Smartkem

Developing Flexible Integrated Circuits Through Customized Organic TFTs

By Steven Tsai, Head of Technology Transfer, Smartkem

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Our Company

World Class Technology Team

c.**30** full time employees with **200+** combined years industrial and R&D pedigree at Imperial Chemical Industries PLC (**ICI**), Merck & Co., Inc., Koninklijke Philips N.V. (**Philips**), Eastman Kodak Company (**Kodak**), Cambridge Display Technology Ltd. (**CDT**), Motorola Mobility LLC (**Motorola**).

Extensive IP Portfolio

125 granted patents across **19** patent families.

40 codified trade secrets.

Fund Raising To Date

$24.6m raised in February 2021 through private placement.

$14.2m raised in 2023 through private placement.

Over **$80m** raised to date.

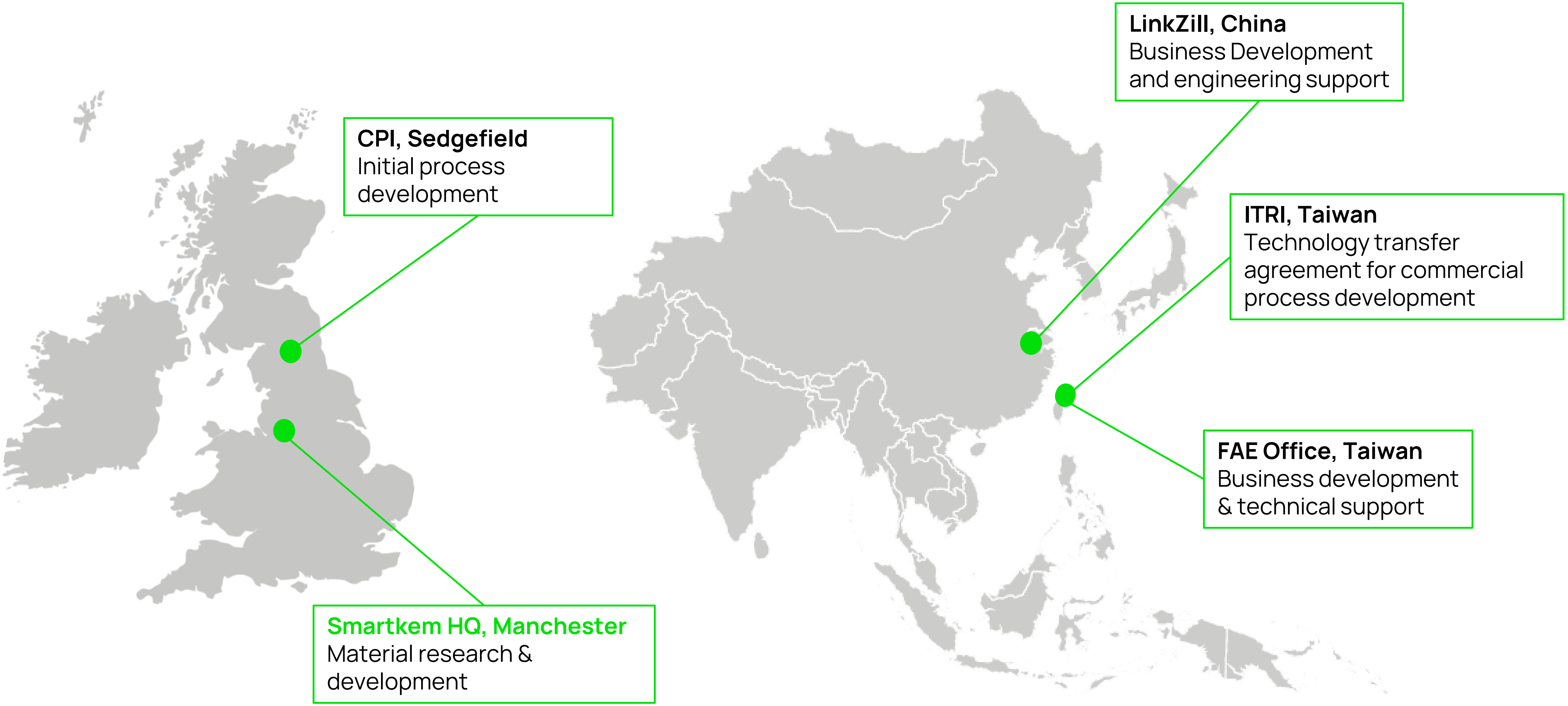
Strategically Positioned

Headquartered in Manchester, UK, with a facility at Centre For Process Innovation (CPI), Sedgefield, UK.

Taiwanese office for technology transfer and business development.

Technology Transfer Agreement with ITRI for product prototyping in Taiwan.

Strategic Positioning in UK & Asia



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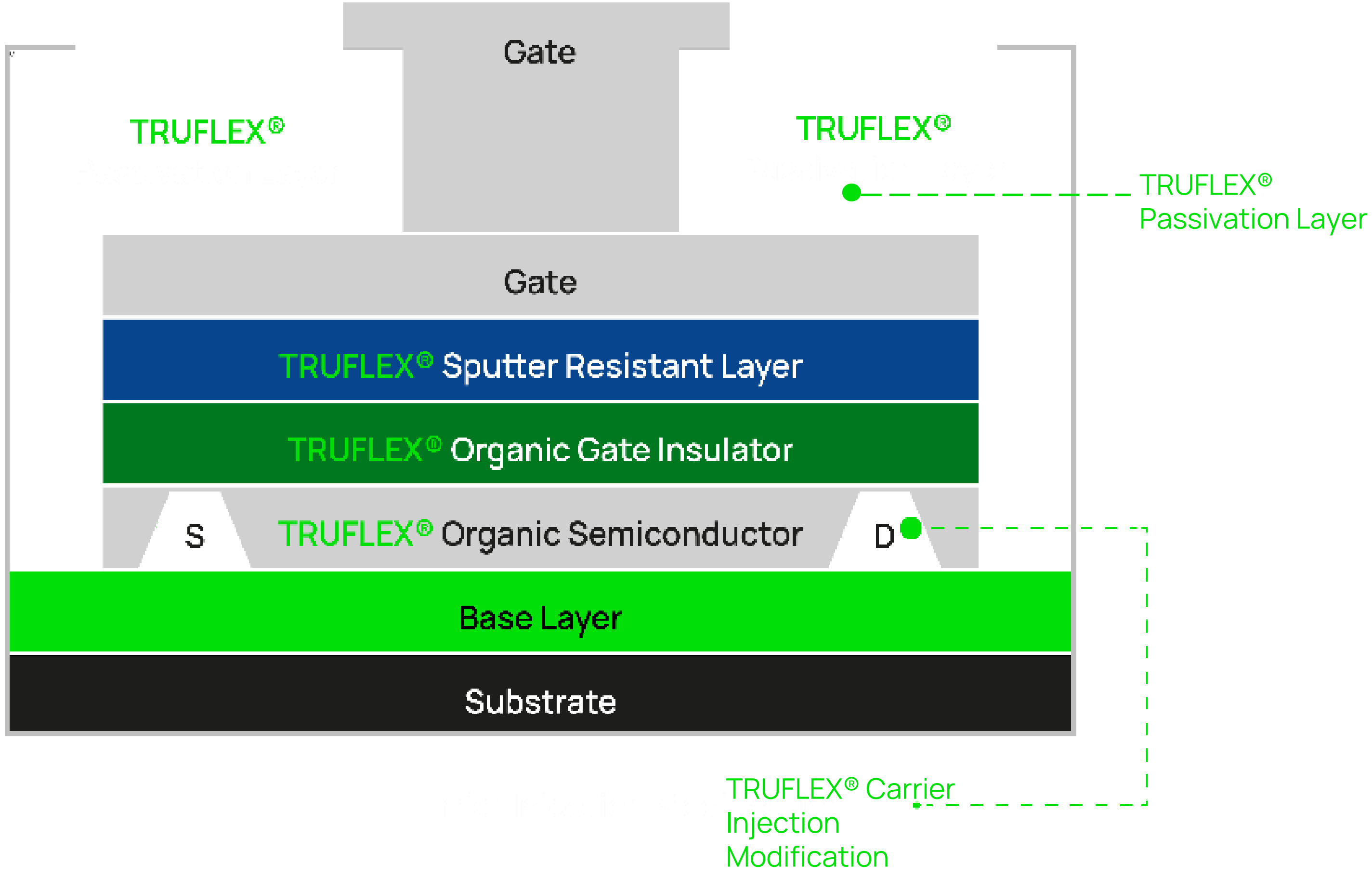
Smartkem's TRUFLEX® Materials

World leading electronic performance

Outperforms market leader a-Si



- Low process temperature
- Compatible with industry-standard manufacturing infrastructure
- Compatible with all frontplane technologies: MicroLED, EPD, LCD & OLED
- Solution processable on low-cost plastics

Organic Semiconductor Polymers Versus Polycrystalline Small Molecules

100% Polymeric Organic Semiconductors

Some chemical companies (BASF, Merck, Sumitomo) developed p-type polymeric semiconductors

Pros

- Excellent uniformity of semiconductor when solution processed.

Cons

- Batch to batch repeatability and purification is difficult for high Mw polymers – impurities contribute to bias stress instability of devices.
- Polymers have insufficient pi-pi overlap - low mobilities
- (<1cm²/Vs @ short channel length, L<5μm).
- Attempts to increase mobility by designing 'structure' into polymers results in performance degradation at typical device processing temperatures (100-150°C).

100% Polycrystalline Organic Semiconductors

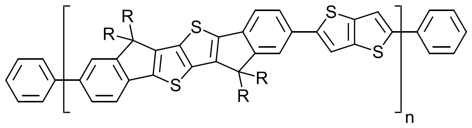
Others (Nippon Kayaku, Asahi Kasei) developed polycrystalline small molecule semiconductors (p-type & n-type)

Pros

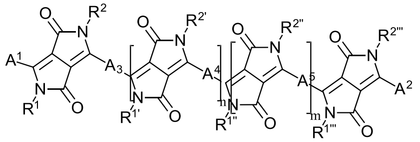
- Polycrystalline OSCs have high mobility (2- 5cm²/Vs).
- Discrete molecules can be purified to <ppb levels required for semiconductor applications

Cons

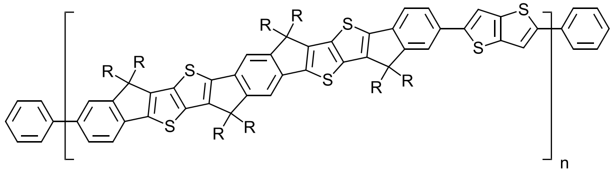
- Inks comprising **only** polycrystalline small molecules deposit with poor uniformity (non-uniformity is exacerbated with increasing
- substrate size (> Gen 2)
- Lack of formulation latitude if the semiconducting formulation (poor viscosity optimisation).



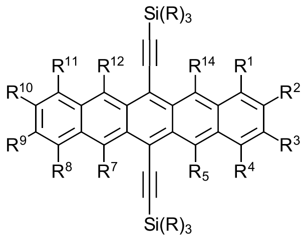
Merck P3

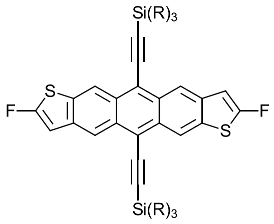


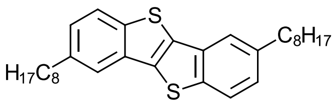
BASF (CLAP) DPP

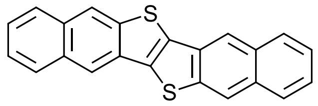


Merck P2









Smartkem's Hybrid Chemistry Approach: TRUFLEX®

Smartkem developed hybrid OSCs by combining a polycrystalline small molecule with a matched/bespoke low molecular weight amorphous semiconducting polymer.

Benefits: High mobility (> $3 cm^2/Vs$@ L=4µm and processes like a polymer.

High mobility, p-type small molecule (SM)

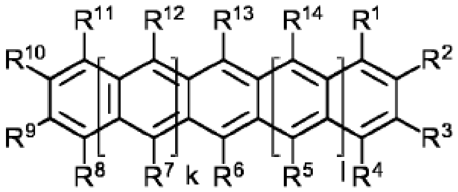
- Intrinsic mobility ≥ 5 -15 cm^2/Vs

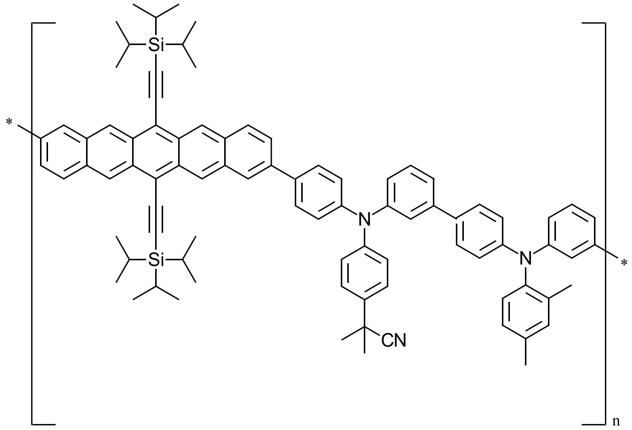
Semiconducting polymer 'controls':

- Crystallinity of SM
- Phase segregation of SM
- Uniformity of high mobility small molecule
- Viscosity of ink

Solvents

- Solubilise SM & polymer
- Modify surface tension
- Influence ink viscosity
- Solvents optimised for printing

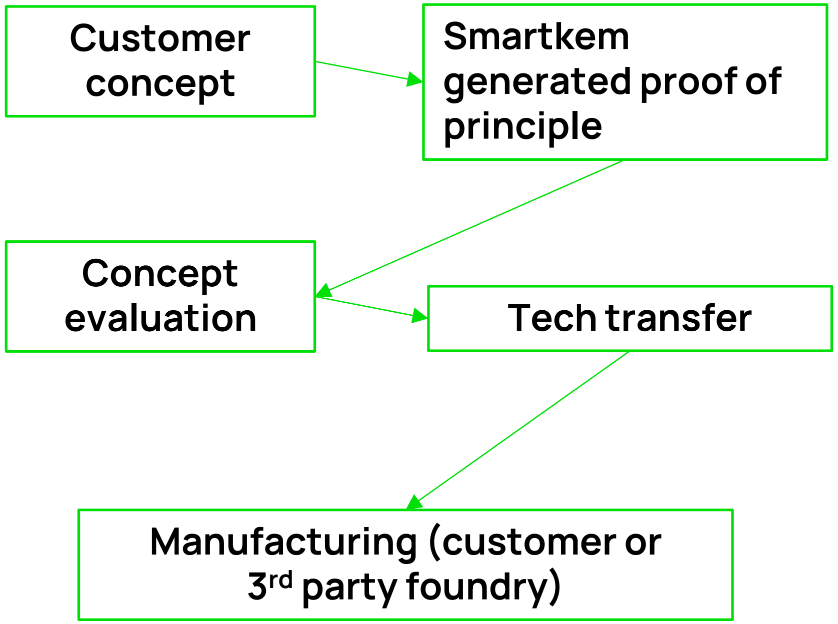




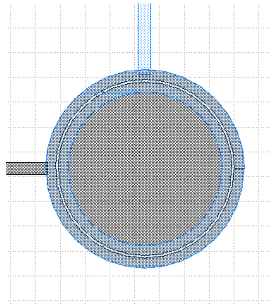
Prototyping and Manufacturing Readiness

Digital Lithography

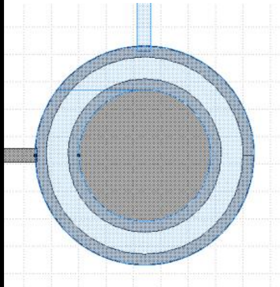
- Minimum L/S in resist = 1.5um
- Alignment accuracy = +/-0.5um
- Maximum size of exposed area = 300mm x 300mm
- Turnaround from design to patterned layer = 1 hour
- Throughput = 10 minutes per 8” plate
- Cost of use = 2X vs mask aligner
- Wavelength = 405nm
- Mode = Non-contact
- NRE = £0



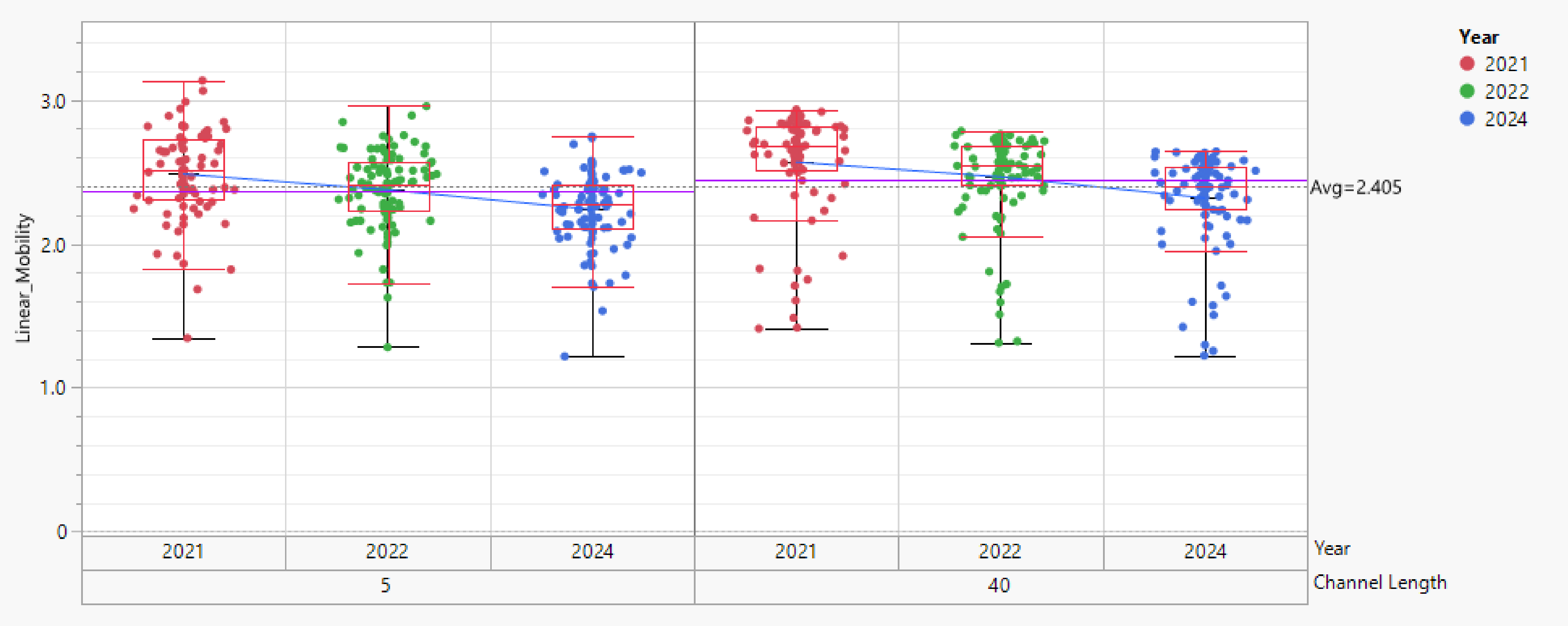
Stability Over Time – More Than 3 Years



L=5um
Corbino



L=40um
Corbino

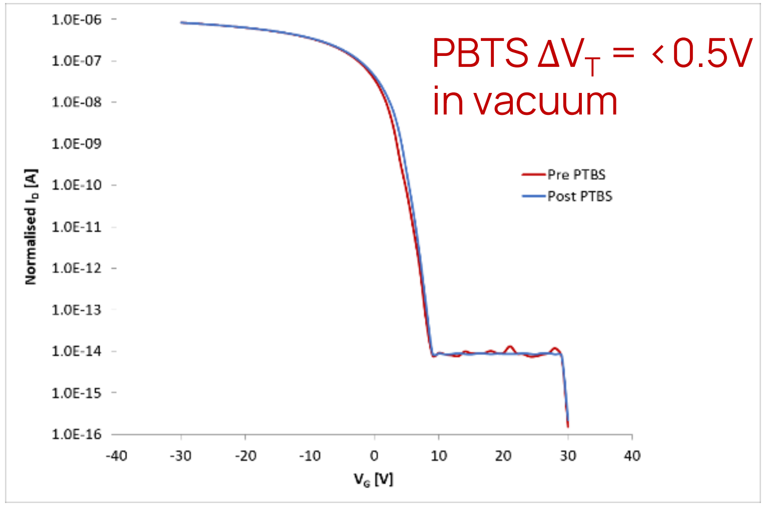


- Process control substrates tested repeatedly over 3-4 years.
- Average Charge Mobility decreased by 0.25 CM^2/VS.
- Devices stored at room temp. and humidity, and in dark. No encapsulation.

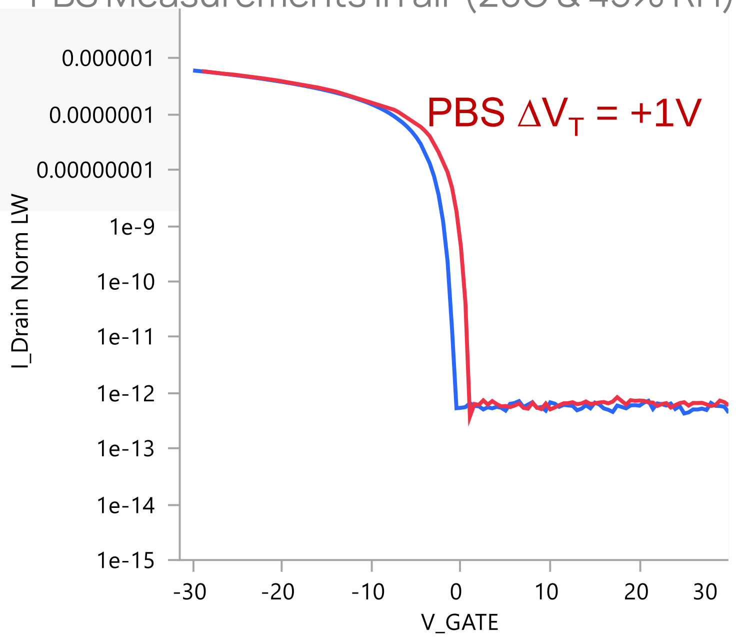
Bias Stress Stability

No Encapsulation

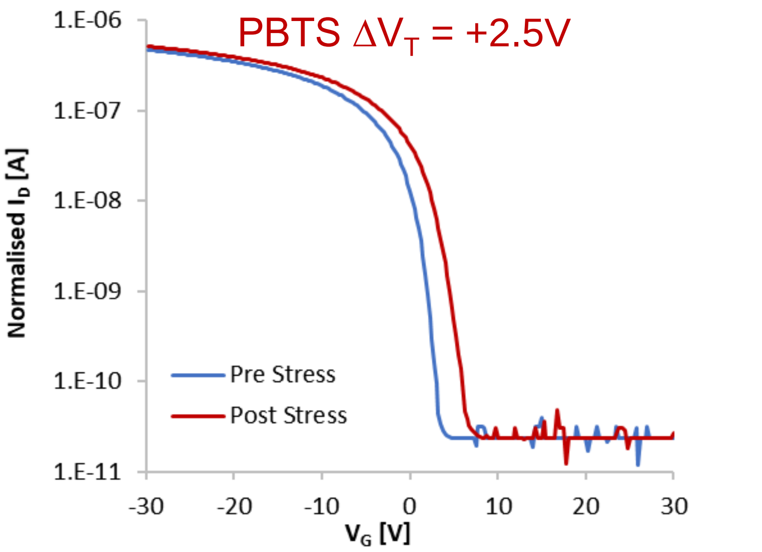
- Bias stress tests in air +/- 30V stress voltage for 1 hour at 60 °C (curves shown are before/after stress at temperature)
- PBTS at 60°C in Cryostat (pressure 3 x 10^{-6} mbar) has minimal bias stress effects – V_{to} shifts in air are due to water absorbed in the device

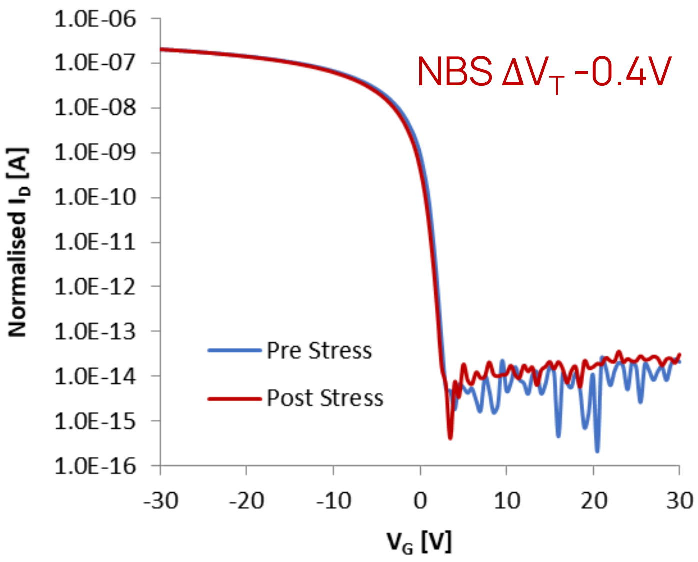


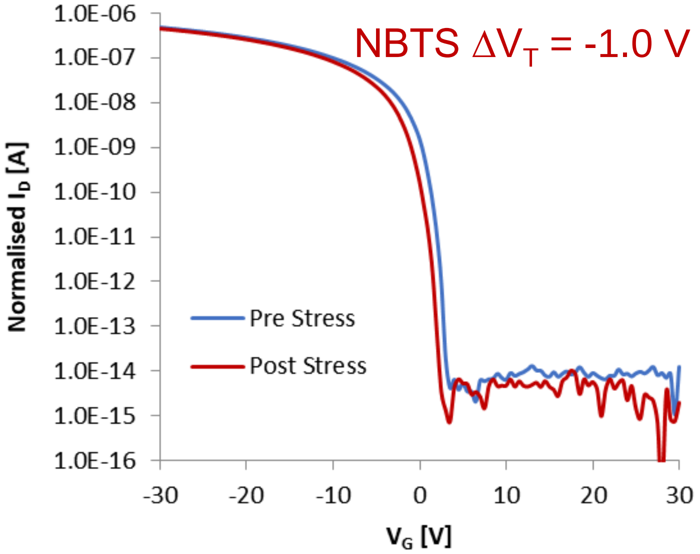
PBS Measurements in air (20C & 45% RH)



PBTS Measurements in air (60C, 60%RH)

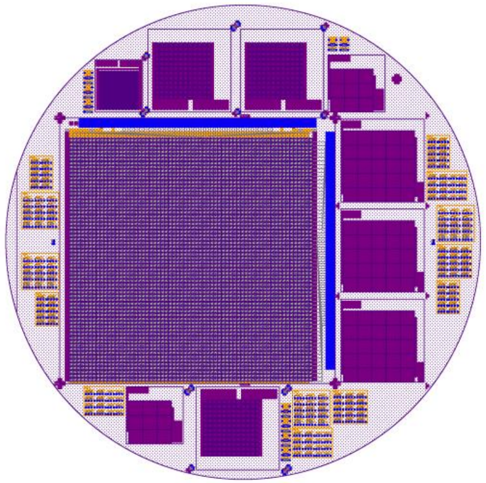


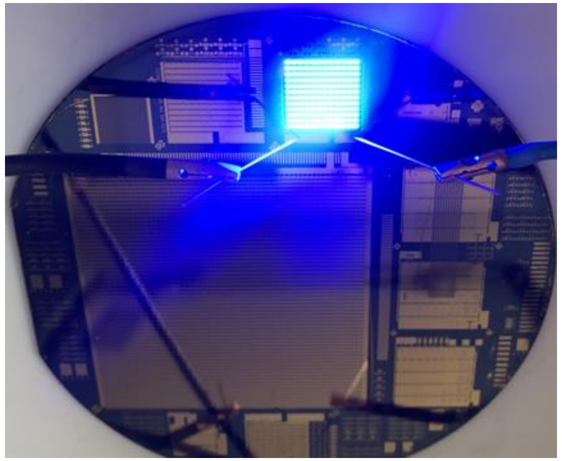




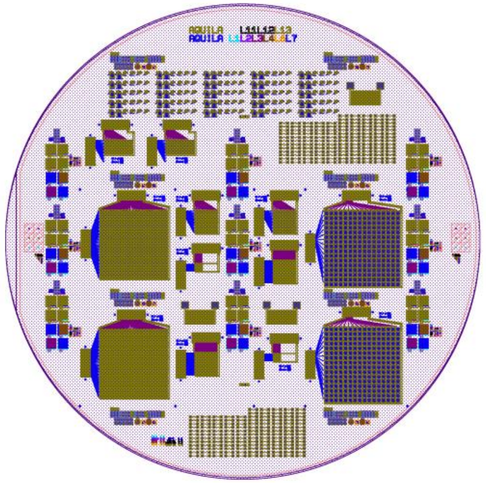
Project Aquila – Monolithic MicroLED (March 2022-to date)

Ver 1 – SJTU design



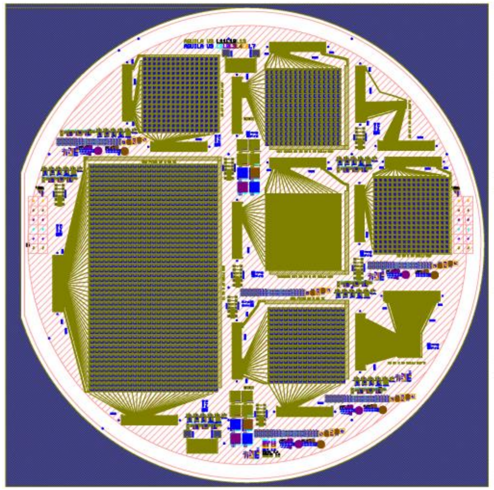


Ver 2 – SK design

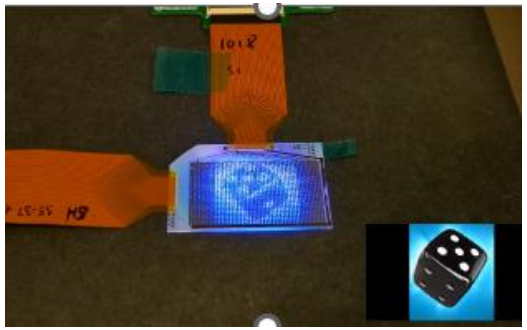


10x16 (nearly perfect)

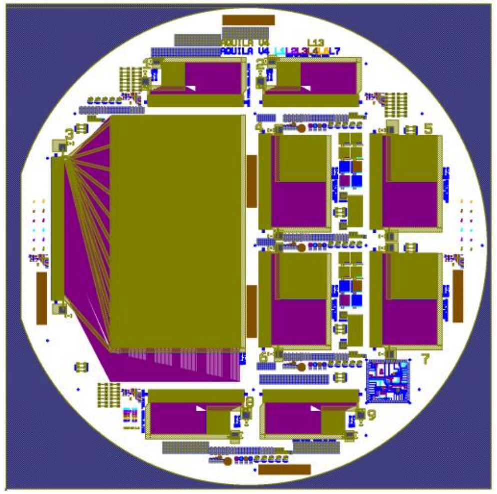
Ver 3 – SK design



27x48

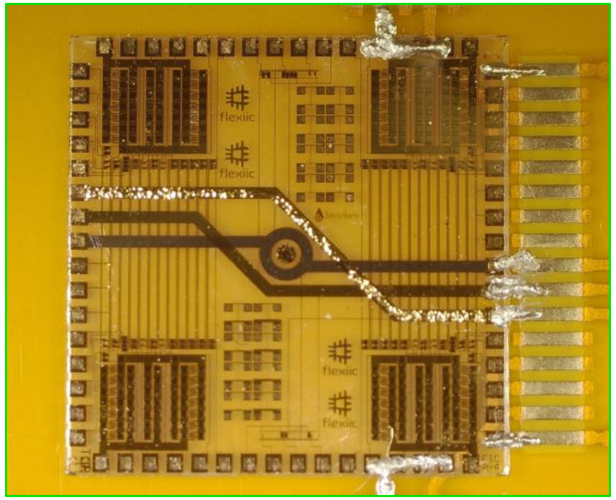


Ver 4 – SK design



96x96 - 508ppi (no visible defects)

Sensors

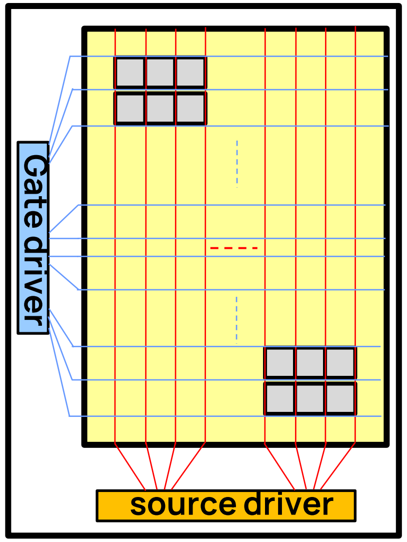


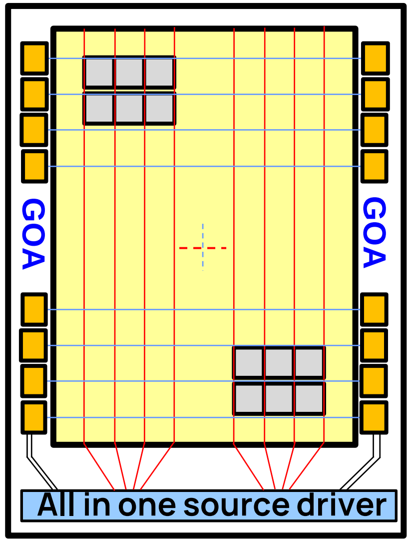
- FlexIC used TFT logic – built by Smartkem – to make a prototype flexible sensor.
- Product authentication sensor (PUF).

OTFT GOA (Gate on Array)

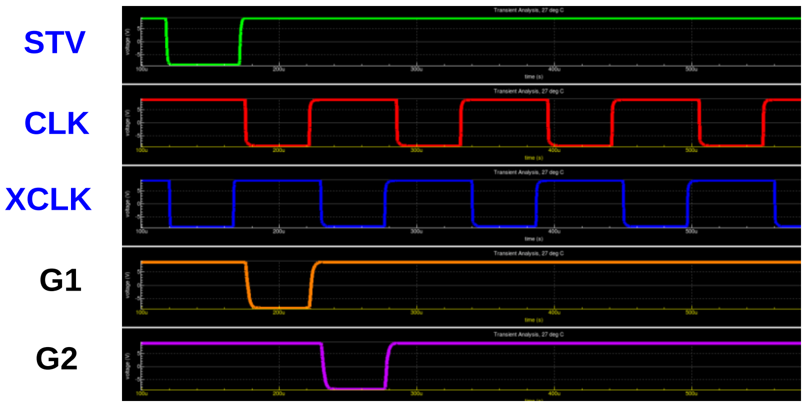
OTFT GOA, Gate driver circuit On Array

- Design the simple circuit to achieve the gate driver function.
- Manufacture the gate driver circuit by TFT array process.
- Advantages are narrow-bezel, and reduce the gate IC cost.
- Disadvantages are more TFT array yield loss, and more power consumption.





■ The operational waveform



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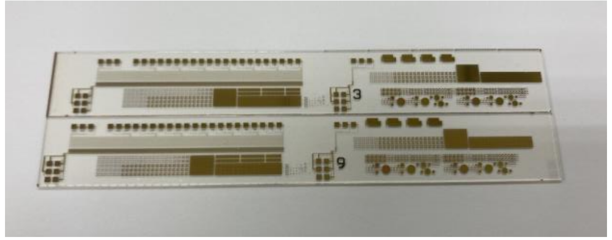
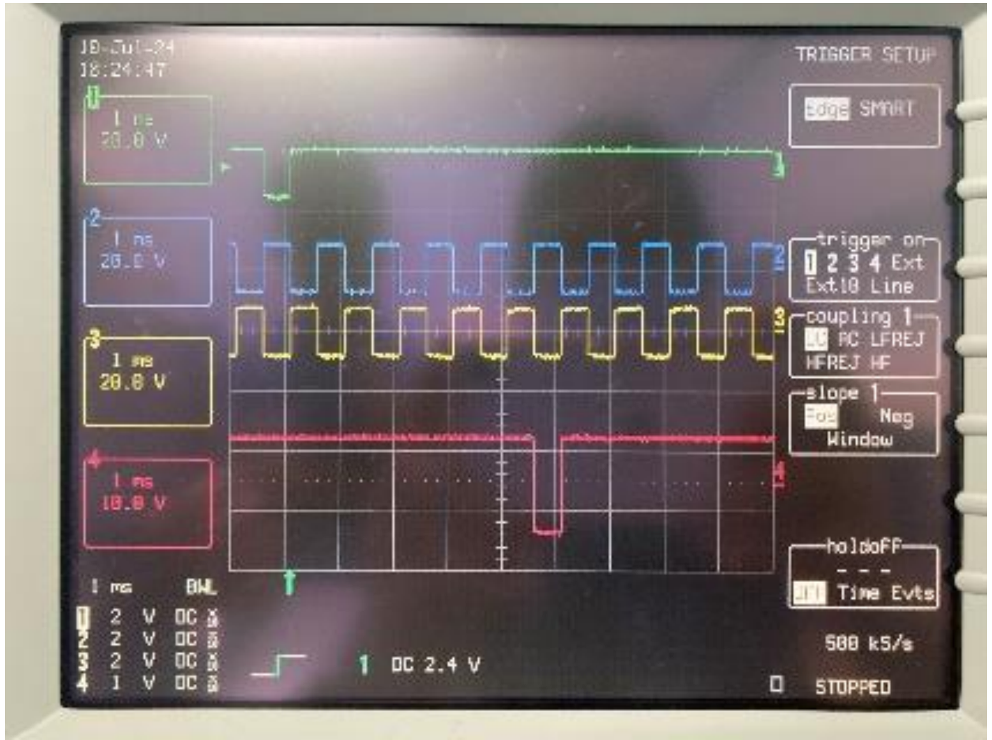
OTFT GOA (Gate on Array)

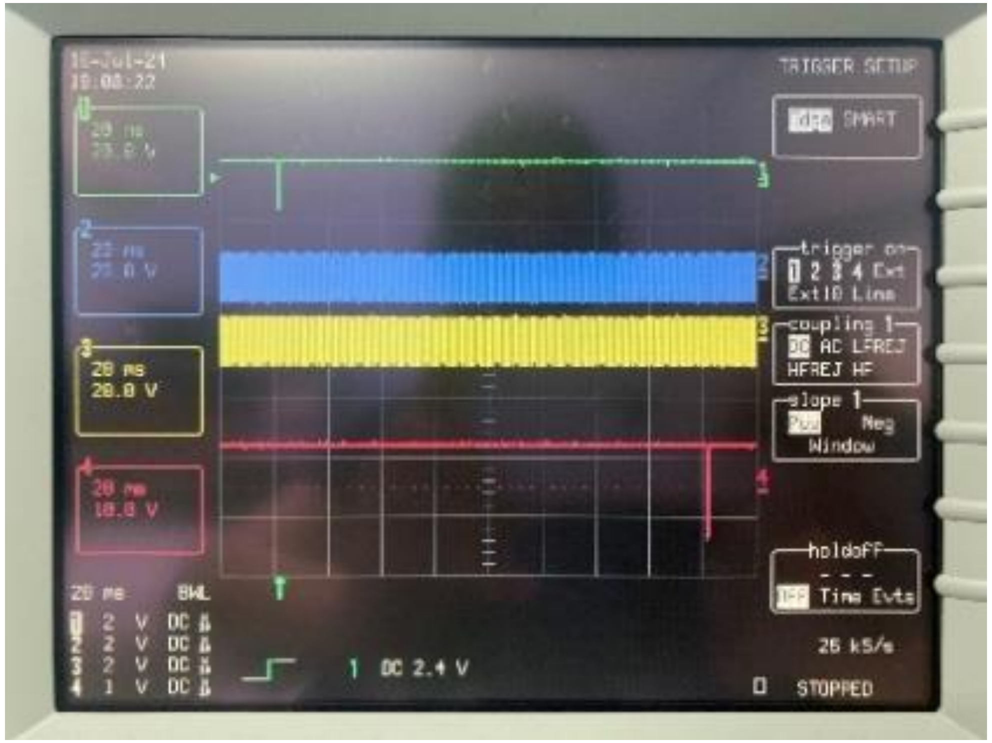
OTFT GOA Testkits



OTFT GOA : 10th



OTFT GOA : 320th



Our Offering

- 4", 8", 12", G2 (370mmx470mm) are available to realize your designs and applications.
- OTFTs GOA circuitry is available for commercial applications.
- Welcome to commercial and academic partners to collaboration together.

General Enquiries: enquiries@smartkem.com

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Smartkem

Thank you

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