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# Acceleration Sensors based on Polymer-Electronic Materials

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**Abstract**

The paper focuses on acceleration sensors which are based on polymer-electronic materials. The sensors have been fabricated by using ink-jet technologies on flexible substrates. Amongst details of the fabrication process, reached parameters and a comparison to FEM-simulations are presented.



Keywords: acceleration sensors; printed electronic; organic electronics; capacity sensors; PEDOT:PSS

## 1. Introduction

Acceleration sensors are used in many applications. Besides measuring acceleration, for instance to start airbags in automotive application, they are also used to measure tilting and vibration. In the middle price segment a lot of silicon based sensors are available today. These sensors are small and have also a convincing price-performance ratio. However, there are still requirements which cannot be achieved by Silicon-MEMS like the use of flexible substrates, low prices in the range of cents and effective large-area detection.

For these requirements new approaches have been developed, which use polymer structures to realize MEMS [1,2]. With the help of polymer-electronical materials, technologies and devices these sensors could also be combined with read-out and interface electronics to realize smart sensor systems [1,3].

The aim of our project is to build an acceleration sensor on the basis of organic electronic materials and technologies. To achieve this, a new sacrificial layer technology was developed, which allows producing freestanding polymer structures by ink-jet printing. The acceleration sensor is realized as spring-mass-system. The mass deflection, aroused by an external acceleration, is detected by a capacitance measurement.

## 2. Sensor Approach

The new developed technology uses a saturated hydrocarbon (cyclododecane) as a sacrificial layer. Fig.1a shows this technology. Printed circuit boards (PCB) are used as a substrate with 40 $\mu$m solder resist as spacer. The cavity

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between the spacer is filled up with the cyclododecane. Afterwards a PEDOT-mesh is printed on the surface with an ink jet printer (Dimatix DMP2831). The material of the sensor element is the PEDOT:PSS (H.C. Starck).

The sacrificial layer sublimated by itself. The sublimation of cyclododecane is about 1$\mu$m per hour at room temperature. After a period of approximately 40 hours the PEDOT-mesh will be a freestanding structure as seen in Fig. 1b. It is possible to speed up the sublimation by raising the temperature.

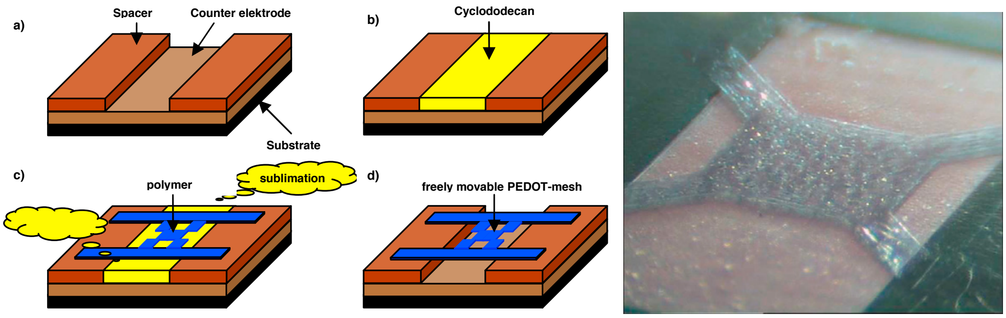


Fig. 1. (a) Sacrificial layer technology to produce free standing polymer structures; (b) Printed acceleration sensor structure

Fig 1b showed the complete sensor structure. The lateral dimension of the sensor is about 3x3mm. The layer thickness is 3 $\mu$m. The gap size against the counter electrode is 40$\mu$m

## 3. Simulation

Fig. 2 shows the FEM-simulation of the PEDOT-mesh displacement at 1g-acceleration in z-direction. The simulated maximum displacement is 3.9 $\mu$m. It can be seen, that the displacement of the mass-area is caused by an elongation of the four beams at the corners. As parameters for the active PEDOT-layer literature values are used (see Table 1).

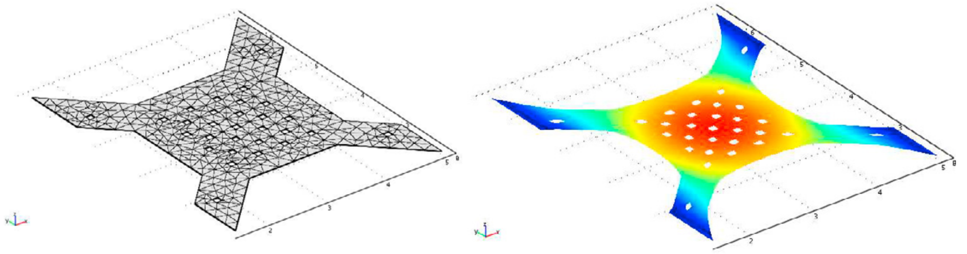

Fig. 2: (a) FEM-model of the active PEDOT-layer; (b) Displacement of the PEDOT-layer at 1g-acceleration in z-direction direction (max. red area 3.9 $\mu$m)

Table 1. Mechanical parameters of PEDOT:PSS layer

| Young's Modules | Poisson's Ratio | Tensile Strength | Mass Density |
|---|---|---|---|
| 1.9 GPa [a] | 0.34 [a] | 33.7 ± 10 MPa [a] | 1.45 g/cm3 [b] |
| [a] from [4] for 40% relative humidity | | [b] from [5] | |

A displacement of 3.9 $\mu$m should lead to a capacitive change of 0.2 pF, which is detectable for printed CV-convert [2]. However, further measurements had shown that the real displacement is much lower. A reason for the much lower sensitivity, we assumed, is a stress stiffening effect, caused by initial stress at the PEDOT-layer.
The simulation results in Table 2 show that the sensitivity of the sensor highly depends on the initial stress in the PEDOT-layer.

Table 2. Displacement in z-direction for 1g-acceleration and the capacity change and the stress into the PEDOT-layer base on it

| Initial strain ε | Initial stress (beams) | Displacement in z-direction | Capacity change |
|---|---|---|---|
| 0 | 1 | 3.9 $\mu$m | 227 fF |
| $-10^{-6}$ | 2.9 kPa | 3.4 $\mu$m | 195 fF |
| $-10^{-4}$ | 0.29 MPa | 0.18 $\mu$m | 10 fF |
| $-10^{-3}$ | 2.9 MPa | 0.022 $\mu$m | 1 fF |

After further analysis we got an initial stress of about 2 MPa. This stress level is caused by a shrinking of the PEDOT-layer during the drying process and leads to a much lower sensitivity of 1fF/g.

## 4. Result

To enhance the sensitivity of the sensor an additional mass of $8.77*10^{-3}$ g was mounted on the Pedot layer (Fig. 3). The primarily mass of the sensor is about $4.59*10^{-5}$ g, those 190 times lighter than added mass. With this add-on the sensor has an initial capacity of about 7.5 pF and a sensitivity of 0.235 pF/g.
To detect the capacity a conventional CVC (Capacity Voltage-Converter HT133 [6]) is used. Fig 4 shows the output voltage of CVC during a rotation of 360°.

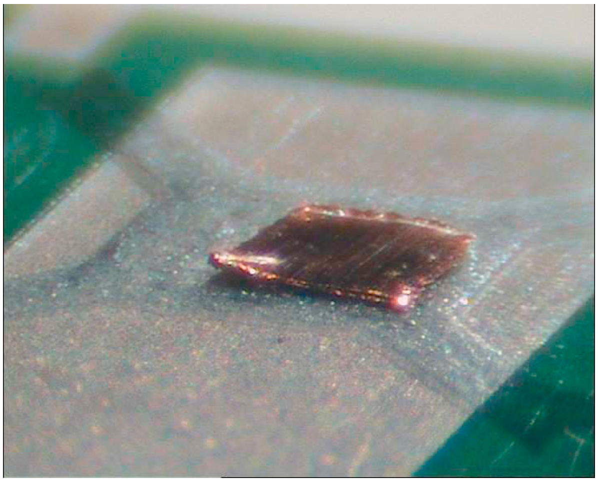

Fig. 3: Printed acceleration sensor with additional mass on the sensor-membrane

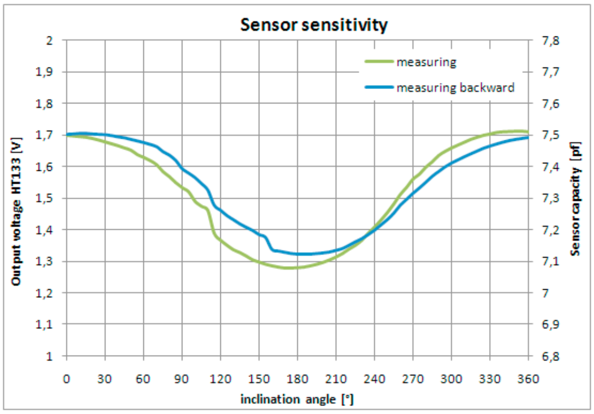


Fig. 4: Output voltage of CVC at different inclination angles of the sensor

It can be seen that the deflection is sufficient and a maximum of ±0.235 pF is achieved. The hysteresis effect can be recognized by the second reverse measurement. The small deviation of the both measuring is the effect of the hysteresis. We have some jumps in the middle and at the end of sine curve, which must be further investigated.

## 5. Summary

It is shown that PEDOT:PSS layers are movable. The next steps should be to optimize the sensor structure in order to raise flexibility. At the end we will achieve a displacement without additional mass on. Furthermore, the sensor will be read out with a printed CV-converter[3].

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## References

[1] Ng, T.; Daniel, J. H.; Garner, S.; Lavery, L.; Whiting, G. L.; Arias, A. C. Inkjet-printed, organic complementary circuits integrated with polymer mechanical sensors. American Chemical Society Meeting; 2010 March 21-25; San Francisco, CA

[2] D. Zielke, T. Heitjohann, C. Fromm, A. Jspers, D. Kaczorowski. Polymer Electronic Acceleration Sensor Element, proceedings Lope-c, 2009.

[3] C. Fromm, A. Hense, D. Zielke. Printed Capacitance-Voltage-Converter, proceedings Lope-c, 2010.

[4] U. Lang, N. Naujoks, J. Dual, Synthetic Metals, Volume 159, Issues 5-6, March 2009, p. 473-479.

[5] U. Lang, E. Müller, N. Naujoks, J. Dual, Advanced Functional Materials, 2009, Volume 19, No 8, p. 1215-1220.

[6] Datasheet HT133, Evaluation circuit for capacitive sensors, GEMAC mbH, 2004.