PROCESS OF RECORD

PEDOT:PSS based OECTs

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Content

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Introduction

The organic electrochemical transistor (OECT) is based on a 3-terminal architecture. The source and drain electrodes are connected with an organic mixed ionic-electronic conductor (OMIEC), while the channel is coupled with the gate via an electrolyte. This POR focuses on a side-gate configuration, featuring the benchmark polymer blend poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) as the channel material and an in-house developed solid-state-electrolyte (SSE), as schematically illustrated in Figure 1 and 2.

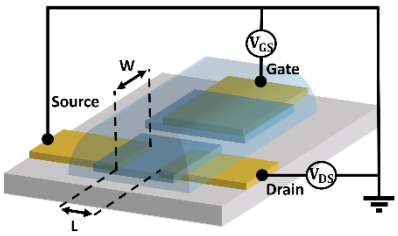


Figure 1: 3D schematic of an OECT

The transconductance and saturation of OECTs are determined by the transistor geometry, where *W*, *L*, and *d* represent the channel width, length, and thickness, respectively. It is essential to control these geometry parameters with micrometer precision to ensure highest reliability and uniformity of transistor parameters. For this purpose, different fabrication techniques have been investigated, ranging from large-area and cost-effective printing methods, where high spatial resolution is not a critical factor, to higher-cost integration within the lower micrometer range through photolithography. However, the fabrication of the OECT can be systematically divided into 3 different stages.

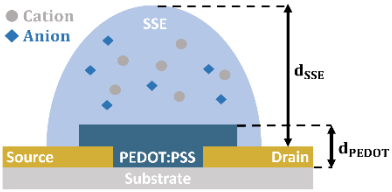
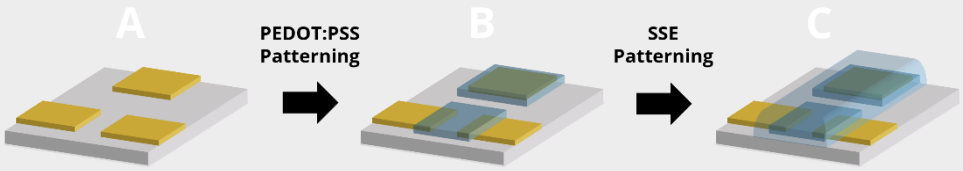


Figure 2: Cross-section of an OECT

Overview Fabrication Steps:



In the following sections, each of the three fabrication steps will be broken down into detailed processes with various fabrication techniques such as lithography, parylene peel-off, screen printing, and inkjet printing. All the laboratory work is done in a ISO-7 classified cleanroom with a size of 250m^2. Every process description consists of an equipment list, material list and their required quantities, a step-by-step instruction with remarks and a checklist for quality control of the final product. The focus of this description centers on the OECT reference layout (see Figure 3) – a configuration featuring a 1x1inch glass substrate with 50nm thick Au electrodes. This layout accommodates 14 individual transistors, all sharing the same geometry (W/L = 5, length L = 30µm, gate distance 60µm). OECTs based on this layout are characterized by a remarkable transfer reproducibility, high on/off ratios (>10^4), persistent current hysteresis, and low threshold voltages ~0.4V (see Figure 4-5, uniformity analysis [1]).
In addition to the POR, a comprehensive life-cycle-assessment (LCA) is conducted for each step. This assessment aims to evaluate and quantify the environmental impact associated with the in-house fabrication of an OECT.

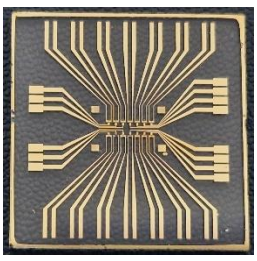


Figure 3: 1x1inch reference layout

Parameter	Printed OECT	Hybrid OECT
V_T (V)	0.88±0.11	0.4±0.04
g_{max} (mS)	0.5±0.1	0.59±0.06
Ψ (V)^2	5.1±0.7	2.7±0.4
On/Off	23476±16183	30430±3038
SS (mV/dec)	70±12	82±6

Figure 4: Transfer characterization

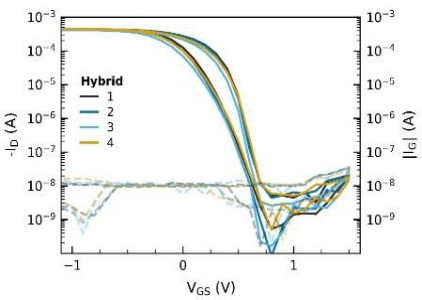


Figure 4: Transfer curve of 4 OECTs

[1]Meier, T., Yoon, Y., Teuerle, L. *et al.* A hybrid process for integration of organic electrochemical transistors for high uniformity & reliability. *MRS Communications* (2023)

Overview

End-Product System:
PEDOT:PSS based Organic Electrochemical Transistor (OECT)

System A: Electrode Patterning

- **A1** Page 4-7 — Lithography Au/Ag Electrodes
- **A2** Page 3 — Inkjet Printing Ag Electrodes
- **A3** Page 4 — Screen Printing Ag Electrodes
- **A4** Page 5 — Microplotting Ag Electrodes

System B: Channel Material Patterning

- **B1** Page 6 — Lithography PEDOT:PSS
- **B2** Page 7 — Inkjet Printing PEDOT:PSS
- **B3** Page 8 — Screen Printing PEDOT:PSS
- **B4** Page 9 — Microplotting PEDOT:PSS
- **B5** Page 10-11 — Parylene Peel-off PEDOT:PSS

System C: Electrolyte Patterning

- **C1** Page 12 — Lithography SSE
- **C2** Page 13-14 — Inkjet Printing SSE
- **C3** Page 15 — Microplotting Electrolytes

Fabrication System Compatibility:

A->B	B1	B2	B3	B4	B5
A1/1					
A1/2					
A2					
A3					
A4					

B->C	C1	C2	C3
B1			
B2			
B3			
B4			
B5			

Fabrication System A

- Electrode Patterning -

System A1: Lithography Au Electrodes

This section describes all unit processes involved in the lithographic patterning of gold (Au) electrodes on a 1"x1" glass substrate at the IAPP lab. Although gold as an electrode material comes with a higher cost, it is recommended for use in OECTs due to its electrochemical stability, resistance to oxidation, and good electrical conductivity. A pre-evaporated Au layer provides a highly planar surface with nanometer-scale layer thickness accuracy. Using lithography as an industry-standard patterning process, lateral resolutions of 1µm can be achieved. Therefore, this fabrication method is ideal for precise, small-scale structures, but comes with drawbacks like high energy and chemical consumption, resulting in a larger environmental impact and operational costs compared to printing techniques.

Pre-processing

Substrate: 6"x6" glass wafer (Schott Borofloat® 33, composition according to DIN ISO 3585 / EN 1748 T1, thickness of 1.1±0.1mm)
Info: Process done by IAPP Lesker-Team, wafer ordering at https://osol-db.iap.phy.tu-dresden.de/ (IAP intranet)

(1) Wet cleaning process: 10min DI water + 10min ethanol ultrasonic bath (solvent reusable: ~200ml DI water, ~50ml ethanol per wafer)
(2) Removal of residues (12min, 20L DI water) and drying (3min, 100L N_2) in a spin-rinse-dryer
(3) Surface activation by UV ozone-plasma for 10min
(4) Vacuum evaporation of a 3nm Cr adhesion layer (60mg Cr, rate 0.1Å/s) followed by a 50nm Au layer (2.5g Au, rate 0.3Å/s)
(5) Spin-coating (5s ramp-up, 60s 2000rpm, 5s ramp-down) of 18ml AZ 1518 photoresist to protect Au-layer
(6) Cutting wafer into 1"x1" substrates

Overview Unit Processes:

1h45min (1-4 Substrates)

1 Cleaning → 2 Resist Coating → 3 UV Exposure → 4 Development → 5 Au Etching → 6 Cr Etching → 7 Resist Stripping → 8 Plasma Cleaning

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Ultrasonic cleaner, 100mL + 20mL Beaker	*30mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Rinsing substrate with acetone 2. Ultrasonic bath for 15min (substrate in 25mL acetone in small beaker, nested in 10mL water in large beaker) 3. Rinsing substrate with acetone followed by isopropanol 4. Blow away residual solvents with N_2	Clean and dustless substrate surface	Cleaning and removal of scratch-protective AZ 1518 layer
2	Spin-coater, Pipette, Hotplate, Light-shielded box	*0.5mL* AZ 1518 (pos. photoresist) *(stored in fridge at 5°C)*	1. Spin-coating AZ1518 Photoresist – use 1"x1" holder (5s ramp-up, 60s 3000rpm, 5s ramp-down) 2. Soft baking at 110°C for 60s (use precise hotplate) 3. Store substrate in a light-shielded box	~2800nm thick AZ 1518 layer, reddish, wavy surface, no bubbles	See appendix Figure **1** for AZ thickness at various rpms
3	Mask aligner exposure unit, Photomask		1. Install electrode photomask + load substrate 2. Perform WEC (Wedge Error Compensation) + alignment of substrate with photomask 3. UV exposure (I-line 365nm, intensity 5.2 mW/cm^2) of substrate for 13s		If the lamp is at the end of its lifecycle, increase exposure time to 14-17s
4	2x40mL Beaker	*40mL* AZ 726 MIF *(multiple reuse)* *40mL* DI water, *2.5L* N_2	1. Submerge substrate in AZ 726 MIF developer and slowly swing it back and forth for 60s (do not block layout areas with tweezer) 2. Cleaning in DI water for 10s 3. Blow away residual water with N_2	Layout is slightly visible on substrate surface.	Removal of exposed photoresist
5	2x40mL Beaker	*40mL* Au etchant (1:10 DI water) *(multiple reuse)* *40mL* DI water, *2.5L* N_2	1. Submerge substrate in gold etchant and slowly swing it back and forth for at least 30s (stop once Au is completely removed from the exposed areas, do not block the Au electrode areas with the tweezer) 2. Cleaning in DI water for 10s 3. Blow away residual water with N_2	Clean Au electrode layout is visible without unwanted particles or Au dots. Glass substrate is transparent but slightly greyish.	If the Au cannot be removed completely, the exposure time or the development time was too short.
6	2x40mL Beaker	*40mL* Cr etchant (1:10 DI water), *40mL* DI water, *2.5L* N_2	1. Submerge substrate in chromium etchant and slowly swing it back and forth for 20s 2. Cleaning in DI water for 10s 3. Blow away residual water with N_2	Glass substrate is fully transparent and non-conductive on its surface. (Multimeter check).	Disposal of Cr etchant in Cr waste bottle (acid shelf)
7	Ultrasonic cleaner, 100mL + 20mL Beaker	*25mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Ultrasonic bath for 15min (substrate in 25mL acetone in small beaker, nested in 10mL water in large beaker) 2. Rinsing substrate with acetone followed by isopropanol 3. Blow away residual solvents with N_2	Clean Au electrodes (Au 50nm: 1.64Ω/□), step 8 if residual photoresist is visible	Cleaning and removal of unexposed photoresist
8	Plasma Cleaner **OPTIONAL**	*250mL* O_2 *50L* N_2 (venting 2x)	Reactive O_2 plasma cleaning of substrate surface for 5min (program ‚O2_cleaning_300s', RF Generator 50W and 250V, 30ml$_n$/min O_2, start at 8.0e-05mbar)	No residual photoresist on substrate surface.	Further cleaning and removal of residual photoresist

System A1: Lithography Au Electrodes

Additional Information

(A) For structure sizes <10µm, exposure time and development time need to be tuned and precisely timed.
(B) If the glass substrate is contaminated with particles after the final cleaning step, it is recommended to renew the developer solution and/or the gold etchant solution.
(C) Polyimid (PI) as flexible substrate is available. It has to be manually cut into the desired shape and attached to a corresponding glass substrate using spray glue. Detaching is done using acetone in an ultrasonic cleaner.
(D) As alternative to the SÜSS MicroTec mask aligner system, a Heidelberg Instruments µMLA maskless aligner (365nm, dose 330mJ/cm^2) for the photoresist exposure (step 3) is available. The layout for the maskless tool needs to be in a .gds file format.
(E) Other photoresist like AZ nLOF 2020 (neg. photoresist, soft baking 110°C for 60s, exposure time 15s, development 60s) and AZ 5214-E (image reversal pos. photoresist, soft baking 110°C for 60s, exposure time 7s) are available in the IAP laboratory. The Image reversal of AZ 5214-E is achieved by an additional reversal bake step at 120°C for 2min after the inital UV exposure (step 3), followed by a flood exposure (no mask) for 25s. For lift-off processes, the AZ 5214-E thickness should be 1.2-1.5x of the deposited layer and for a sufficient undercut, a 30% over-development is recommended.

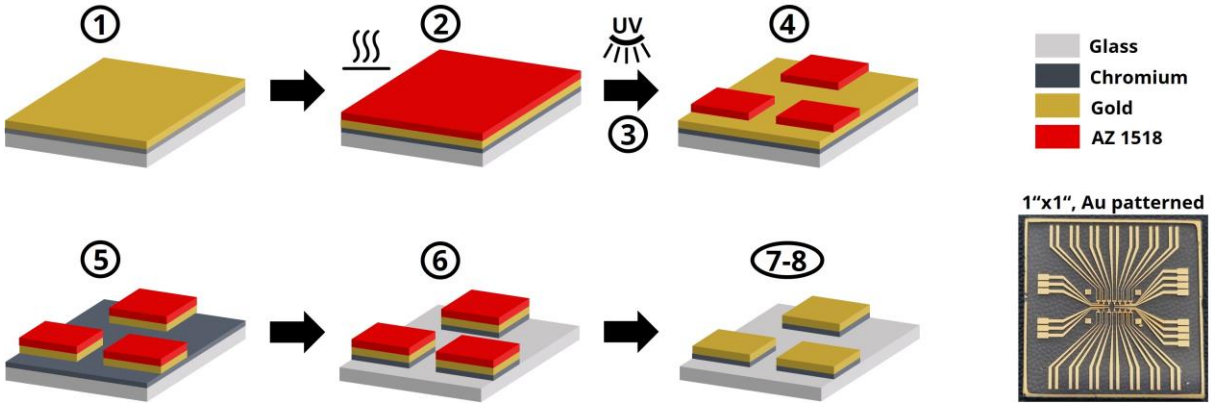
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool and the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
1	Ultrasonic bath: 10x substrates at once (5x beaker setup) 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 50x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
2	Hotplate (soft baking): 25x substrates at once	Spin-coating is limited to one substrate at a time.
3	-	Only the maskless tool can process multiple substrates at a time.
4	40mL AZ MIF 726: 25x 40mL DI water: 5x	The same DI water can be used for step 4-6. The developer is disposed of after a maximum of 25 substrates.
5	40mL Au etchant: 25x 40mL DI water: 5x	The same DI water can be used for step 4-6. The Au etchant is disposed of in the Au waste bottle (acid shelf) after a maximum of 25 substrates.
6	40mL Cr etchant: 25x 40mL DI water: 5x	Same DI water can be used for step 4-6. Cr etchant must be used within a single day and disposed of in the Cr waste bottle (acid shelf) afterward.
7	Ultrasonic bath: 10x substrates at once (5x beaker setup) 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 50x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
8	Plasma etcher: 25x substrates at once (250mL O_2 and 50L N_2 fixed amounts per run)	

Process Schematic:



System A1: Lithography Ag Electrodes

This section describes all unit processes involved in the lithographic patterning of silver (Ag) electrodes on a 1"x1" glass substrate at the IAPP lab. Silver, as an electrode material, offers a significantly lower cost than gold while still providing good electrical conductivity. However, it is less electrochemically stable and tends to form an undesired oxide layer on the surface, especially when patterned using wet etching or oxygen plasma. Additionally, the pre-evaporated Ag layer provides a highly planar surface with nanometer-scale layer thickness accuracy. Using lithography as an industry-standard patterning process, lateral resolutions of 1µm can be achieved. Therefore, this fabrication method is ideal for precise, small-scale structures but comes with drawbacks like high energy and chemical consumption, resulting in a larger environmental impact and operational costs compared to printing techniques.

Pre-processing

Substrate: 6"x6" glass wafer (Schott Borofloat® 33, composition according to DIN ISO 3585 / EN 1748 T1, thickness of 1.1±0.1mm)
Info: Process done by IAPP Lesker-Team, wafer ordering at https://osol-db.iap.phy.tu-dresden.de/ (IAP intranet)

(1) Wet cleaning process: 10min DI water + 10min ethanol ultrasonic bath (solvent reusable: ~200ml DI water, ~50ml ethanol per wafer)
(2) Removal of residues (12min, 20L DI water) and drying (3min, 100L N_2) in a spin-rinse-dryer
(3) Surface activation by UV ozone-plasma for 10min
(4) Vacuum evaporation 50nm Ag-layer (1.4g Ag, rate 0.3Å/s)
(5) Spin-coating (5s ramp-up, 60s 2000rpm, 5s ramp-down) of 18ml AZ 1518 photoresist to protect Au-layer
(6) Cutting wafer into 1"x1" substrates

Overview Unit Processes:

1h15min (1-4 Substrates)

1 Cleaning → 2 Resist Coating → 3 UV Exposure → 4 Development → 5 Ag Etching → 6 Resist Stripping

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Ultrasonic Cleaner, 100mL + 20mL Beaker	*30mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Rinsing substrate with acetone 2. Ultrasonic bath for 15min (substrate in 25mL acetone in small beaker, nested in 10mL water in large beaker) 3. Rinsing substrate with acetone followed by isopropanol 4. Blow away residual solvents with N_2	Clean and dustless substrate surface	Cleaning and removal of scratch-protective AZ 1518 layer
2	Spin-coater, Pipette, Hotplate, Light-shielded box	*0.5mL* AZ 1518 (pos. photoresist)	1. Spin-coating AZ1518 Photoresist – use 1"x1" holder (5s ramp-up, 60s 3000rpm, 5s ramp-down) 2. Soft baking at 110°C for 60s (use precise hotplate) 3. Store substrate in a light-shielded box	~2800nm thick AZ 1518 layer, reddish, wavy surface, no grains/bubbles	See appendix Figure **1** for AZ thickness at various rpms
3	Mask aligner exposure unit, Photomask		1. Install electrode photomask + load substrate 2. Perform WEC (Wedge Error Compensation) + alignment of substrate with photomask 3. UV exposure (I-line 365nm, intensity 5.2 mW/cm²) of substrate for 13s with appropriate photomask		If the lamp is at the end of its lifecycle, increase exposure time to 14-17s
4	2x40mL Beaker	*40mL* AZ 726 MIF *(multiple reuse)* *40mL* DI water, *2.5L* N_2	1. Submerge substrate in AZ 726 MIF developer and slowly swing it back and forth for 60s (do not block layout areas with tweezer) 2. Cleaning in DI water for 60s 3. Blow away residual water with N_2	Layout is slightly visible on substrate surface	Removal of exposed photoresist
5	2x40mL Beaker	*40mL* Au etchant (1:10 DI water) *(multiple reuse)* *40mL* DI water, *2.5L* N_2	1. Submerge substrate in gold etchant (also suitable for silver) and slowly swing it back and forth for at least 30s (stop once Ag is completely removed from the exposed areas, do not block the Ag electrode areas with the tweezer) 2. Cleaning in DI water for at least 120s to remove silver oxide surface layer 3. Blow away residual water with N_2	Clean Ag electrode layout is visible without unwanted particles or Ag dots.	If the Ag cannot be removed completely, the exposure time or the development time was too short.
6	Ultrasonic Cleaner, 100mL + 20mL Beaker	*25mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Ultrasonic bath for 15min (substrate in 25mL acetone in 20mL beaker, nested in 10mL water in 100mL beaker) 2. Rinsing substrate with acetone followed by isopropanol 3. Blow away residual solvents with N_2	Clean Ag electrodes (Ag 50nm: 1.14Ω/□) Redo step 6 if silver oxide surface layer is visible.	Cleaning and removal of unexposed photoresist/silver oxide surface layer

System A1: Lithography Ag Electrodes

Additional Information

(A) ATTENTION: This process is not optimized. During the development and etching step of Ag substrates, an oxide surface layer can form, which can be effectively removed by an extensive DI water and acetone cleaning step. Additionally, O_2 plasma cleaning is not recommended for Ag electrode substrates due to the formation of an oxide layer. For further processing of these substrates, please use fabrication techniques without plasma steps.
(B) For structure sizes <10µm, exposure time and development time need to be tuned and precisely timed.
(C) If the glass substrate is contaminated with particles after the final cleaning step, it is recommended to renew the developer solution and/or the gold etchant solution.
(D) Polyimid (PI) as flexible substrate is available. It has to be manually cut into the desired shape and attached to glass substrate using spray glue. Detaching is done using acetone in a ultrasonic cleaner.
(E) As alternative to the SÜSS MicroTec mask aligner system, a Heidelberg Instruments µMLA maskless aligner (365nm, dose 330mJ/cm^2)) for the photoresist exposure (step 3) is available. The layout for the maskless tool needs to be in a .gds file format.
(F) Other photoresist like AZ nLOF 2020 (neg. photoresist, soft baking 110°C for 60s, exposure time 15s, development 60s) and AZ 5214-E (image reversal pos. photoresist, soft baking 110°C for 60s, exposure time 7s) are available in the IAP laboratory.
The Image reversal of AZ 5214-E is achieved by an additional reversal bake step at 120°C for 2min after the inital UV exposure (step 3), followed by a flood exposure (no mask) for 25s. For lift-off processes, the AZ 5214-E thickness should be 1.2-1.5x of the deposited layer and for a sufficient undercut, a 30% over-development is recommended.

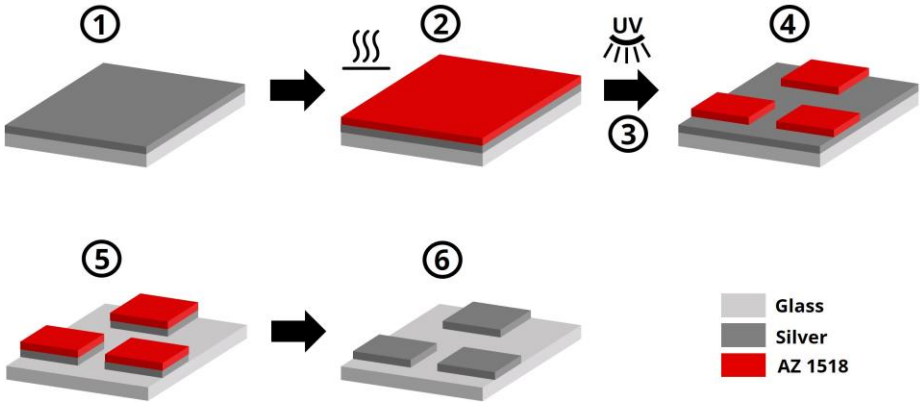
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool and the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
1	Ultrasonic bath: 10x substrates at once 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
2	Hotplate (soft baking): 25x substrates at once	Spin-coating is limited to one substrate at a time.
3	-	Only the maskless tool can process multiple substrates at a time.
4	40mL AZ MIF 726: 25x 40mL DI water: 5x	The same DI water can be used for step 4-6. The developer is disposed of after a maximum of 25 substrates.
5	40mL Au etchant: 25x 40mL DI water: 5x	The same DI water can be used for step 4-6. The Au etchant is disposed of in the Au waste bottle (acid shelf) after a maximum of 25 substrates.
6	Ultrasonic bath: 10x substrates at once 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in the organic solvent waste.

Process Schematic:



System A2: Inkjet Printing Ag Electrodes

This section describes all unit processes involved in the inkjet printing process of silver (Ag) electrodes on a 1"x1" glass substrate using a FUJIFILM Dimatix Materials DMP-2800 inkjet printer equipped with a piezoelectric DoD 12-nozzle 'Samba' cartridge at the IAPP lab. Silver, as an electrode material, offers a significantly lower cost than gold while still providing good electrical conductivity at the expense of electrochemical stability. Inkjet printing is a non-contact, additive fabrication process with localized material positioning which minimizes material waste and process steps. Compared to evaporated layers, inkjet printing offers a lower surface uniformity due to its droplet-shaped layer profile and a minimum lateral resolution of ~30µm. The layer thickness is determined by the number of printed layers and the specific ink properties, but it offers less control compared to evaporated layers. Therefore, this low-cost and environmentally friendly fabrication method is ideal for prototyping and the printing of small- to medium-scale structures where the highest resolution is not required.

Pre-processing

Substrate: 6"x6" glass wafer (Schott Borofloat® 33, composition according to DIN ISO 3585 / EN 1748 T1, thickness of 1.1±0.1mm)
Info: Process done by IAPP Lesker-Team, substrate ordering at https://wiki.iap.phy.tu-dresden.de/index.php?title=Substrates

(1) Wet cleaning process: 10min DI water + 10min ethanol ultrasonic bath (solvent reusable: ~200ml DI water, ~50ml ethanol per wafer)
(2) Removal of residues (12min, 20L DI water) and drying (3min, 100L N_2) in a spin-rinse-dryer
(3) Cutting wafer into 1"x1" substrates

Overview Unit Processes:

45min (1 Substrate)

1 Cleaning → 2 Printer Setup → 3 Ag Printing → 4 Printer Cleanup → 5 Annealing

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Ultrasonic Cleaner, 100mL + 20mL Beaker **OPTIONAL**	*30mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Rinsing substrate with acetone 2. Ultrasonic bath for 15min (substrate in 25mL acetone in small beaker, nested in 10mL water in large beaker) 3. Rinsing substrate with acetone followed by isopropanol 4. Blow away residual solvents with N_2	Clean and dustless substrate surface	Additional surface modification can be done using plasma treatment
2	DMP-2800 Inkjet Printer, ‚Samba' cartridge, Ag fluid module, 1ml syringe, Syringe pump, Tape, la	NovaCentrix JS-A191 Ag ink *(stored in fridge at 5°C)* *50mL* DI water, *10mL* DI water + .1%v/v TritonX-100)	1. Rinse nozzle area of Ag cartridge with DI water 2. Clean cartridge using the syringe pump (withdraw 10mL DI water + 0.1%v/v TritionX-100) 2. Dry cartridge softly with lab tissue 3. Connect Ag fluid module to cartridge - ‚klick' sound (if ink reservoir is nearly empty: fill <1.5mL Ag ink into fluid module using a 1ml syringe and a metal adapter) 4. Start ‚Dimatix Drop Manager' and home the printer 5. Install fluid module + cartridge into inkjet printer 6. Attach lab tissue to cleaning area with tape 7. Close printer cover, select ‚12-jet Samba' cartridge 8. Use ‚Ag_NovaCentrix' setting file 9. Click ‚Run Cleaning Cycle' and perform 1-2 cleaning cycles (‚Purge.3secondsBlot') until ink is visible on tissue 10. Use ‚Drop Watcher' and select working nozzles + adjust voltage for good jetting 11. Click ‚Select Pattern' and choose printing .ptf layout 12. Click ‚Load/Unload Substrate' and place glass substrate on printing area, set substrate thickness to 1150nm	At least 0.5ml of Ag ink in fluid module with no air bubbles. Stable vertical jetting of Ag droplets.	During ink refilling, tilt bottle/fluid module and transfer ink slowly to prevent air bubbles. If air bubbles are present in the module, use the vacuum chamber for degassing. For better substrate adhesion, cover all vacuum suction holes of the print area with a lab paper and turn on vacuum in ‚Load/Unload Substrate' tab.
3	DMP-2800 Inkjet Printer, ‚Samba' cartridge, Ag fluid module	*10µL -50µL* NovaCentrix JS-A191 Ag ink *(per substrate, depending on cleaning cycles and test prints)*	1. Click ‚Fiducial Camera', correct angular substrate offset with ‚Tools' + 'Calibrate Theta' 2. Click ‚Set Print Origin' select position of print origin 3. Click ‚Print Set-Up' tab and check all settings 4. Inkjet printing of Ag electrodes (Settings: 12µm drop spacing, jetting voltage 27-30V, 1-2 layer, no cartridge temperature, use 1-2 nozzles)	Good Ag connection with consistent sharp layout edges, no ink droplets outside the intended pattern	For reliable printing results do multiple test prints on a lab paper with all nozzles enabled. For the final print on glass, use only 1-2 good nozzles
4	DMP-2800 Inkjet Printer, ‚Samba' cartridge, Ag fluid module	*50mL* DI water, *10mL* DI water + .1%v/v TritonX-100)	1. Click ‚Load/Unload Substrate' and unload substrate 2. Click ‚Replace Cartridge' and uninstall fluid module + cartridge, remove lab tissue from cleaning area 3. Separate fluid module from cartridge 4. Rinse nozzle area of Ag cartridge with DI water 5. Clean cartridge using the syringe pump (withdraw 10mL DI water + 0.1%v/v TritionX-100) 6. Store cartridge in Ag container (filled with DI water)	Clean cartridge without any ink residues	Store fluid modules with residual ink in fridge at 5°C for reuse.
5	Hotplate		Annealing at 120°C for 30min (90°C is possible, but requires more time for good conductivity)	1 layer has 1.28Ω/□ and avg. thickness of 1.4µm (droplet-shaped profile)	See appendix Figure **2** for profile shape and thickness relation

System A2: Inkjet Printing Ag Electrodes

Additional Information

(A) Ink Properties: viscosity 10-12mPa·s (max. 30mPa·s), surface tension 28-33mN/m (max. 70mN/m), boiling point >80°C
(B) Printing Layout: Use Paint or similar programs and draw the print layout in black, with 1px corresponding to the drop spacing in µm. Save the layout as a monochromatic .bmp file. Open a random .ptf print file in Dimatix software, and load the new print layout by clicking ‚File' + ‚Open .bmp'. Set the correct drop spacing and convert the layout to a print file by clicking ‚File' + ‚Save as .ptf'.
(C) Polyimid (PI) and tempered polyactide (PLA) as flexible substrates are available. They have to be manually cut into the desired shape and attached to a glass substrate using spray glue if the substrate by itself is not flat. Detaching is done using acetone in a ultrasonic cleaner. Do not expose tempered PLA substrates to temperatures above 90°C.
(D) If none of the nozzles yields a good and consistent jetting, wait for 15min to allow the ink to settle and try again.
(E) Printing with enabled ‚Leader Bar' can increase the quality of small structures.
(F) The thickness and profile shape of inkjet printed Ag electrodes strongly depends on the lateral size of the printed structure and the the drop spacing parameter. Lateral structures smaller than 1mm exhibit a symmetric droplet-shaped profile, while larger ones have an asymmetric profile with a pronounced height peak close to the electrode edge. To achieve consistent height profiles across different structure sizes, the drop spacing parameter must be optimized, and the layout adjusted accordingly.

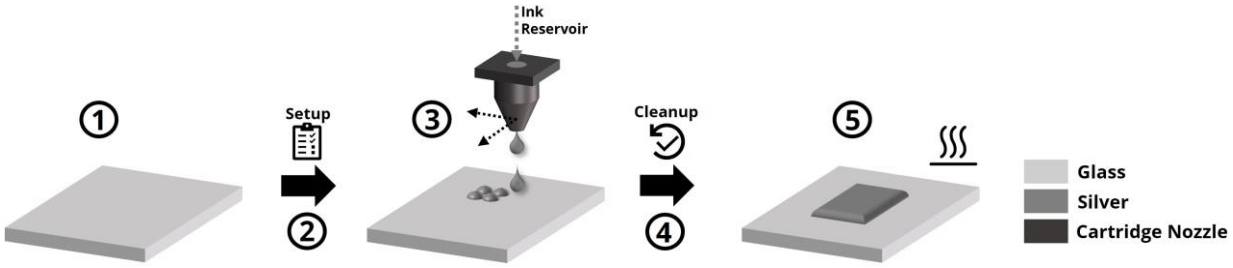
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
1	Ultrasonic bath: 10x substrates at once 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
2	-	
3	Inkjet printer: 5x substrates at once (total time ~1h) JS-A191 Ag ink: 25% reduction	For 5 substrates only a single printer setup is necessary, and the cleaning cycles can be optimized.
4	-	
5	Hotplate (annealing): 25x substrates at once	

Process Schematic:



System A3: Screen Printing Ag Electrodes

This section describes all unit processes involved in the screen printing process of silver (Ag) electrodes on a 1"x1" glass substrate using an EKRA E2 semi-automatic screen printer at the IAPP lab. Silver, as an electrode material, offers a significantly lower cost than gold while still providing good electrical conductivity at the expense of electrochemical stability. Screen printing is an additive fabrication process in which a squeegee is used to transfer ink through a patterned mesh onto a substrate. Like inkjet printing, this method minimizes material waste and process steps while offering easier production scalability. However, it comes with trade-offs, including an uneven layer surface, a minimum lateral resolution of ~1200µm, and layer thicknesses of up to several micrometers, which are mainly defined by the mesh screen density and ink properties. Therefore, this low-cost and environmentally friendly fabrication method is ideal for prototyping and the printing of medium- to large-scale structures where high production throughput and efficiency are needed.

Pre-processing

Substrate: 6"x6" glass wafer (Schott Borofloat® 33, composition according to DIN ISO 3585 / EN 1748 T1, thickness of 1.1±0.1mm)
Info: Process done by IAPP Lesker-Team, substrate ordering at https://wiki.iap.phy.tu-dresden.de/index.php?title=Substrates

(1) Wet cleaning process: 10min DI water + 10min ethanol ultrasonic bath (solvent reusable: ~200ml DI water, ~50ml ethanol per wafer)
(2) Removal of residues (12min, 20L DI water) and drying (3min, 100L N_2) in a spin-rinse-dryer
(3) Cutting wafer into 1"x1" substrates

Screen Preparation:

(1) Manually coat both sides of a clean screen with a thin, uniform Foteco FOTECOAT 1105 photoresist layer using an emulsion scoop coater
(2) Soft-baking at 40°C in a BELTRON screen drying cabinet until screen is completely dry (30-45min)
(3) Print desired layout on a transparent DIN A4 foil (monochrome black, 1200x1200dpi, repeat printing 3x for thicker layer)
(4) Place the foil and the coated screen in a Vastex E-200 screen exposure unit (5min vacuum evacuation, 0.8min exposure time)
(5) Wash out exposed screen area with a high-pressure water stream using a Bosch EasyAquatak120 and use cloth to remove excess water
(6) Drying at 40°C in a BELTRON screen drying cabinet until screen (30-45min)

Overview Unit Processes:

30min (1-25 Substrates)

1 Cleaning → 2 Printer Setup → 3 Ag Printing → 4 Printer Cleanup → 5 Annealing

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Ultrasonic Cleaner, 100mL + 20mL Beaker **OPTIONAL**	*30mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Rinsing substrate with acetone 2. Ultrasonic bath for 15min (substrate in 25mL acetone in small beaker, nested in 10mL water in large beaker) 3. Rinsing substrate with acetone followed by isopropanol 4. Blow away residual solvents with N_2	Clean and dustless substrate surface	Additional surface modification can be done using plasma treatment
2	E2 screen printer, Print squeegee, Flood squeegee, Screen		1. Activate ‚Control' and perform ‚Basic Position' procedure 2. Turn on vacuum pump and activate ‚Vacuum' 3. Place substrates on print table and cover all remaining vacuum suction holes with a thin foil 4. Place screen in mounting and click ‚Transport' twice 5. Move print table up (‚Table up/down') 6. Align screen layout with the substrate positio; fix screen in place by activating ‚Screen clamping' 7. Install print and flood squeegee 8. Adjust substrate thickness in printing parameters (1.0mm for glass substrates) 9. **Adjust pressure of print squeegee** (move print squeegee to the middle of the substrate position by holding ‚Print'; move print squeegee down (‚Squeegee up/down'); turn pressure adjuster clockwise until you feel resistance, then anticlockwise by ~2 turns; raise print squeegee (‚Squeegee up/down') 10. **Adjust height of flood squeegee** (Hold ‚Print' until end of print area is reached and the table moves down; move flood squeegee down (‚Squeegee up/down'); turn pressure adjuster until there is no gap between screen and flood squeegee; raise print squeegee (‚Squeegee up/down') 11. Hold ‚Print' until start position is reached or use ‚Basic Position' 12. Adjust print speed and start/end position in printing parameters		The 1st click on 'Transport' will activate the vacuum of the print stage, the 2nd click moves the print stage beneath the screen. Shine a flashlight behind the flood squeegee to check if light passing through the gap between screen and flood squeegee. Stop adjusting the height once the gap is closed. The screen printer will only permit automatic movements when all covers are closed.

System A3: Screen Printing Ag Electrodes

3	E2 screen printer, Print squeegee, Flood squeegee, Screen	*1g* DYCOTEC DM-SIP-3060S Ag ink *(quantity depends on the structure and layout size)*	1. Distribute a generous amount of Ag ink in a continuous line between print squeegee and screen layout 2. Hold ‚Print' until print squeegee reaches end of print area 3. Click ‚Transport' and evaluate printed Ag electrodes 4. If electrode quality is bad, move ink back to the start position using the lowered flood squeegee and reprint	Good Ag connection with consistent sharp layout edges, no smeared ink traces on substrate	Make sure that the Ag ink is distributed along the entire length of the print squeegee to reduce friction and wear of the screen.
4	Drying cabinet, EasyAquatak120, Print squeegee, Flood squeegee, Screen, Cleaning cloth	*10mL* PGMEA, *10mL* Ethanol, *1L* Water hard to clean: 2-Butoxyethanol *(quantity depends on the screen layout size)*	1. Gently recover residual ink from the screen for reuse 2. Use PGMEA and cleaning cloths remove remaining non-recoverable Ag ink on the screen; clean screen afterwards with ethanol (to prevent tearing, apply counterpressure with another cloth on the underside while cleaning the top side) 3. Cleaning of print and flood squeegee 4. Cleaning of screen using high-pressure water stream 5. Dry the screen at 40°C in a drying cabinet for 30-45min	Clean screen without any leftover Ag ink	**ATTENTION!** Lab ventilation and exhaust hood needed during cleaning step.
5	Hotplate		Annealing at 120°C for 30min (90°C is possible, but requires more time for good conductivity)	Layer printed with 165-31 mesh has 0.11Ω/□ and avg. thickness of 3.2µm with a rough surface	See appendix Figure **3** for profile shape and thickness relation

Additional Information

(A) Ink Properties: viscosity 2-10Pa·s, surface tension 20-70mN/m

(B) Polyimid (PI) and tempered polyactide (PLA) as flexible substrates are available. They have to be manually cut into the desired shape and can be attached to a glass substrate using spray glue if the substrate is not flat. Detaching is done using acetone in a ultrasonic cleaner. Do not expose tempered PLA substrates to temperatures above 90°C.

(C) A wide range of screen sizes with different mesh specifications are available at IAPP. The mesh, made from polyester fabric, is characterized by **mesh counts (threads per cm) – thread diameter (µm)**, which defines the max. deposited theoretical ink volume and thereby the thickness of the layer (see more at https://www.koenen.de/en/products/meshes-and-frames/polyesterfabric.html): **165-31** (43x53cm, 50x60cm, 54x64cm), **120-34** (50x60cm), **90-40** (47x55cm), **61-64** (30x40cm, 47x55cm, 54x64cm, 63x73cm), **36-90** (43x53cm, 54x64cm), **24-140** (54x64cm)

(D) A variety of conductive screen printing inks for electrodes are available: C ink, Zn ink(experimental), Cu ink (experimental), cellulose-based micro-particle Ag ink (annealing possible at 30°C for 24h), Ag/AgCl ink (annealing 120°C for 30min, cleaning with 2-ethoxy-1-propanol). Cleaning of the screens after printing is normally done using only ethanol.

(E) Activate ‚Automatic' mode after the first print to speed up the fabrication process for multiple subsequent prints using the same layout. Only the substrate needs to be changed manually, and the printing will resume automatically once the print table cover is closed. It is recommended to use the ‚MOPS' camera system to fine-tune the alignment of the substrate before the next print starts.

(F) Number all substrates involved in a print if a second layer with a different layout is planned. Before starting the second print, ensure the substrates are positioned exactly as they were previously to minimize alignment issues.

(G) To remove an existing layout from a screen, apply Foteco FOTOCHEM 1170E decoater solution to both sides, followed by a high-pressure water stream cleaning process until the old photoresist is completely removed. Next, spray both sides of the screen with Foteco FOTOCHEM 1190P degreasing solution, and clean again with a high-pressure water stream. Use a cloth to remove excess water and dry the screen at 40°C in the drying cabinet until for 30-45min.
ATTENTION: Wear an air-purifying respirator and googles during the decoating and degreasing process!

A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

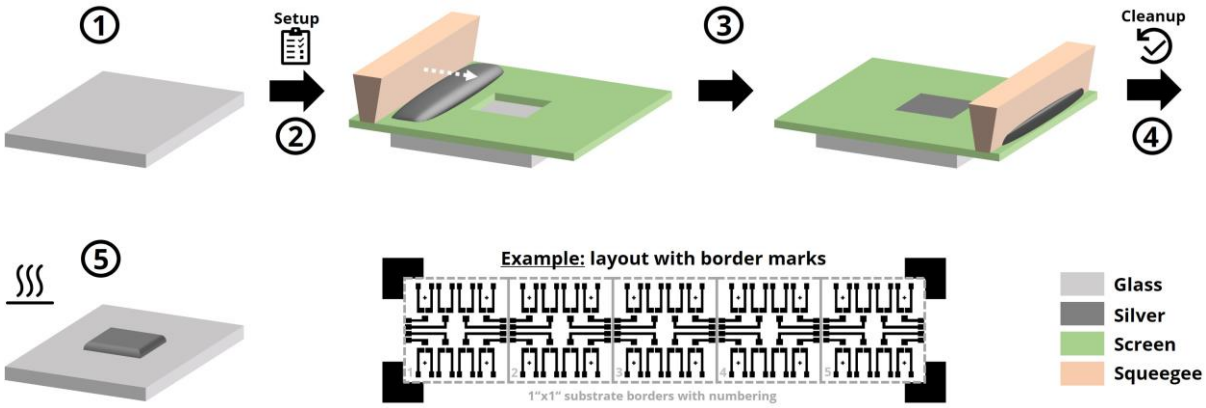
Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
1	Ultrasonic bath: 10x substrates at once 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
2	-	-
3	Screen printer: 25x substrates at once (total time ~30min) DM-SIP-3060S Ag ink: 1g for up to 25 substrates in one run	For 25 substrates only a single printer setup is necessary, and the impact of the non-recoverable Ag ink on the screen is reduced
4	-	-
5	Hotplate (annealing): 25x substrates at once	

System A3: Screen Printing Ag Electrodes

Process Schematic:



System A4: Microplotting Ag Electrodes

This section describes all unit processes involved in the microplotting process of silver (Ag) electrodes on a 1"x1" glass substrate using a Sonoplot Microplotter Proto at the IAPP lab. Silver, as an electrode material, offers a significantly lower cost than gold while still providing good electrical conductivity at the expense of electrochemical stability. Microplotting uses a precision ultrasonic plotter technology for rapid and localized material positioning with minimum feature sizes of 20µm - 200µm, depending on the micropipette diameter. Like inkjet printing, this method minimizes material waste and process steps while still enabling the printing of higher-viscosity inks. However, the thickness of a printed layer is not directly adjustable, and the substrate surface must be relatively flat to avoid damaging the micropipette tip. Therefore, this ultra-low-cost and environmentally friendly fabrication method is ideal for prototyping and small- to medium-scale structures where the highest precision and layer thickness control are not required.

Pre-processing

Substrate: 6"x6" glass wafer (Schott Borofloat® 33, composition according to DIN ISO 3585 / EN 1748 T1, thickness of 1.1±0.1mm)
Info: Process done by IAPP Lesker-Team, substrate ordering at https://wiki.iap.phy.tu-dresden.de/index.php?title=Substrates

(1) Wet cleaning process: 10min DI water + 10min ethanol ultrasonic bath (solvent reusable: ~200ml DI water, ~50ml ethanol per wafer)
(2) Removal of residues (12min, 20L DI water) and drying (3min, 100L N_2) in a spin-rinse-dryer
(3) Cutting wafer into 1"x1" substrates

Overview Unit Processes:

20min (1 Substrate)

1 Cleaning → **2** Printer Setup → **3** Ag Printing → **4** Printer Cleanup → **5** Annealing

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Ultrasonic Cleaner, 100mL + 20mL Beaker **OPTIONAL**	*30mL* Acetone, *5mL* Isopropanol, *10mL* DI water, *2.5L* N_2	1. Rinsing substrate with acetone 2. Ultrasonic bath for 15min (substrate in 25mL acetone in small beaker, nested in 10mL water in large beaker) 3. Rinsing substrate with acetone followed by isopropanol 4. Blow away residual solvents with N_2	Clean and dustless substrate surface	Additional surface modification can be done using plasma treatment
2	Microplotter, Pipette	*50µL* NovaCentrix JS-A191 Ag ink *(stored in fridge at 5°C)*	1. Start software ‚SonoGuide', remove dust cover and home printer 2. Install dispenser cartridge + click ‚Calibrate Dispenser' 3. Turn on light in ‚Camera Settings' and adjust the xyz-thumbscrews until the micropipette tip is visible in the live camera feed (field of view 1.2mm) 4. Place substrate on print stage and manually move tip with direction controls to desired print position (maintain >1mm z-distance from the surface) 5. Click ‚Find Surface' to automatically lower tip until surface is reached and manually retract by 20-50µm. For fine adjustments, use direction controls, and save print position at z-distance of 20-50µm from the surface 6. Click ‚Safe Height' and manually move tip with direction controls to the middle of solution well A1 (~1mm z-distance) and click ‚Set A1 well' to align printer with the solution plate 7. Fill 50µL of Ag ink into an empty solution well 8. Select Ag ink well number in ‚Solution plate' tab to automatically move tip to ink reservoir; decrease manually z-position until tip is submerged in ink reservoir and wait for the micropipette to load the ink due to the capillary effect 9. Load .dxf print geometry by clicking ‚File' + ‚Opening Pattern' and manually change the crosshair position (indicating tip start position for print) to upper left corner of print geometry	Micropipette is filled with Ag ink	**ATTENTION!** Avoid any direct contact with the fragile micropipette tip to prevent damage. Always ensure that the tip is not in contact with the substrate surface before using the direction controls. If print geometry exceeds size of 1x1mm, perform 'Calibrate Surface' after step 4 to prevent tip damage due to surface height variations.
3	Microplotter	*10µL* NovaCentrix JS-A191 Ag ink	1. Select the saved print start position to automatically move tip to substrate start position 2. Perform dispenser calibration and click ‚Find Surface' 3. Adjust dispensing strength (2.5V – 4.5V) in ‚Dispenser Controls tab' 4. **Test:** Perform a manual dispensing test with 0.2s duration to ensure that the dispensing strength is suitable for ejecting the ink (ideally, this test should be done with a small offset to the planned start position) 5. **Print:** Press Strg + P to open the print window, select dispensing mode and print	Good Ag connection with consistent layout edges and uniform ink deposition	Increase dispensing strength if the ink fails to eject; decrease it if too much ink is dispensed. Ensure that the ink droplet is in contact with the tip and the surface.

System A4: Microplotting Ag Electrodes

4	Pipette, Lab tissue	*1mL* DI water *1mL* Isopropanol	1. Click ‚Safe Height' to automatically retract tip 2. Cleaning of the micropipette (use manual spraying mode at 12-20V with 5-10s duration to eject unused Ag ink into a lab tissue; fill isopropanol/DI water into an empty well; load the micropipette with it and eject again; repeat until the micropipette is clean) 3. Recover unused Ag ink in solution well and clean everything with isopropanol and DI water 4. Home printer and protect setup with the dust cover	Clean micropipette and solution plate, ready for re-use	Do not touch the micropipette tip with the lab tissue! Alternatively, use a waste well for the ejection of the ink.
5	Hotplate		Annealing at 120°C for 30min	Clean Ag electrodes	90°C is possible, but requires more time for good conductivity

Additional Information

(A) Ink Properties: viscosity <450mPa·s, surface tension 20-40mN/m
(B) Printing Layout: Use KLayout or similar programs to draw print geometry as path, setting the path width to match the tip diameter. Leave a small gap at the end of the path to have a uniform ink deposition at this position. Save the print layout as a hatch entity in a .dxf file format (refer to the process schematic for an example).
(B) It is recommended to use only relatively flat substrates and the surface calibration option to prevent damage to the tip during printing. If the print area is already covered with a soft layer, maintain a z-distance of 20-30µm to the surface during printing to avoid scratching the underlying layer (adjust dispensing strength if necessary, ensure that droplet remains in contact with tip and surface)
(C) If the micropipette tip is clogged, try to use dispensing mode at a higher voltage strength or spraying mode for 1-2s to clear the blockage or perform the micropipette cleaning procedure.
(D) The Microplotter allows the automatic handling (loading ink, printing, ejecting into waste well, rinsing in solvent well) of multiple inks by defining them in the ‚Solutions' tab. Please refer to the manual at https://sonoplot.com/donwloads.

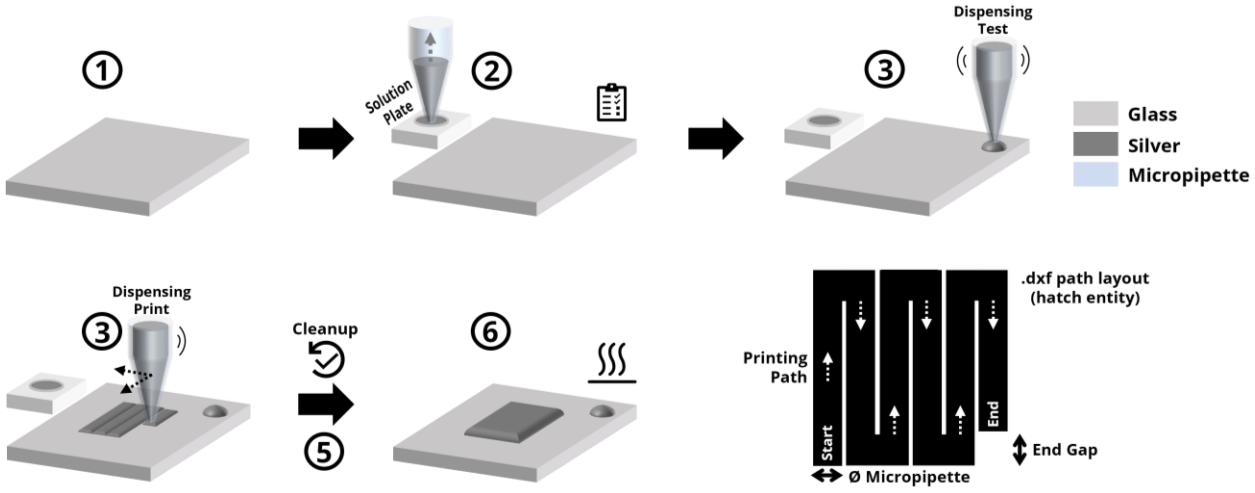
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
1	Ultrasonic bath: 10x substrates at once 25ml Acetone (ultrasonic) 5x (2 substrates at once) 10ml DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in the organic solvent waste.
2	-	
3	Microplotter: 1x substrates at once	No upscaling is possible.
4	-	
5	Hotplate (annealing): 25x substrates at once	

Process Schematic:



Fabrication System B

- PEDOT:PSS Patterning -

System B1: Lithography PEDOT:PSS

This section describes all unit processes involved in the lithographic patterning of poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) on a 1"x1" glass substrate with pre-patterned electrodes at the IAPP lab. PEDOT:PSS is a well-studied OMIEC material known for its good solution processability, widespread commercial availability, high electrochemical stability, and excellent conductivity. Spin-coating is used to apply PEDOT:PSS, resulting in a uniform layer with an adjustable thickness ranging from 70nm to 300nm, depending on the rotational speed. Using lithography as an industry-standard patterning process, lateral resolutions of 1µm can be achieved. Therefore, this method is ideal for precise, small-scale structures, but comes with drawbacks like high energy and chemical consumption and larger operational costs compared to printing techniques. In particular, the use of hydrofluoroethers (HFE) based solvents in the OSCoR photoresist and associated developer and stripper solutions results in a significant environmental impact.

Pre-processing

Substrate: 1"x1" glass (d=1.1±0.1mm) or PI substrate with pre-patterned electrodes (for more details refer to system processes A1-A4)
Info: This system involves reactive plasma etching steps, which may result in undesired formation of an oxide layer on Ag electrodes
Recommended prior system: A1 - lithography of highly planar Au/Cr electrodes

Clean substrate condition needed – perform cleaning procedure if necessary:
(1) Ultrasonic bath for 15min in acetone (25mL)
(2) Rinsing substrate with acetone (5mL) followed by isopropanol (5mL)
(4) Blow away residual solvents with N_2 (2.5L)

Overview Unit Processes:

6h (1-4 Substrates)

1 Plasma Cleaning → 2 PEDOT:PSS Coating → 3 Resist Coating → 4 UV Exposure → 5 Development → 6 Plasma Etching → 7 Resist Stripping → 8 Cleaning

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Plasma cleaner	*250mL* O_2 *50L* N_2 (Venting 2x)	Reactive O_2 plasma cleaning of substrate surface for 5min (program ‚O2_cleaning_300s', RF Generator 50W and 250V, 30ml_n/min O_2, start at 8.0e-05mbar)	Clean, dustless and reactive substrate surface	Enhancing substrate wettability for PEDOT:PSS coating
2	Spin-coater, Pipette, Hotplate	*0.5mL* PEDOT:PSS (Clevios PH1000 + 5%v/v EG)	1. Spin-coating PEDOT:PSS – use 1"x1" holder (5s ramp-up, 60s 3000rpm, 5s ramp-down) 2. Annealing at 120°C for 20min 3. Allow cooling of substrate for at least 2min	~75nm thick PEDOT:PSS layer, blueish color, evenly spread	See appendix Figure **4** for PEDOT:PSS thickness at various rpms
3	Spin-coater, Pipette, Hotplate, Light-shielded box	*0.5mL* OSCoR 4020 (neg. photoresist) *(stored in fridge at 5°C)*	1. Spin-coating OSCoR 4020 Photoresist (5s ramp-up, 60s 3000rpm, 5s ramp-down) 2. Soft baking at 100°C for 60s (use precise hotplate) 3. Store substrate in a light-shielded box	~1100nm thick OSCoR 4020 layer, transparent	Allow the photoresist to reach room temperature before spin-coating
4	Mask aligner, Photomask, Hotplate		1. Install PEDOT:PSS photomask + load substrate 2. Perform WEC (Wedge Error Compensation) + alignment of pre-patterned electrodes with photomask 3. UV exposure (I-line 365nm, intensity 5.2 mW/cm^2) of substrate for 14s 4. Post-baking at 100°C for 60s (use precise hotplate)		If the lamp is at the end of its lifecycle, increase exposure time to 15-18s
5	Spin-coater, Pipette, Microscope	*2x1mL* Orthogonal Developer 103a **or** Developer 100	1. Place substrate on spin-coater - use 1"x1" holder 2. Cover entire substrate surface with developer, wait 60s 3. Spin-coating for removal of developer (5s ramp-up, 45s 3000rpm, 5s ramp-down) 4. Repeat step 3 with 30s waiting time 5. Check with microscope if unexposed OSCoR layer is completely removed - if not, repeat procedure with 20s waiting time	OSCoR protective layer only in channel/gate area, no ‚rainbow' colors on substrate or other artifacts (check with microscope)	Long interaction time with the developer may compromise integrity of the protective OSCoR layer
6	Plasma cleaner, Multimeter	*160mL* O_2, *30mL* Ar, *50L* N_2 (venting 2x)	1. Reactive O_2/Ar plasma etching of surface for 75s (program ‚PEDOT_75s', RF Generator 50W and 250V, 30ml_n/min O_2, 10ml_n/min Ar, start at 8.0e-05mbar) 2. Multimeter check of channel resistance and parasitic connections (e.g. source/drain - gate connection) 3. If parasitic connections are detected, repeat plasma etching step for 20s – be careful not to overetch!	Source-drain resistance 150Ω – 300Ω (reference layout), no parasitic connections	Removal of undesired PEDOT:PSS ‚OECT_same' layout: 150Ω -250Ω as channel resistance
7		*40mL* Orthogonal Stripper900 *(stored in screw cap tube, multiple reuse)*	Submerge substrate in stripper, wait at least 4h but not longer than 24h to avoid potential adhesion problems with inkjet printable SSE (refer to system process C2)		Removal of protective OSCoR layer on top of PEDOT:PSS
8	Ultrasonic cleaner, 100mL + 20mL Beaker	*25mL* Ethanol, *10mL* DI water	1. Ultrasonic bath with ethanol for 15min (substrate in 25mL ethanol in small beaker, nested in 10mL water in large beaker) 2. Store substrates in glovebox with N_2 atmosphere (if SSE will not be applied immediately afterwards)	Clean patterned PEDOT:PSS on channel and gate	Cleaning and removal of residual stripper

System B1: Lithography PEDOT:PSS

Additional Information

(A) For structure sizes <10µm, exposure time and development time need to be tuned and precisely timed.
(B) As alternative to the SÜSS MicroTec mask aligner system, a Heidelberg Instruments µMLA maskless aligner (365nm, dose 330mJ/cm^2) for the photoresist exposure (step 4) is available. The layout for the maskless tool needs to be in a .gds file format.

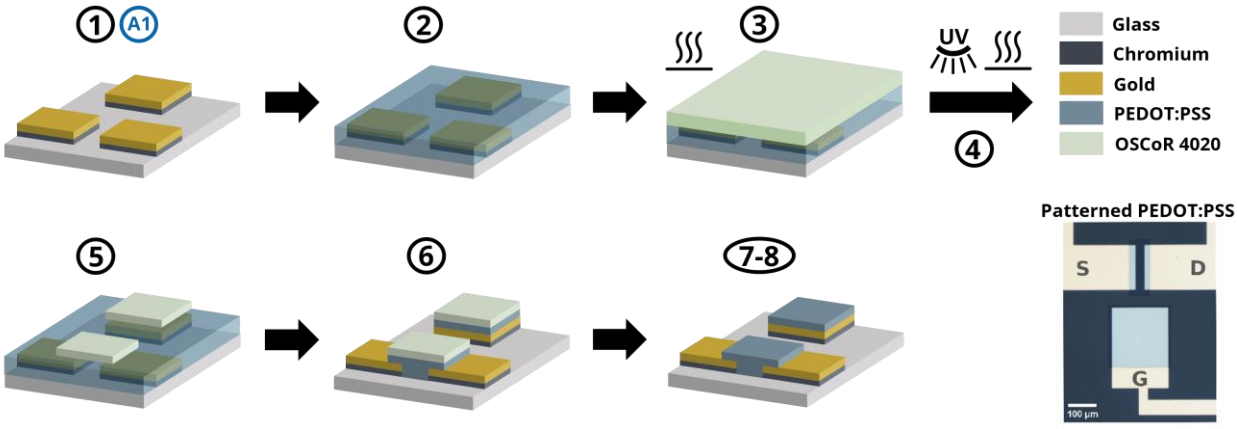
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool and the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
PRE	Ultrasonic bath: 10x substrates at once (5x beaker setup) 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 50x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
1	Plasma etcher: 25x substrates at once (250mL O_2 and 50L N_2 fixed amounts per run)	
2	Hotplate (annealing): 25x substrates at once	Spin-coating is limited to one substrate at a time.
3	Hotplate (soft baking): 25x substrates at once	Spin-coating is limited to one substrate at a time.
4	Hotplate (post-baking): 25x substrates at once	Only the maskless tool can process multiple substrates at a time.
5	-	Spin-coating is limited to one substrate at a time.
6	Plasma etcher: 25x substrates at once (160mL O_2, 30mL Ar and 50L N_2 fixed amounts per run)	
7	40mL Stripper900: 100x (4 substrates at once)	The stripper solution is disposed of in halogenated solvent waste.
8	Ultrasonic bath: 10x substrates at once (5x beaker setup) 25mL Ethanol (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 50x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in ethanol. Ethanol is disposed of in organic solvent waste.

Process Schematic:



System B2: Inkjet Printing PEDOT:PSS

This section describes all unit processes involved in the inkjet printing process poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) on a 1"x1" glass substrate with pre-patterned electrodes using a FUJIFILM Dimatix Materials DMP-2800 inkjet printer equipped with a piezoelectric DoD 12-nozzle 'Samba' cartridge at the IAPP lab. PEDOT:PSS is a well-studied OMIEC material known for its good solution processability, widespread commercial availability, high electrochemical stability, and excellent conductivity. Inkjet printing is a non-contact, additive fabrication process with localized material positioning which minimizes material waste and process steps. Compared to lithography, it offers a significantly lower surface uniformity due to its irregular droplet-shaped layer profile and a minimum lateral resolution of ~30µm. The layer thickness is determined by the number of printed layers and the specific ink properties. While this method offers less precise control than spin-coated layers, it allows for the deposition of significantly thicker films. Therefore, this low-cost and environmentally friendly fabrication method is ideal for prototyping and the printing of small- to medium-scale structures where the highest resolution is not required.

Pre-processing

Substrate: 1"x1" glass (d=1.1±0.1mm) or PI substrate with pre-patterned electrodes (for more details refer to system processes A1-A4)
Recommended prior system: A1 (lithography), A2 (inkjet printing), A3 (screen printing), A4 (microplotting)

Clean substrate condition needed – perform cleaning procedure if necessary:
(1) Ultrasonic bath for 15min in acetone (25mL)
(2) Rinsing substrate with acetone (5mL) followed by isopropanol (5mL)
(4) Blow away residual solvents with N_2 (2.5L)

PEDOT:PSS Inkjet Ink Preparation:

(1) Mixing together 1:1 volume ratio of PEDOT:PSS and DI water + 5%v/v DMSO + 1%v/v TritonX-100
(2) Stirring of the ink solution at room temperature for at least 30min
(3) Filtration of the ink solution using a 0.45µm PVDF filter into a clean bottle (label ‚Filtered PEDOT:PSS ink ' + date)

Overview Unit Processes:

45min (1 Substrate)

1 Printer Setup → **2** PEDOT:PSS Printing → **3** Printer Cleanup → **4** Annealing

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	DMP-2800 Inkjet Printer, ‚Samba' cartridge, PEDOT:PSS fluid module, 1ml syringe, Syringe pump, Tape, Lab tissue	PEDOT:PSS ink *(filtered and stored in fridge at 5°C)* *50mL* DI water, *10mL* DI water + .1%v/v TritonX-100)	1. Rinse nozzle area of PEDOT:PSS cartridge with DI water 2. Clean cartridge using the syringe pump (withdraw 10mL DI water + 0.1%v/v TritionX-100) 2. Dry cartridge softly with lab tissue 3. Connect PEDOT:PSS fluid module to cartridge - ‚klick' sound (if ink reservoir is nearly empty: fill <1.5mL PEDOT:PSS ink into fluid module using a 1ml syringe and a metal adapter) 4. Start ‚Dimatix Drop Manager' and home the printer 5. Install fluid module + cartridge into inkjet printer 6. Attach lab tissue to cleaning area with tape 7. Close printer cover, select ‚12-jet Samba' cartridge 8. Use ‚PEDOT_PSS' setting file 9. Click ‚Run Cleaning Cycle' and perform 1-2 cleaning cycles (‚Purge.3secondsBlot') until ink is visible on tissue 10. Use ‚Drop Watcher' and select working nozzles + adjust voltage for good jetting 11. Click ‚Select Pattern' and choose printing .ptf layout 12. Click ‚Load/Unload Substrate' and place glass substrate on printing area, set substrate thickness to 1150nm	At least 0.5ml of PEDOT:PSS ink in fluid module with no air bubbles. Stable vertical jetting of PEDOT:PSS droplets.	During ink refilling, tilt bottle/fluid module and transfer ink slowly to prevent air bubbles. If air bubbles are present in the module, use the vacuum chamber for degassing. For better substrate adhesion, cover all vacuum suction holes of the print area with a lab paper and turn on vacuum in ‚Load/Unload Substrate' tab.
2	DMP-2800 Inkjet Printer, ‚Samba' cartridge, PEDOT:PSS fluid module	*10µL -50µL* PEDOT:PSS ink *(per substrate, depending on cleaning cycles and test prints)*	1. Click ‚Fiducial Camera', correct angular offset to the pre-patterned electrodes with ‚Tools' – 'Calibrate Theta' 2. **Test:** Select origin of test print by using ‚Set Print Origin' at a designated test area, click on ‚Print Set-Up' tab and check all settings and print (Settings: 12µm drop spacing, jetting voltage 25-30V, 2-3 layers, cartridge temperature 31-33°C, only 1-2 nozzles) 3. Evaluate xy-offset of test print to the print origin 4. **Print:** Select origin of print by using ‚Set Print Origin' and align it with the pre-patterned electrodes while accounting for the xy-offset, perform inkjet printing of layout with same settings as test print	PEDOT:PSS layout with consistent sharp edges and good alignment with the electrodes, no ink droplets outside the intended pattern	The actual start of the print layout will always differ up to 50µm from the chosen print origin. A test print is a mandatory step to evaluate the xy-offset of this displacement for accurate alignment of small structures.

System B2: Inkjet Printing PEDOT:PSS

3	DMP-2800 Inkjet Printer, ‚Samba' cartridge, PEDOT:PSS fluid module	*50mL* DI water, *10mL* DI water + .1%v/v TritonX-100)	1. Click ‚Load/Unload Substrate' and unload substrate 2. Click ‚Replace Cartridge' and uninstall fluid module + cartridge, remove lab tissue from cleaning area 3. Separate fluid module from cartridge 4. Rinse nozzle area of PEDOT:PSS cartridge with DI water 5. Clean cartridge using the syringe pump (withdraw 10mL DI water + 0.1%v/v TritionX-100) 6. Store cartridge in PEDOT container (filled with DI water)	Clean cartridge without any ink residues	Store fluid modules with residual ink in fridge at 5°C for reuse.
4	Hotplate		Annealing at 120°C for 20min	2 layers have avg. thickness of 115nm (irregular droplet-shaped profile)	See appendix Figure **3** for profile shape and thickness relation

Additional Information

(A) Ink Properties: viscosity 10-12mPa·s (max. 30mPa·s), surface tension 28-33mN/m (max. 70mN/m), boiling point >80°C
(B) Printing Layout: Use Paint or similar programs and draw the print layout in black, with 1px corresponding to the drop spacing in µm. Save the layout as a monochromatic .bmp file. Open a random .ptf print file in Dimatix software, and load the new print layout by clicking ‚File' + ‚Open .bmp'. Set the correct drop spacing and convert the layout to a print file by clicking ‚File' + ‚Save as .ptf'.
(C) Polyimid (PI) and tempered polyactide (PLA) as flexible substrates are available. They have to be manually cut into the desired shape and attached to a glass substrate using spray glue if the substrate by itself is not flat. Detaching is done using acetone in a ultrasonic cleaner. Do not expose tempered PLA substrates to temperatures above 90°C.
(D) Inkjet printing of PEDOT:PSS will result in clogged nozzles due to polymer accumulation over time. It is recommended to filter the ink of the fluid module weekly, perform regular cleaning cycles during the printing and avoid leaving the printer with installed PEDOT:PSS cartridge idle for extended periods.
(E) Inkjet printing of single small (< 200x200µm) PEDOT:PSS geometries will typically result in bad prints. Printing quality can be improved if multiple small geometries are printed in a row at the same time. Printing with an enabled ‚Leader Bar' can also increase the quality of small structures.
(F) The thickness and profile shape of inkjet printed PEDOT:PSS strongly depends on the lateral size of the printed structure and the the drop spacing parameter. To achieve consistent height profiles across different structure sizes, the drop spacing parameter must be optimized, and the layout adjusted accordingly. However, for structure sizes <1mm, the profile shapes are largely comparable.

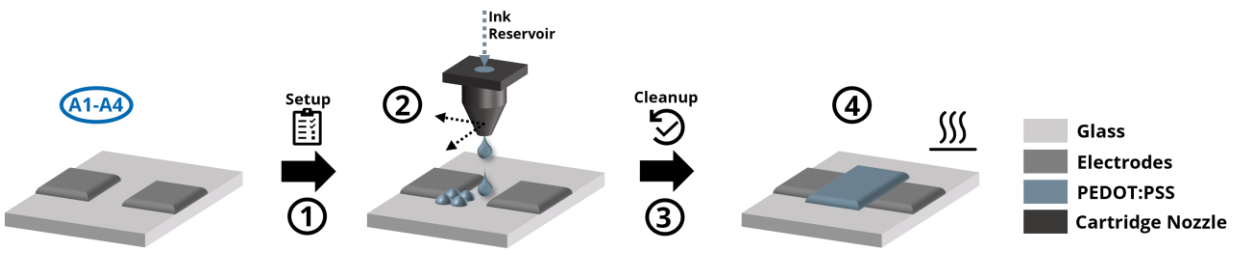
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
P **R** **E**	Ultrasonic bath: 10x substrates at once 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
1	-	
2	Inkjet printer: 5x substrates at once (total time ~1h) PEDOT:PSS ink: 25% reduction	For 5 substrates only a single printer setup is necessary, and the cleaning cycles can be optimized.
3	-	
4	Hotplate (annealing): 25x substrates at once	

Process Schematic:



System B3: Screen Printing PEDOT:PSS

This section describes all unit processes involved in the inkjet printing process poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) on a 1"x1" glass substrate with pre-patterned electrodes using an EKRA E2 semi-automatic screen printer at the IAPP lab. PEDOT:PSS is a well-studied OMIEC material known for its good solution processability, widespread commercial availability, high electrochemical stability, and excellent conductivity. Screen printing is an additive fabrication process in which a squeegee is used to transfer ink through a patterned mesh onto a substrate. Like inkjet printing, this method minimizes material waste and process steps while offering easier production scalability. However, it comes with trade-offs, including an uneven layer surface, a minimum lateral resolution of ~200µm, and layer thicknesses of up to several micrometers, which are mainly defined by the mesh screen density and ink properties. Therefore, this low-cost and environmentally friendly fabrication method is ideal for prototyping and the printing of medium- to large-scale structures where high production throughput and efficiency are needed.

Pre-processing

Substrate: 1"x1" glass (d=1.1±0.1mm) or PI substrate with pre-patterned electrodes (for more details refer to system processes A1-A4)
Recommended prior system: A1 (lithography), A2 (inkjet printing), A3 (screen printing), A4 (microplotting)

Clean substrate condition needed – perform cleaning procedure if necessary:
(1) Ultrasonic bath for 15min in acetone (25mL)
(2) Rinsing substrate with acetone (5mL) followed by isopropanol (5mL)
(4) Blow away residual solvents with N_2 (2.5L)

Screen Preparation:

(1) Manually coat both sides of a clean screen with a thin, uniform Foteco FOTECOAT 1105 photoresist layer using an emulsion scoop coater
(2) Soft-baking at 40°C in a BELTRON screen drying cabinet until screen is completely dry (30-45min)
(3) Print desired layout on a transparent DIN A4 foil (monochrome black, 1200x1200dpi, repeat printing 3x for thicker layer)
(4) Place the foil and the coated screen in a Vastex E-200 screen exposure unit (5min vacuum evacuation, 0.8min exposure time)
(5) Wash out exposed screen area with a high-pressure water stream using a Bosch EasyAquatak120 and use cloth to remove excess water
(6) Drying at 40°C in a BELTRON screen drying cabinet until screen (30-45min)

Overview Unit Processes:

30min (1-25 Substrates)

1 Cleaning → 2 Printer Setup → 3 Ag Printing → 4 Printer Cleanup → 5 Annealing

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	E2 screen printer, Print squeegee, Flood squeegee, Screen		1. Activate ‚Control' and perform ‚Basic Position' procedure 2. Turn on vacuum pump and activate ‚Vacuum' 3. Place substrates on print table and cover all remaining vacuum suction holes with a thin foil 4. Place screen in mounting and click ‚Transport' twice 5. Move print table up (‚Table up/down') 6. Align screen layout with the substrate position and the pre-patterned electrodes; fix screen in place by activating ‚Screen clamping' 7. Install print and flood squeegee 8. Adjust substrate thickness in printing parameters (1.0mm for glass substrates) 9. **Adjust pressure of print squeegee** (move print squeegee to the middle of the substrate position by holding ‚Print'; move print squeegee down (‚Squeegee up/down'); turn pressure adjuster clockwise until you feel resistance, then anticlockwise by ~2 turns; raise print squeegee (‚Squeegee up/down') 10. **Adjust height of flood squeegee** (Hold ‚Print' until end of print area is reached and the table moves down; move flood squeegee down (‚Squeegee up/down'); turn pressure adjuster until there is no gap between screen and flood squeegee; raise print squeegee (‚Squeegee up/down') 11. Hold ‚Print' until start position is reached or use ‚Basic Position' 12. Adjust print speed and start/end position in printing parameters		The 1st click on 'Transport' will activate the vacuum of the print stage, the 2nd click moves the print stage beneath the screen. Shine a flashlight behind the flood squeegee to check if light passing through the gap between screen and flood squeegee. Stop adjusting the height once the gap is closed. The screen printer will only permit automatic movements when all covers are closed.

System B3: Screen Printing PEDOT:PSS

2	E2 screen printer, Print squeegee, Flood squeegee, Screen	*1g* PEDOT:PSS screen printable ink (Sigma Aldrich, 5.0wt%) *(quantity depends on the structure and layout size)*	1. Distribute a generous amount of ink in a continuous line between print squeegee and screen layout 2. **Alignment Test** *(for small structures)*: - Place alignment sheet on top of print table and increase substrate thickness in printing parameters by 0.5mm - Use ‚MOPS' camera system and manually adjust camera position to print location on substrate; press ‚Teach' to save the image - Click ‚Transport' twice; move print table up (‚Table up/down'); lower print squeegee (‚Squeegee up/down') - Hold ‚Print' until print squeegee reaches end of print area; keep holding ‚Print' and lowered flood squeegee moves ink back to start position - Move print table back (‚Transport') and evaluate displacement of test print on alignment sheet relative to the underlying substrate using the camera system and the previously saved image - Compensate displacement using the xy- and angular adjustment screws of the print table - Remove alignment sheet from print table and reduce substrate thickness in printing parameters by 0.5mm 3. **Print:** - Click ‚Transport' twice; move print table up (‚Table up/down'); lower print squeegee (‚Squeegee up/down') - Hold ‚Print' until print squeegee reaches end of print area - Click ‚Transport' and evaluate printed PEDOT:PSS layer - If layer quality is bad, moves ink back to start position using lowered flood squeegee and reprint	PEDOT:PSS layout with consistent sharp edges and good alignment with the electrodes, no smeared ink traces on substrate	Make sure that the PEDOT:PSS ink is distributed along the entire length of the print squeegee to reduce friction and wear of the screen. If a good alignment with the pre-patterned electrodes cannot be guaranteed with the first print, perform the alignment test print (step 2).
3	Drying cabinet, EasyAquatak120, Print squeegee, Flood squeegee, Screen, Cleaning cloth	*10mL* Ethanol, *1L* Water *(quantity depends on the screen layout size)*	1. Gently recover residual ink from the screen for reuse 2. Use ethanol and cleaning cloths to remove remaining non-recoverable PEDOT:PSS on the screen (to prevent tearing, apply counterpressure with another cloth on the underside while cleaning the top side) 3. Cleaning of print and flood squeegee 4. Cleaning of screen using high-pressure water stream 5. Dry the screen at 40°C in a drying cabinet for 30-45min	Clean screen without any leftover PEDOT:PSS ink	**ATTENTION!** Lab ventilation needed during cleaning step.
4	Hotplate		Annealing at 120°C for 20min	Layer printed with 165-31 mesh has avg. thickness of -- µm with a rough surface	See appendix Figure - for profile shape and thickness relation

Additional Information

(A) Ink Properties: viscosity 2-10Pa·s, surface tension 20-70mN/m

(B) Polyimid (PI) and tempered polyactide (PLA) as flexible substrates are available. They have to be manually cut into the desired shape and can be attached to a glass substrate using spray glue if the substrate is not flat. Detaching is done using acetone in a ultrasonic cleaner. Do not expose tempered PLA substrates to temperatures above 90°C.

(C) A wide range of screen sizes with different mesh specifications are available at IAPP. The mesh, made from polyester fabric, is characterized by **mesh counts (threads per cm) – thread diameter (µm)**, which defines the max. deposited theoretical ink volume and thereby the thickness of the layer (see more at https://www.koenen.de/en/products/meshes-and-frames/polyesterfabric.html): **165-31** (43x53cm, 50x60cm, 54x64cm), **120-34** (50x60cm), **90-40** (47x55cm), **61-64** (30x40cm, 47x55cm, 54x64cm, 63x73cm), **36-90** (43x53cm, 54x64cm), **24-140** (54x64cm)

(E) Activate ‚Automatic' mode after the first print to speed up the fabrication process for multiple subsequent prints using the same layout. Only the substrate needs to be changed manually, and the printing will resume automatically once the print table cover is closed. It is recommended to use the ‚MOPS' camera system to fine-tune the alignment of the substrate before the next print starts.

(F) Number all substrates involved in a print if a second layer with a different layout is planned. Before starting the second print, ensure the substrates are positioned exactly as they were previously to minimize alignment issues.

(G) To remove an existing layout from a screen, apply Foteco FOTOCHEM 1170E decoater solution to both sides, followed by a high-pressure water stream cleaning process until the old photoresist is completely removed. Next, spray both sides of the screen with Foteco FOTOCHEM 1190P degreasing solution, and clean again with a high-pressure water stream. Use a cloth to remove excess water and dry the screen at 40°C in the drying cabinet until for 30-45min.
ATTENTION: Wear an air-purifying respirator and googles during the decoating and degreasing process!

A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

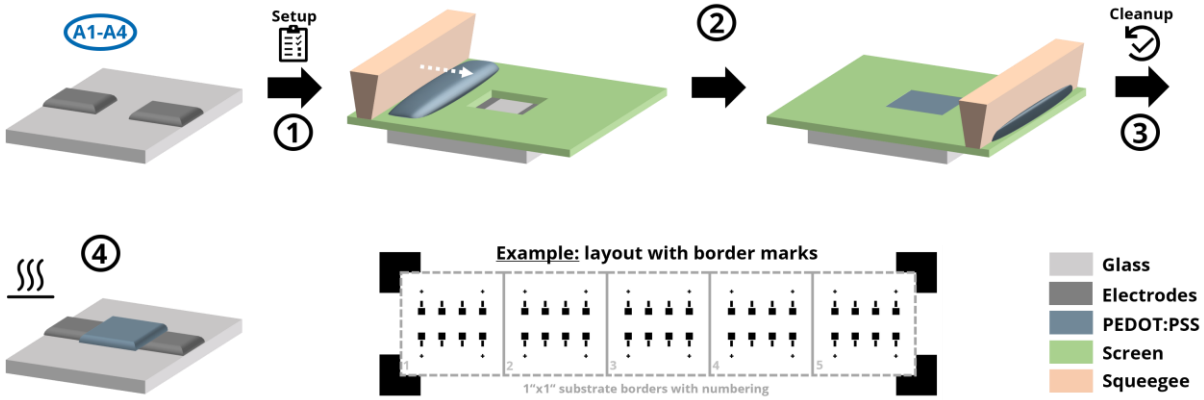
System B3: Screen Printing PEDOT:PSS

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
P R E	Ultrasonic bath: 10x substrates at once 25mL Acetone (ultrasonic) 5x (2 substrates at once) 10mL DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in organic solvent waste.
1	-	-
2	Screen printer: 25x substrates at once (total time ~30min) PEDOT:PSS ink: 1g for up to 25 substrates in one run	For 25 substrates only a single printer setup is necessary, and the impact of the non-recoverable PEDOT:PSS ink on the screen is reduced
3	-	-
4	Hotplate (annealing): 25x substrates at once	

Process Schematic:



System B4: Microplotting PEDOT:PSS

This section describes all unit processes involved in the inkjet printing process poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) on a 1"x1" glass substrate with pre-patterned electrodes using a Sonoplot Microplotter Proto at the IAPP lab. PEDOT:PSS is a well-studied OMIEC material known for its good solution processability, widespread commercial availability, high electrochemical stability, and excellent conductivity. Microplotting uses a precision ultrasonic plotter technology for rapid and localized material positioning with minimum feature sizes of 20µm - 200µm, depending on the micropipette diameter. Like inkjet printing, this method minimizes material waste and process steps while still enabling the printing of higher-viscosity inks. However, the thickness of a printed layer is not directly adjustable, and the substrate surface must be relatively flat to avoid damaging the micropipette tip. Therefore, this ultra-low-cost and environmentally friendly fabrication method is ideal for prototyping and small- to medium-scale structures where the highest precision and layer thickness control are not required.

Pre-processing

Substrate: 1"x1" glass (d=1.1±0.1mm) or PI substrate with pre-patterned electrodes (for more details refer to system processes A1-A4)
Recommended prior system: A1 (lithography), A2 (inkjet printing), A3 (screen printing), A4 (microplotting)

Clean substrate condition needed – perform cleaning procedure if necessary:
(1) Ultrasonic bath for 15min in acetone (25mL)
(2) Rinsing substrate with acetone (5mL) followed by isopropanol (5mL)
(4) Blow away residual solvents with N_2 (2.5L)

Overview Unit Processes:

20min (1 Substrate)

1 Cleaning → **2** Printer Setup → **3** Ag Printing → **4** Printer Cleanup → **5** Annealing

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Microplotter, Pipette	*50µL* PEDOT:PSS (Clevios PH1000 + 5%v/v E) *(filtered with 0.45µm PVDF filter)*	1. Start software ‚SonoGuide', remove dust cover and home printer 2. Install dispenser cartridge + click ‚Calibrate Dispenser' 3. Turn on light in ‚Camera Settings' and adjust the xyz-thumbscrews until the micropipette tip is visible in the live camera feed (field of view 1.2mm) 4. Place substrate on print stage and manually move tip with direction controls to desired print position (maintain >1mm z-distance from the surface) 5. Click ‚Find Surface' to automatically lower tip until surface is reached and manually retract by 20-50µm. For fine adjustments, use direction controls, and save print position at z-distance of 20-50µm from the surface 6. Click ‚Safe Height' and manually move tip with direction controls to the middle of solution well A1 (~1mm z-distance) and click ‚Set A1 well' to align printer with the solution plate 7. Fill 50µL of PEDOT:PSS ink into an empty solution well 8. Select PEDOT:PSS ink well number in ‚Solution plate' tab to automatically move tip to ink reservoir; decrease manually z-position until tip is submerged in ink reservoir and wait for the micropipette to load the ink due to the capillary effect 9. Load .dxf print geometry by clicking ‚File' + ‚Opening Pattern' and manually change the crosshair position (indicating tip start position for print) to upper left corner of print geometry	Micropipette is filled with PEDOT:PSS ink	**ATTENTION!** Avoid any direct contact with the fragile micropipette tip to prevent damage. Always ensure that the tip is not in contact with the substrate surface before using the direction controls. If print geometry exceeds size of 1x1mm, perform 'Calibrate Surface' after step 4 to prevent tip damage due to surface height variations.
2	Microplotter	*10µL* PEDOT:PSS (Clevios PH1000 + 5%v/v EG) *(filtered with 0.45µm PVDF filter)*	1. Select the saved print start position to automatically move tip to substrate start position 2. Perform dispenser calibration and click ‚Find Surface' 3. Adjust dispensing strength (2.5V – 4.5V) in ‚Dispenser Controls tab' 4. **Test:** Perform a manual dispensing test with 0.2s duration to ensure that the dispensing strength is suitable for ejecting the ink (ideally, this test should be done with a small offset to the planned start position) 5. **Print:** Press Strg + P to open the print window, select dispensing mode and print	PEDOT:PSS layout with consistent sharp edges and uniform ink deposition + good alignment with the electrodes	Increase dispensing strength if the ink fails to eject; decrease it if too much ink is dispensed. Ensure that the ink droplet is in contact with the tip and the surface.

System B4: Microplotting PEDOT:PSS

3	Pipette, Lab tissue	*1mL* DI water *1mL* Isopropanol	1. Click ‚Safe Height' to automatically retract tip 2. Cleaning of the micropipette (use manual spraying mode at 12-20V with 5-10s duration to eject unused PEDOT:PSS into a lab tissue; fill isopropanol/DI water into an empty well; load the micropipette with it and eject again; repeat until the micropipette is clean) 3. Recover unused PEDOT:PSS in solution well and clean everything with isopropanol and DI water 4. Home printer and protect setup with the dust cover	Clean micropipette and solution plate, ready for re-use	Do not touch the micropipette tip with the lab tissue! Alternatively, use a waste well for the ejection of the ink.
4	Hotplate		Annealing at 120°C for 20min	PEDOT:PSS layer with 100-150nm avg. thickness	

Additional Information

(A) Ink Properties: viscosity <450mPa·s, surface tension 20-40mN/m
(B) Printing Layout: Use KLayout or similar programs to draw print geometry as path, setting the path width to match the tip diameter. Leave a small gap at the end of the path to have a uniform ink deposition at this position. Save the print layout as a hatch entity in a .dxf file format (refer to the process schematic for an example).
(B) It is recommended to use only relatively flat substrates and the surface calibration option to prevent damage to the tip during printing. If the print area is already covered with a soft layer, maintain a z-distance of 20-30µm to the surface during printing to avoid scratching the underlying layer (adjust dispensing strength if necessary, ensure that droplet remains in contact with tip and surface)
(C) If the micropipette tip is clogged, try to use dispensing mode at a higher voltage strength or spraying mode for 1-2s to clear the blockage or perform the micropipette cleaning procedure.
(D) The Microplotter allows the automatic handling (loading ink, printing, ejecting into waste well, rinsing in solvent well) of multiple inks by defining them in the ‚Solutions' tab. Please refer to the manual at https://sonoplot.com/donwloads.

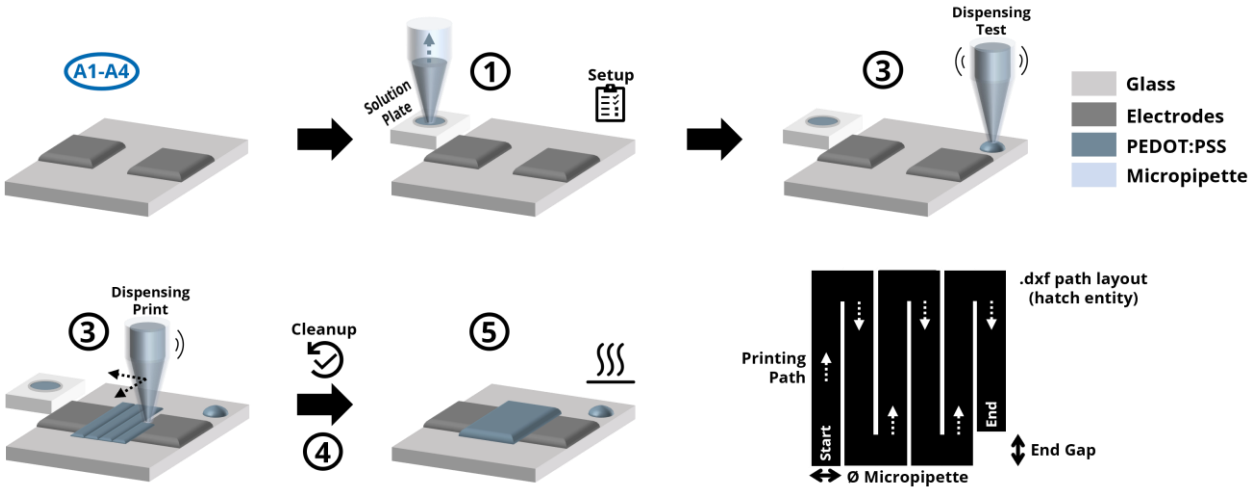
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
P **R** **E**	Ultrasonic bath: 10x substrates at once 25ml Acetone (ultrasonic) 5x (2 substrates at once) 10ml DI water (ultrasonic): 100x	To arrange 2 substrates in the 20mL beaker, place them back-to-back with the active sides facing outward for cleaning in acetone. Acetone/isopropanol is disposed of in the organic solvent waste.
1	-	
2	Microplotter: 1x substrates at once	No upscaling is possible.
3	-	
4	Hotplate (annealing): 25x substrates at once	

Process Schematic:



System B5: Parylene Peel-off PEDOT:PSS

This section describes all unit processes involved in the inkjet printing process poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) on a 1"x1" glass substrate with pre-patterned electrodes using a SCS PDS2010 parylene coater at the IAPP lab. PEDOT:PSS is a well-studied OMIEC material known for its good solution processability, widespread commercial availability, high electrochemical stability, and excellent conductivity. This fabrication method combines a parylene coating and peel-off patterning process with lithography, achieving lateral resolutions of 1µm without requiring etching of the PEDOT:PSS layer or the use of hydrofluoroethers (HFE) based photoresists (see system B1). Additionally, it has a high fabrication throughput due to the parylene coating of multiple substrates at a time and allows the patterning of OMIECs that are incompatible with a purely lithography-based approach. Therefore, this method is a more versatile alternative to fabrication system B1 for precise and small-scale structures but comes still with drawbacks like high energy and chemical

Pre-processing

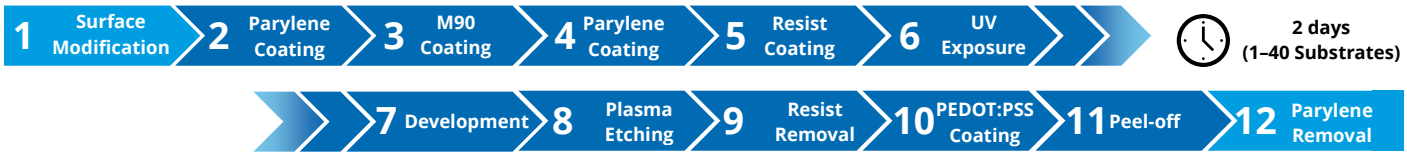
Substrate: 1"x1" glass (d=1.1±0.1mm) or PI substrate with pre-patterned electrodes (for more details refer to system processes A1-A4)
Info: This system involves reactive plasma etching steps, which may result in undesired formation of an oxide layer on Ag electrodes
Recommended prior system: A1 - lithography of highly planar Au/Cr electrodes

Clean substrate condition needed – perform cleaning procedure if necessary:
(1) Ultrasonic bath for 15min in acetone (25mL)
(2) Rinsing substrate with acetone (5mL) followed by isopropanol (5mL)
(4) Blow away residual solvents with N_2 (2.5L)

***Maintenance* - Parylene Coater Lockdown:**

Info: This process needs to be performed before starting the substrate coating process if the protective inner parylene layer of the chamber or lid is damaged or begins to peel-off
(1) Cleaning of the coater chamber and lid using DI water + 2%v/v M90 to completely remove the old parylene layer
(2) Wipe the inner chamber and the lid with a cleaning cloth soaked in DI water + 2%v/v M90 to weaken adhesion of protective parylene
(3) Cleaning of the cooling rod + wipe rod using DI water + 2%v/v M90
(4) Perform parylene coater run with 2g of Parylene DPX-C to build up a ~1.12µm thick protective inner parylene layer (for more information on setting up the coating process, see process stage 2)

Overview Process Stages:



	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	Hotplate, Petri dish	*50µL* Silane A174, *5mL* DI water, *5mL* Isopropanol *(adhesion promoter is reusable, given amount for 4 substrates simultaneously)*	1. Mix together: Silane A174, DI water and Isopropanol in 1:100:100 ratio 2. Fill adhesion promoter solution in small petri dish 3. Submerge clean substrate in solution for 30min at room temperature (cover petri dish to prevent evaporation) 4. Rinse thoroughly substrate with isopropanol 5. Drying on hotplate for 10min at 100°C	Clean, dustless and reactive substrate surface	Pre-treatment of the substrate to enhance adhesion of 1st parylene layer.
2	Parylene Coater, Scale, Razor blade	*1g* Parylene C (DPX - C), *10mL* DI water + 2%v/v M90 DI	1. Press ‚Main Power', switch on furnace and press ‚Process start' to start heating up the furnace 2. Vent coating chamber, remove chamber lid vertically 3. Remove clean cooling rod + wipe rod using DI water + 2%v/v M90 4. Place substrates on sample tray, switch on vaporizer (make sure that the sample tray is standing upright and freely spin inside the chamber) 5. Place chamber lid flush on the chamber top 6. Use a scale and weigh out 1g Parylene C, insert Parylene into furnace chamber 7. Place cooling rod into its insertion point and start evacuating the chamber 8. Parylene coating will automatically start if start pressure of 12mtorr is reached (coating settings: furnace 690°C, chamber gauge 130°C, vaporizer start 175°C, coating pressure 40mtorr, full duration ~45min) 9. Once coating is done, remove substrates, clean cooling rod (removal of parylene layer with razor blade), evacuate chamber for 2min, and turn of coater	~1µm thick Parylene layer, yellowish color, evenly covered	If the protective inner parylene layer of the chamber and the lid is damaged, perform a maintenance lockdown beforehand. **ATTENTION!** Wait until the process start pressure is reached, before leaving the coater alone. If the pressure cannot be reached after 30min, the inner parylene layer is compromised.

System B5: Parylene Peel-off PEDOT:PSS

3	Spin-coater	*0.5mL* DI water + 2%v/v M90	Spin-coating 2%v/v M90 solution, no annealing (5s ramp-up, 60s 3000rpm, 5s ramp-down)		For better separation of the 2nd parylene layer
4	Parylene Coater, Scale, Razor blade	*4g* Parylene C (DPX - C), *10mL* DI water + 2%v/v M90 DI	1. Repeat parylene coating procedure from step 2, using 4g of Parylene C (full duration ~180min) 2. Once coating is done, remove substrates, clean cooling rod (removal of parylene layer with razor blade), evacuate chamber for 2min, and turn of coater	3-4µm thick Parylene layer, yellowish color, evenly covered	See remarks of step 2
5	Spin-coater, Pipette, Hotplate, Light-shielded box	*1mL* AZ 1518 (pos. photoresist) *(stored in fridge at 5°C)*	1. Spin-coating AZ 1518 Photoresist (5s ramp-up, 60s 3000rpm, 5s ramp-down) 2. Annealing 100°C for 60s (use precise hotplate) 3. Wait 5min (allow the substrate to reach room temperature before spin-coating the 2nd layer) 4. Spin-coating AZ 1518 Photoresist (5s ramp-up, 60s 3000rpm, 5s ramp-down) 5. Annealing 100°C for 60s (use precise hotplate) 6. Store the substrate in a light-shielded box	~5400nm thick AZ 1518 layer, reddish, wavy surface, no bubbles	See appendix Figure **1** for AZ thickness at various rpms Thick AZ layer needed to protect underlying parylene during long plasma etching step
6	Mask aligner exposure unit, Photomask		1. Install PEDOT:PSS photomask + load substrate 2. Perform WEC (Wedge Error Compensation) + alignment of pre-patterned electrodes with photomask 3. UV exposure (I-line 365nm, intensity 5.2 mW/cm^2) of substrate for 18s		If the lamp is at the end of its lifecycle, increase exposure time to 20s.
7	2x40mL Beaker, Hotplate, Lab tissue	*40mL* AZ 726 MIF *(multiple reuse)* *40mL* DI water	1. Submerge substrate in AZ 726 MIF developer and swing it back and forth very slowly for at least 90s 2. Carefully clean substrate in DI water for 10s 3. Carefully blot the substrate dry using a lab tissue 4. Drying on hotplate at 60°C for at least 30min	Layout is slightly visible on substrate surface.	Removal of exposed photoresist
8	Plasma cleaner, Microscope	*750mL – 1L* O_2, *50L* N_2 (Venting 2x)	1. Reactive O_2 plasma etching of substrate surface for 13x60s (program ‚Parylene_13x60s', RF Generator 150W and 465V, 30ml$_n$/min O_2, start at 8.0e-05mbar) 2. Check with microscope if the two parylene layers in the AZ patterned area are completely etched away (thin parylene layer appears milky) - if not, repeat procedure with 1x60s reactive O_2 plasma etching and check again until the parylene covering the gold is gone (it is recommended to additionally check with a sacrificial substrate, see notes below)	Clean, reflective gold electrodes visible in patterned area with no parylene layer on top (use microscope)	Plasma quality depends on number of substrates etched at the same time (ideally < 4) **ATTENTION!** Excessive plasma etching will damage underlying parylene layer and the gold electrodes.
9	Mask aligner exposure unit, 2x40mL Beaker, Hotplate, Lab tissue	*40mL* AZ 726 MIF *(multiple reuse)* *40mL* DI water	1. Load etched substrate into mask aligner (no photomask/WEC required) 2. Flat UV Exposure (I-line 365nm, intensity 5.2 mW/cm^2) of substrate for 40s 3. Submerge substrate in AZ 726 MIF developer and swing it back and forth very slowly for at least 90s 4. Carefully clean substrate in DI water for 10s 5. Carefully blot the substrate dry using a lab tissue 6. Drying on hotplate at 60°C for at least 30min		Flat UV Exposure is required to make the entire AZ 1518 layer soluble in developer (this step prevents the dissolution of AZ 1518 with solvents of the spin-coated OMIEC layer in step 10)
10	Spin-coater, Pipette, Hotplate	*0.5mL* PEDOT:PSS (Clevios PH1000 + 5%v/v EG)	1. Spin-coating PEDOT:PSS – use 1"x1" holder (5s ramp-up, 60s 3000rpm, 5s ramp-down) 2. First annealing step at 100°C for 10min (Do not heat up the parylene layer above 110°C before performing the peel-off!)	~75nm thick PEDOT:PSS layer, blueish color, evenly spread	See appendix Figure **4** for PEDOT:PSS thickness at various rpms
11	Tweezer, Hotplate, Microscope		1. Peel-off slowly and carefully the 2nd parylene (scratch parylene layer with a tweezer at the edge of the substrate until a tangible "tab" of Parylene is formed, remove parylene by pulling it vertically over the patterned area) 2. Second annealing step at 120°C for 120min 3. Check with microscope if patterned area is fine (especially separation of gate and channel or other small features)	Clean patterned PEDOT:PSS covering the channel and the gate	SSE can be printed (see C2) directly on the substrate without further surface modification
12	Razor blade, Multimeter, N_2 Glovebox		1. Scrape the parylene flat from the gold contacts with a razor blade, check with multimeter channel resistance 2. Substrates should be stored in glovebox with N_2	‚OECT_same' layout: 150Ω -250Ω as channel resistance	

System B5: Parylene Peel-off PEDOT:PSS

Additional Information

(A)

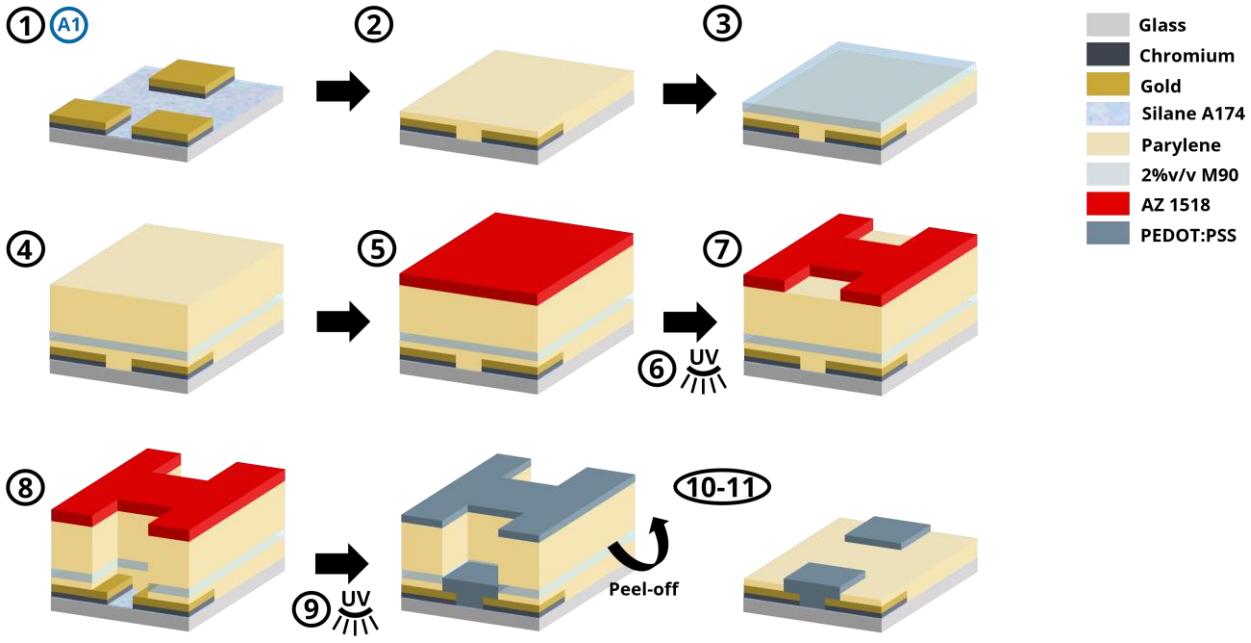
A list of all required chemicals and tools, along with their respective maximum power consumption, is provided in the appendix.

Scaling:

This section specifies the max. number of substrates that can be processed simultaneously with each equipment tool, the max. number of substrates for which a chemical can be reused before requiring replacement with a fresh solution, and the extent to which ink consumption can be reduced by printing multiple substrates at once. Additionally, it provides information on the disposal of chemicals after use. Tools and chemicals not listed are single-use per substrate or can only process one substrate at a time.

	PROCESSING CAPACITY & REUSE	Comments & Disposal Info
PRE		
1		
2		
3		
4		

Process Schematic:



Fabrication System C

- Electrolyte Patterning -

System C1: Lithography Solid-State Electrolyte

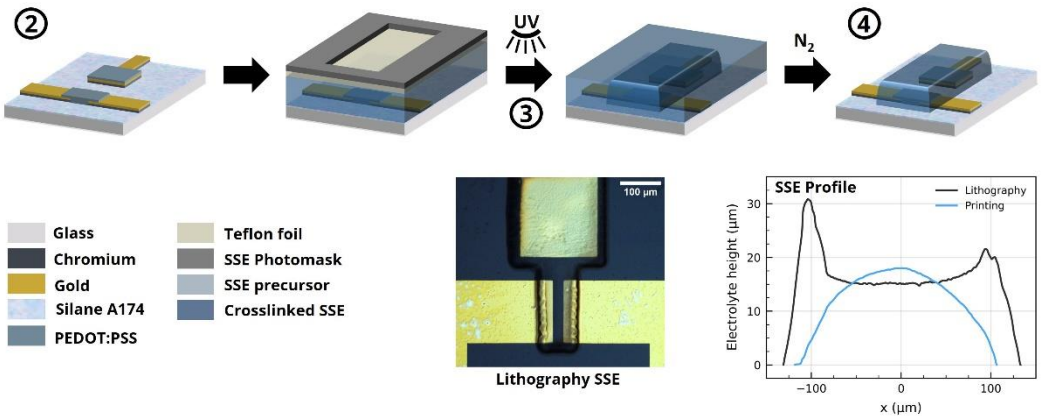
This section provides details on the formulation and preparation of the solid-state-electrolyte (SSE) ink, along with its application via the lithography approach. Although this method offers a quicker alternative to printed SSEs, it lacks control over the SSE height, resulting in variations of a few µm across the substrate. These deviations result in different OECT transfer characteristics, limiting its usecase to testing purposes. Moreover, non-removeable residues from the SSE precursor solution contribute to leakage currents that are an order of magnitude higher compared to OECTs with printed SSEs.

Overview Process Stages:

40min (1 Substrate)
w/o ink preparation

1 Ink Preparation → 2 Surface Modification → 3 UV Exposure → 4 Unexposed SSE Removal

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	UV bottle, .45µm PVDF filter, Micropipette, Fridge, Micro scale	*1mL* DI water, *1.5mL* [EMIM][EtSO4], *750mg* NIPAm, *200mgl* MBAm, *20mg* HHPAA	1. Mixing together in this specific order: 1mL DI water, 1.5mL ionic liquid [EMIM][EtSO4], 750mg of monomer NIPAm, 200mg of crosslinker MBAm, 20mg of photoinitiator HHPAA 2. Let it stir in closed UV shielded bottle at room temperature for > 4h 3. Filtration of the SSE ink with a 0.45µm PVDF Filter 4. Store in fridge 5-10°C, label bottle with ‚Lithography SSE', date and name	Transparent and filtered SSE ink, all components are completely dissolved	Overview of SSE components in Figure of section C2
2	Hotplate, Petri dish, Micropipette, Measuring tube	*9mL* Ethanol, *180µL* Acetic Acid, *90µL* Silane 174	1. Mixing together: 9mL ethanol, 90µL Silane A174, 180µL concentrated acetic acid 2. Fill adhesion promoter solution in small petri dish 3. Submerge clean PEDOT:PSS patterned substrate in solution for 10min at 50°C (cover petri dish to prevent evaporation of solution) 4. Rinse thoroughly substrate with ethanol 5. Annealing for 10min at 100°C		This step increases the surface energy/adhesion of the substrate Optional: Clean substrate with Ethanol beforehand
3	Mask aligner, Teflon foil, Micropipette, Light-shielded box	*100µL* SSE ink (Lithography)	1. Perform WEC (Wedge Error Compensation) + alignment 2. Turn the WEC knob back by half a rotation (left) 3. Open contact lever and move substrate holder back to loading position 4. Use pipette and place a very small amount of SSE ink on top of transistor area 5. Carefully place Teflon foil on top of substrate 6. Move substrate holder back to exposure position 7. Perform accurate alignment 8. UV exposure (I-line 365nm, intensity 5.2 mW/cm^2) of substrate for 20s with appropriate photomask		During movement of the substrate holder, hold the vacuum knob to fix substrate in place Simply holding the pipette applies enough pressure to collect the correct ink volume
4	Tissue, Microscope	*5mL* Ethanol, *10L* N_2	1. Carefully remove unexposed SSE precursor solution by blowing with N_2 (try to remove the precursor solution as much as possible, especially in transistor area); don't blow to strong, otherwise patterned SSE can lose its adhesion) 2. Check with microscope if SSEs are patterned correctly and separated from each other 3. Wet tip of a clean tissue with ethanol and carefully clean electrode area and surrounding, don't come to close to the transistor area (otherwise, SSE can be damaged)	Quasi-solid core, SSE has steep edges and flat plateau in the middle (see profile) Liquid shell of SSE is completely removed	Removal of parasitic connections due to unexposed SSE solution covering the substrate Precursor residues leads to higher gate leakages in contrast to printed SSEs



System C2: Inkjet Printing Solid-State Electrolyte 1/1

This section provides details on the formulation and preparation of the solid-state-electrolyte (SSE) ink, along with its application via inkjet printing. This technique allows for precise control of the max. SSE height by adjusting the number of printed layers and ensures reproducible OECT transfer characteristics. Furthermore, key parameter such as threshold voltage, hysteresis and electrolyte resistance will decrease with an increasing SSE height and will reach saturation at around 20µm, corresponding to 4 printed layers (see appendix I. Figure **d-f**).

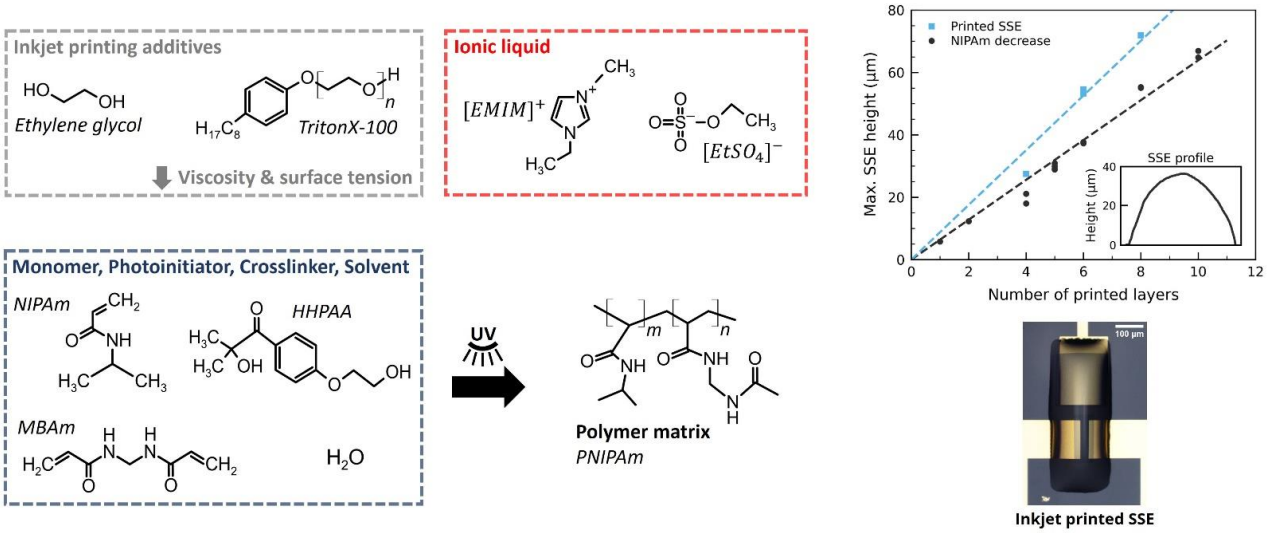
2h-3h
(1 Substrate)
w/o ink preparation

Overview Process Stages:

1 Ink Preparation → 2 Surface Modification → 3 Printing Preparation → 4 SSE Printing → 5 Printing Follow-up → 6 UV Exposure

	EQUIPMENT	CHEMICALS	PROCESS DESCRIPTION	QUALITY CONTROL	REMARKS
1	UV bottle, .45µm PVDF filter, Micropipette, Fridge, Micro scale	*1mL* DI water, *1.5mL* EG, *1.5mL* [EMIM][EtSO4], *750mg* NIPAm, *200mg* MBAm, *20mg* HHPAA, *50µL* TritonX-100	1. Mixing together in this specific order: 1mL DI water, 1.5mL ethylene glycol, 1.5mL ionic liquid [EMIM][EtSO4], 750mg of monomer NIPAm, 200mg of crosslinker MBAm, 20mg of photoinitiator HHPAA, 2-3 drops of TritonX-100 2. Let it stir in closed UV shielded bottle at room temperature for > 4h 3. Filtration of the SSE ink with a 0.45µm PVDF filter 4. Store in fridge 5-10°C, label bottle with ‚Filtered SSE normal', date and your name	Transparent and filtered SSE ink, all components are completely dissolved	Additional salts should be added to the 1ml DI water as the starting point of the mixture. Ethylene glycol added to decrease viscosity, Triton added to decrease surface tension
2	Hotplate, Micropipette, Petri dish, Measuring tube	*9mL* Ethanol, *180µL* Acetic Acid, *90µL* Silane 174	1. Mixing together: 9mL ethanol, 90µL Silane A174, 180µL concentrated acetic acid 2. Fill adhesion promoter solution in small petri dish 3. Submerge PEDOT:PSS patterned substrate in solution for 10min at 50°C (cover petri dish to prevent evaporation of solution) 4. Rinse thoroughly substrate with ethanol 5. Annealing for 10min at 100°C		This step increases the surface energy of the substrate for a good inkjet printed SSE structure.
3	Inkjet Printer, ‚Samba' cartridge, Fluid module, 1ml syringe, Syringe pump,	*<1.5mL* SSE ink (Filtered), *10mL* DI water + .1%v/v TritonX-100	1. Clean SSE cartridge with DI water + 0.1%v/v TritionX-100 (use syringe pump, withdraw 10mL) 2. Dry cartridge + clean nozzle area softly with wet tissue 3. Fill <1.5mL SSE ink from ‚Filtered SSE normal' bottle (fridge) in fluid module using a 1ml syringe and a metal adapter (tilt bottle/fluid module during this process, pump/release ink slowly to prevent air bubbles in fluid module) OR use pre-filled SSE fluid module (fridge) 4. Connect fluid module with cartridge (‚klick'-sound) 5. Load fluid module + cartridge into inkjet printer 6. Fix in place clean tissue on nozzle cleaning area 7. Close printer cover, select ‚12-jet Samba' cartridge 8. Use ‚SE_Ali' setting file 9. Perform 2-3 cleaning cycles (‚Purge.3secondsBlot') 10. Click ‚Drop Watcher' and search for working nozzles (tune jetting voltage and cartridge temperature for good jetting) 11. Select appropriate printing geometry (.ptf file) 12. Place lab paper on printing area (covering holes) 13. Turn on vacuum, set thickness to 1150nm (glass) 14. Place PEDOT:PSS patterned substrate on top of lab paper in printing area		If air bubbles are in SSE ink, expose fluid module for short time to vacuum A rectangular shaped SSE geometry is recommended with features > 50µm New print geometry: **1.** Draw geometry in windows paint in black (1px = 15µm) **2.** Save file as mono-chromatic .bmp **3.** Open random print file in software **4.** File – open .bmp **5.** File – save as .ptf **6.** Select .ptf as new print geometry
4	Inkjet Printer, ‚Samba' cartridge, Fluid module	*150µL* Filtered SSE ink	1. Move with ‚Fiducial Camera' to substrate, correct phi 2. Perform 3-layer test print on alignment square or other clear space 3. Evaluate deviation from actual print start point to manually set origin point 4. Use the deviation to correctly set origin point for first SSE print in transistor area 2. Inkjet printing of the SSE with 5-6 layers (15µm drop spacing, jetting voltage 27V-32V, cartridge temperature 32°C-35°C, use only 1 jet, if needed adjust print origin for better alignment)	Clean SSE structure, perfectly aligned (covering whole gate and channel)	Relation max. SSE height vs. number of printed layer see plot below If SSE structure is not well defined or a lot of ink droplets appear, change jetting nozzle

5	Light-shielded box, Spatula, Syringe pump	*10mL* DI water + .1%v/v TritonX-100, *50mL* DI water	1. Click ‚Replace Cartridge', open printer cover 2. Remove substrate and store it in light-shielded box 3. Remove tissue in cleaning area, lab paper (reusable) and fluid module + cartridge 4. Carefully separate fluid module and cartridge with the help of large spatula (insert in gap and use it as a lever) 5. Rinse cartridge with DI water 6. Carefully wipe the nozzle area with a tissue + DI water 7. Clean SSE cartridge with DI water + 1%v/v TritionX-100 (use syringe pump, withdraw 10mL with 0.6mL/min), if finished store cartridge in tube with DI water 8. Close fluid module and store it in fridge 5-10°C		Optional: carefully wipe nozzle area with acetone for better cleaning
6	Mask aligner, Microscope		1. UV exposure (I-line 365nm, intensity 5.2 mW/cm^2, no photomask needed) for 2x60s (20s pause) 2. Check with microscope if electrolyte is solidified - if not repeat UV exposure for 60s	Quasi-solid core (boundary visible with microscope 10x-20x), covered with a water/ionic liquid mixture, droplet-shape profile	**Note:** SSEs with 1-3 printed layers are sometimes not completely solidified due to small volume and ink component segregation



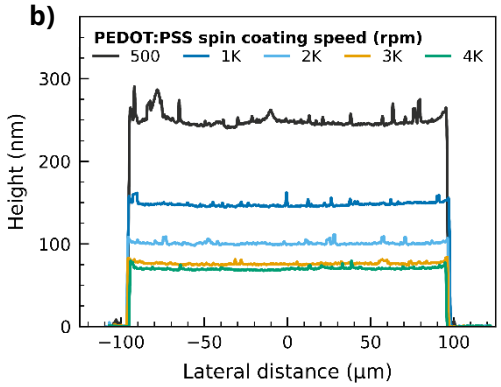
Appendix

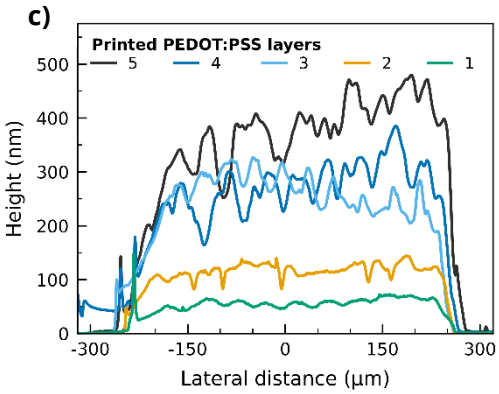
I. Appendix: Supporting Information

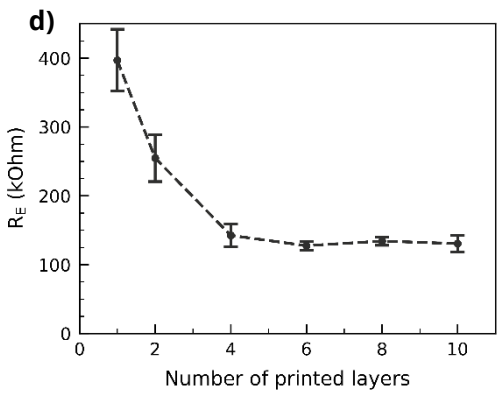
a)

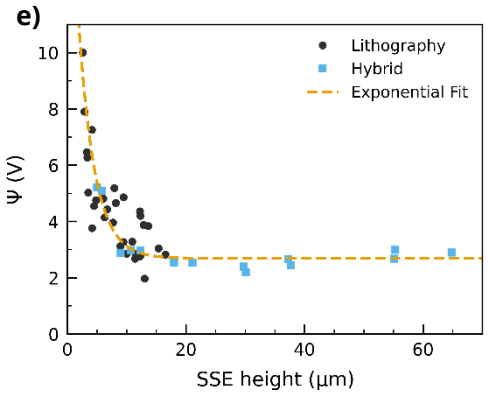
AZ 1518 spin-coating thickness:

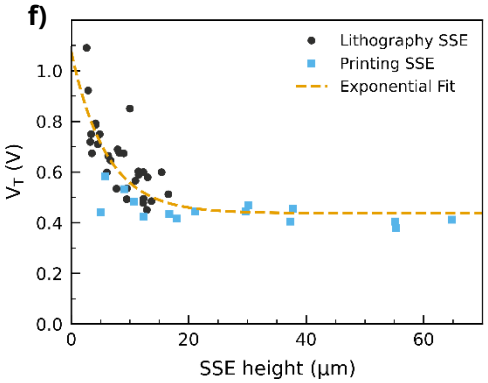
500rpm 60s:	7100nm	(22s UV)
1k rpm 60s:	5000nm	(18s UV)
2k rpm 60s:	3600nm	(15s UV)
3k rpm 60s:	2800nm	(12s UV)
2x3k rpm 60s:	5400nm	(18s UV)
3x3k rpm 60s:	7600nm	(22s UV)











II. Appendix: Equipment List

This section lists all important tools needed for the different fabrication techniques, for performing measurements and other utensils and materials. It includes details on their respective commercial manufacturers, estimated power consumption during operation, and their location within the IAP laboratory is given. The laboratory itself is an ISO-7 classified cleanroom with a size of 250m^2 and a regular power consumption of ~ Wh.

Fabrication tools:

EQUIPMENT NAME	COMMERCIAL MANUFACTURER	POWER	LOCATION
Dimatix Materials DMP-2800 inkjet printer	Fujifilm Dimatix Inc., USA	375W	
Sonoplot Microplotter Proto	Sonoplot Inc., USA	330W	
EKRA E2 screen printer	EKRA Automatisierungssysteme GmbH, Germany	950W	
E-200 High Output LED screen exposure unit	Vastex International Inc., USA	420W	
WPI AL-1000 syringe pump	World Precision Instruments, USA	9W	
BD-20AC Laboratory Corona Treater	Electro-Technic-Products Inc., USA	40W	
SÜSS Microtech MJB4 mask aligner systems	SÜSS MicroTech AG, Germany	1500W	
SCS PDS2010 parylene coater	Speciality Coating Systems Inc, USA	3300W	
CYCLOS 400 RIE plasma cleaner	Aurion Anlagentechnik GmbH, Germany	4400W	
SAWATEC SM-180-BT spin-coater	SAWATECH AG, Switzerland	2500W	
SAWATEC HP-150 hotplate	SAWATECH AG, Switzerland	350W	
AS 110.R2 PLUS Analytical Balance	RADWAG Balances and Scales, Poland	3W	
VWR USC600T ultrasonic cleaner	VWR International, USA	130W	
Photomasks (4inch, custom made, soda-lime glass with Cr)	Compugraphics Jena GmbH, Germany	-	
Ultra Airbrush	Harder & Steenbeck GmbH & Co. KG, Germany	-	
µMLA Maskless Aligner	Heidelberg Instruments Mikrotechnik GmbH	1380W	
Manucut I Schneideanlage	HEGLA GmbH & Co. KG, Germany	-	

Measurement tools:

EQUIPMENT NAME		COMMERCIAL MANUFACTURER	POWER	LOCATION
N_2	MB 200B + MB 20G nitrogen-filled glovebox	M. Braun Inertgas-Systeme GmbH, Germany	1800W	
N_2	Keithley 236 SMU	Keithley Instruments, USA	100W	
Air	Keithley 4200-SCS	Keithley Instruments, USA		
Air	Everbeing C-6 Probe Station	Everbeing Int'l Corp., Taiwan	5W	
Air/N_2	HP 4145B SMU	HP Inc., USA	270W	
Air/N_2	JANIS ST-500 Probe Station	Lake Shore Cryotronics Inc., USA	-	
Air/N_2	T-Station 75 Vacuum Pump	Edwards Ltd, UK	230W	
Air/N_2	Model 9700 Temperature Controller	Scientific Instruments Inc.,	100W	
Autolab PGSTAT302N		Metrohm AG, Switzerland	300W	
Nikon Eclipse LV100ND microscope + DS-Fi2 camera		Nikon, Japan		
Veeco Dektak 150 surface profiler		Vecco Instruments Inc., USA		
AIST-NT Combiscope 1000 AFM		AIST-NT Inc., USA		
Bruker Dimension Icon AFM		Bruker Corporation, USA		
MSO5074 Digital Oscilloscope		RIGOL Technologies Inc., China	75W	

III. Appendix: Chemical List

This section lists all chemicals/materials needed for the different fabrication techniques with their corresponding commercial supplier and location in the IAP laboratory (including the preparation lab KRO 0.27 and the printing lab KRO 0.19).
A full list of all chemicals is available at \\groups.iap.phy.tu-dresden.de\groups-neu\IAPP\IAPP-ODS.

PRODUCT NAME	TYPE	DENSITY	SUPPLIER	LOCATION
DI water	Solvent	0.99823g/mL		
Acetone	Solvent	0.7900g/mL	TU Dresden Chemical Storage	
Isopropanol	Solvent	0.7854g/mL	TU Dresden Chemical Storage	
Ethanol	Solvent	0.7892g/mL	TU Dresden Chemical Storage	
Ethylene glycol (EG) ≥ 95%	Solvent	1.113g/mL	Sigma Aldrich	
Dimethyl Sulphoxide (DMSO)	Solvent	1.1004g/mL	VWR Chemicals	
AZ 1518	Photoresist (positive)	1g/mL	Merck Performance Materials GmbH	
OSCoR 4020	Photoresist (negative)		Orthogonal Inc.	
AZ 726 MIF	Developer	1g/mL	Merck Performance Materials GmbH	
Orthogonal Developer 103a	Developer		Orthogonal Inc.	
Orthogonal Developer 100	Developer		Orthogonal Inc.	
Orthogonal Stripper 900	Stripper		Orthogonal Inc.	
Chromium Etchant	Etchant	1.16g/mL	Sigma Aldrich	
Gold Etchant	Etchant	1.16g/mL	Sigma Aldrich	
Acetic acid 100%	Acid	1.049g/mL	Sigma Aldrich	
Clevios PH1000	PEDOT:PSS	0.985g/mL	Heraeus Deutschland GmbH & Co. KG	
Clevios PH1000 + 5%v/v EG	PEDOT:PSS			
(3-Glycidyloxypropyl)trimethoxysilane	GOPS	1.07g/mL	Sigma Aldrich	
NIPAm 97%	Monomer		Thermo Scientific Chemicals	
HHPAA 98%	Photoinitiator		Sigma Aldrich	
MBBAm 99%	Crosslinker		Sigma Aldrich	
Silane A174	Adhesion promoter	1.045g/mL	TCI Chemicals	
Triton X-100	Noninonic surfactant	1.07g/mL	Sigma Aldrich	
[EMIM][$EtSO_4$]	Ionic liquid	1.24g/mL	Sigma Aldrich	
Dichloro-p-cyclophane (DPX-C)	Parylene C		Speciality Coating Systems	
DI water + 2%v/v M90	Soapy water			
Micro-90 (M90)	Cleaning Solution		Sigma Aldrich	
JS-A191 silver ink	Ink	1.6g/ml	NovaCentrix	
DM-SIP-3060S Ag ink	Ink	2.25g/ml	DYCOTEC	
FOTECOAT 1105	Photoresist		Foteco	
FOTOCHEM 1170E	Decoater		Foteco	
FOTOCHEM 1090P	Degreaser		Foteco	
2-Butoxyethanol				