IEEE FLEPS 2020

Inkjettable, Polydimethylsiloxane Based Soft Electronics

Riikka Mikkonen and Prof. Matti Mäntysalo
Tampere University

matti.mantysalo@tuni.fi
https://research.tuni.fi/lfe/
Soft electronics

Conformable
Deformable
Thin

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

Ultra-thin skin-like electronics
Our approach

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

Inks

Soft substrates

Printing technologies
LFE infrastructure

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

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

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

Contact: Dr. Jari Keskinen, Staff Scientist
jari.keskinen@tuni.fi
research.tuni.fi/lfe
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**

- **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
Red alarms

- HR exceeds 240 bpm for longer than 4 s, Ventricular fibrillation is diagnosed and red alarm is raised.
- Three consecutive ventricular beats with HR over 120 bpm, ventricular tachycardia is diagnosed, and red alarm is raised.
- RR-interval of two consecutive beats is more than 4 s, asystole is diagnosed, and red alarm is raised.

Yellow alarms

- Average HR over 160 bpm, extreme tachycardia is diagnosed, and yellow alarm is raised.
- Average HR under 35 bpm, severe bradycardia is diagnosed, and yellow alarm is raised.
- RR-interval of two consecutive beats is more than 2 s, pause is diagnosed, and a green alarm is raised.

Green alarms

- Average HR of three consecutive beats lower than 40 bpm, bradycardia is diagnosed, and green alarm is raised.
- Three consecutive ventricular beats with HR under 120 bpm, ventricular rhythm is diagnosed, and green alarm is raised.
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

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>AVERAGE</th>
<th>STD. DEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI, SENSOR</td>
<td>0.388</td>
<td>0.031</td>
</tr>
<tr>
<td>RI, OUTPUT</td>
<td>0.404</td>
<td>0.044</td>
</tr>
<tr>
<td>RAIX, SENSOR</td>
<td>0.615</td>
<td>0.045</td>
</tr>
<tr>
<td>RAIX, OUTPUT</td>
<td>0.626</td>
<td>0.057</td>
</tr>
</tbody>
</table>
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
**PDMS ink results**

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

**Results of jetting trials:**
- IBA inks were not successful
- OA inks were successful
  - 1:2 PDMS-OA requires heating above 35°C
  - 1:3 PDMS-OA was selected to maximize the PDMS content

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

R. Mikkonen, et al, DOI: [10.1021/acsami.9b19632](https://doi.org/10.1021/acsami.9b19632)
Composition of cured PDMS ink

The ink was cured at 120 °C temperature for 25 min.

R. Mikkonen, et al, DOI: 10.1021/acsami.9b19632
## PDMS pre-treatment

<table>
<thead>
<tr>
<th>Method</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen plasma</td>
<td>Exposure power: 100 W, time: 1 min, chamber pressure 0.6 mbar, gas flow 700 sccm</td>
</tr>
<tr>
<td>Pyrolytic coating</td>
<td>Treat substrate with a steady back-and-forth movement for 4 times</td>
</tr>
<tr>
<td>MPTMS</td>
<td>A 6 % solution in ethanol, spin coat for 2 min at 1600 rpm on plasma treated PDMS, bake for 30 min at 120 °C</td>
</tr>
</tbody>
</table>
Peel test

plasma treated PDMS  PDMS with pyrolytic coating  MPTMS-coated PDMS
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.
Acknowledgement

• This work was funded by the Academy of Finland (grant no.: 292477) and Business Finland (grant no. 2947/31/2018). This work was supported in part by the Academy of Finland “Printed Intelligence Infrastructure” (PII-FIRI, grant no. 320019).

• M. Mäntysalo was supported by the Academy of Finland (grant no. 288945).

• R. Mikkonen would like to thank Nokia Foundation and Walter Ahlström Foundation for support.

matti.mantysalo@tuni.fi
https://research.tuni.fi/lfe/