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Inkjettable, Polydimethylsiloxane Based Soft Electronics

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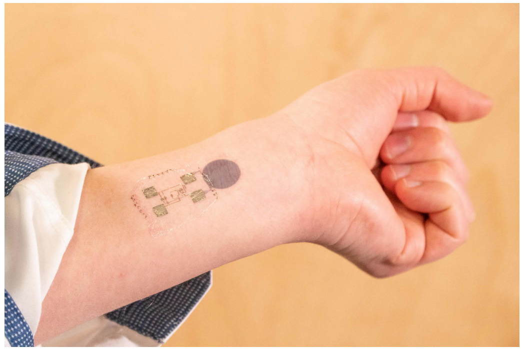
Soft electronics

Conformable
Deformable
Thin

- Health / wellbeing
- Automotive
- Soft robotics /machinary
- Aviation
- Human-machine interface
- Smart building



Ultra-thin skin-like electronics

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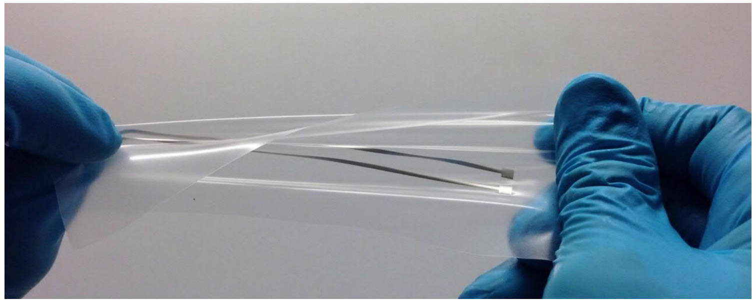
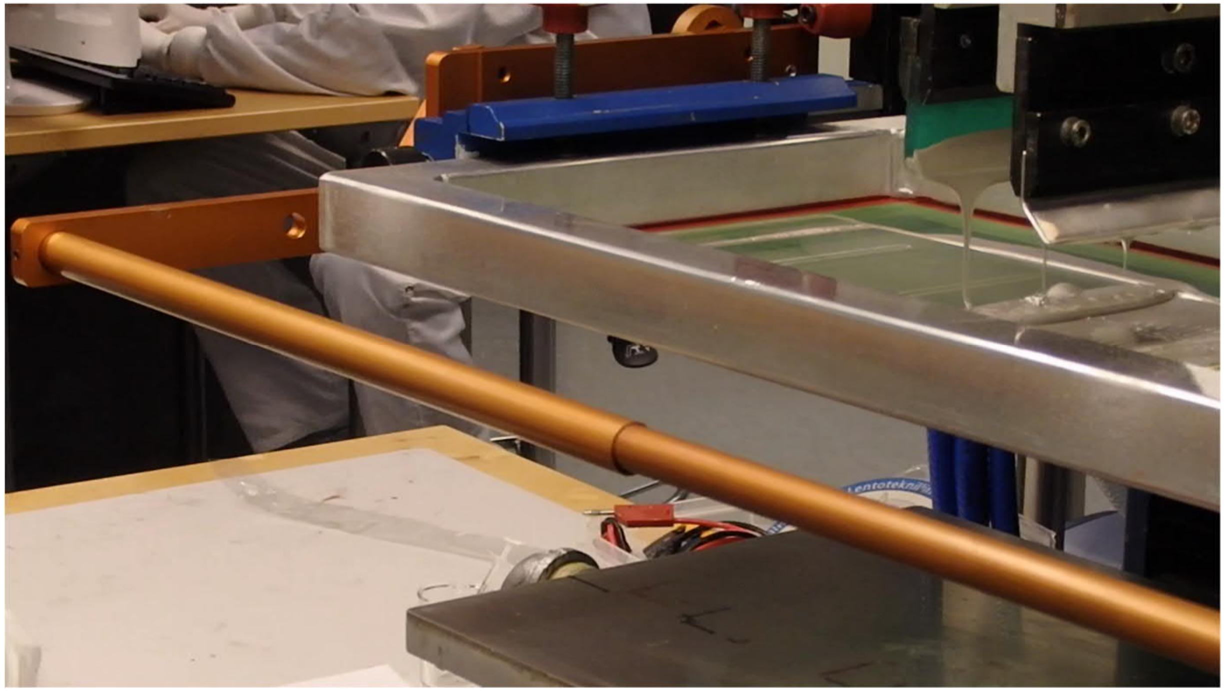
Our approach

Main advantages:
- Simplified process
- Large-area
- Cost-effective

Inks



Soft substrates



Printing technologies

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LFE infrastucture

250 m2 Lab space
60 m2 Clean-room
PrintLab
Thin-film fabrication

Inkjet (with NIR and UV post processing), Modular printing system (gravure/flexo/rotary screen/wet and dry lamination / online annealing), screen printer, high-resolution inkjet

Inert glovebox-system including evaporator (thermal, e-beam), probe station, spin-coating, vacuum hot-plate, inkjet, ALD (thermal and plasma)

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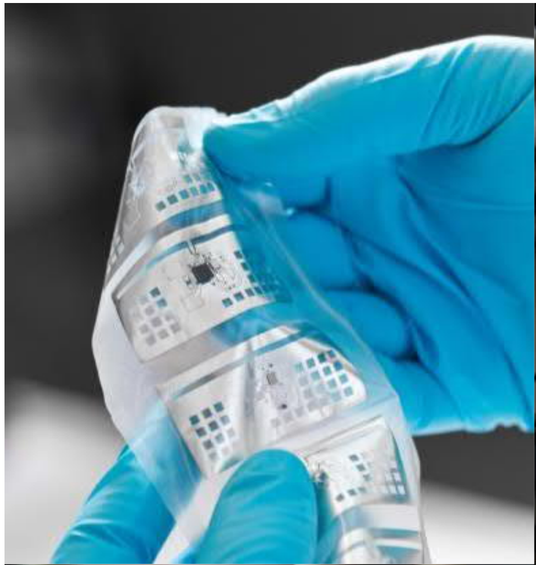
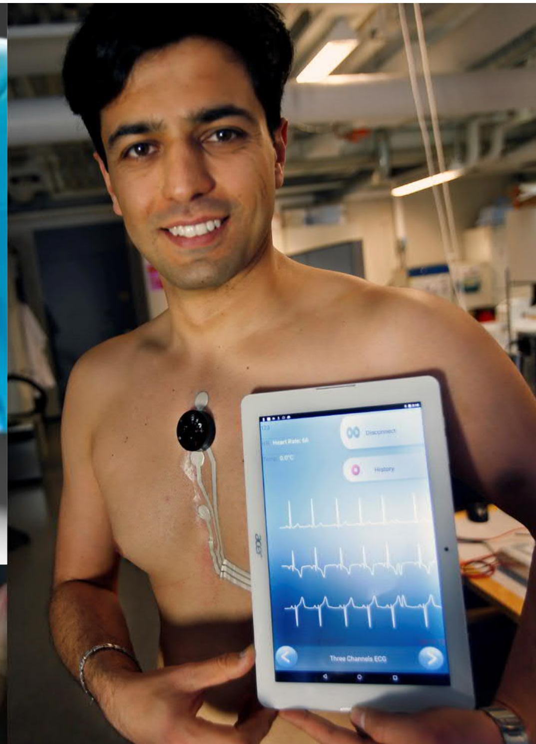
Printed on-skin sensors

Examples of previous research related to wireless skin sensors

- Wireless node
  - H. Sillanpää, et al, DOI: 10.1109/ESTC.2014.6962739
  - H. Sillanpää, et al, DOI: 10.1109/ICEP.2014.6826704
- Circuit board and wiring
  - R. Mikkonen, et al, DOI: 10.1021/acsami.9b19632
  - M. Mosallaei, et al, DOI: 10.1088/2058-8585/ab68ae
  - J. Suikkola, et al, DOI: 10.1038/srep25784
- Temperature sensors
  - T. Vuorinen, DOI: 10.1038/srep35289
  - T. Vuorinen, DOI: 10.1007/978-981-10-5122-7_210
- ECG
  - T. Vuorinen, et el. DOI: 10.1002/admt.201900246
  - T. Vuorinen, et el. DOI: 10.1002/aisy.202000030
- Pulse wave sensor
  - M.-M. Laurila, et al., DOI: 10.1109/JSEN.2019.2934943
- Thin-film circuitry
  - Laurila, et al., DOI:10.1109/JEDS.2019.2915028

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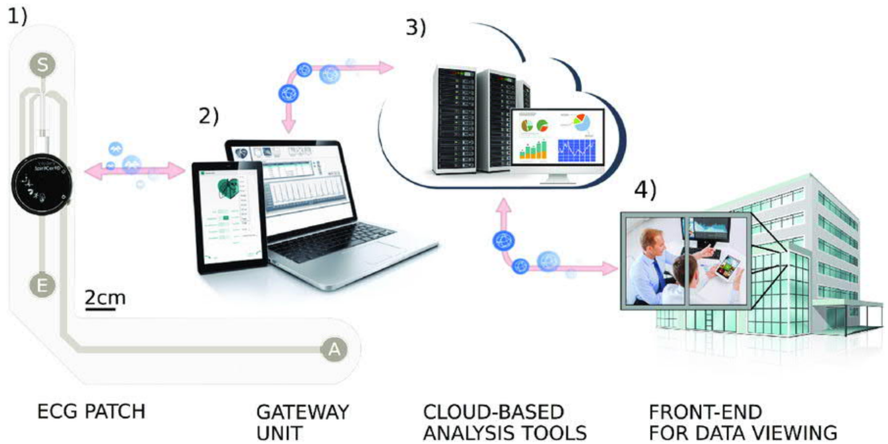
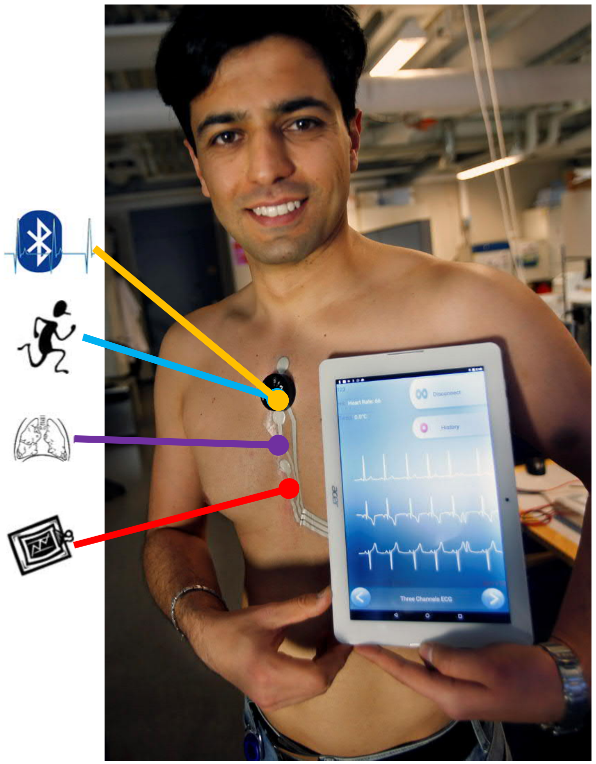
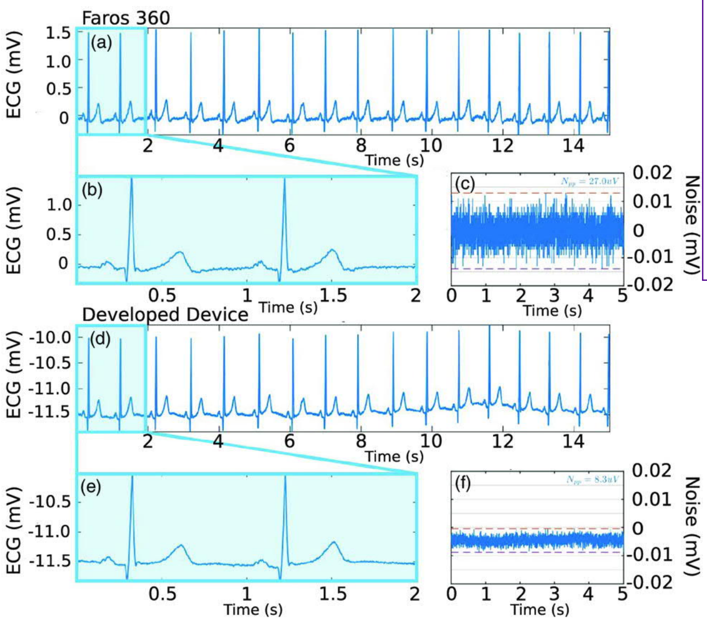
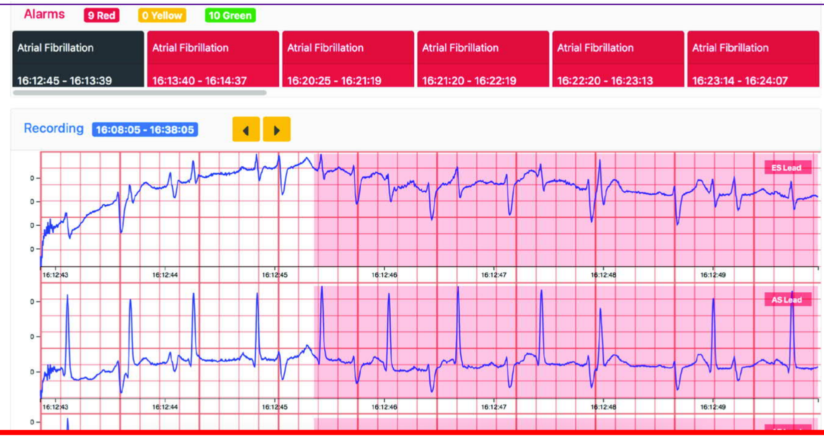


Red alarms	Yellow alarms	Green alarms
HR exceeds 240 bpm for longer than 4 s, Ventricular fibrillation is diagnosed and red alarm is raised.	Average HR over 160 bpm, extreme tachycardia is diagnosed, and yellow alarm is raised.	Average HR of three consecutive beats lower than 40 bpm, bradycardia is diagnosed, and green alarm is raised.
Three consecutive ventricular beats with HR over 120 bpm, ventricular tachycardia is diagnosed, and red alarm is raised.	Average HR under 35 bpm, severe bradycardia is diagnosed, and yellow alarm is raised.	Three consecutive ventricular beats with HR under 120 bpm, ventricular rhythm is diagnosed, and green alarm is raised.
RR-interval of two consecutive beats is more than 4 s, asystole is diagnosed, and red alarm is raised.	–	RR-interval of two consecutive beats is more than 2 s, pause is diagnosed, and a green alarm is raised.







T. Vuorinen, et al., DOI: 10.1002/aisy.202000030

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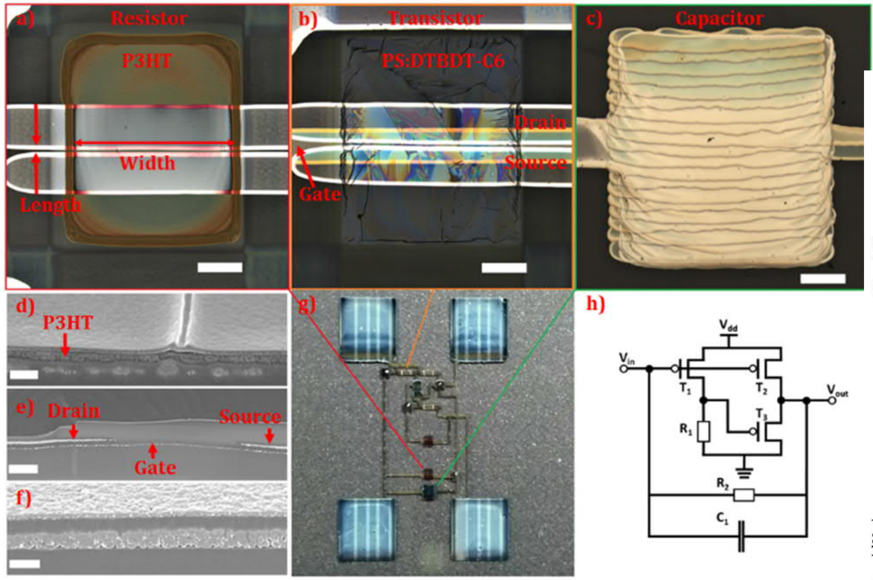
Laurila, DOI:10.1109/JEDS.2019.2915028

Charge amplifier

Collaboration between Tampere University, Tampere University Hospital and Yamagata University (Prof. Tokito)

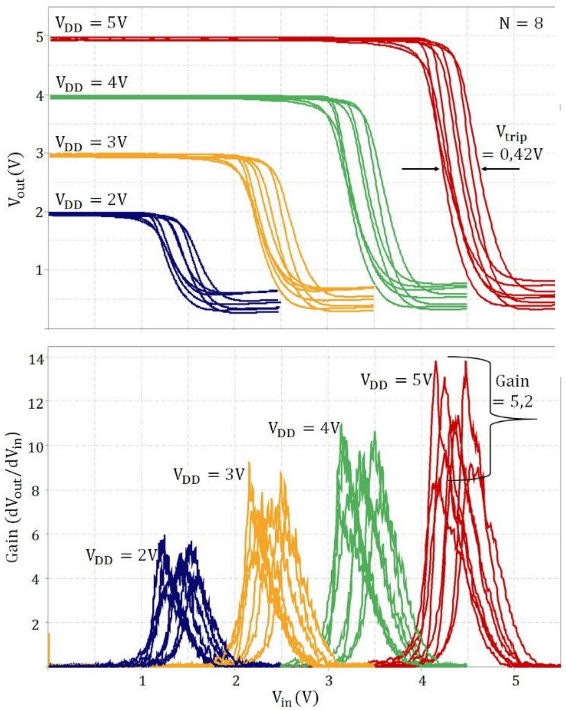


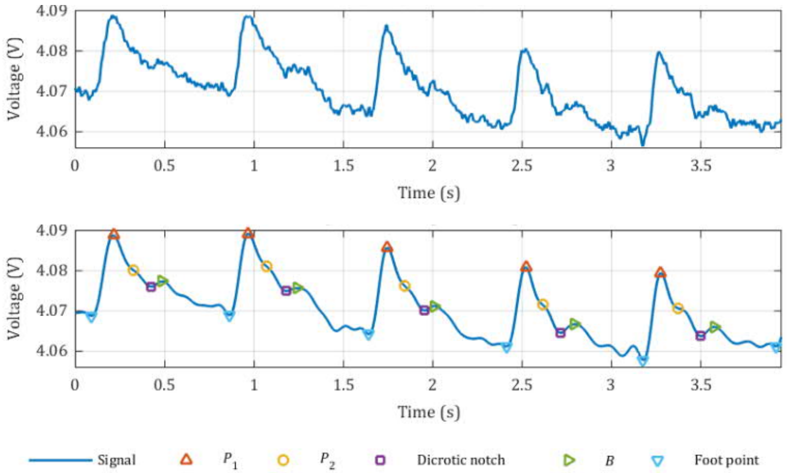
Substrate: parylene

Conductors: NPS-JL

Semiconductor: PS:DTBDT-C6

Resistor: P3HT

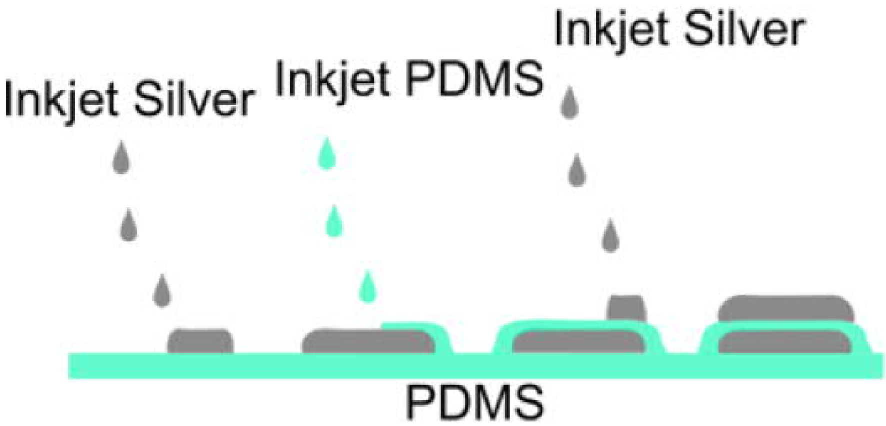




Parameter (n=25)	Average	Std. dev
RI, sensor	0.388	0.031
RI, output	0.404	0.044
rAIx, sensor	0.615	0.045
rAIx, output	0.626	0.057

Polydimethylsiloxane (PDMS)

- PDMS is
  - inexpensive,
  - optically transparent and
  - biocompatible soft elastomer.
- The traditional manufacturing methods (lithography, mold casting) make PDMS fabrication both time-consuming and inconvenient.
- This work focus on **additive** and **digital manufacturing** of PDMS.
  - Drop on demand
  - Low material consumption
  - Contactless printing



Inkjet printing

- Fujifilm Dimatix DMP 2800-printer
  - Common inkjet printer
  - 10 pl cartridge (approx. 20µm)
- PDMS polymer is pre-mixed
  - **One component** printing – not two component
  - Previously reported studies with one component have life time from some hours to couple of days.
  - In this research, several days.
- Silverjet DGP 10LT-15C, Advanced Nano Products

PDMS inks:
- Sylgard 184 (Dow Corning)
- 10:1 ratio (base to catalyst)

Solvents:
- Isobutyl acetate (IBA, 98%)
- Octyl acetate (OA, ≥ 99%)

Targets:
Viscosity: 10-20 mPa·s
Surface tension: 20-35 mN/m

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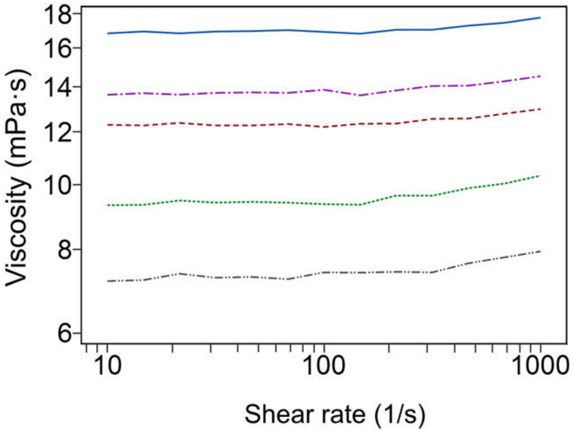
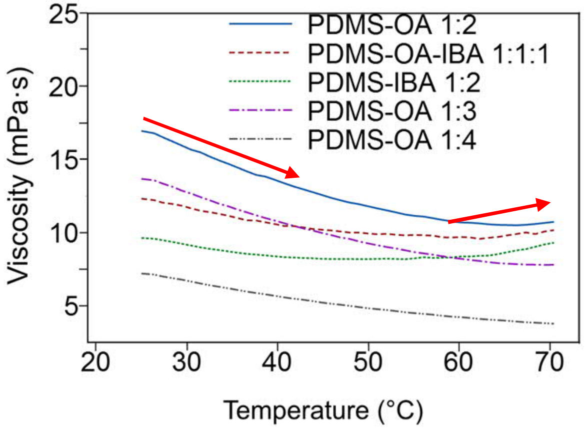
PDMS ink results

Rather stable

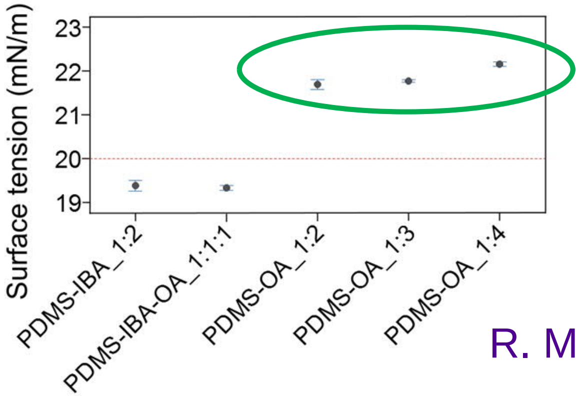




Solvent evaporation increases PDMS concentration

Results of jetting trials:

- IBA inks were not successful
- OA inks were successful
    - 1:2 PDMS-OA requires heating above 35C
- 1:3 PDMS-OA was selected to maximize the PDMS content

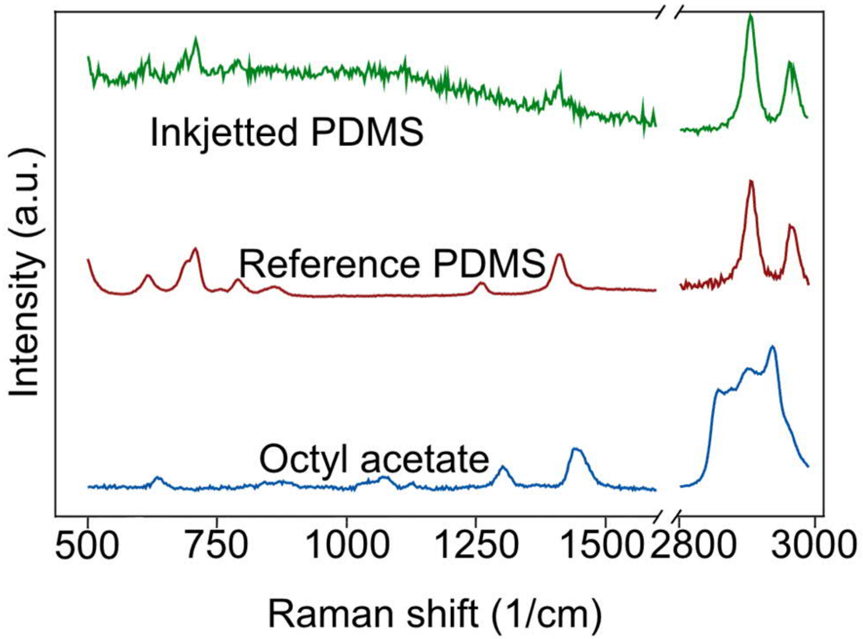


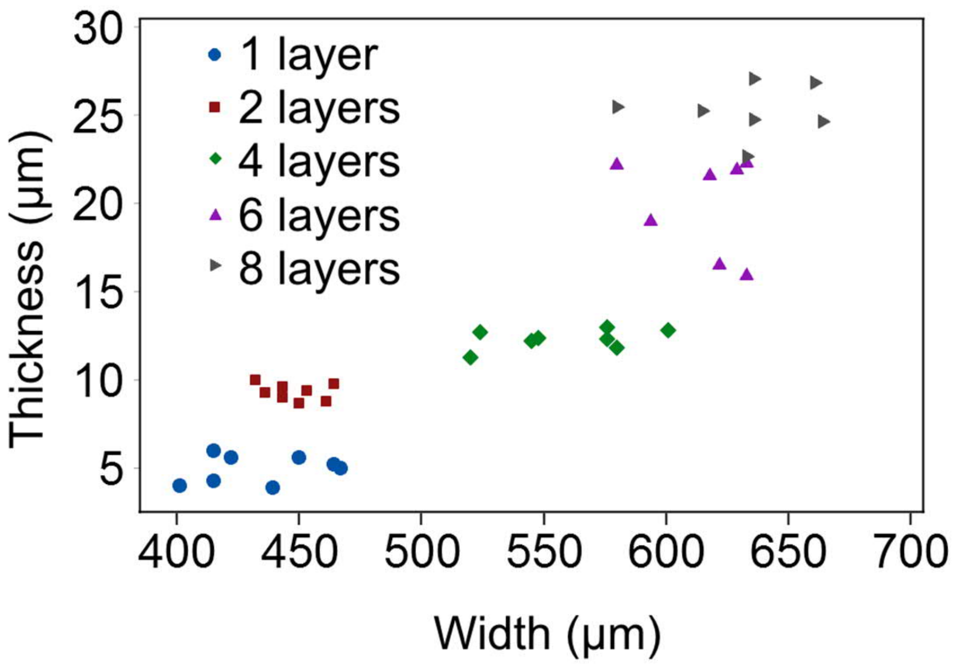
OA-based inks were on the theoretical printable range (γ > 20 mN/m)

R. Mikkonen, et al, DOI: 10.1021/acsami.9b19632

Composition of cured PDMS ink

The ink was cured at 120 ºC temperature for 25 min.





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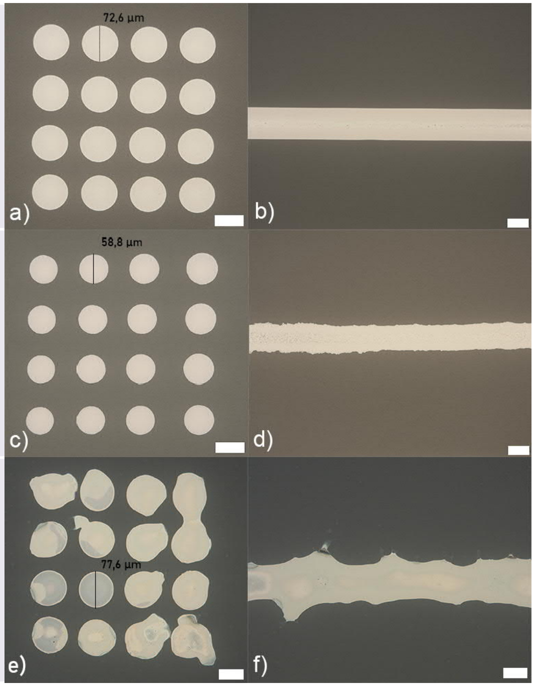
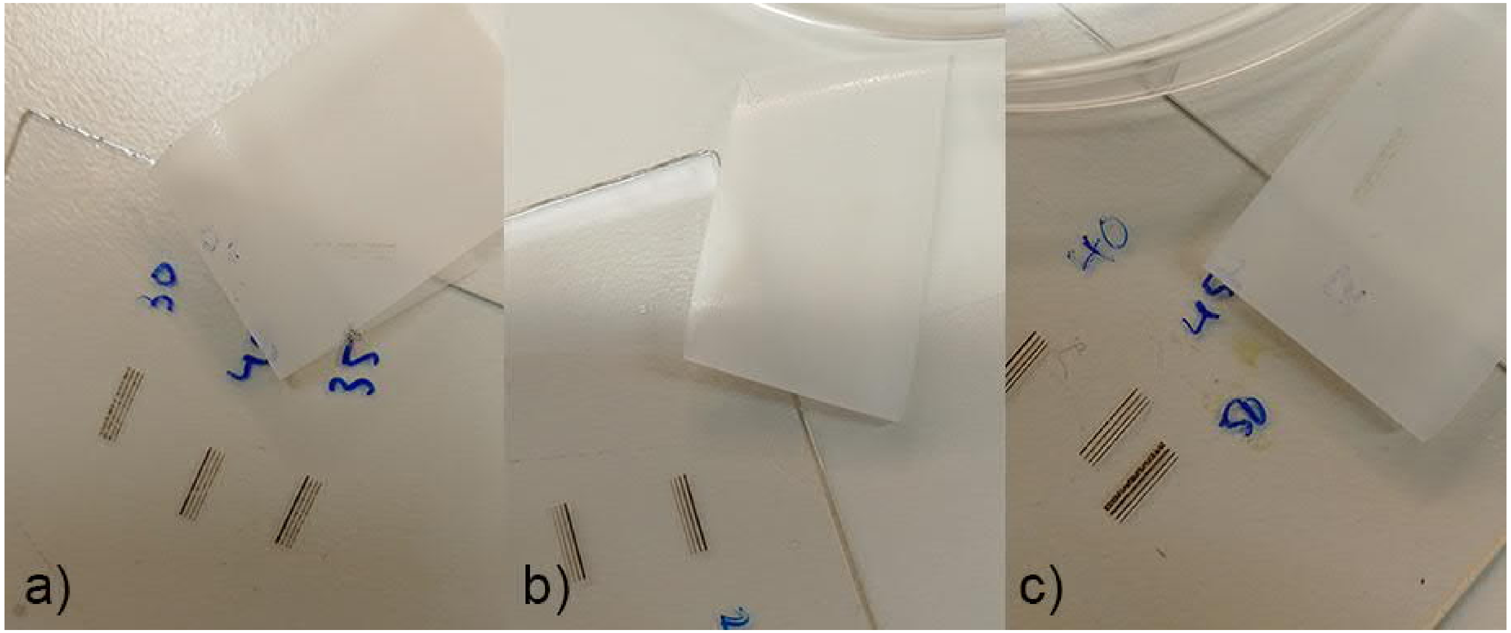
PDMS pre-treatment

Nitrogen plasma	Exposure power: 100 W, time: 1 min, chamber pressure 0.6 mbar, gas flow 700 sccm
Pyrolytic coating	Treat substrate with a steady back-and-forth movement for 4 times
MPTMS	A 6 % solution in ethanol, spin coat for 2 min at 1600 rpm on plasma treated PDMS, bake for 30 min at 120 ºC



Peel test



plasma treated PDMS | PDMS with pyrolytic coating | MPTMS-coated PDMS

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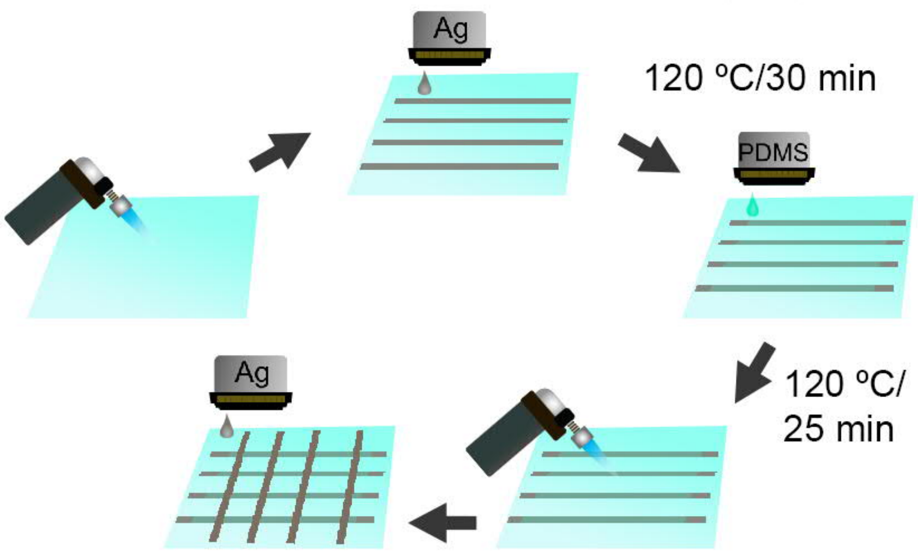
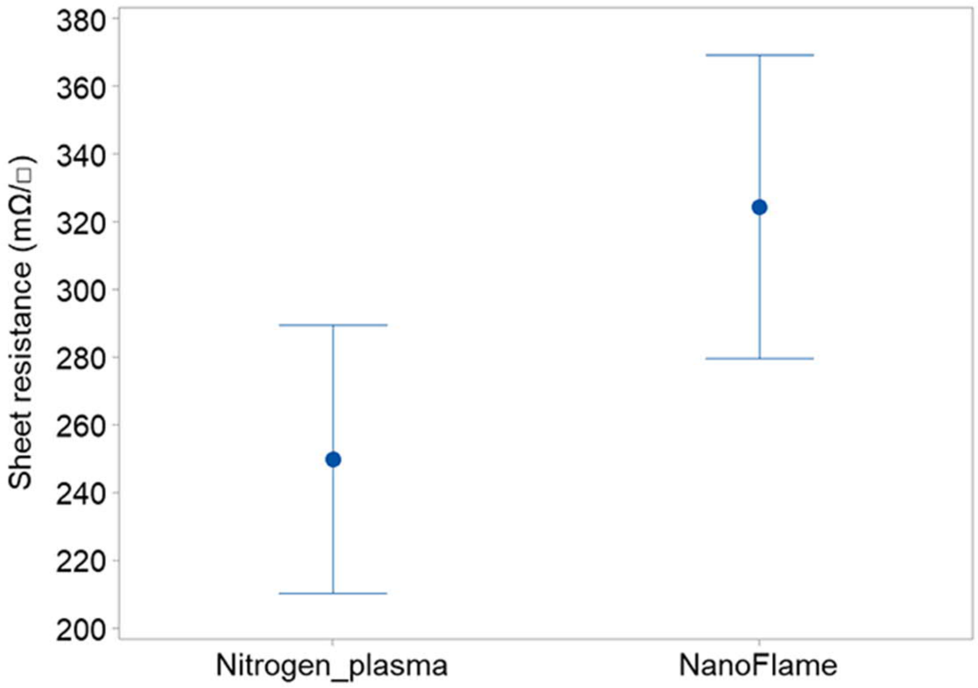
Multilayer circuit board





Conclusions

- Here, an approach for an all-inkjet printed PDMS based electrical multilayer structures was presented
- The optimization of the solvent type and concentration was shown to have significant effect on the PDMS printability.
- Alternative surface treatments for plasma were studied.
  - Straightforward and fast, flame pyrolytic silicating method, improves the adhesion of the conductive inks significantly in comparison to the previously used plasma treatment.
- PDMS process is designed for the widely used Dimatix material printers
  - Findings could be used in electronics to build, for example, soft sensors and other complex devices

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Acknowledgement

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