All Inkjet-printed, Transparent Piezoelectric Polymer Actuators for Microfluidic Lab-on-a-Chip Systems

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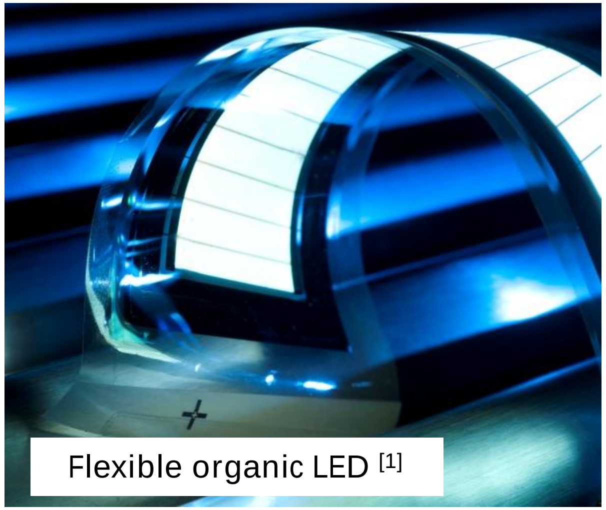
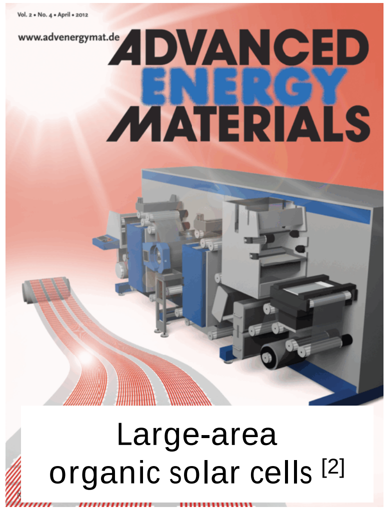
Printed and Organic Electronics

- Additive & flexible deposition
- Metal nanoparticles, conductive polymers, organic semiconductors, ...
- Ambient atmosphere
- Low processing temperatures


Flexible organic LED [1]



Large-area organic solar cells [2]

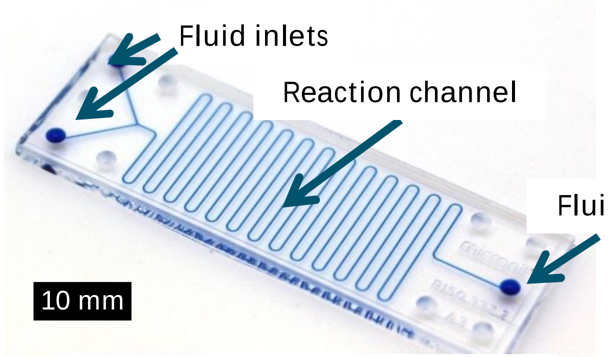
Cooling chain monitoring for food packaging [3]

→ Cost-effective solutions for disposable devices

[1] www2.dupont.com
[2] www.advenergymat.de
[3] www.thinfilm.no

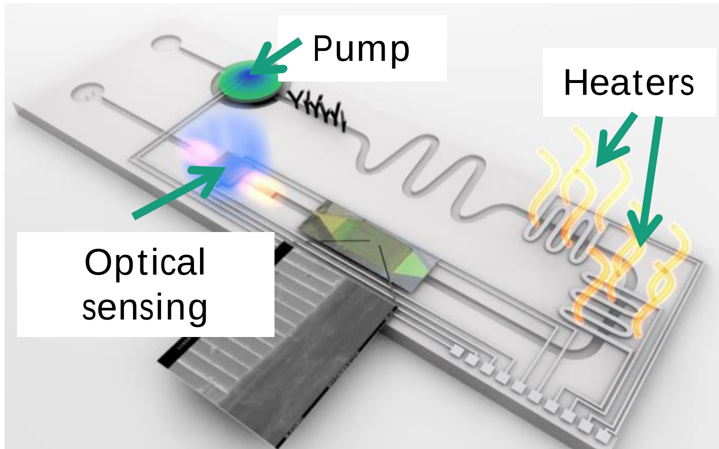
Microfluidic Lab-on-a-Chip Systems (LOC)

- Point-of-care analysis in Life Sciences [1]
  - Disposable polymer chips
  - Currently: Many external functions
  - Key functions:
    Fluid transport + temperature control



Polycarbonate micro-reactor [2]

- Goal: On-chip function integration
  - Localized functionalities
  - Cost-efficient for disposable devices
  - Low processing temperatures



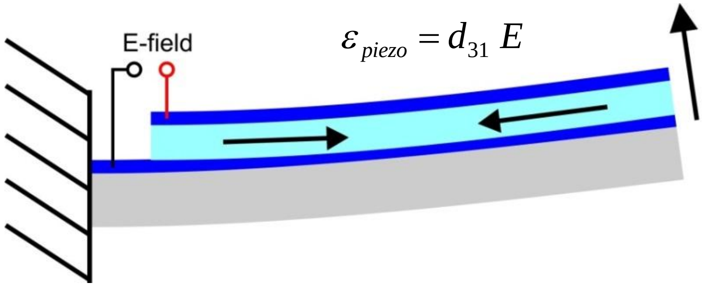
Vision: Integrated Lab-on-a-Chip system

→ Novel cost-effective and low-temperature processes required

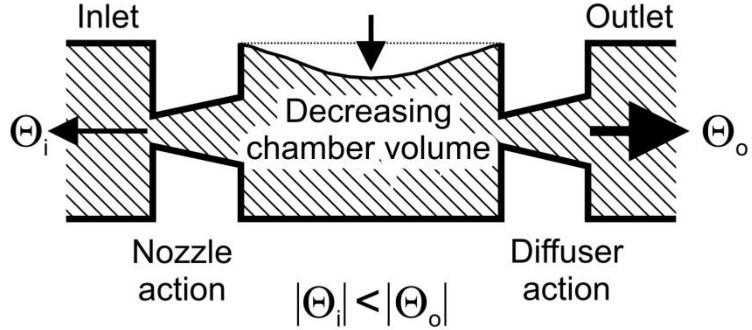
[1] Gervais et al., Adv. Mater. 23 (2011)
[2] www.micronit.com

Goal of Work

- Develop pump actuator for disposable LOC
  - Additive, inkjet-based process chain
  - Active material: Piezoelectric P(VDF-TrFE)
  - Transparent layer stack → optical detection
  - Characterize performance



Pump mode



Fluid flow

- Set up pump demonstrator
  - No joining of separate actuator element
  - Target pump rate 10 – 100 µL min^{-1} [1]

P(VDF-TrFE) – poly(vinylidene fluoride-*co*-trifluoroethylene)

[1] Amirouche et al., Microsyst. Technol. 15 (2009).

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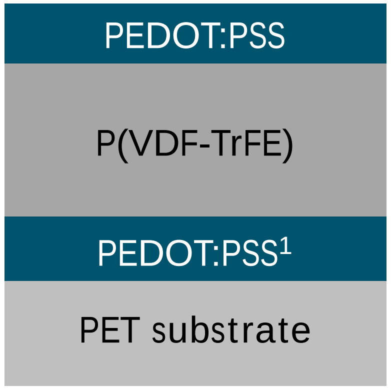
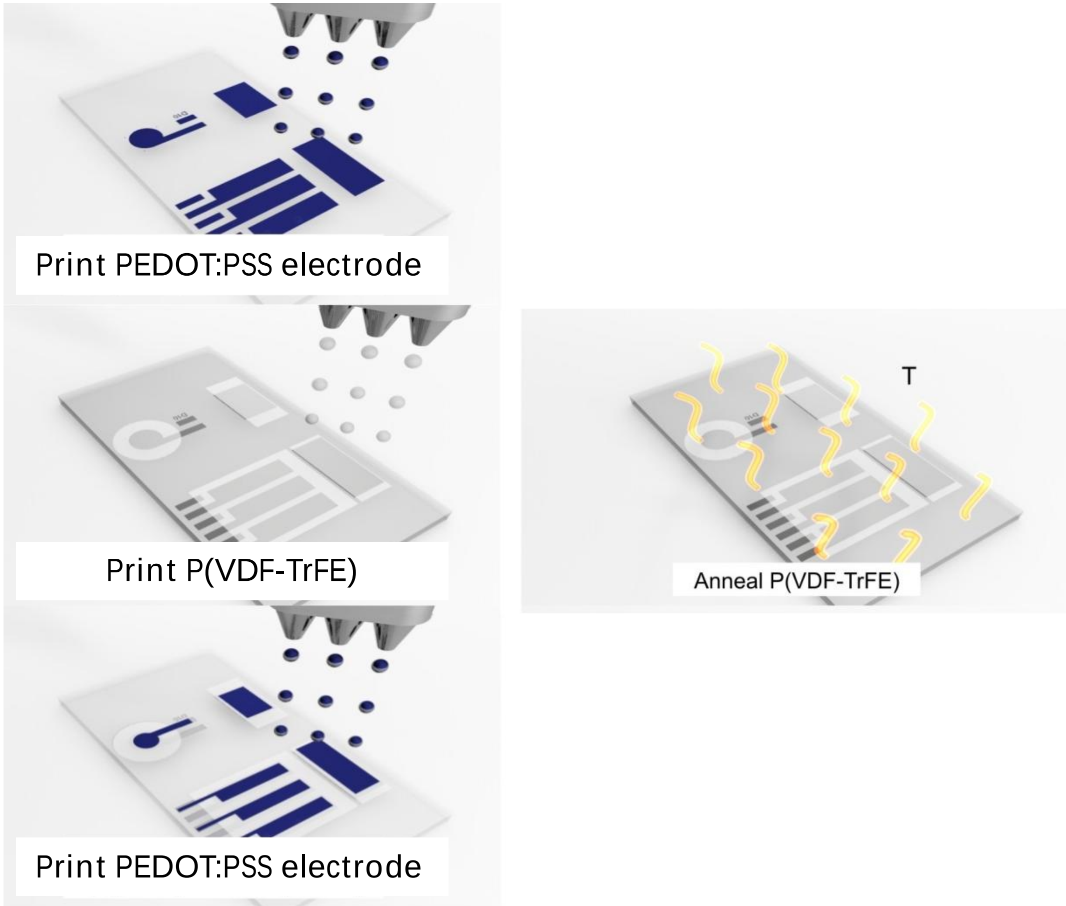
[1] www.bartels-mikrotechnik.de
[2] Amirouche et al., Microsyst. Technol. 15 (2009).

Basic Process Chain





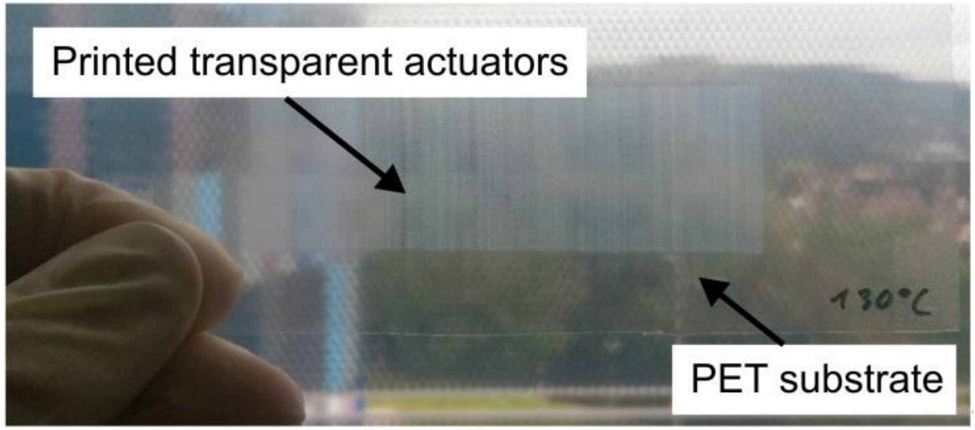
→ Annealing P(VDF-TrFE): Performance vs. low-temperature processing

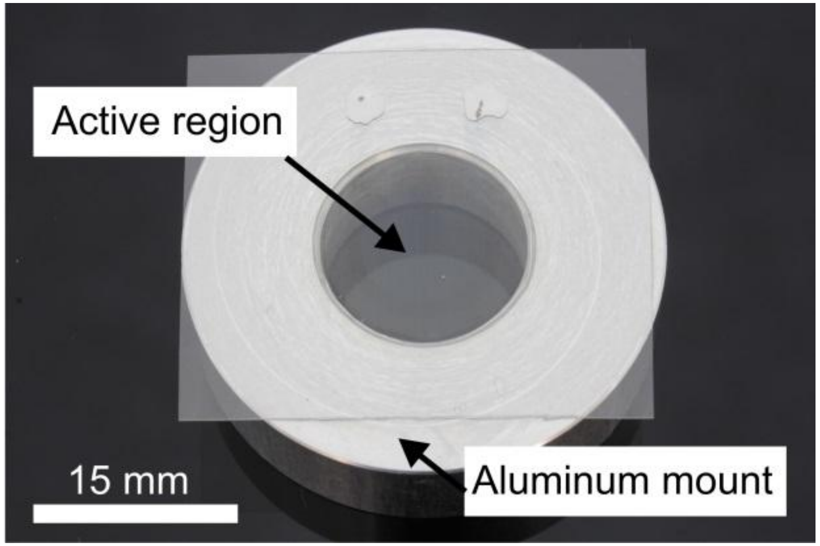
[1] Clevios P Jet HCv2, Heraeus

PET – poly(ethylene terephthalate)

P(VDF-TrFE) – poly(vinylidene fluoride-*co*-trifluoroethylene)

Processing – Fabricated Actuators

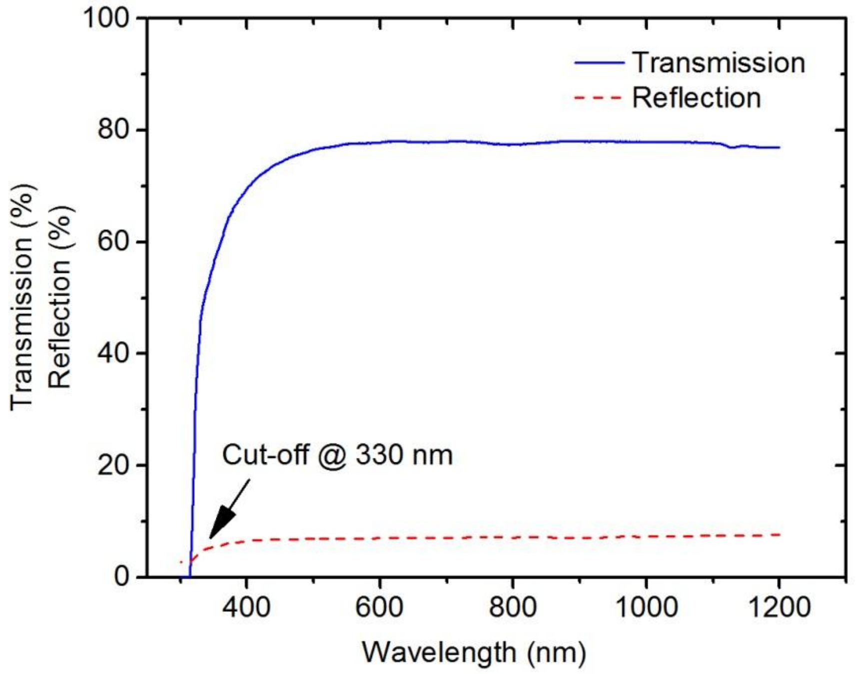




→ First fully inkjet-printed & transparent P(VDF-TrFE) actuators
Process chain suitable for polymer substrates

Device Performance - Optical

- Cut-off wavelength 300 nm
- > 75% transmission @ 460-1200 nm
- Substrate-only: 88% transmission

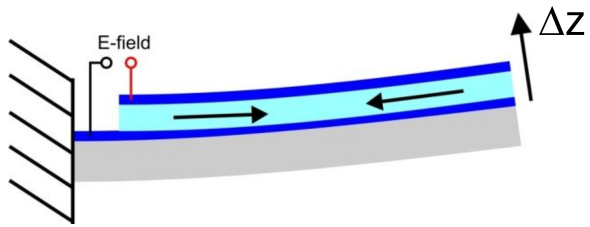


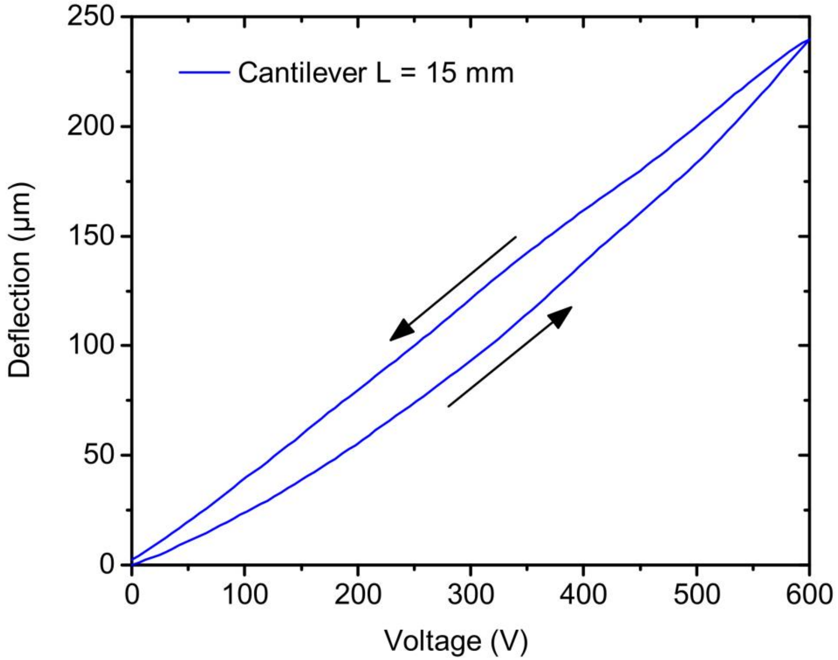
→ Suitable for optical detection through actuator

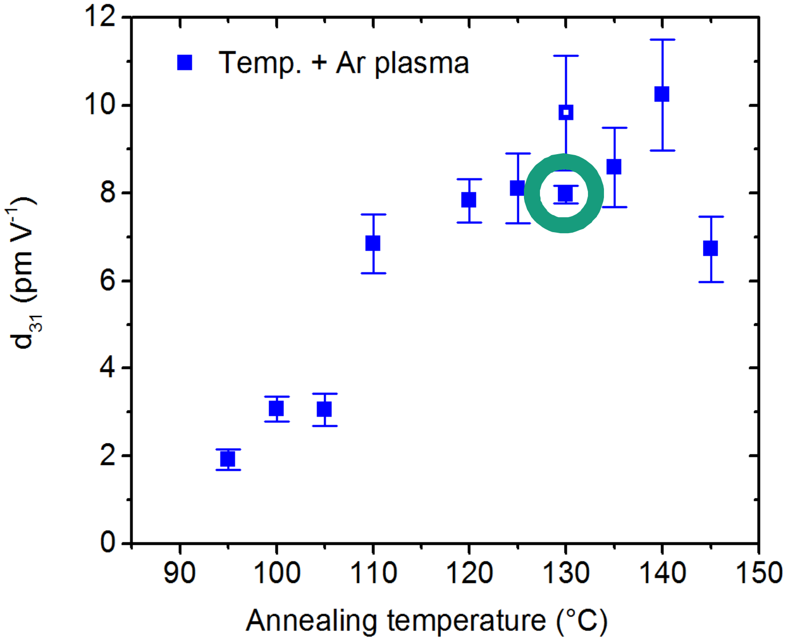
Measurement conditions: Lambda 950 UV/VIS Spectrometer (Perkin Elmer Inc., USA), incident angle 6°

Device Performance - Electromechanical

- Large d_{31} → Large actuator deflection Δz
- Measure Δz → derive d_{31}







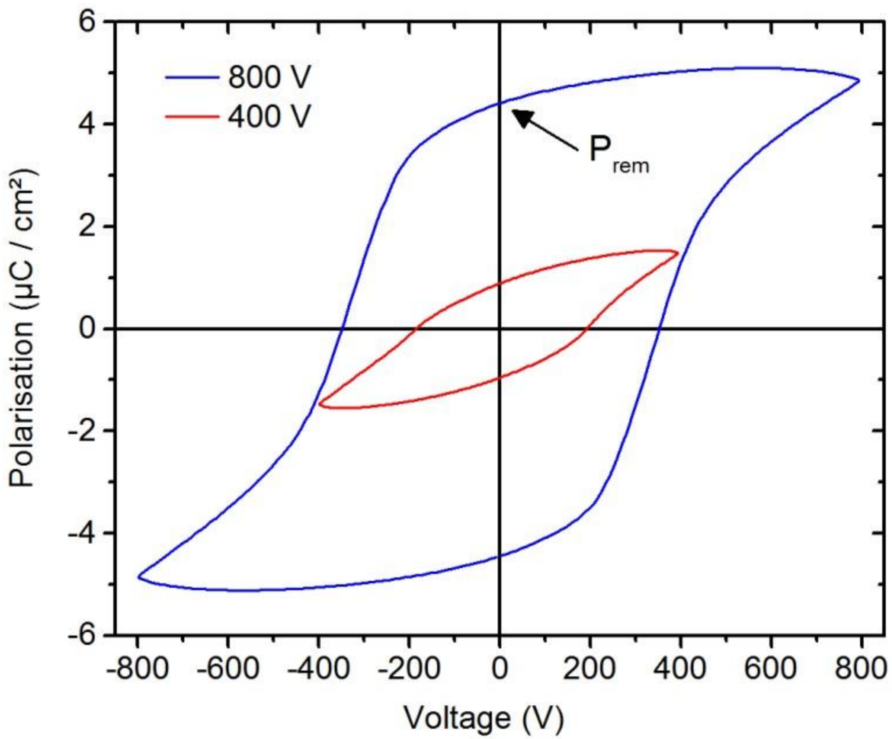
→ Annealing @ 110 °C ≤ T ≤ 145 °C: Significant actuator performance

[Results obtained with silver electrodes]

Pabst et al., *Organic Electronics* 15 (2014).

Device Performance – Ferroelectric

- Ferroelectric hysteresis loops recorded up to 800 V / 89 kV mm^{-1}
- Remanent polarisation P_{rem} = 4.4 µC cm^{-2}



→ Performance comparable to literature values

Measurement setup: EasyCheck 300, Aixacct GmbH, Germany,
three cycles @ 0.05 Hz

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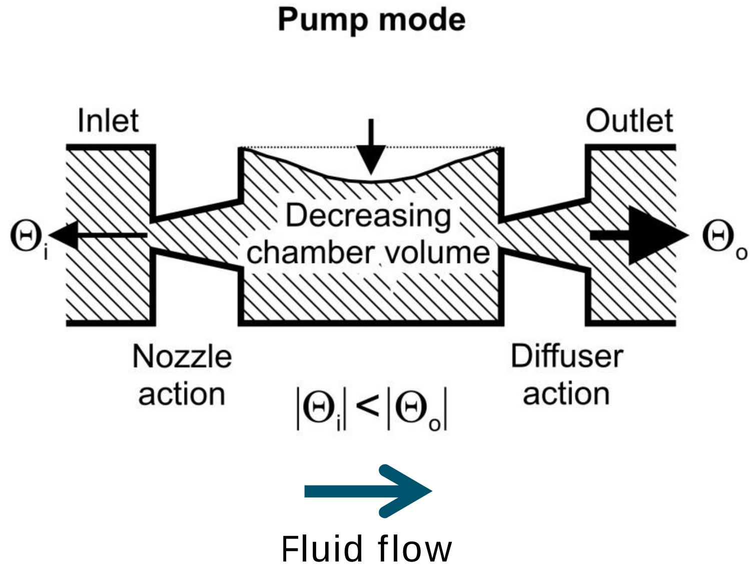

[1] www.bartels-mikrotechnik.de
[2] Amirouche et al., Microsyst. Technol. 15 (2009).

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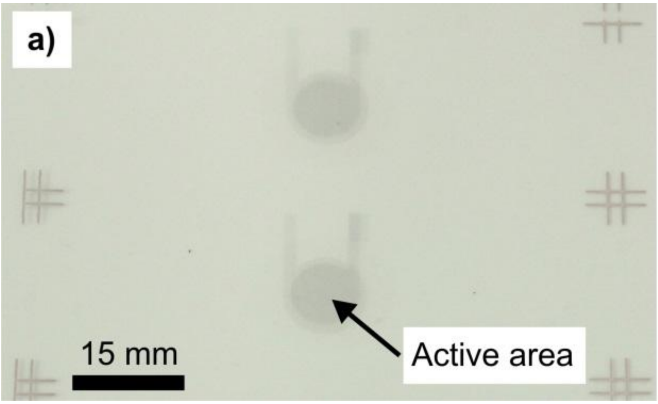
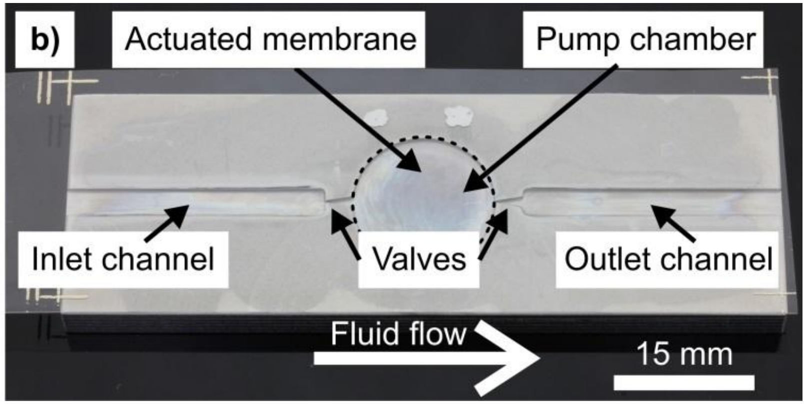
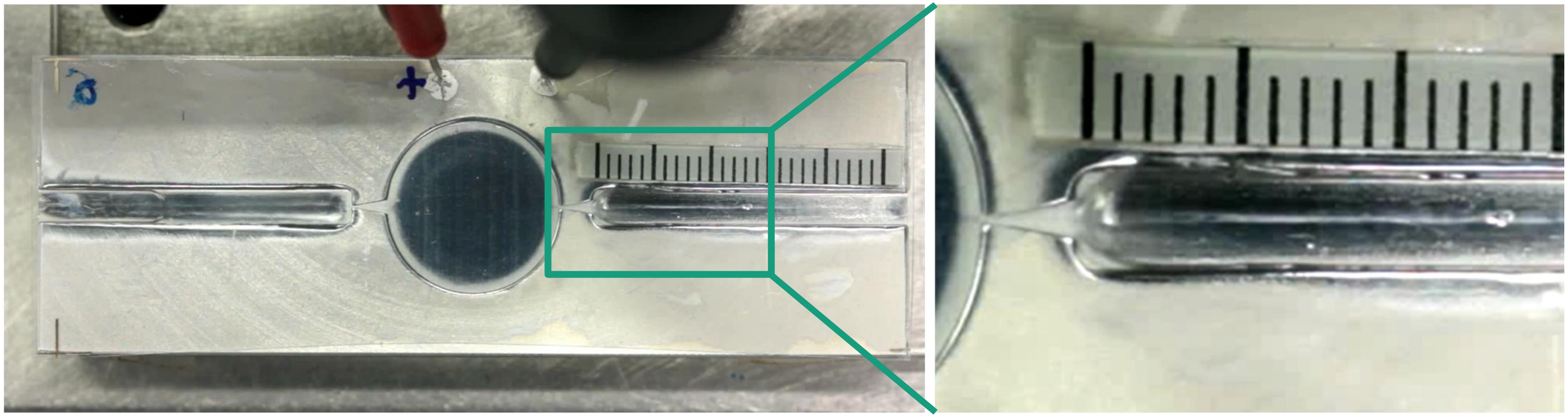
Demonstrator: Micropump

- Milled pump substrate + printed membrane actuator







(*) Design based on A. Olsson, KTH Stockholm (1998).

Beckert, Pabst, Mikropumpe, Patent DE 102011107046 A1 (2013).

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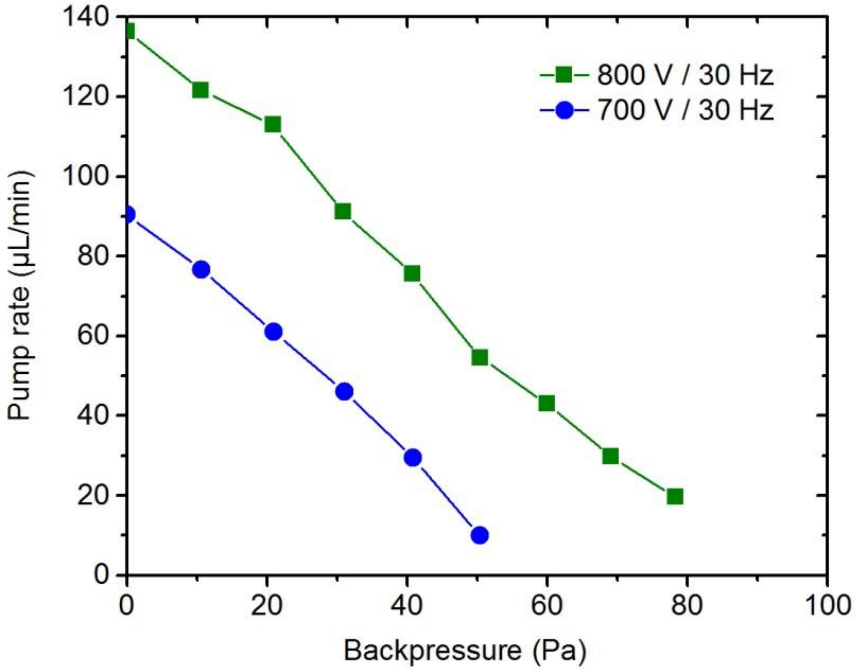
Pump Rate Measurements

- Pump rate vs. backpressure
- Maximum pump rate > 135 µL min^{-1}



Proof-of-concept: First transparent, inkjet-printed micropump actuator
Low backpressure due to passive valves → Modify valve concept

Conclusions

- Function integration in disposable, polymer-based LOC systems
  - Additive low-cost fabrication by inkjet-printed functions
  - Reduced hybrid integration

- Fully printed, transparent P(VDF-TrFE) actuators for micropumps
  - Transmission > 75% @ 460-1200 nm → optical detection through actuator
  - d_{31} coefficient up to 10 pm V^{-1}

- Demonstrator: First micropump with inkjet-printed, transparent actuator
  - Pump rates > 130 µL min^{-1} → Suitable for LOC applications
  - Backpressure needs to be increased by optimized valves

Thank you for your attention!

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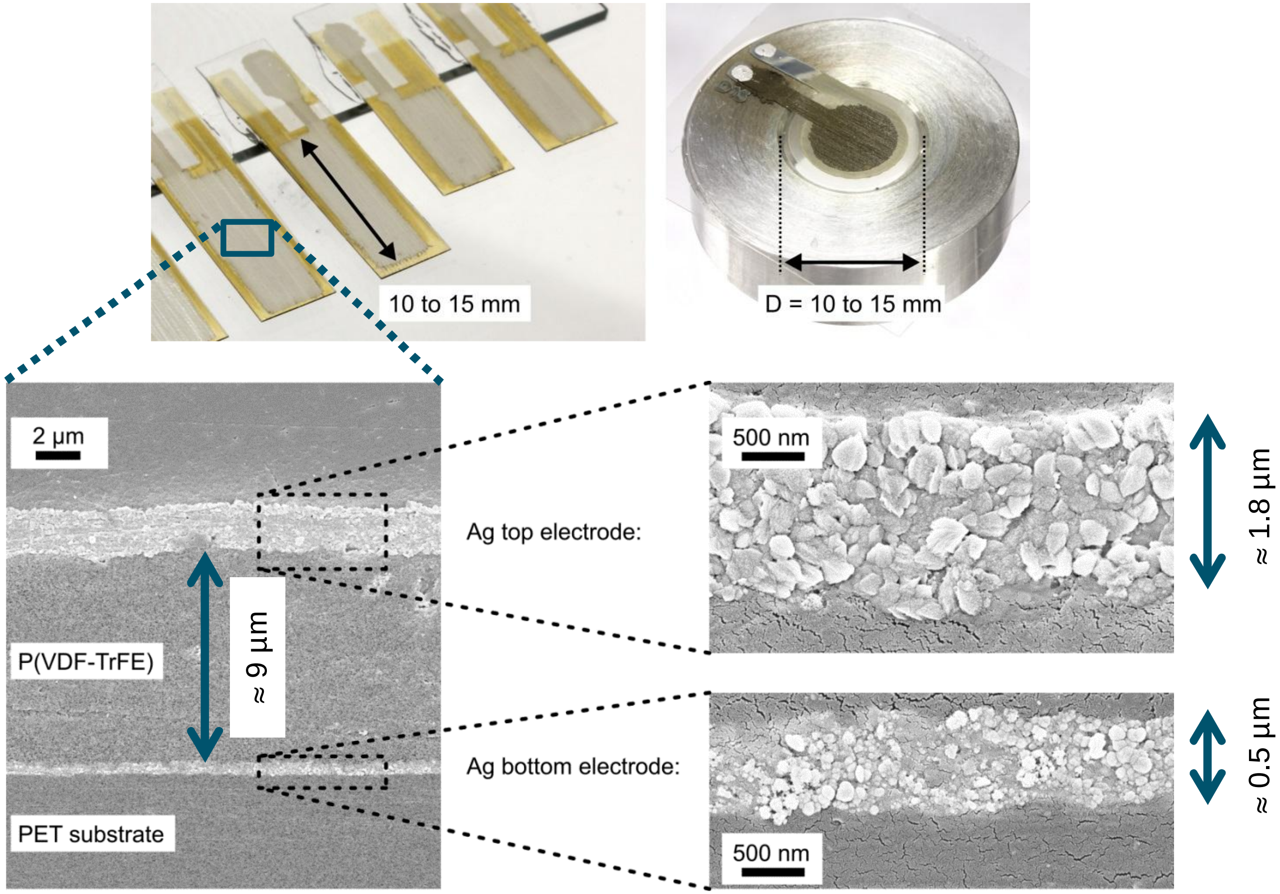
Processing – Fabricated Actuators



→ First all inkjet-printed P(VDF-TrFE) actuators
Process chain suitable for polymer substrates

Pabst et al., *Organic Electronics* 14, 3423–3429 (2013).

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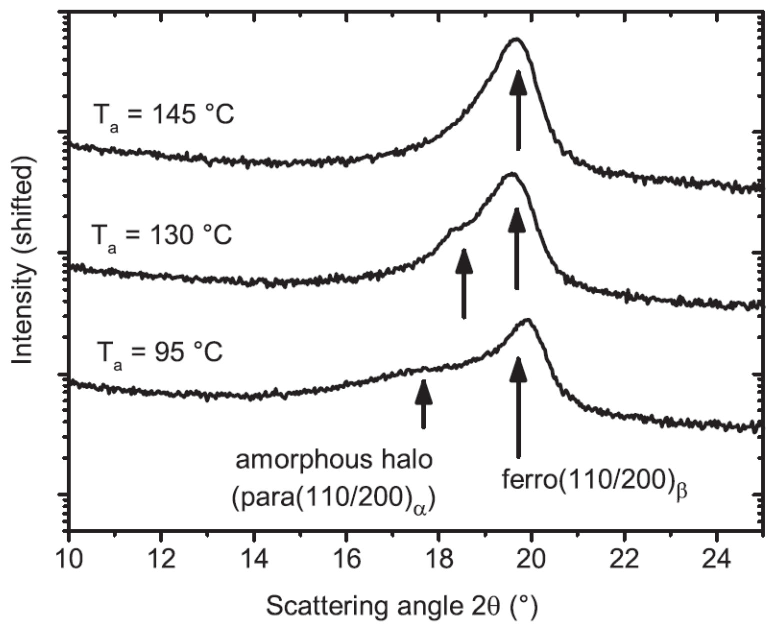
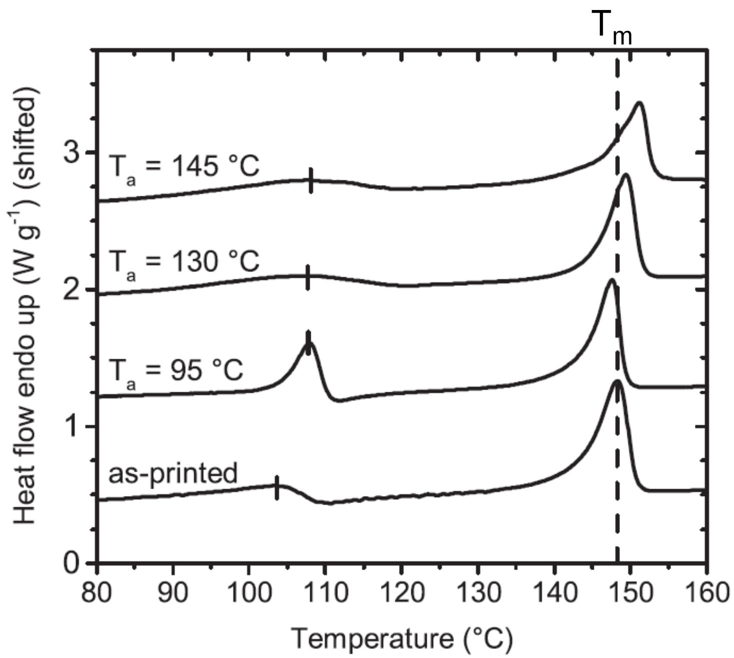
Device Performance – Morphology

- X-ray diffraction



- Differential scanning calorimetry



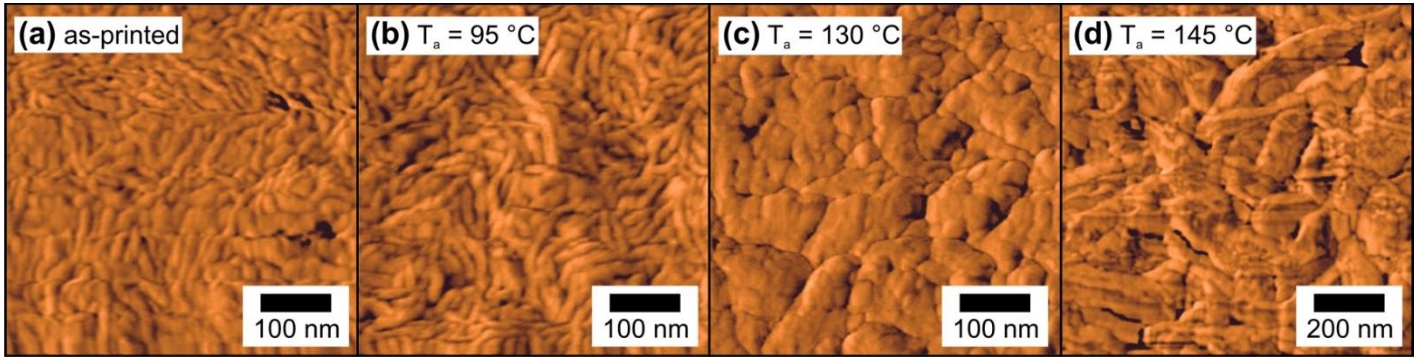
→ Annealing @ 130 – 145 °C: Predominant ß-phase + larger crystallites

T_m – Melting temperature

Pabst et al., *Organic Electronics* 15 (2014).

Device Performance – Morphology

- AFM characterization



Sample	d_{31} (pm V^{-1})	P_{rem} (µC cm^{-2})	Morphology from AFM	Crystallite size (nm)
95 °C	0.8 ± 0.04	0.1 ± 0.01	rod-like	21 ± 7
130 °C + Ar-Plasma	8.0 ± 0.2	5.8 ± 0.1	globular	63 ± 24
145 °C	6.6 ± 0.4	4.3 ± 0.4	globular	138 ± 62
Literature	≈ 10 – 12 [1]	≈ 8 [2]		≈ 180

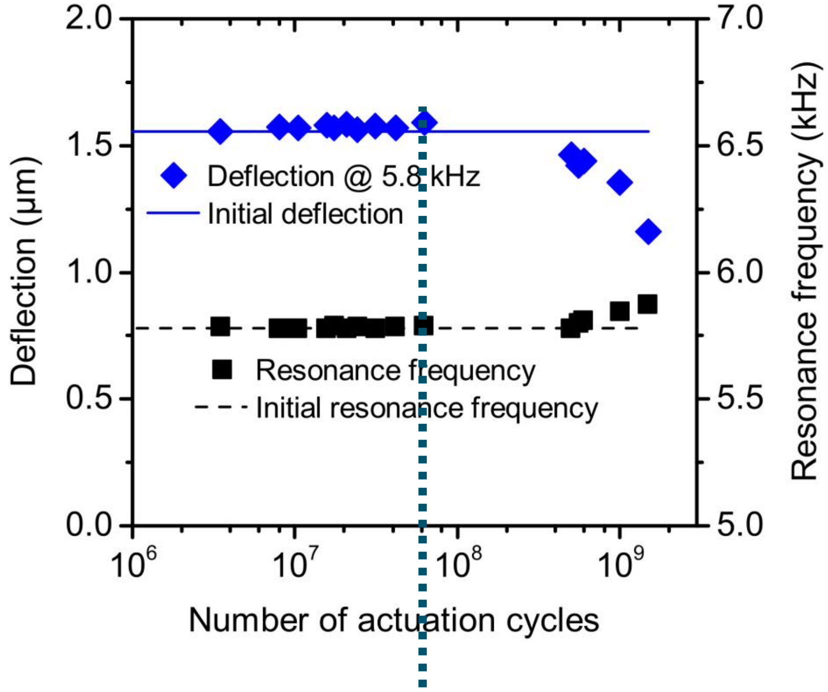
→ Process guidelines: Annealing → Morphology → d_{31}, P_{rem}

Pabst et al., *Organic Electronics* 15 (2014).

[1] Wang et al., J. Appl. Phys. 74 (1993).
[2] Mao et al., Ferroelectrics-Physical Effects, InTech (2011).

Device Stability – Cyclic Operation

- Cyclic stability test in air (1.5 × 10^9 cycles, 75 V @ f_{res})
- Realistic operation in disposable device < 3 hours



→ Degradation for large cycle numbers (> 10^8)

[Results obtained with silver electrodes]

Pabst et al., *Organic Electronics* 14 (2013).

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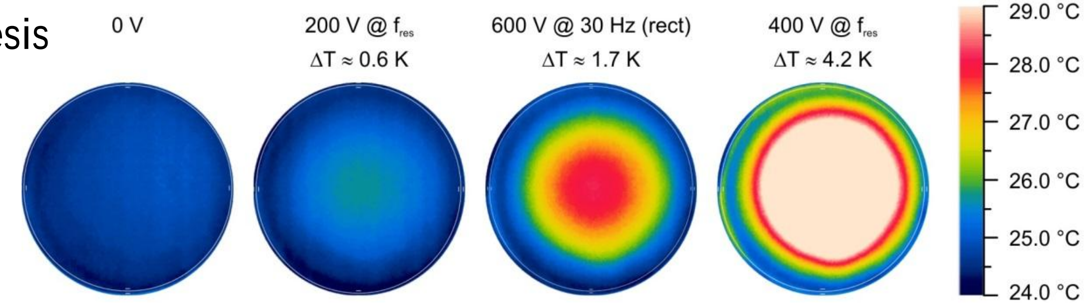
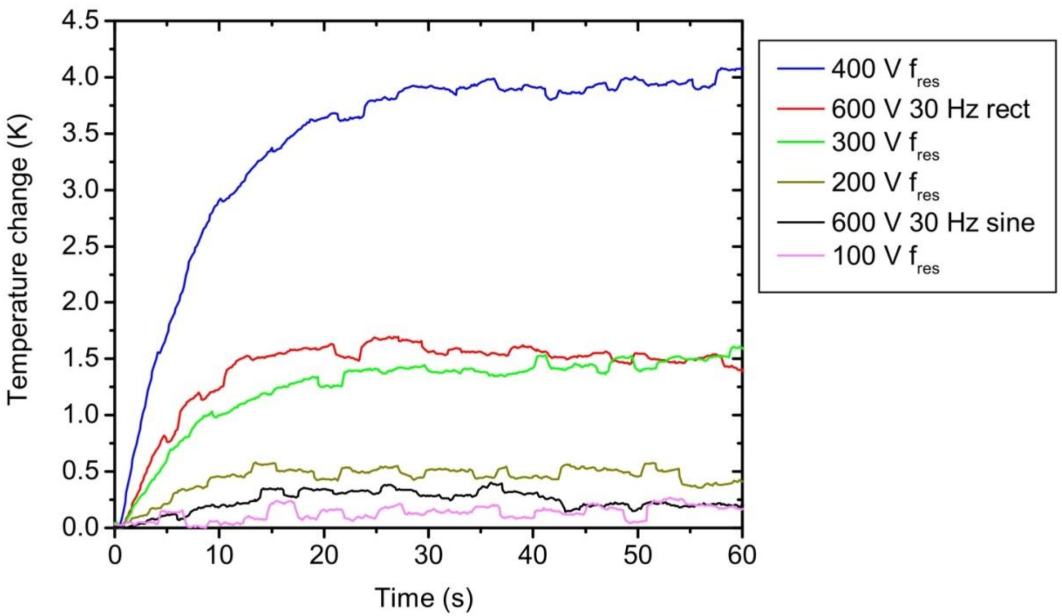
Device Stability – Heat Generation

- Polarization hysteresis
  → Heat generation





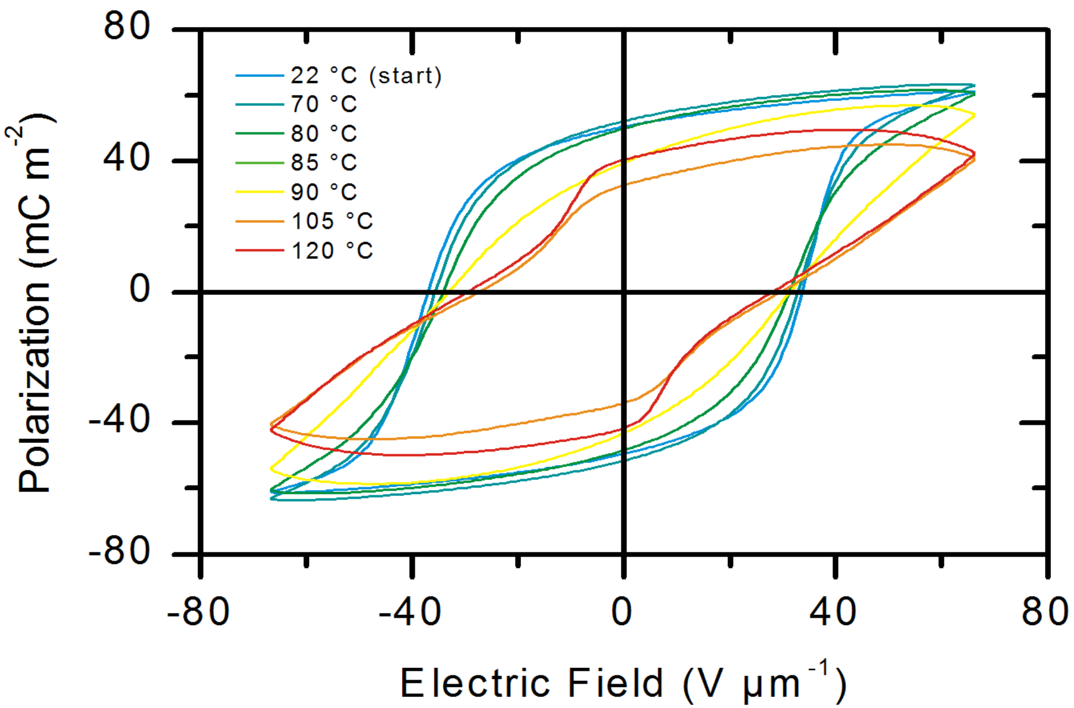
→ Low heat generation (ΔT < 2 K for most driving cases)

[Results obtained with silver electrodes]

O. Pabst, Ph.D. thesis, Friedrich Schiller University Jena, Germany, (2014).

Device Stability – Operating Temperature

- Operational stability @ elevated temperatures



→ Stable operation up to ≈ 80 °C

[Results obtained with silver electrodes]

O. Pabst, Ph.D. thesis, Friedrich Schiller University Jena, Germany, (2014).