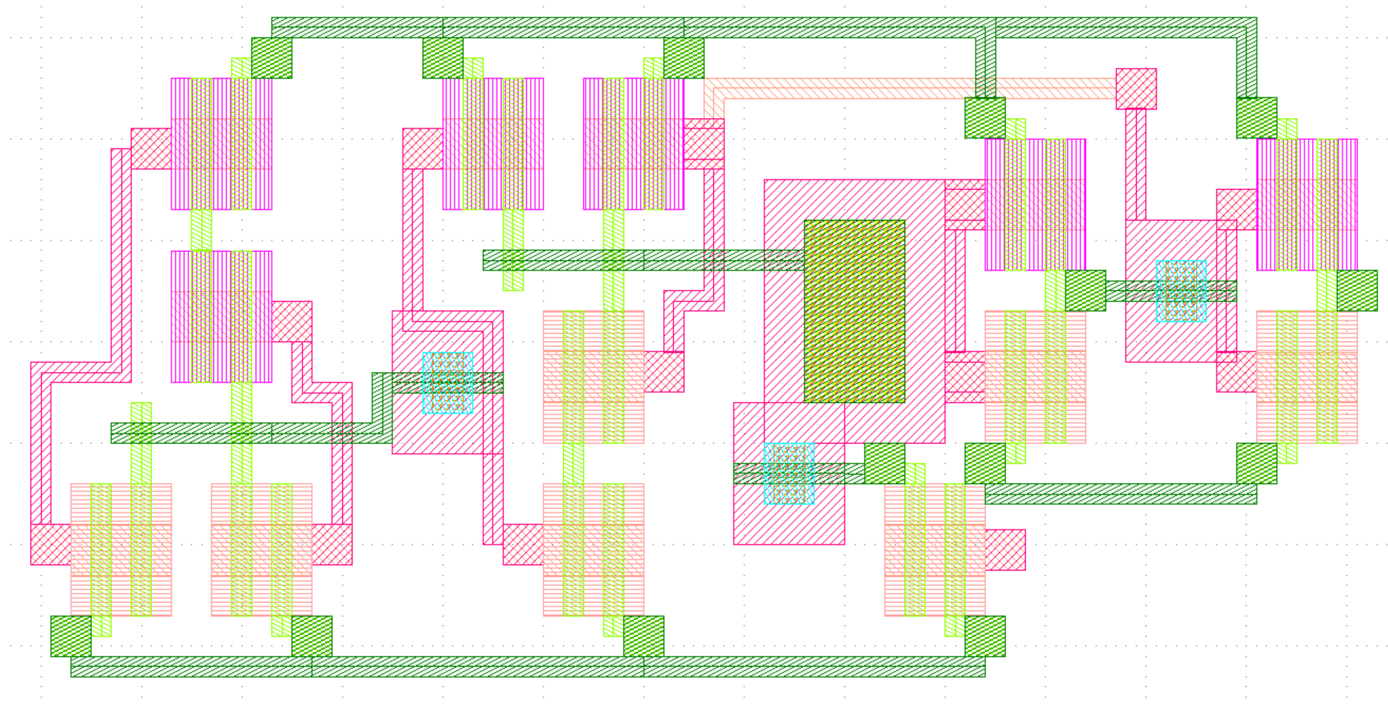
Room Temperature process

Circuits Design

CMOS Inverter, Pseudo-CMOS P-type inverter, Diode pairs (C-type, and P-type), 2T amplifier, 7T CMOS sample-reset circuit, NOR gate, Source follower (P-and N-types), Low-current mirror, Synapse, 5T CMOS amplifier, 9T wide-range CMOS amplifier,

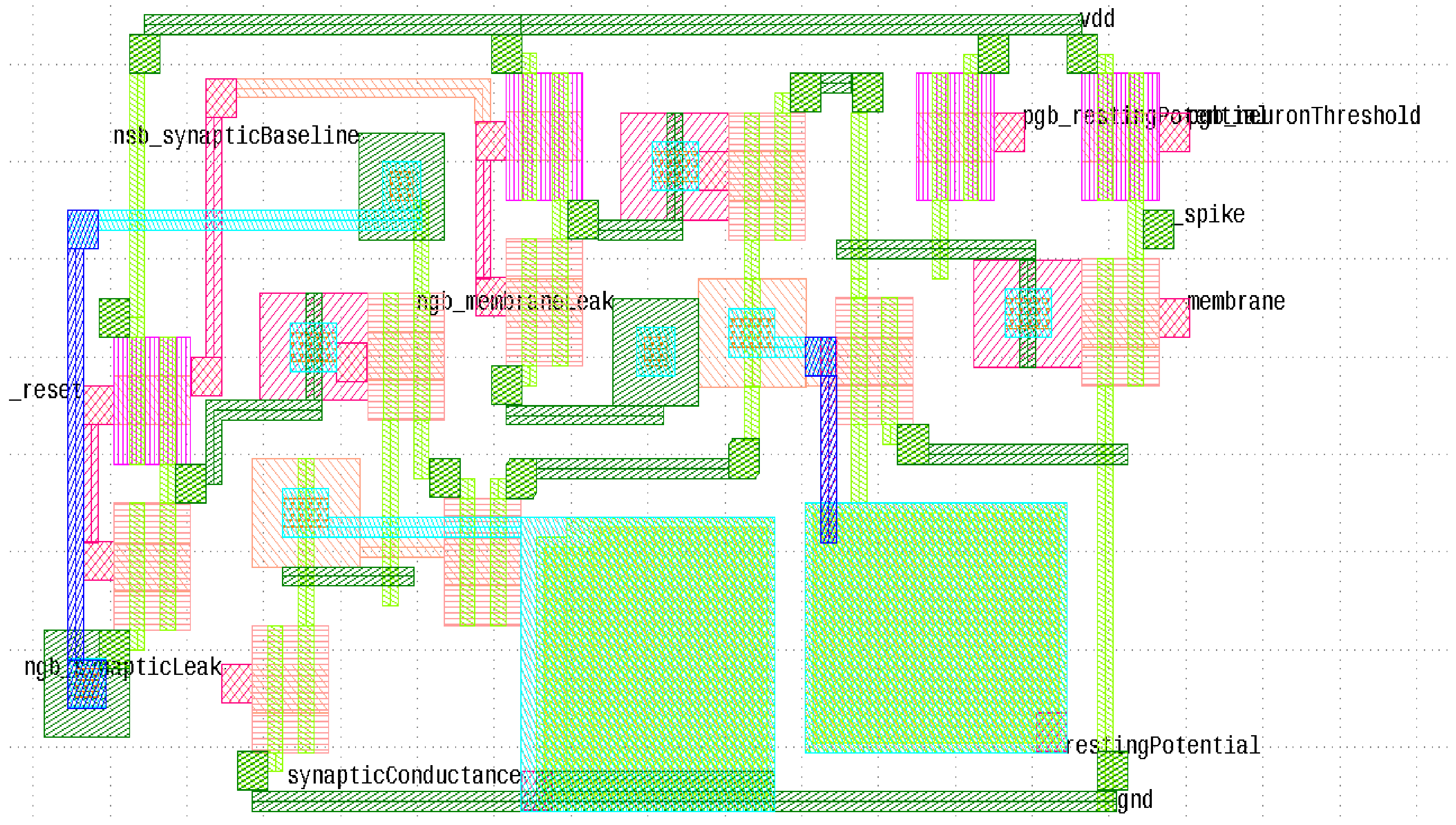
Actuator driver

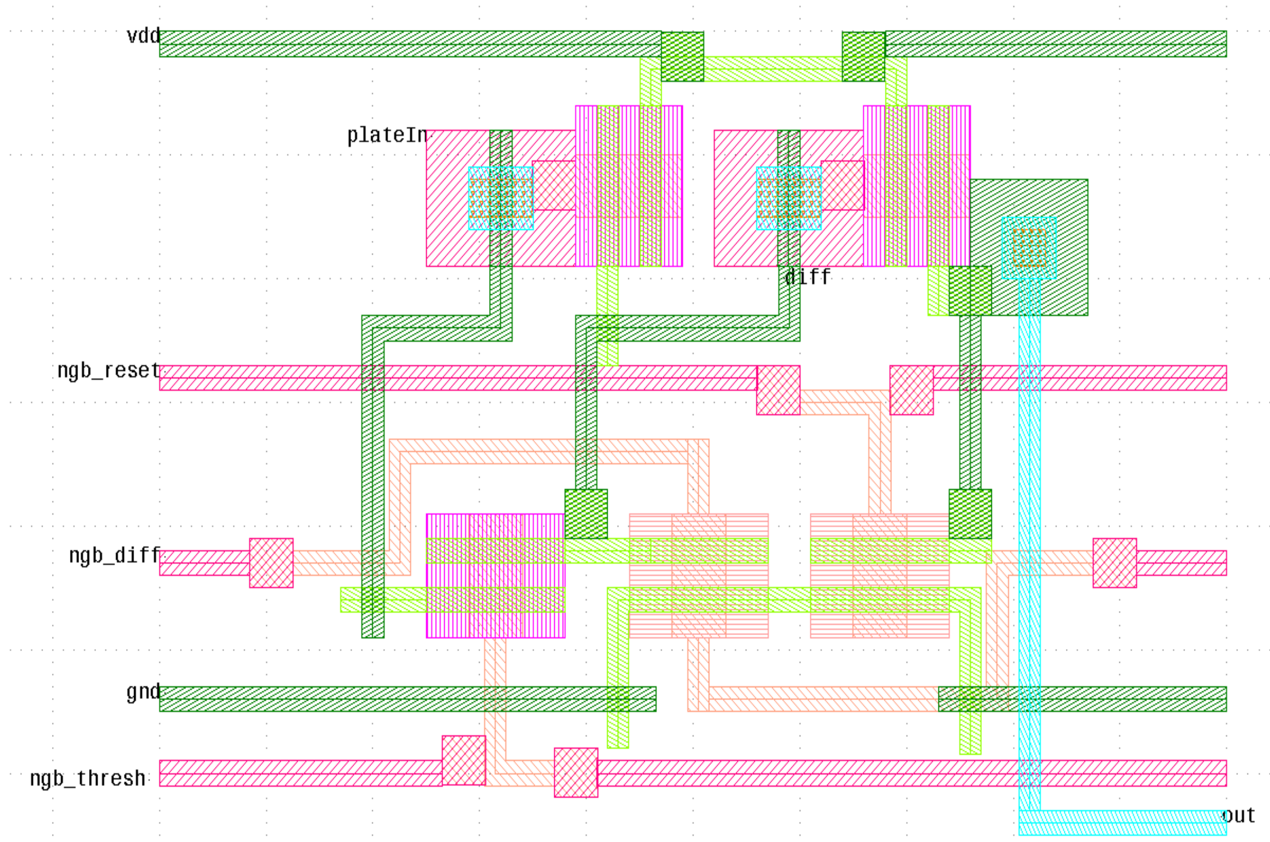




logic and pulse extender for a spike transducer

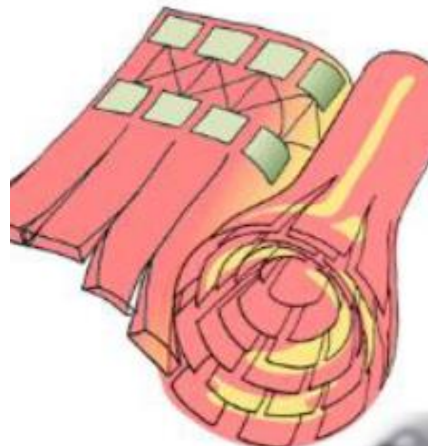
neuron



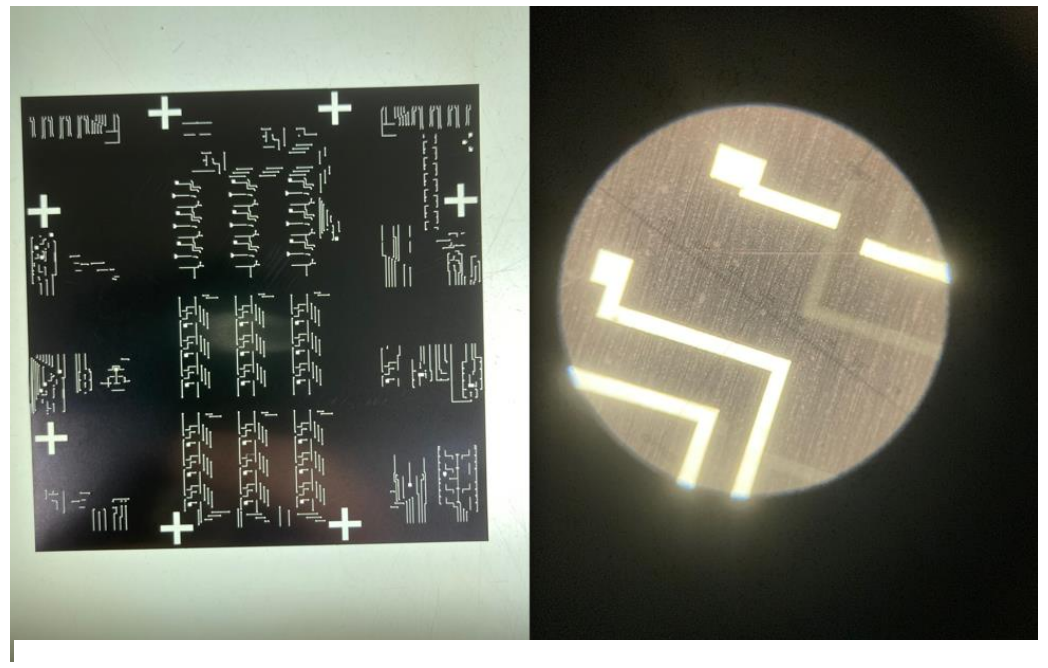


single-ended sample reset, intended as a receiver in capacitively coupled axon

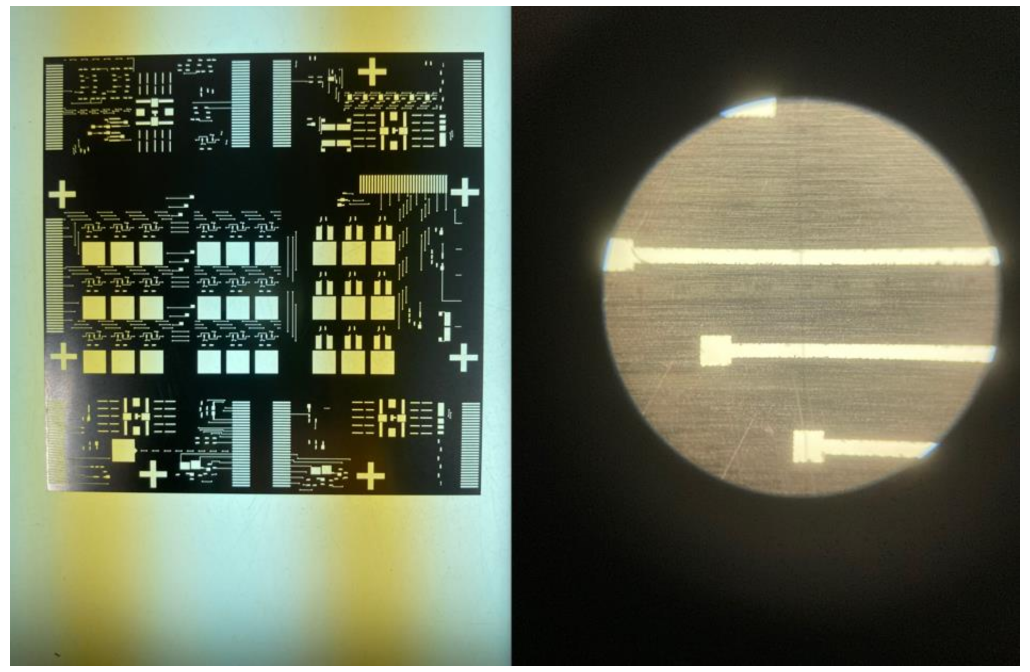
The central area has 2 arrays of 3 x 3 axon receiver circuits and a 3 x 3 array of digital drivers. Each of these senders and receivers are attached to a plate, and this layout can be used to experiment with capacitive coupling in the 3rd dimension.

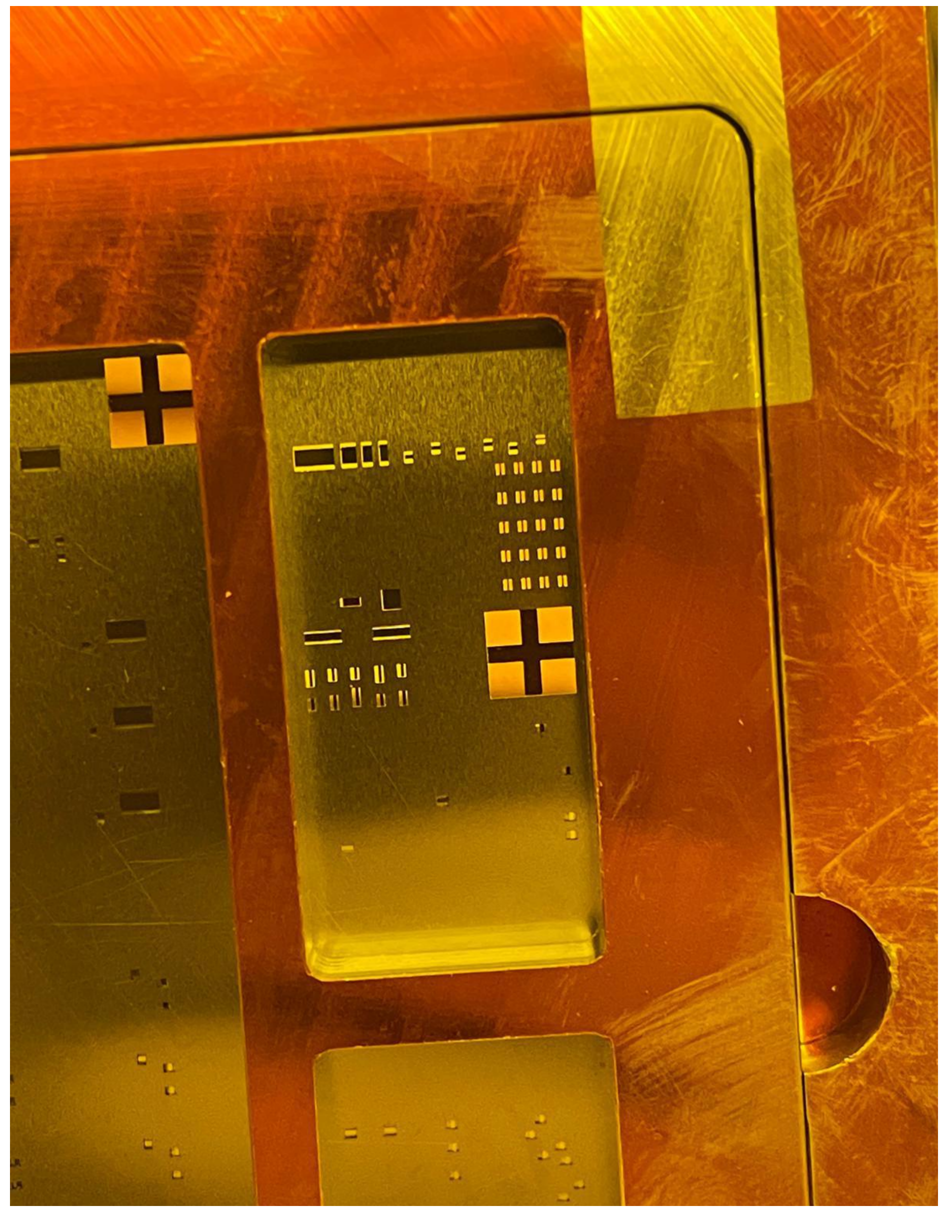


Next-Gen Neuromorphic Circuits: Fabrication of Flexible Full Organic Systems with CMOS Technology

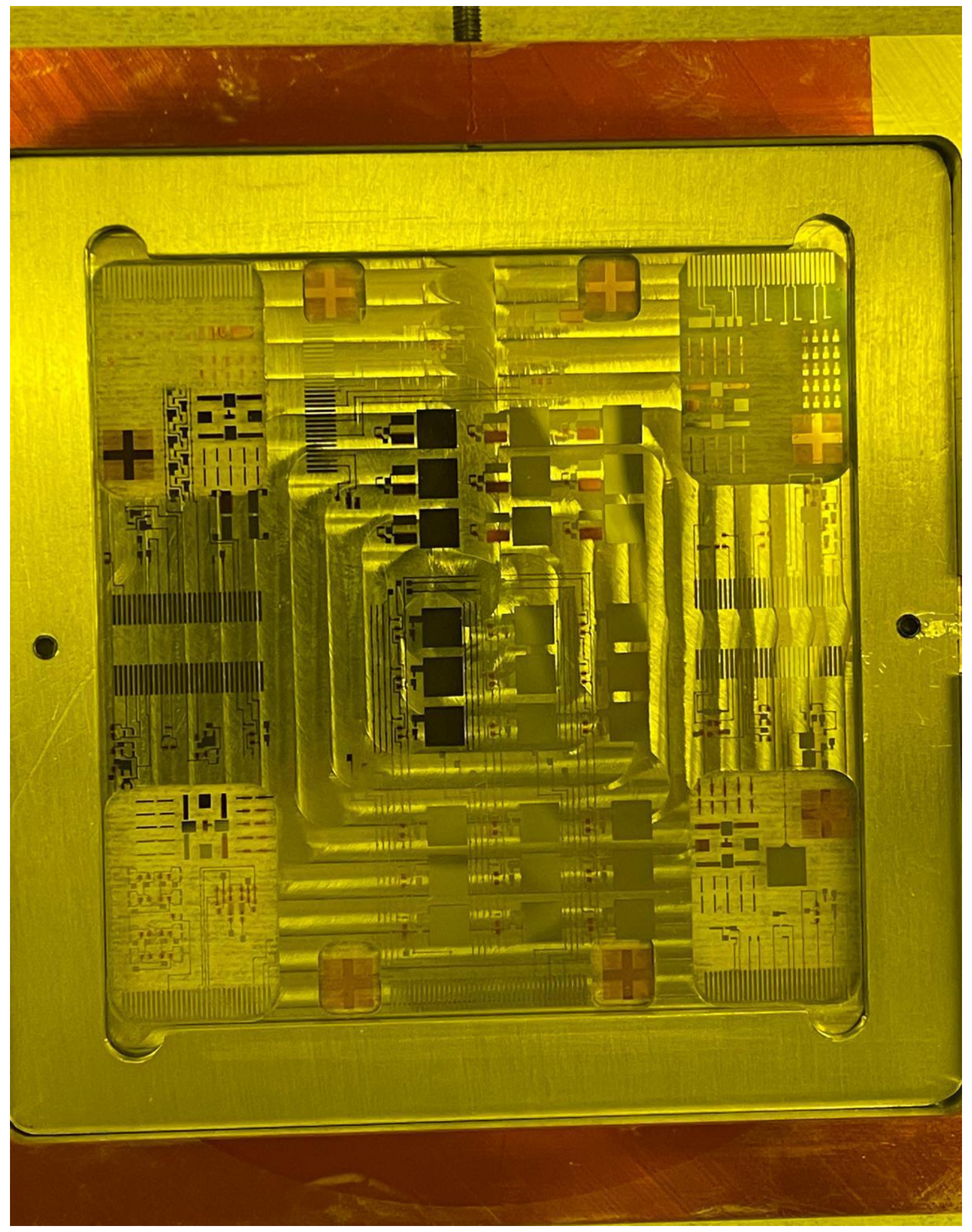


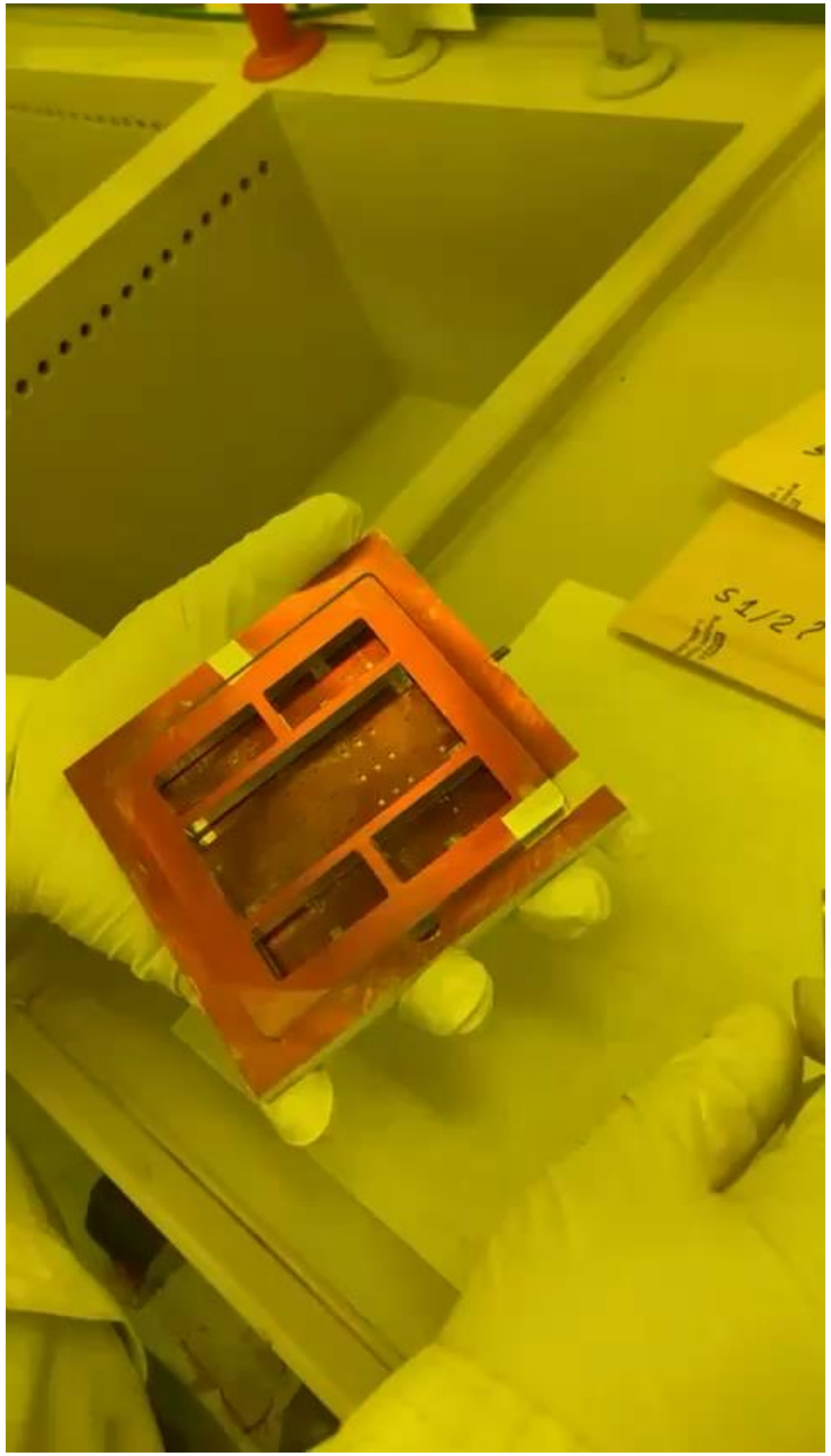
Shadow masks

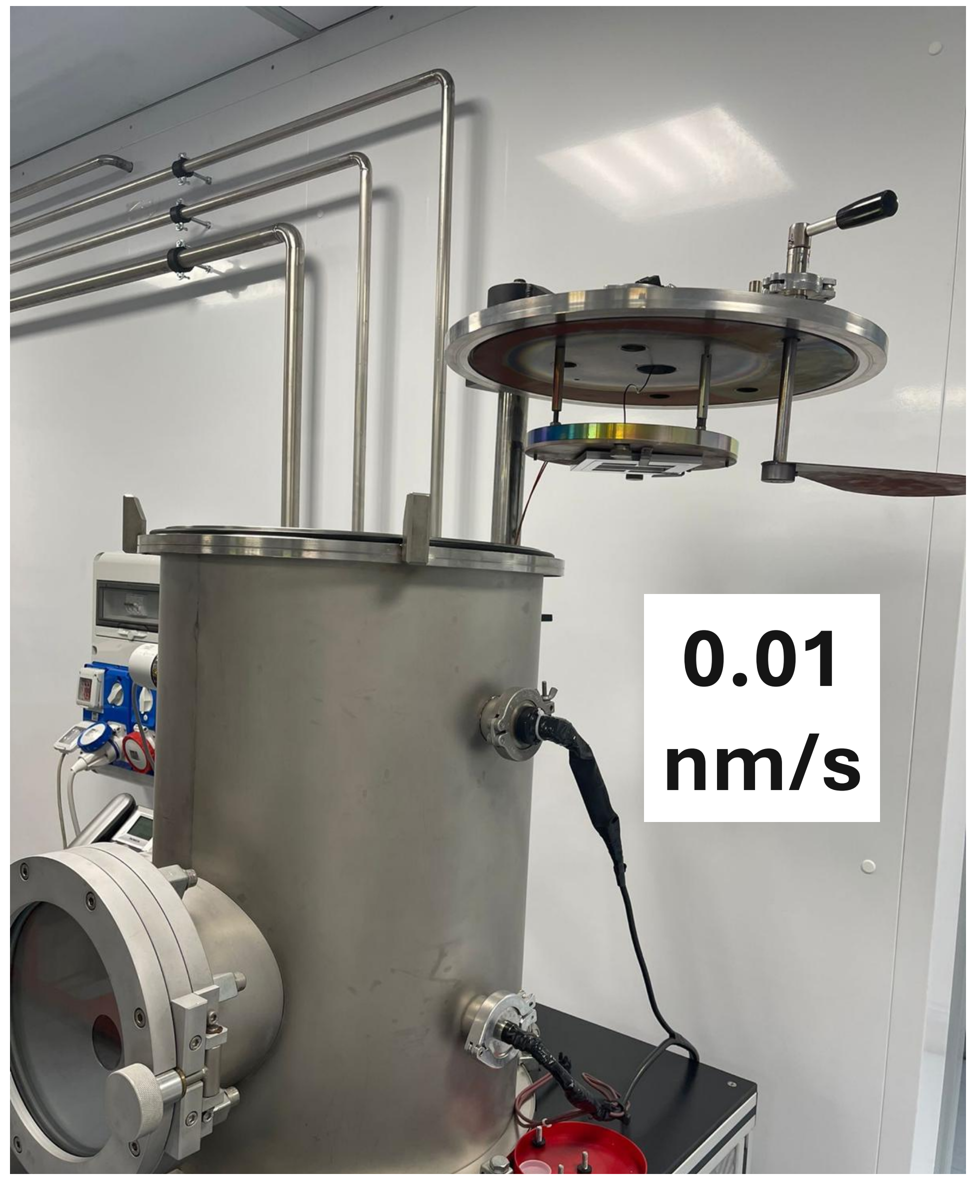




Alignment system

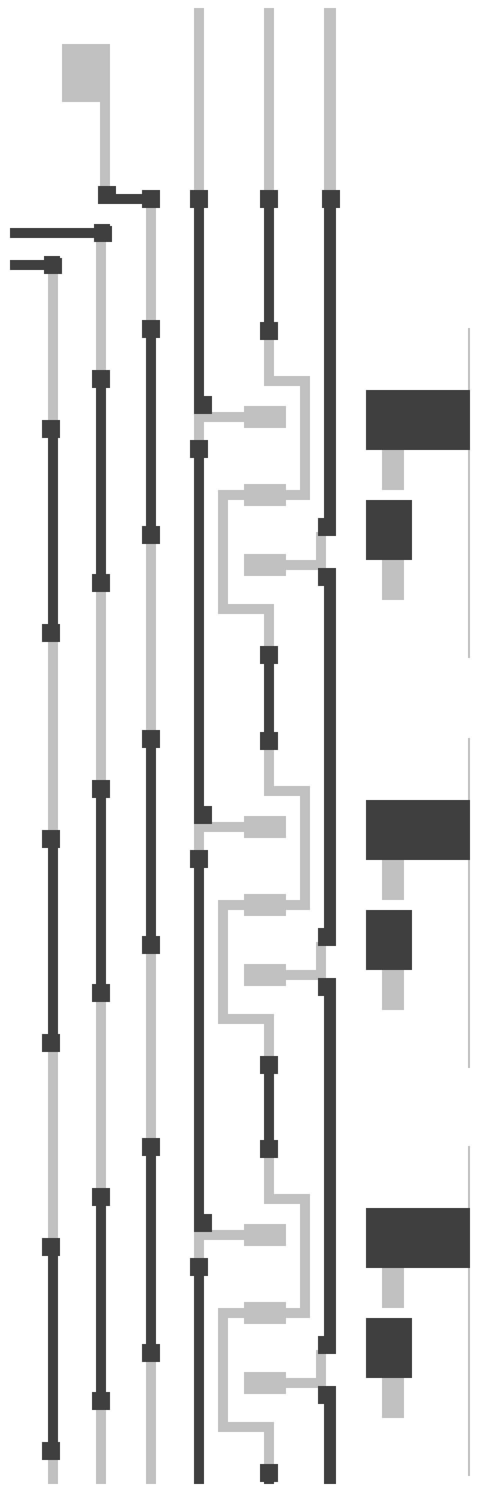




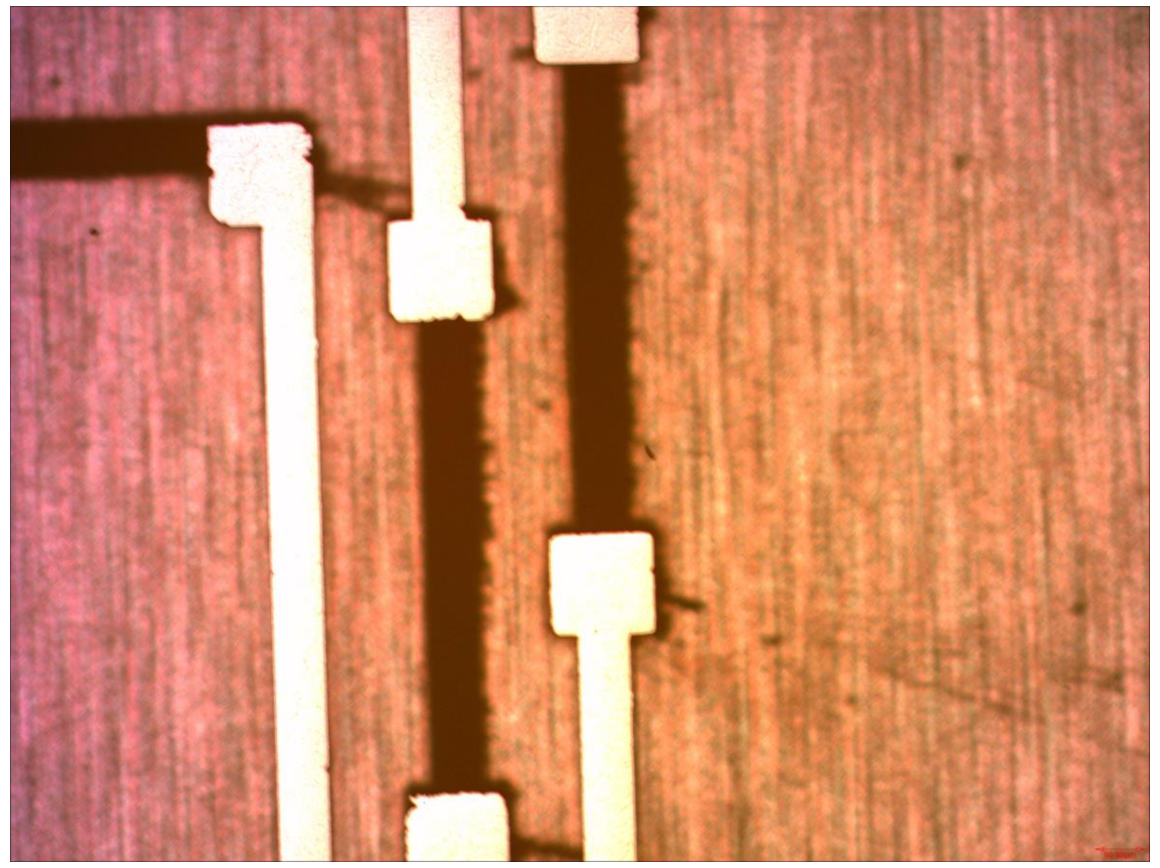


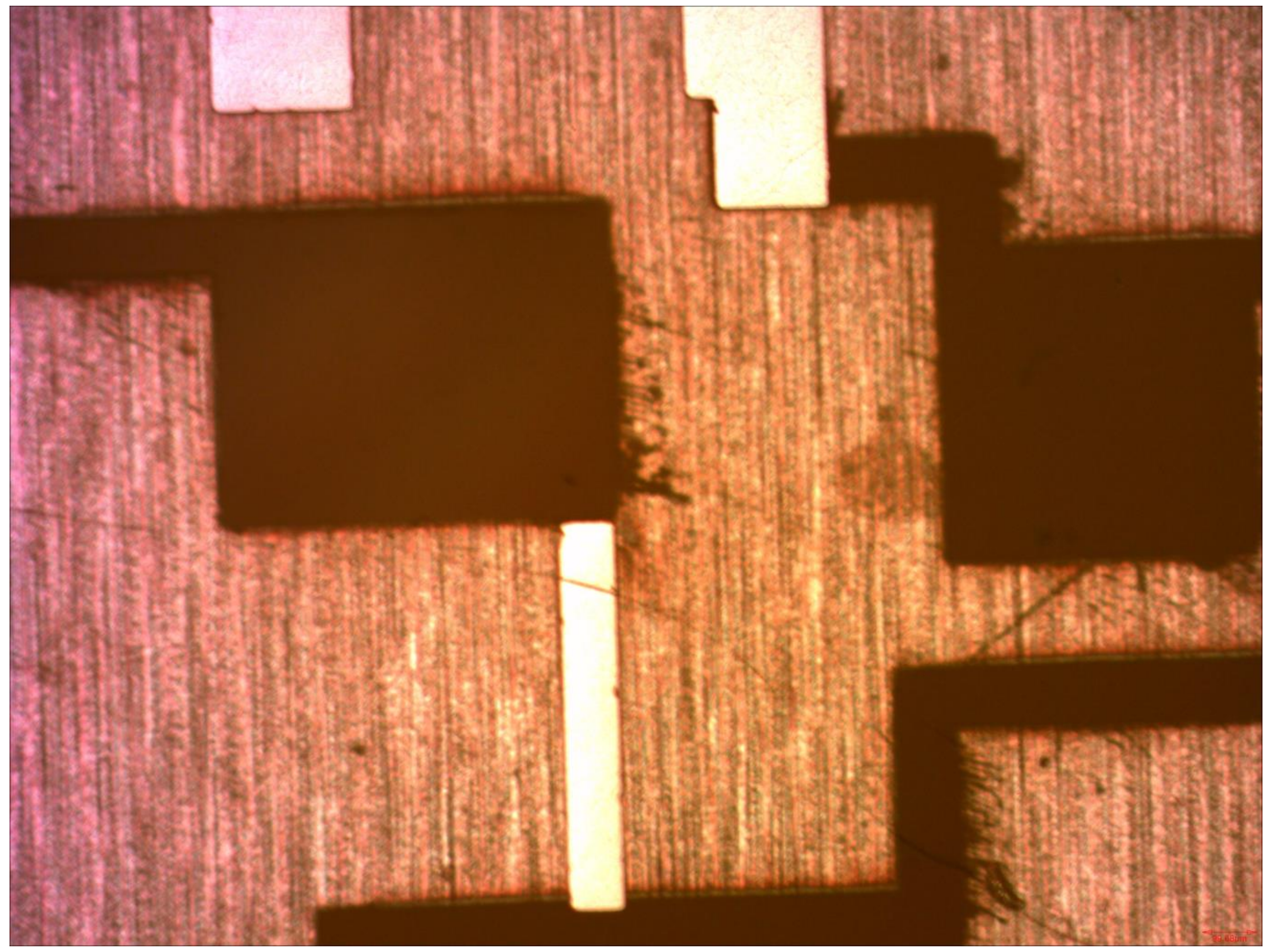
HV evaporation of OSC using a Radak thermal source

Next-Gen Neuromorphic Circuits: Fabrication of Flexible Full Organic Systems with CMOS Technology

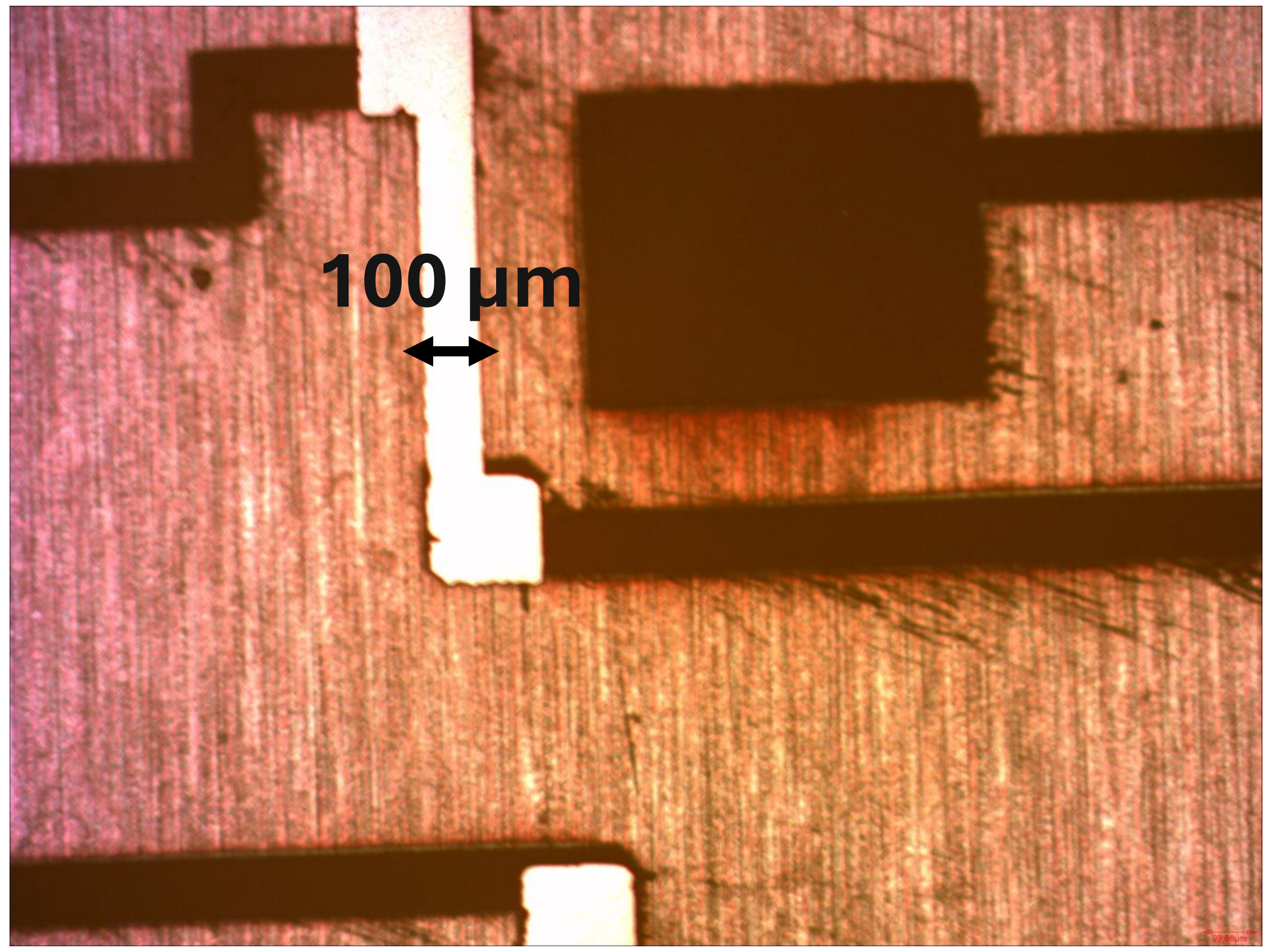


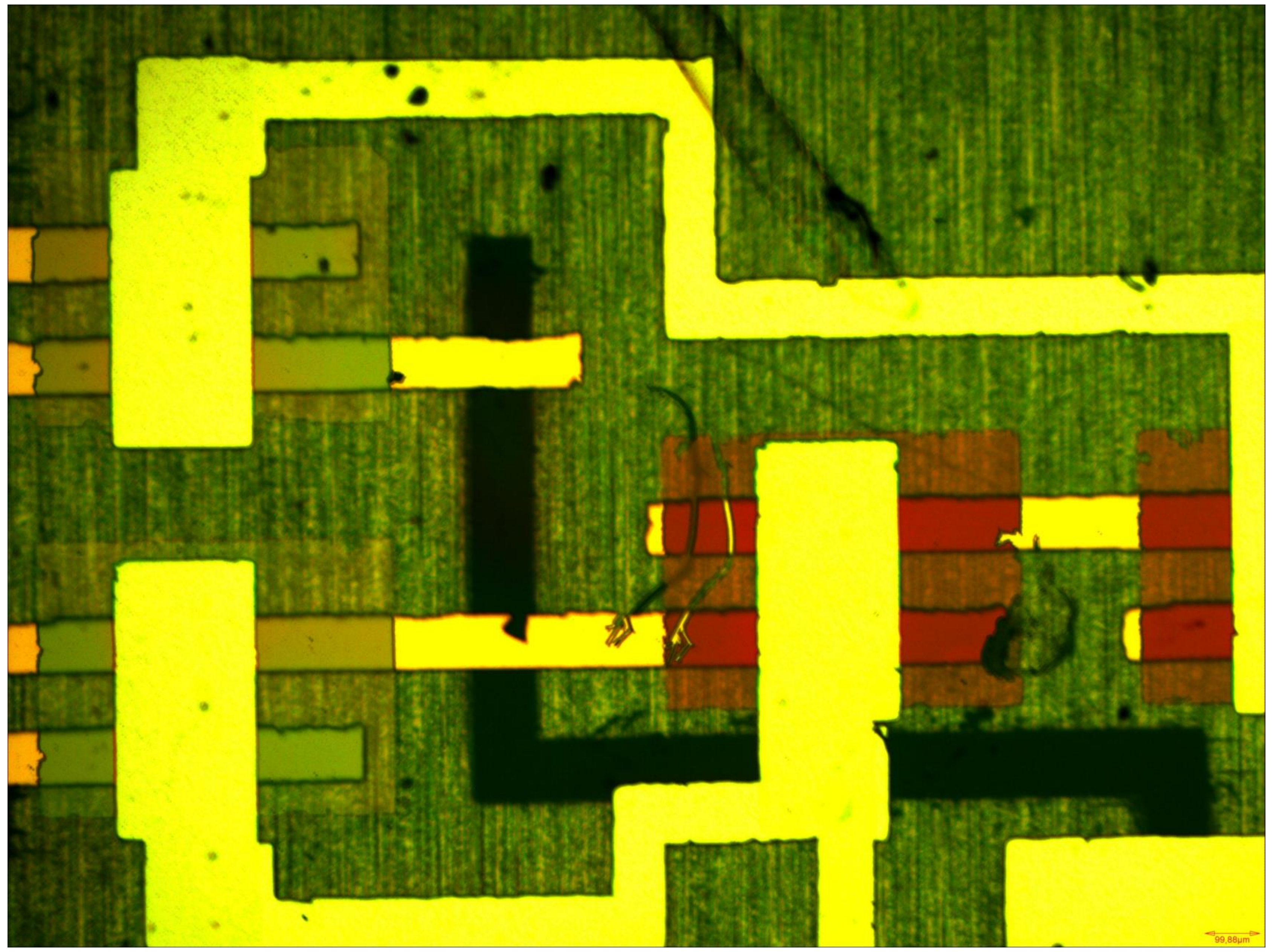
In some cases the layers were splitter on 2 mask

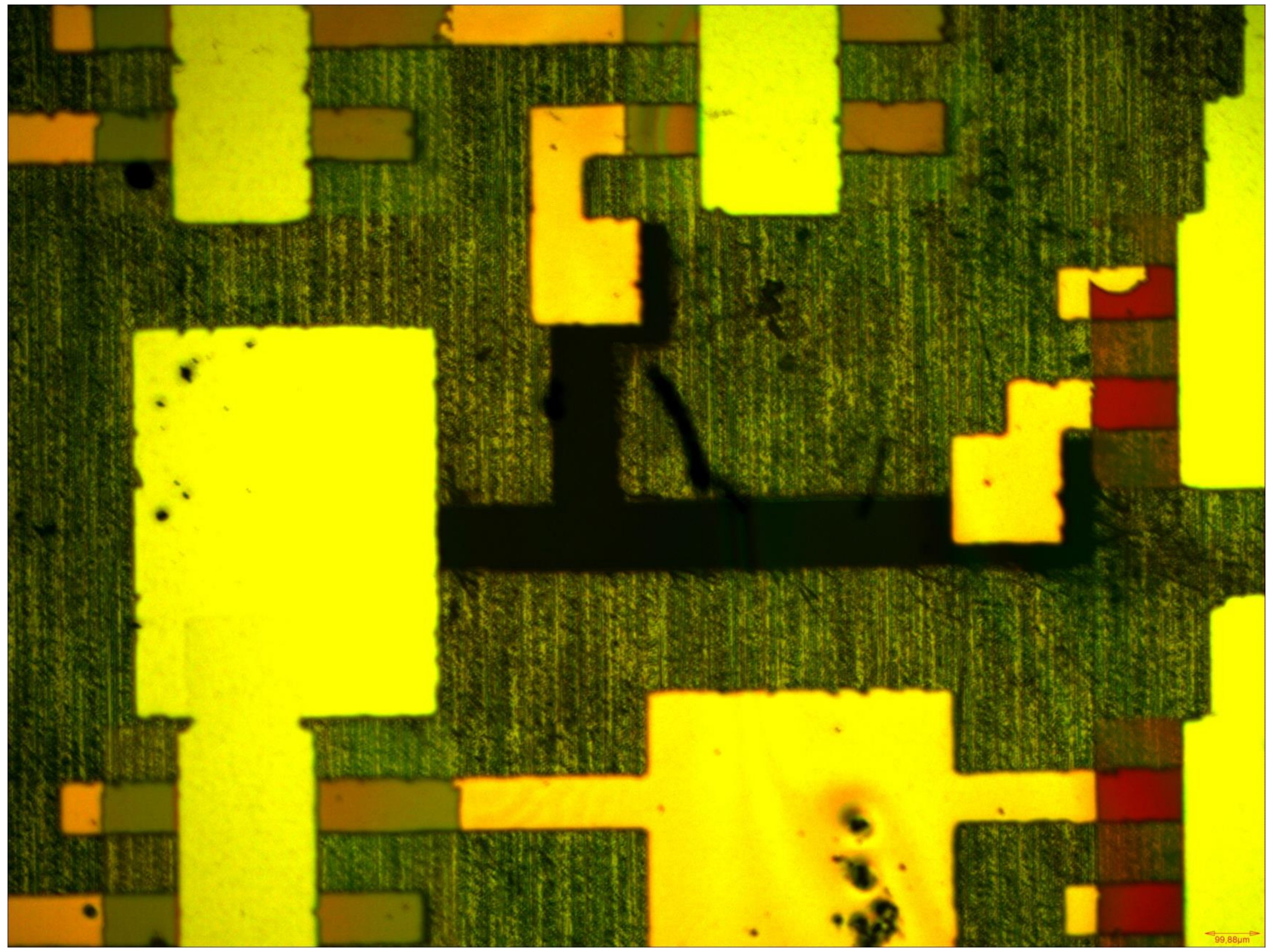




Very good alignment several levels!







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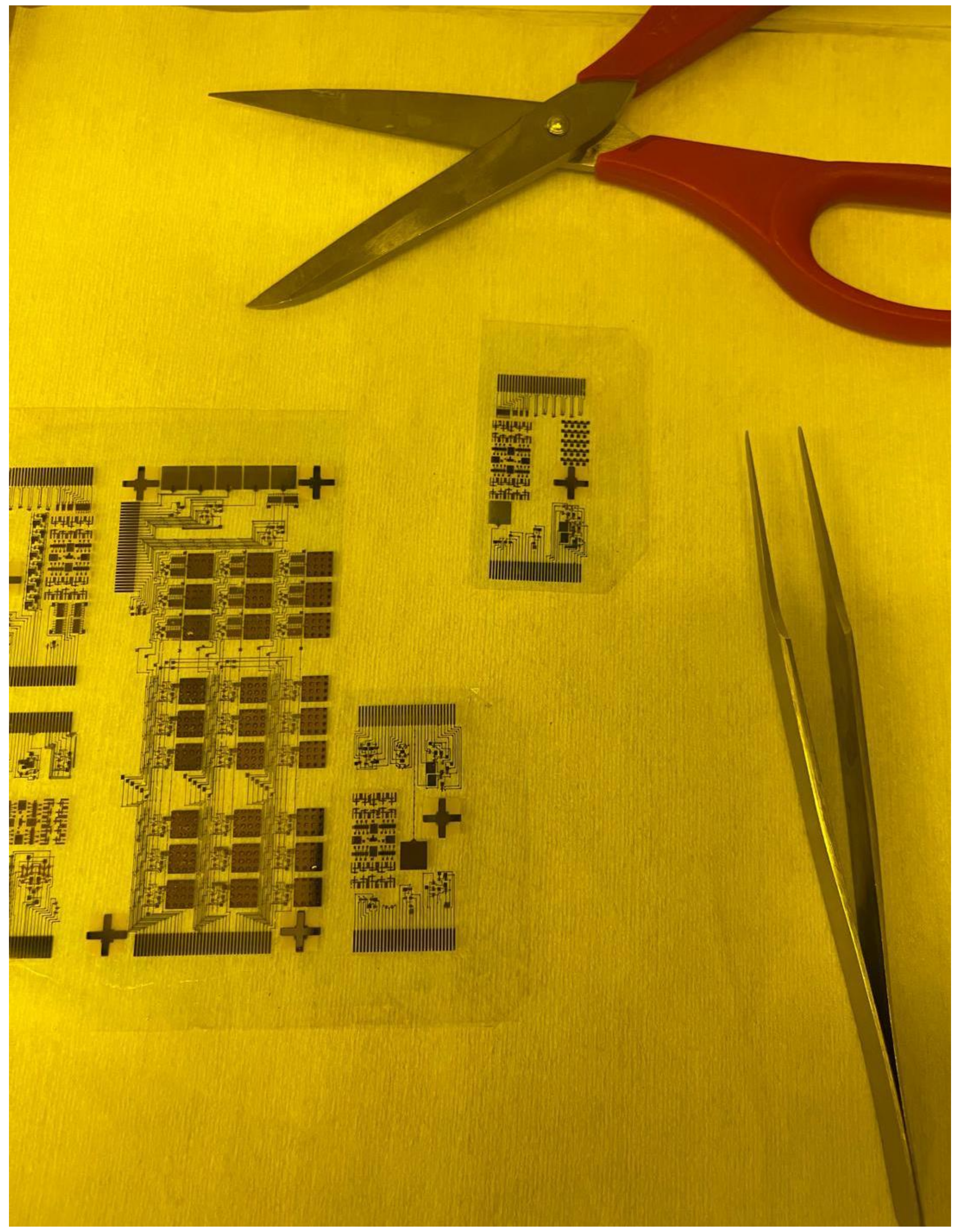
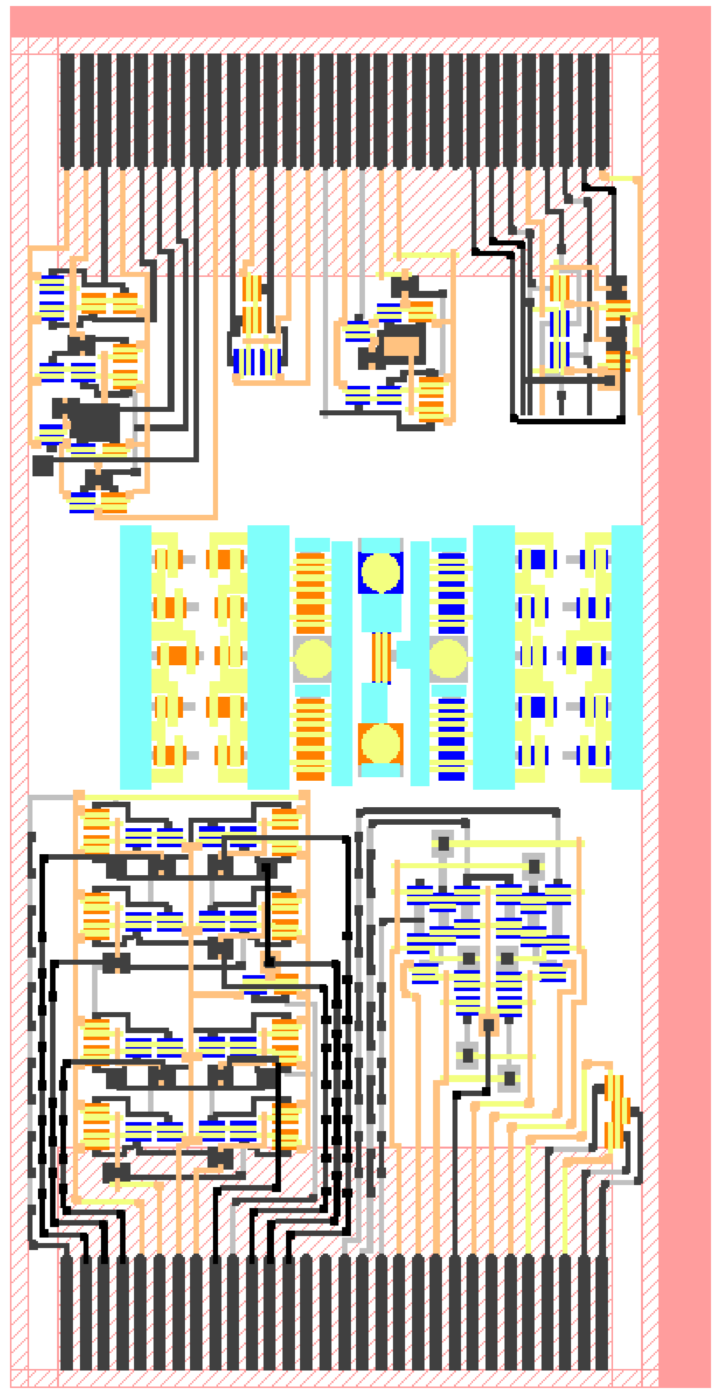
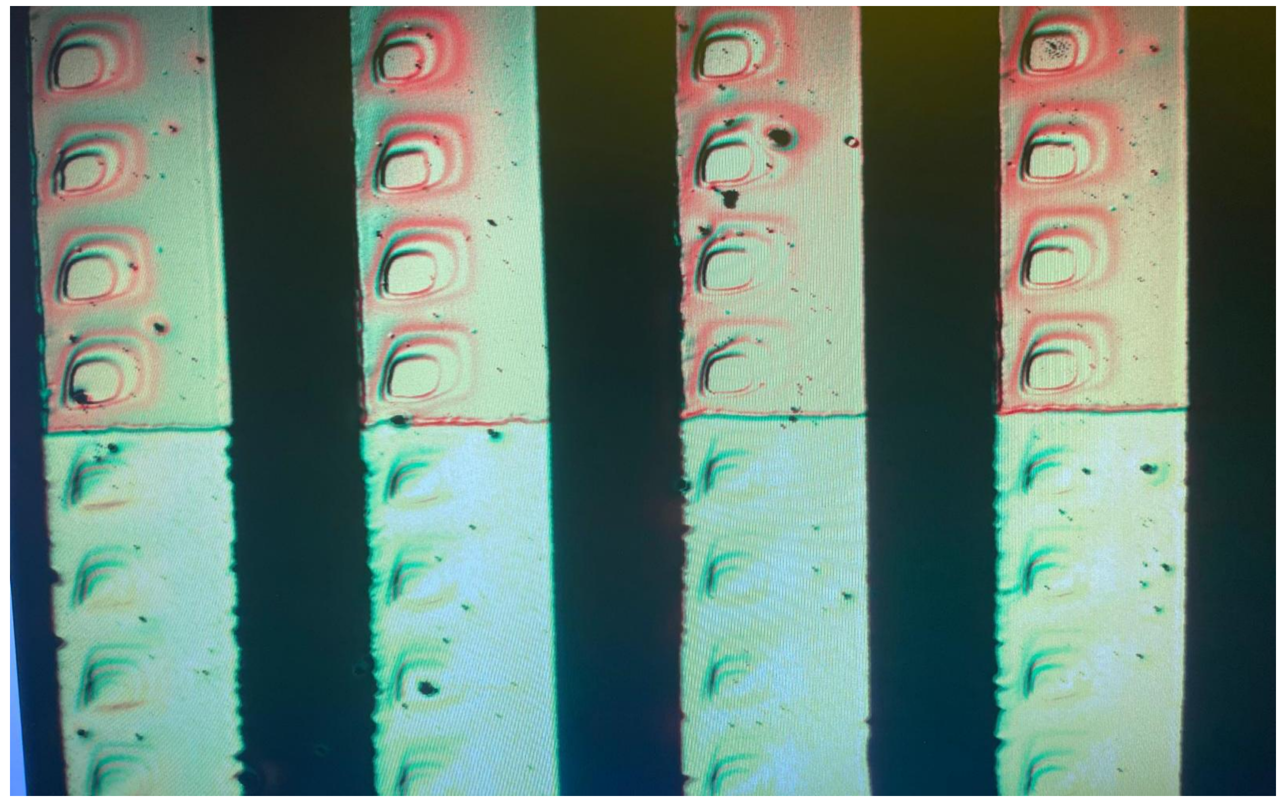
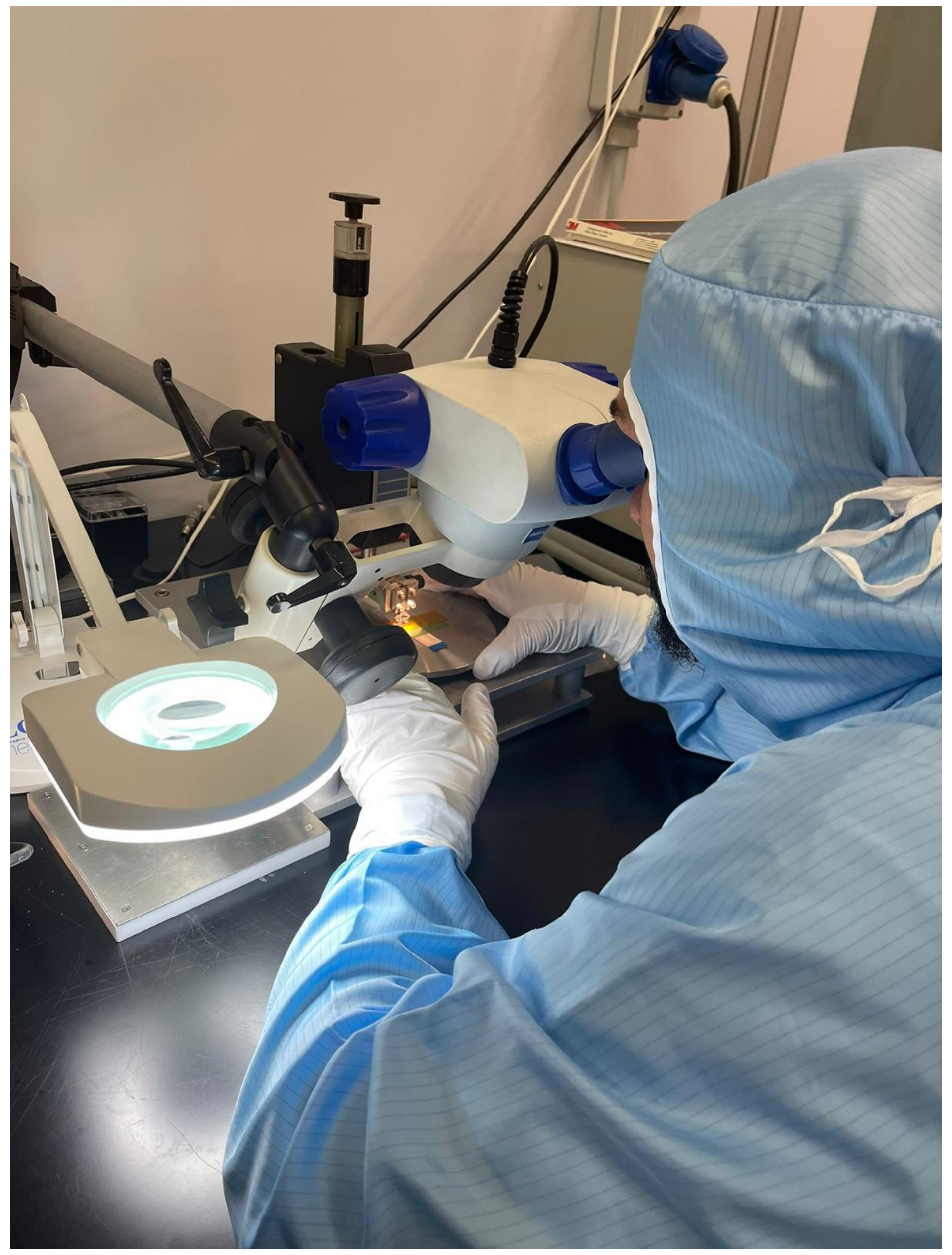
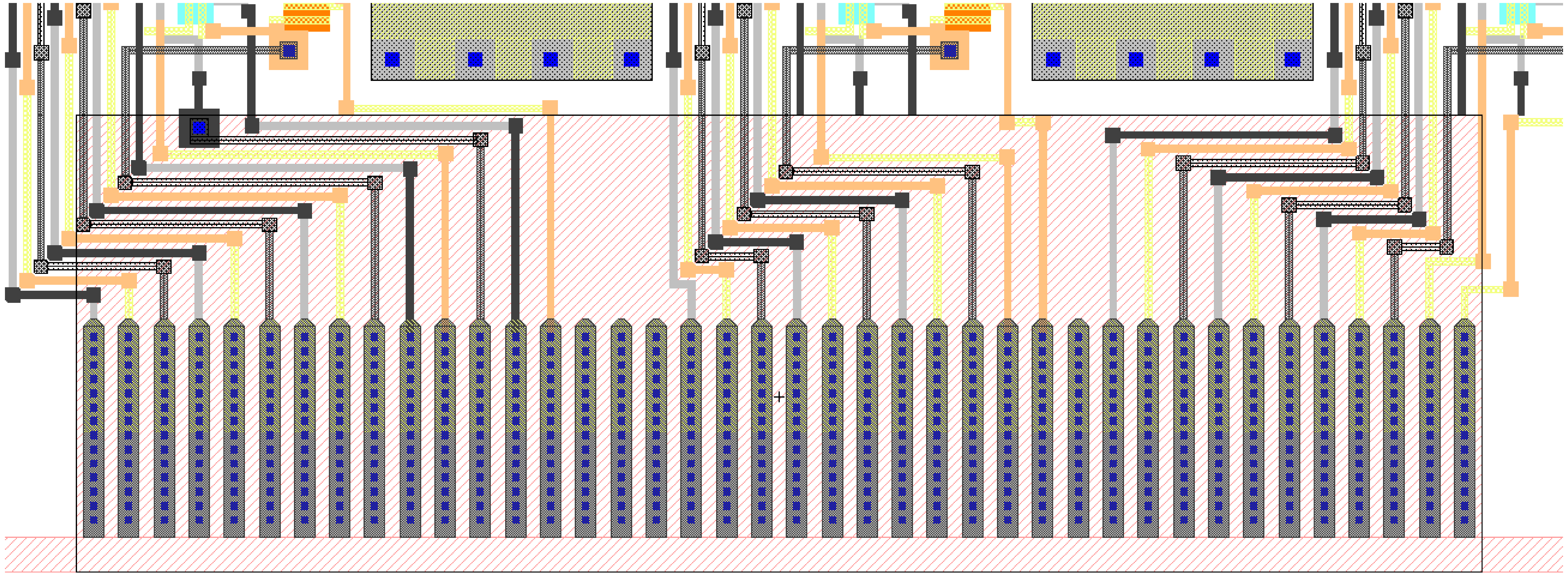


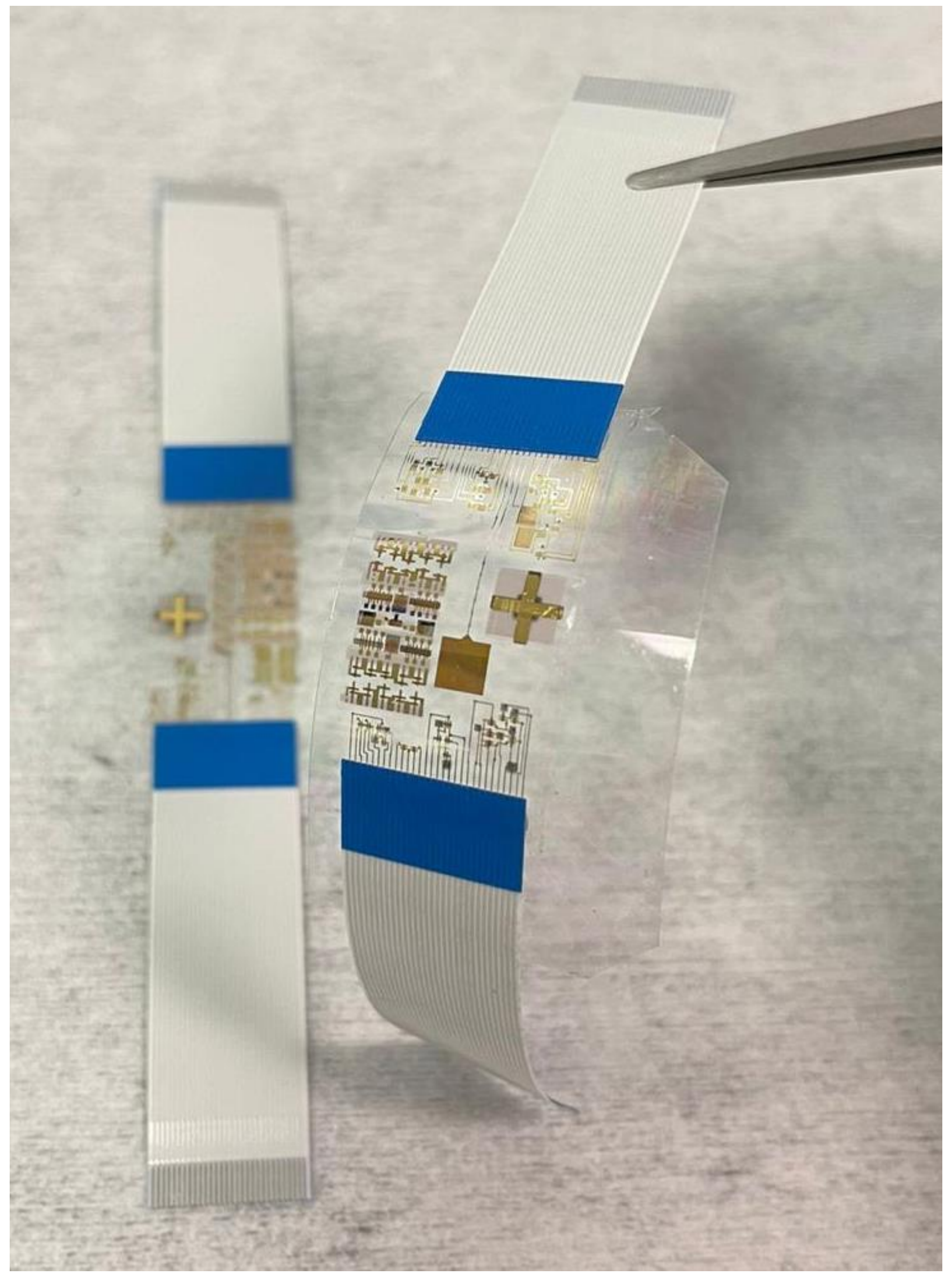




Final **connections** by Low Temperature Anisotropic Conductive Film (**ACF**)







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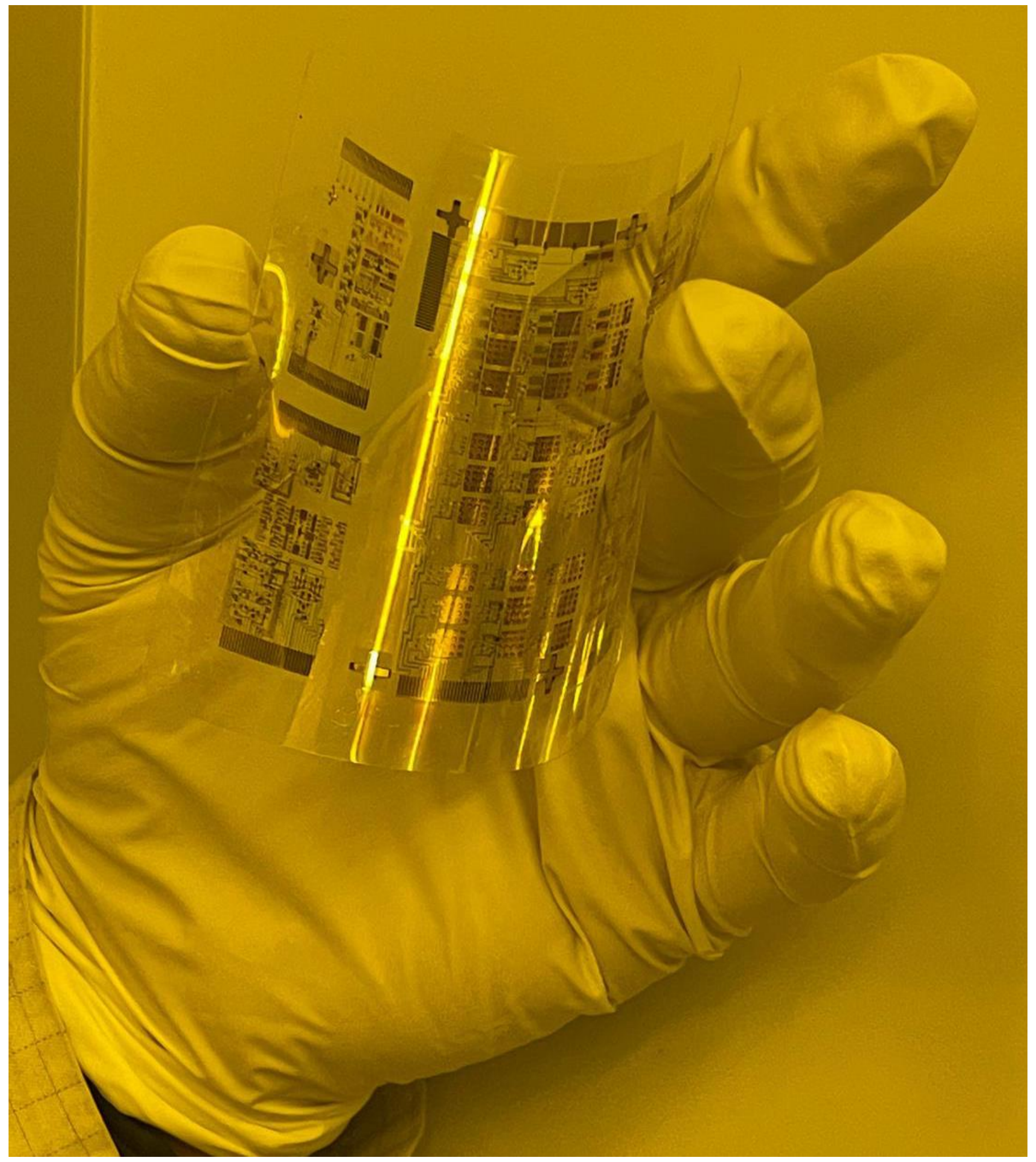
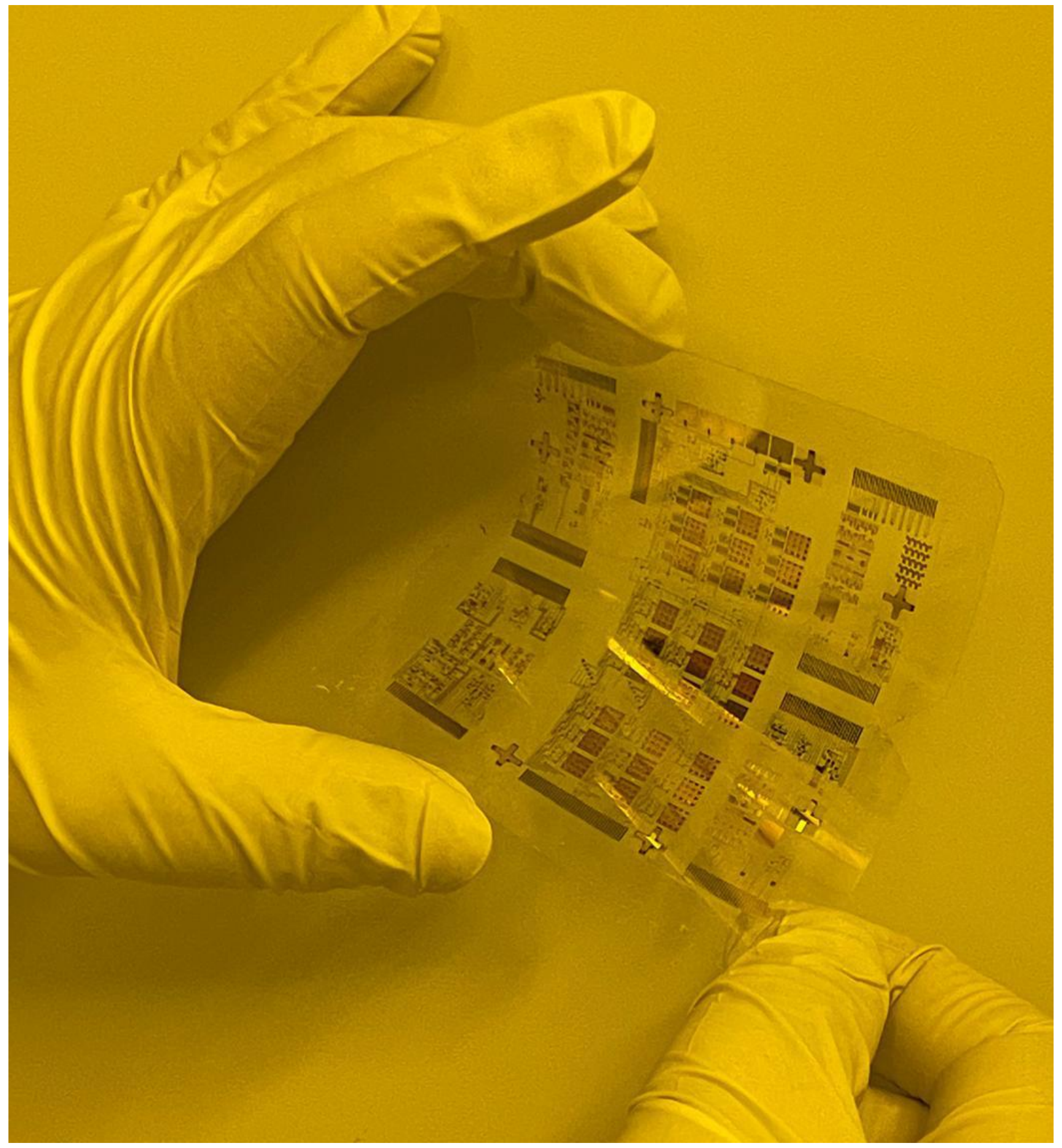
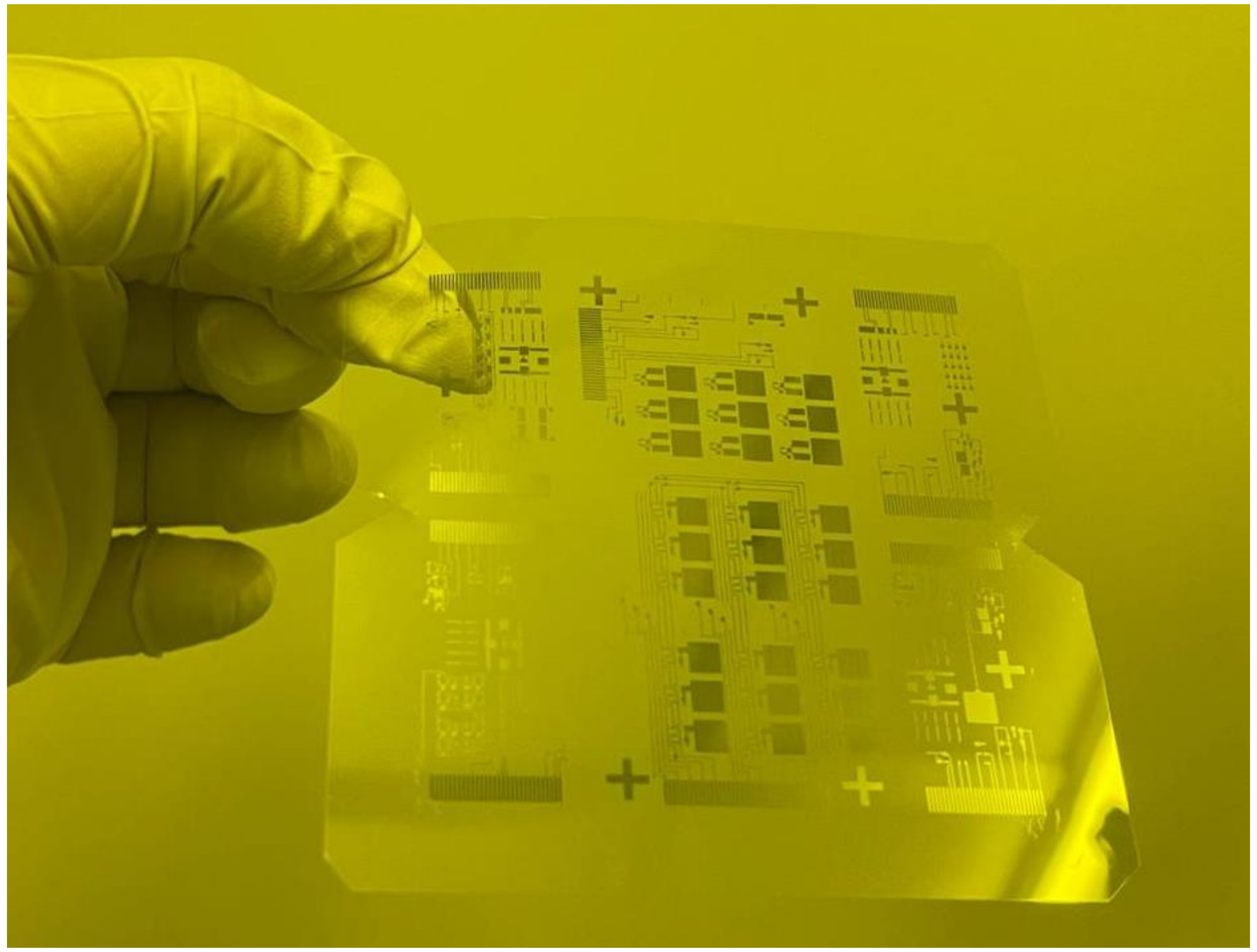


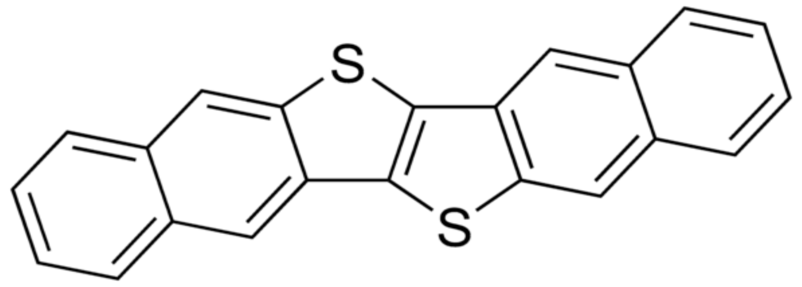




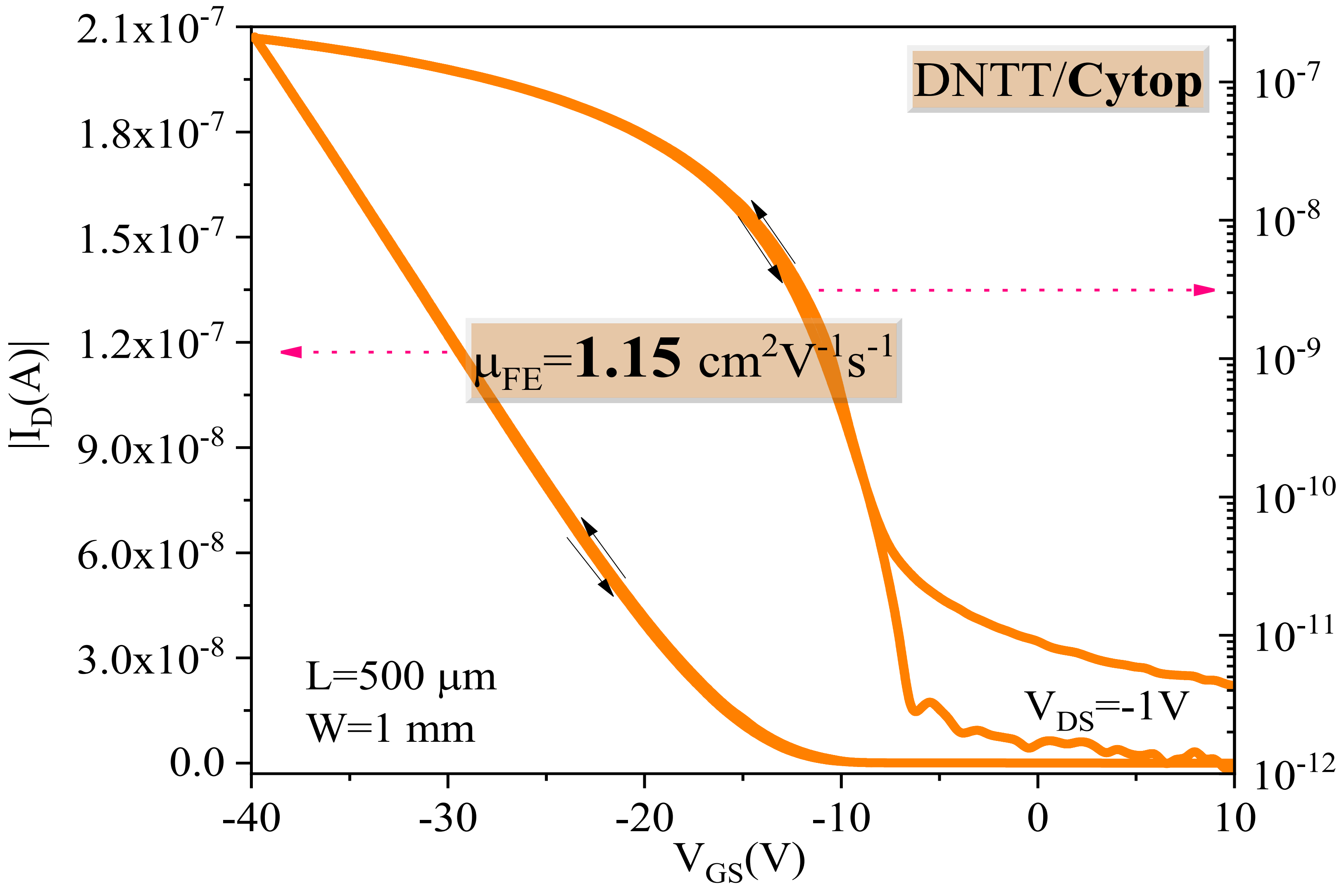
- *No Solvents*
- *No acid and etching solutions*
- *Room Temperature*
- *Flexible and transparent green substrate*
- *Resolution* 50 μm

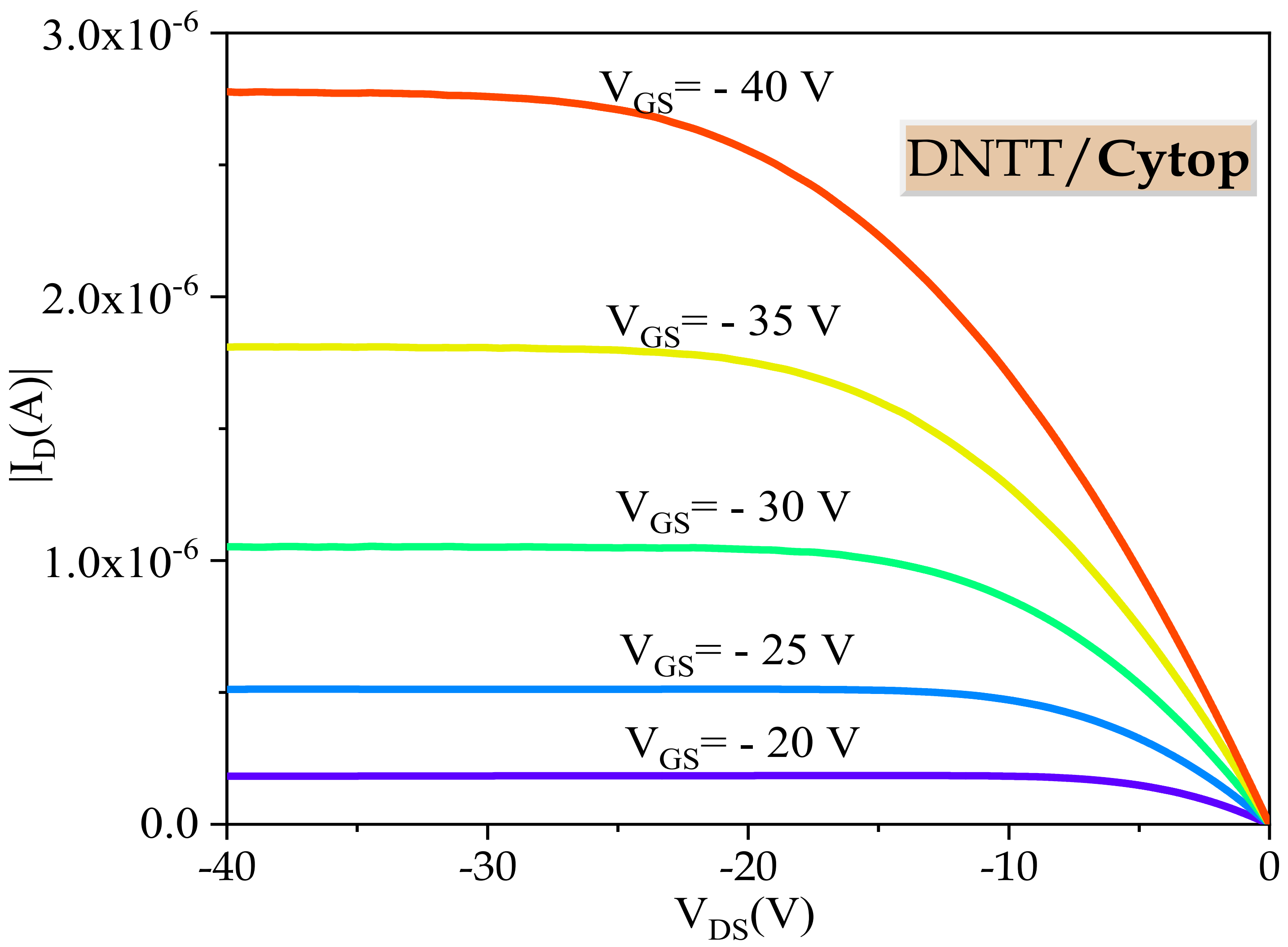
OTFTs CMOS technology

p-type organic semiconductor OTFT DNTT

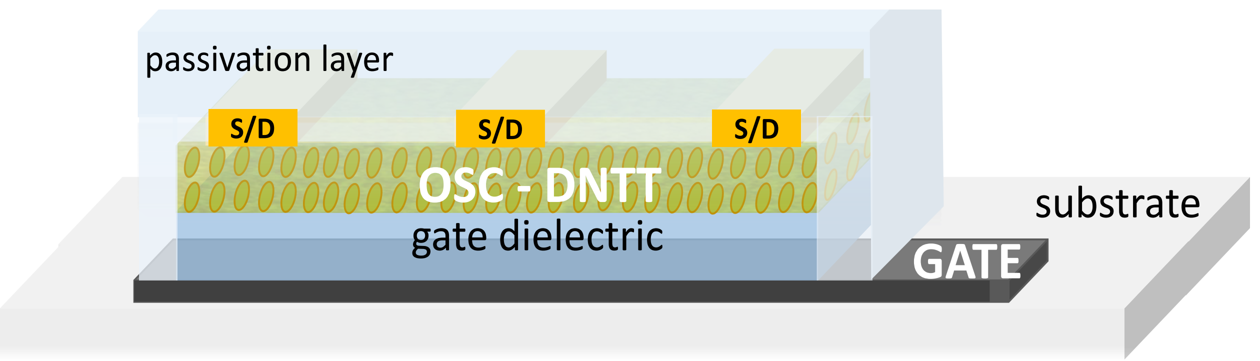


DNTT

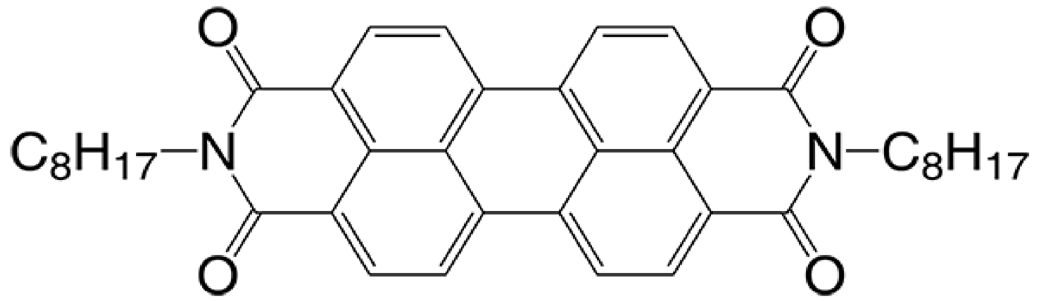




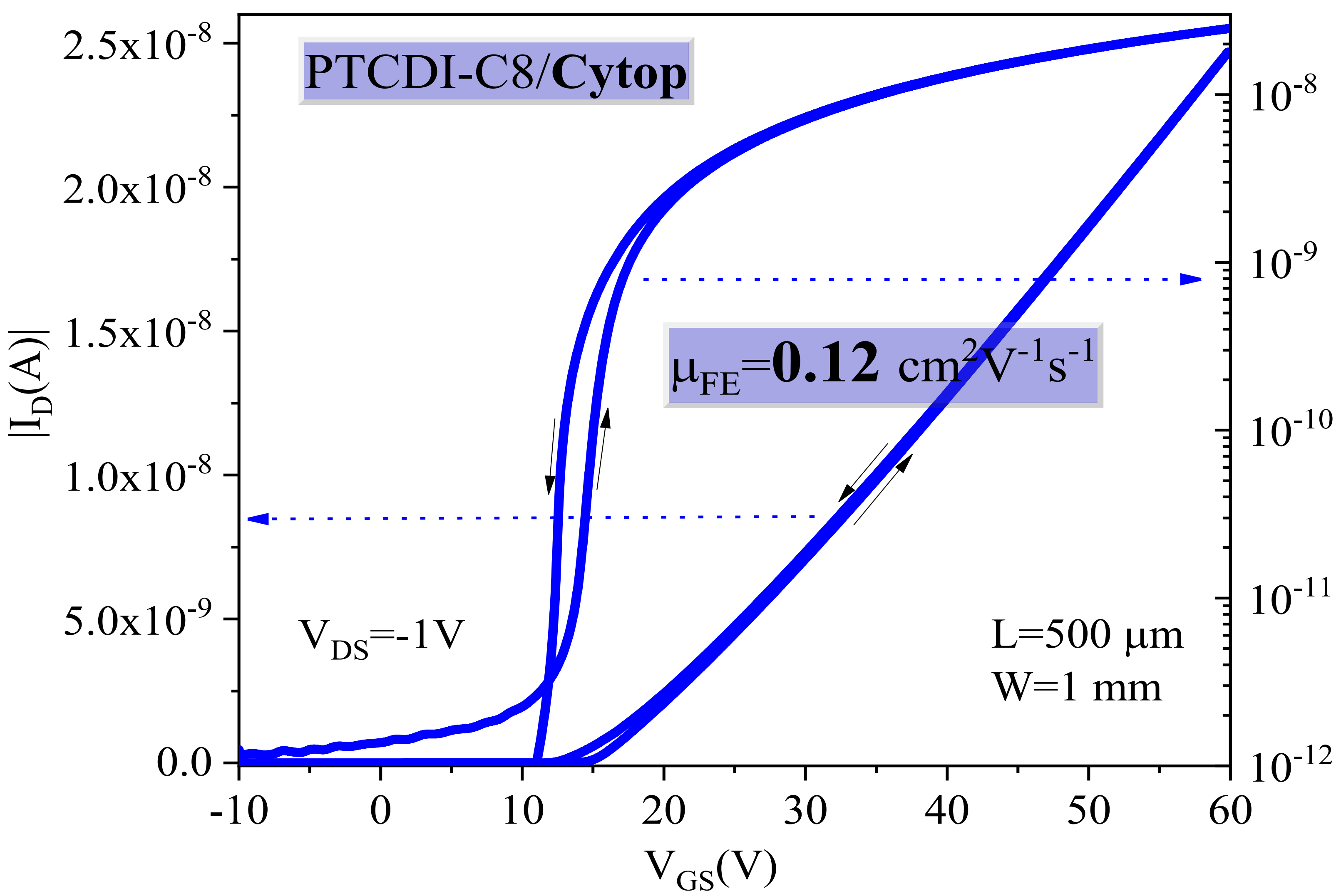
TCBG OTFT structure

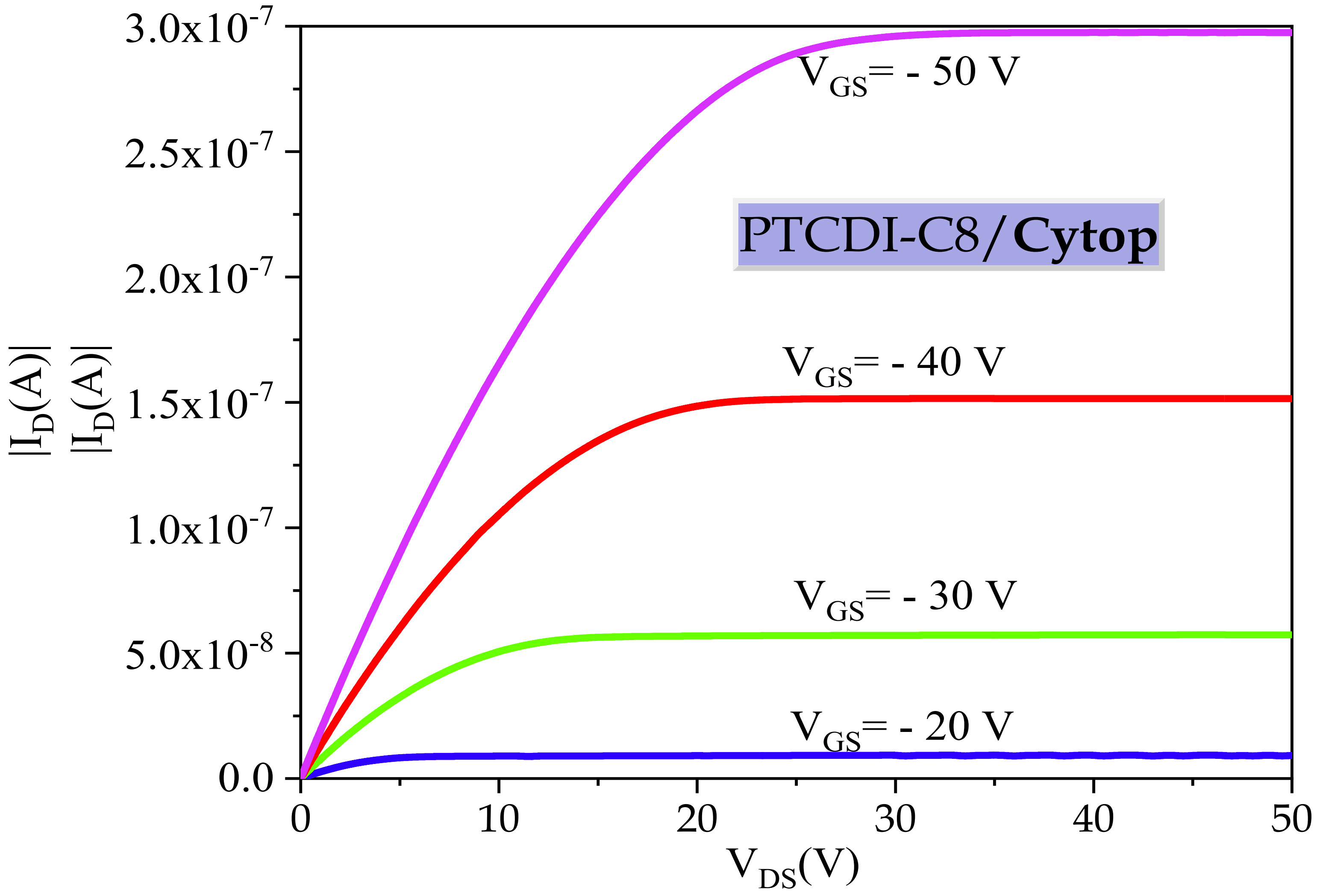


n-type organic semiconductor OTFT PTCDI-C8

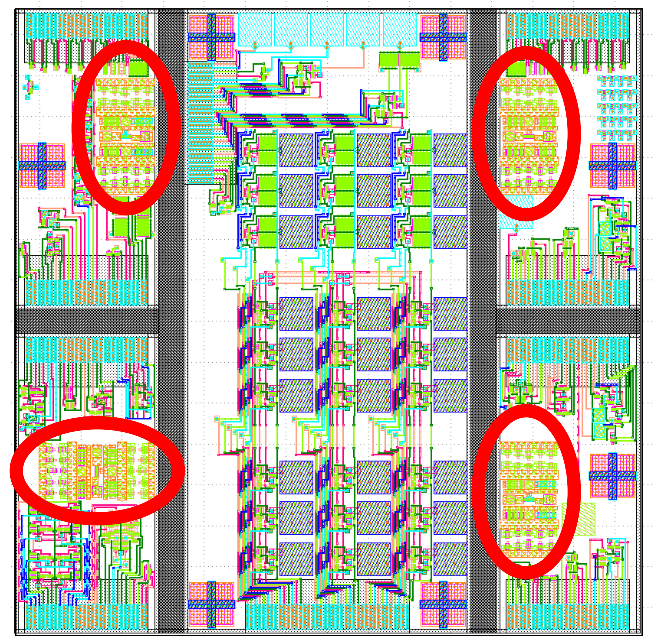


PTCDI-C8



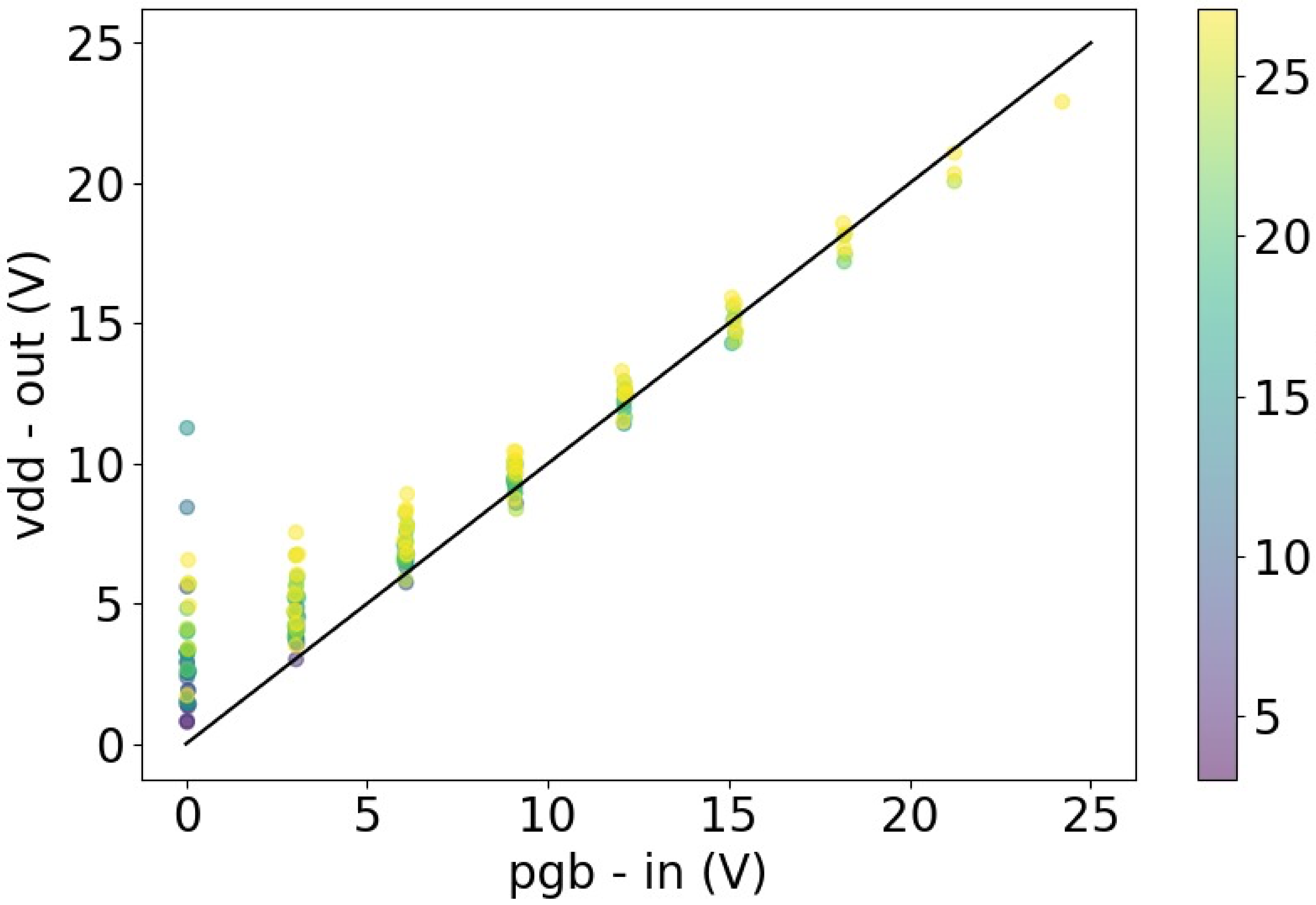


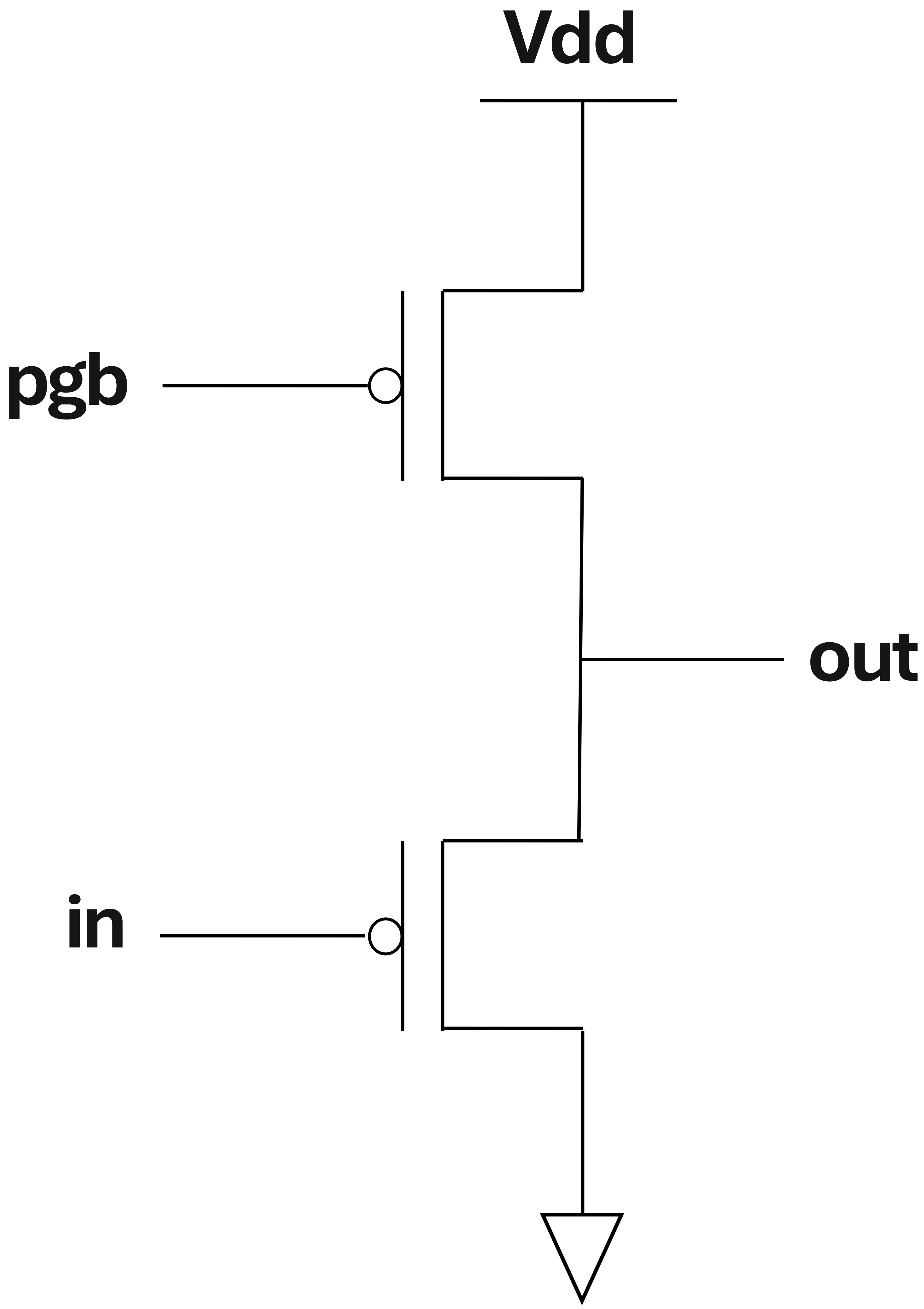
OTFTs test structures



Preliminary Results

Source follower (p-type OSC)





Next steps...

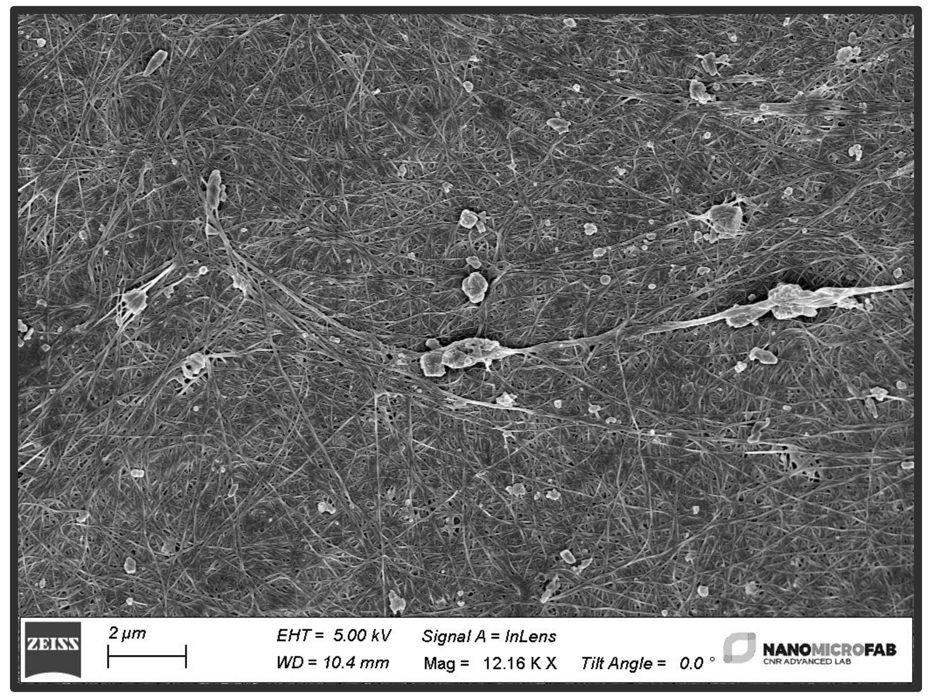
in the future we plan to further integrate the properties of organic electronics into neuromorphic circuits: how?

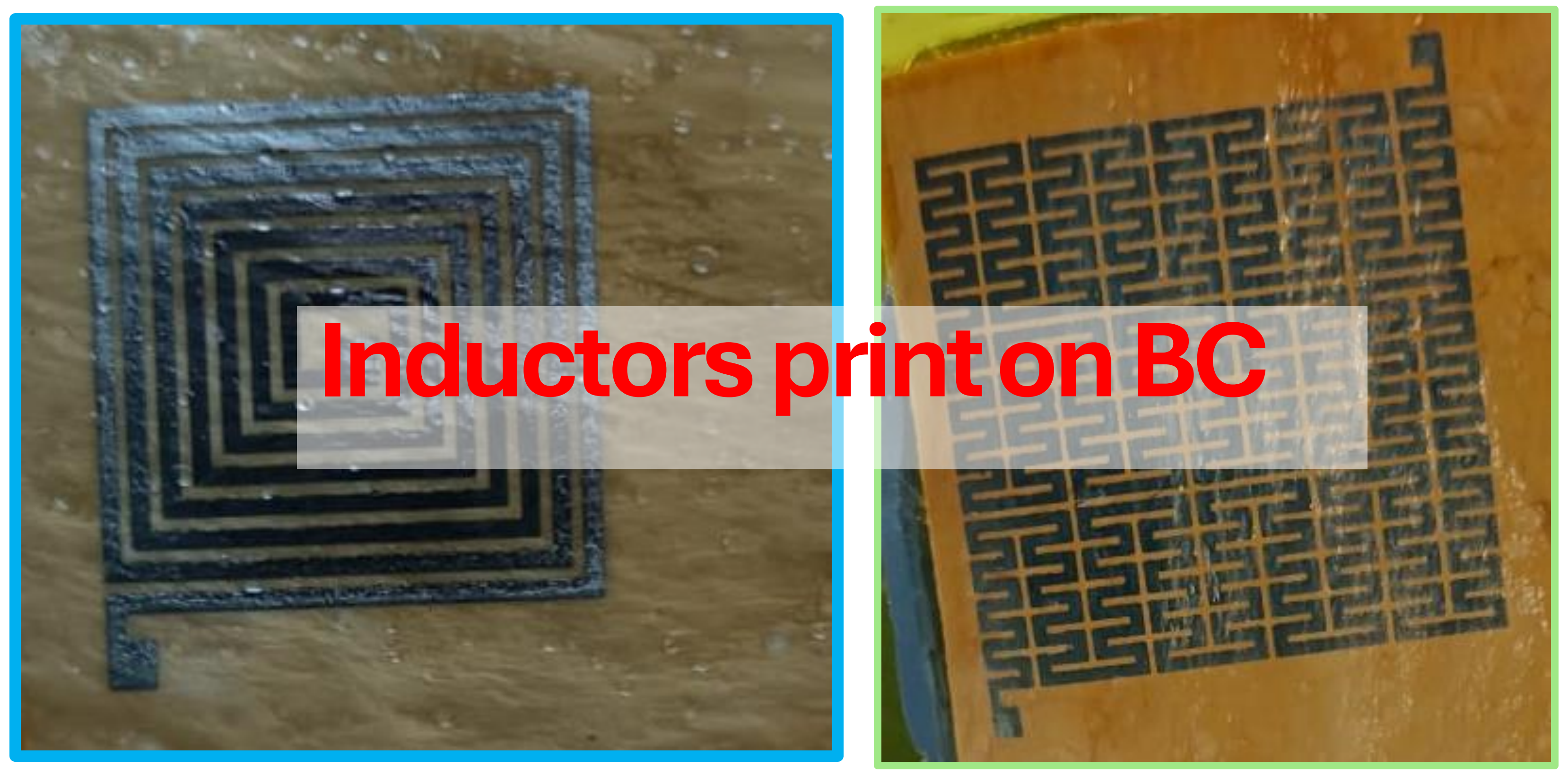
first approach: **green, biodegradable substrates**

Bacterial cellulose (BC)

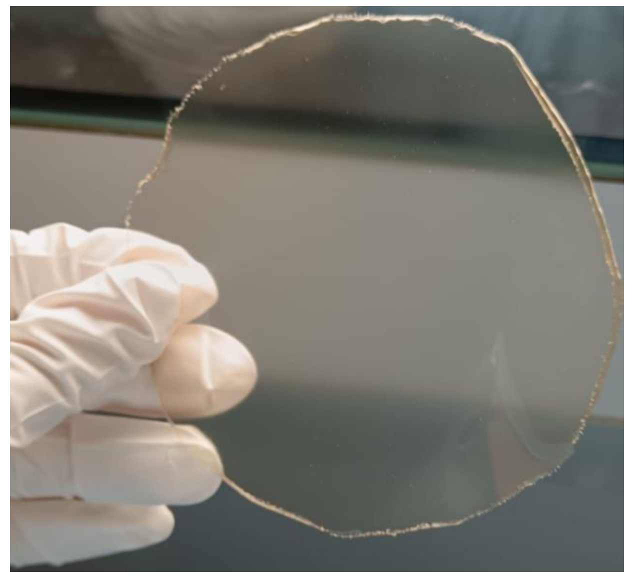
Natural biopolymer produced by gram-negative bacteria. Compared to plant cellulose, BC is purer (absence of lignin and other plant components) and has a unique fibrous structure, providing better mechanical and physical properties.

- Biocompatibility
- Biodegradability
- Flexibility
- Higher surface roughness





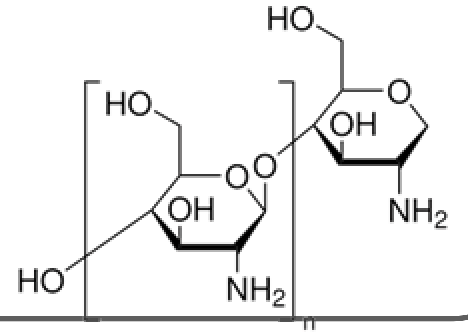
Chitosan Based substrate

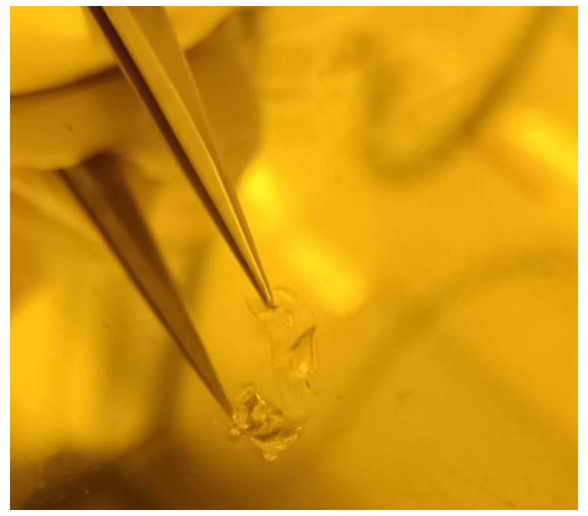


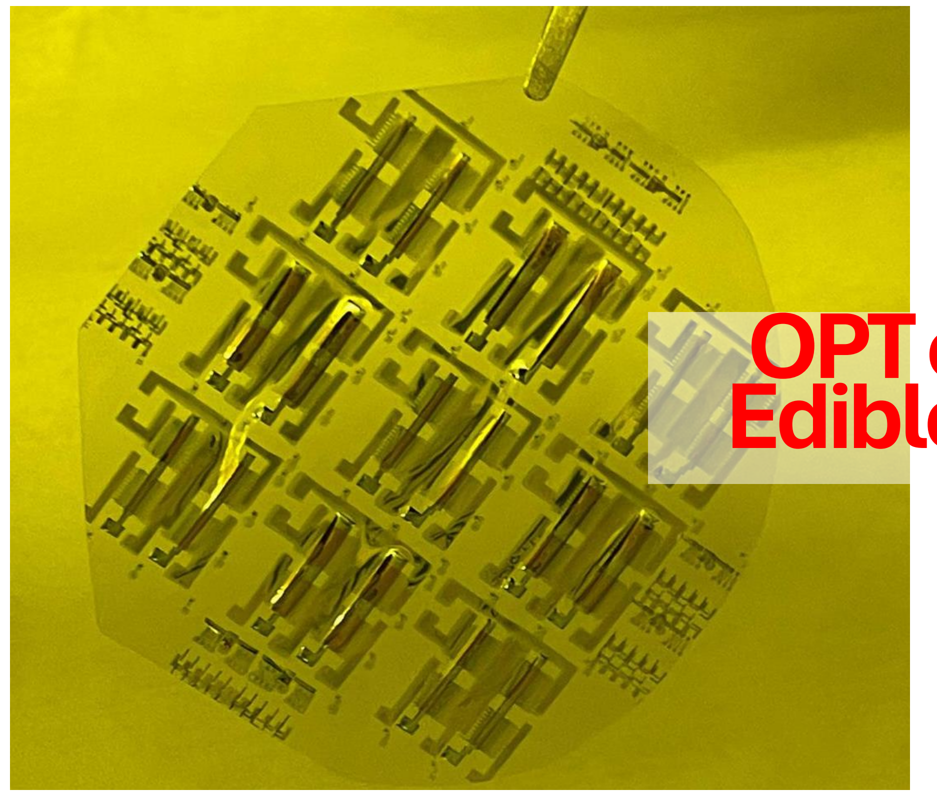
Chitosan

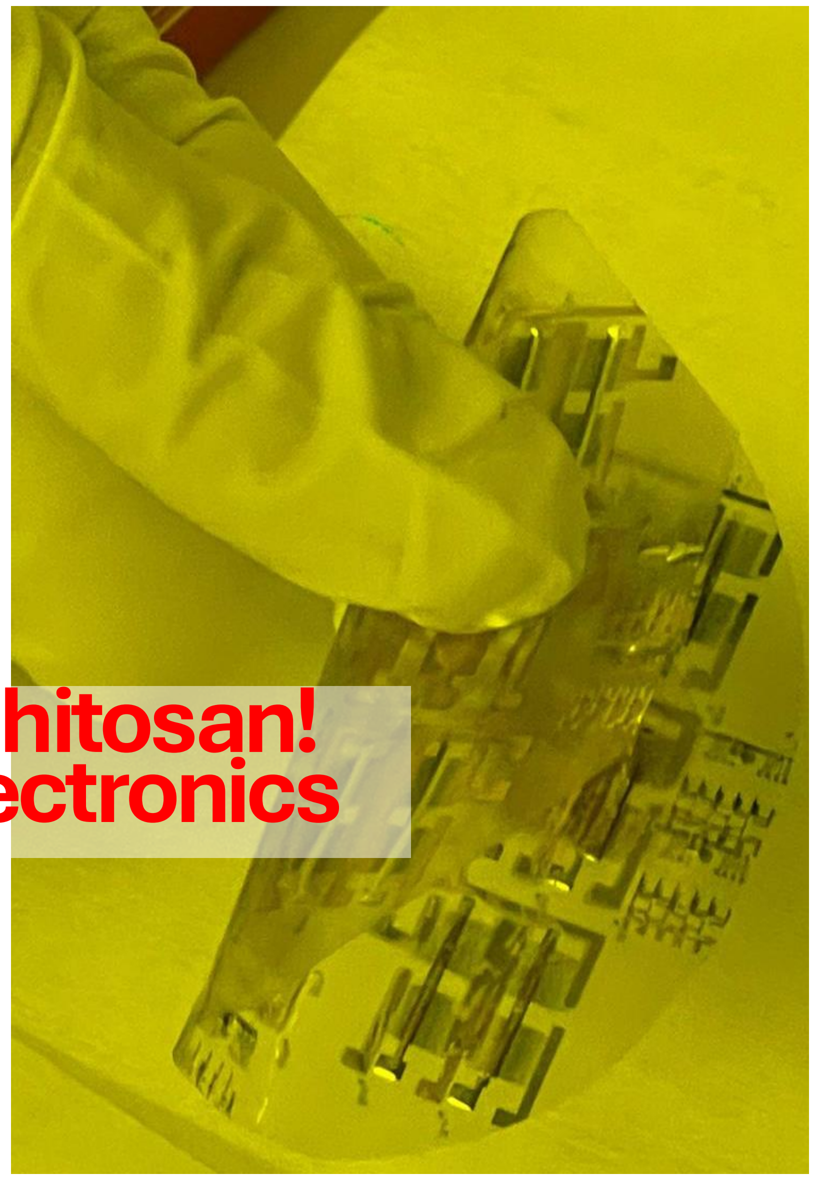
Polysaccharide derived from chitin.

- Biodegradable
- Non-toxic
- Antibacterial









Next-Gen Neuromorphic Circuits: Fabrication of Flexible Full Organic Systems with CMOS Technology

ITC 2025

19th International TFT Conference

March 24 ～ 26 , 2025 / Nara , Japan

Conclusion

- *Advantage to integrate OE in Neuromorphic systems*
- *Fabrication of full organic cmos technologies*
- *Preliminary electrical results*

More results and next steps of the project at the next ITC conference!

Thanks for your attention!

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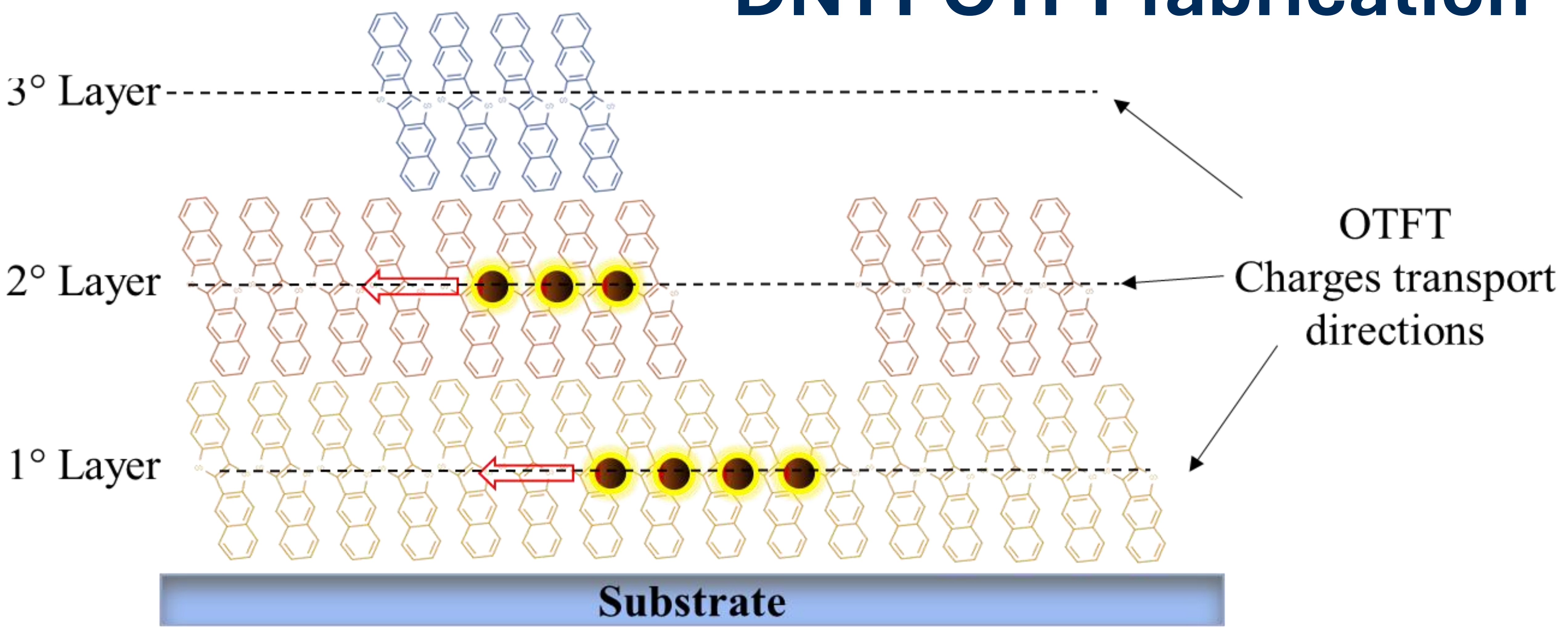
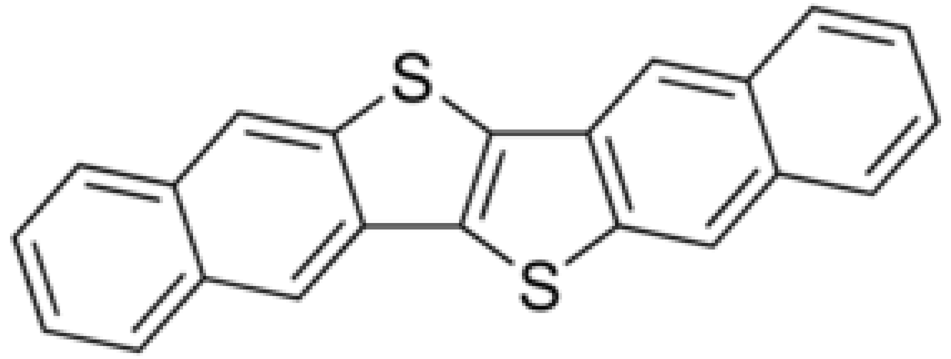
EVENT-DRIVEN PERCEPTION FOR ROBOTICS

DNTT OTFT fabrication



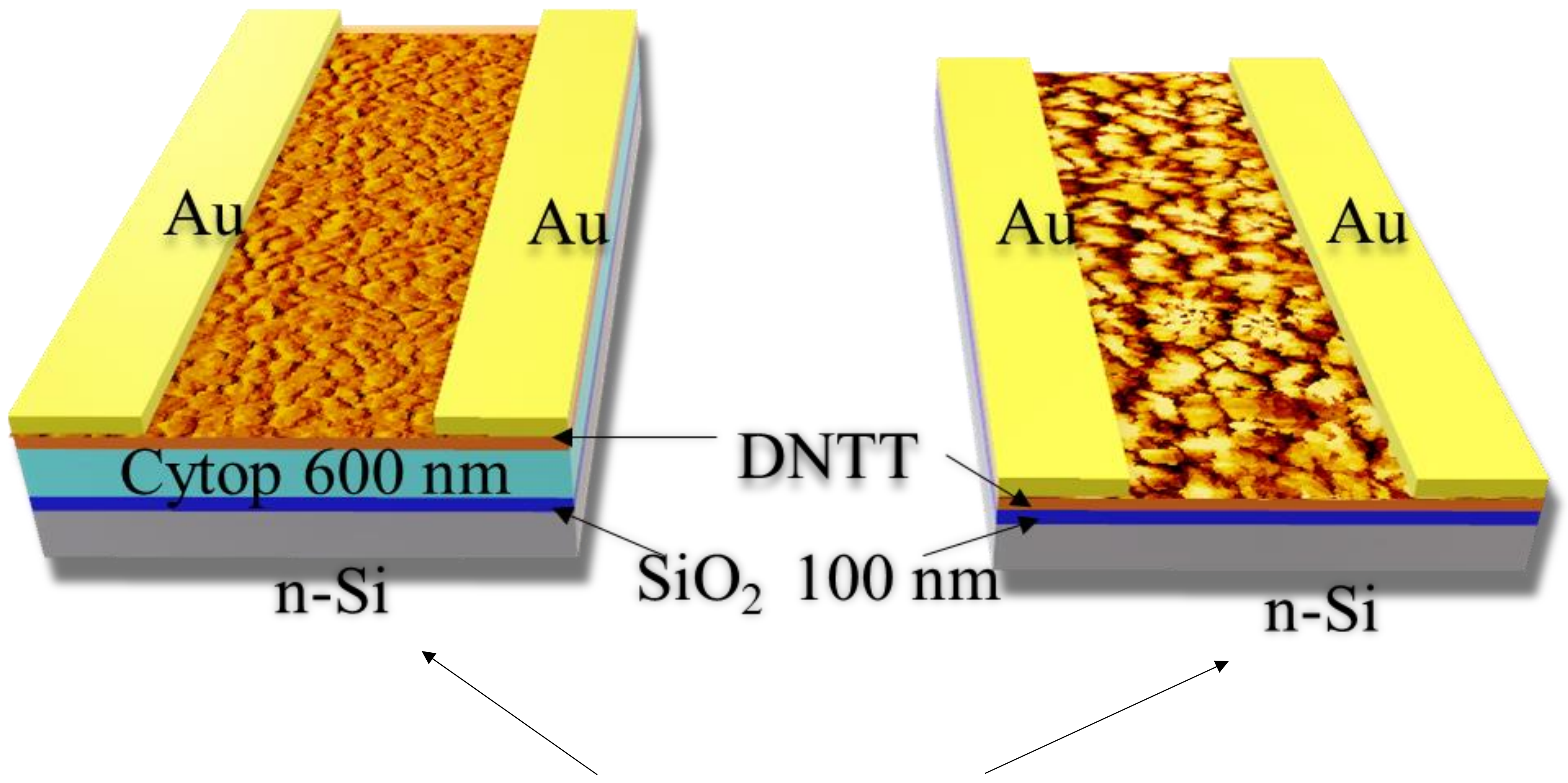
DNTT

Dinaphtho[2,3-b:2',3'-f]thieno[3,2-b]thiophene



p-type organic semiconductor

DNTT/Cytop



DNTT/SiO_2

Patterning by Shadow mask

Channel length L= 50-500 μm

Channel width W= 1 mm

Different dielectric /semiconductor interfaces

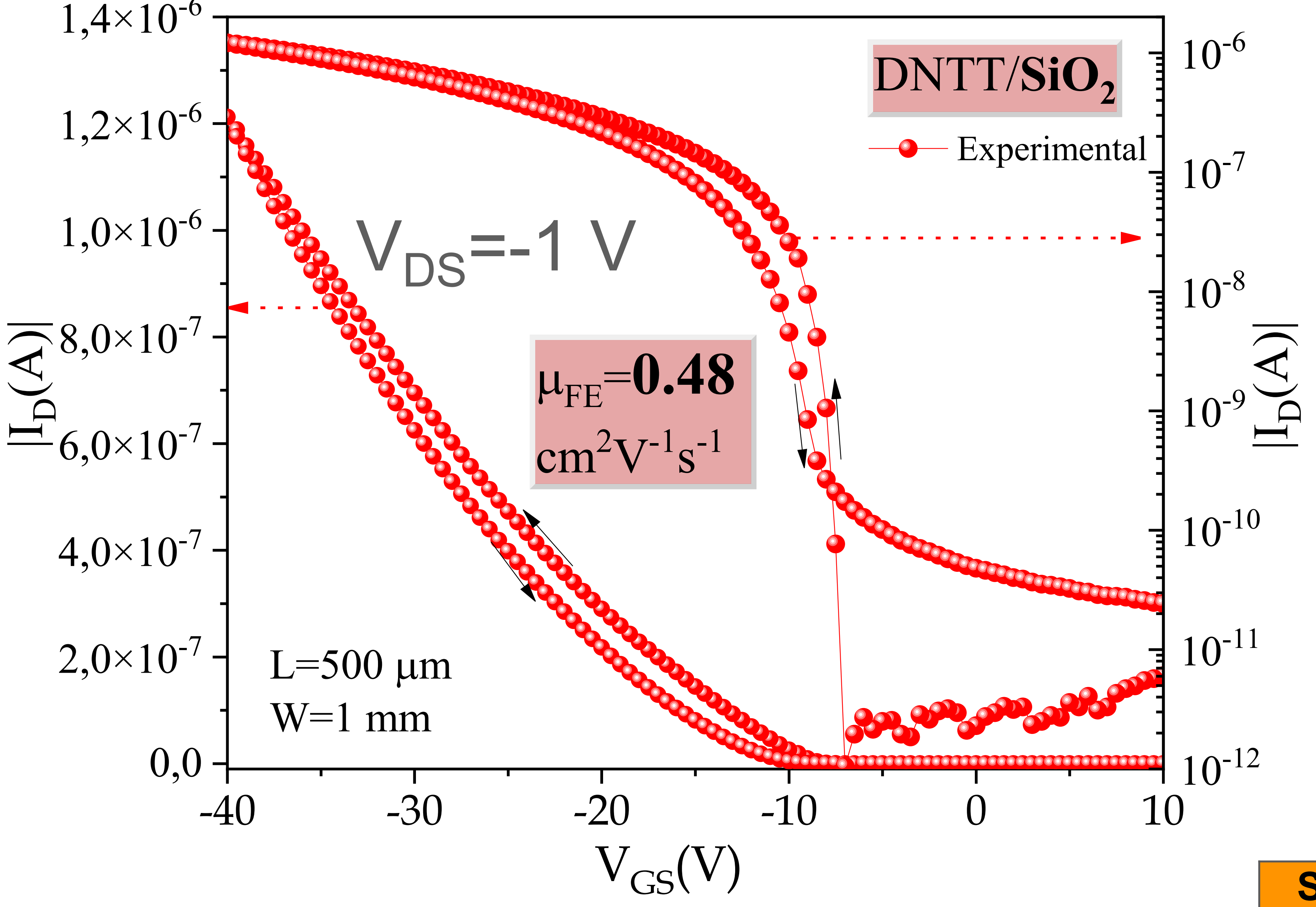
Staggered Bottom Gate Top Contact (**BGTC**) configuration

DNTT is thermally evaporated in high vacuum, at RT with a deposition rate of 0.01 nm/s

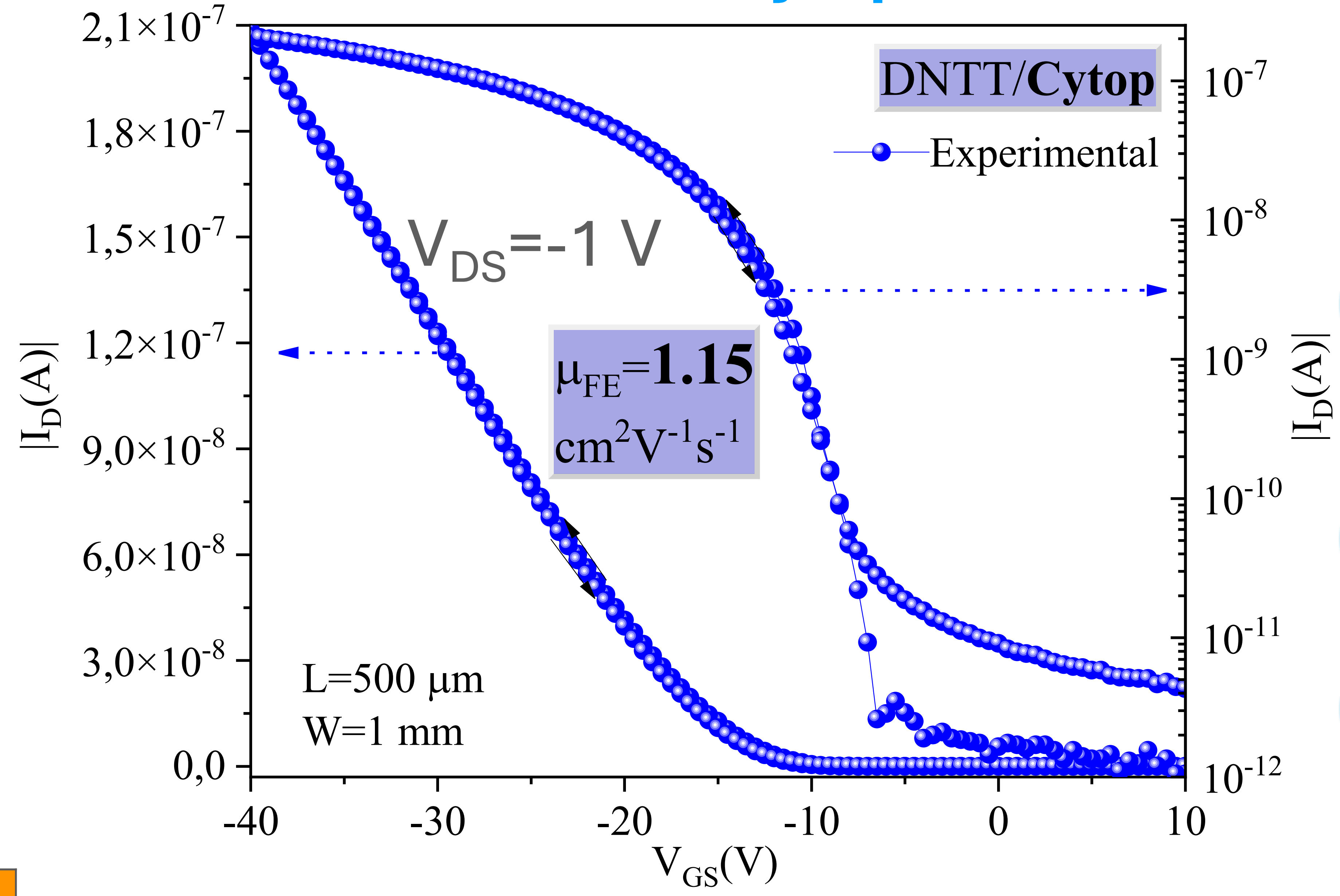
Organic Electronics 2022, 102, 106452.

Electrical OTFT devices characterization

DNTT/SiO_2



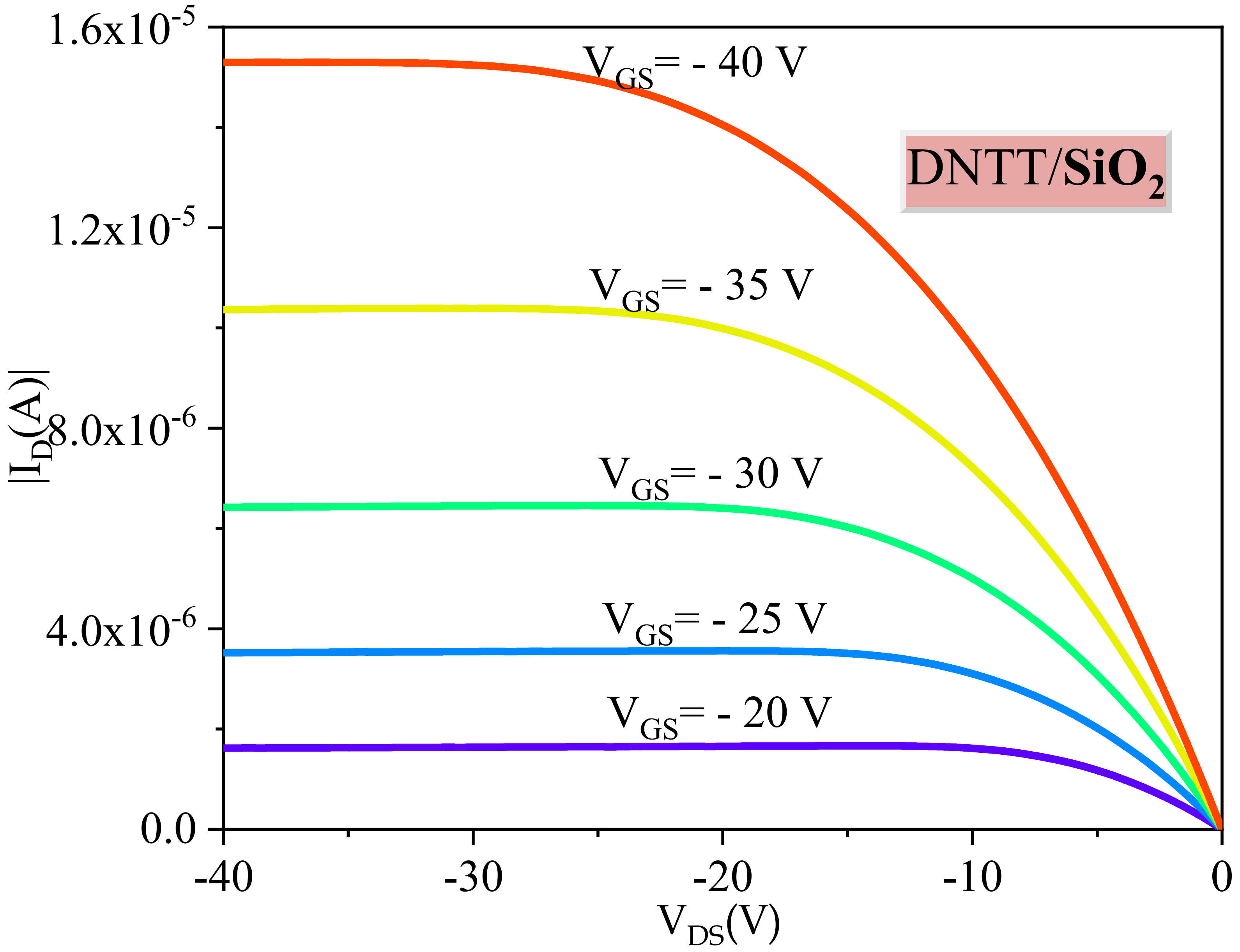
DNTT/Cytop



Typical transfer I_D *vs* V_{GS} characteristics: **excellent OTFT performances**

Structure	μ (cm^2/V· s)	SS (V/dec)	V_{TH} (V)
DNTT/SiO_2	0.48	0.3	-22
DNTT/Cytop	1.15	1.4	-16

difference



- good linearity at low V_{DS}
- flat saturation zone
- absence of contacts effects