SCREEN PRINTED ELECTRODES FOR CAPACITIVE LEVEL SENSORS

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Anotace:
Článek popisuje výrobu a charakterizaci nízkonákladových elektrod pro kapacitní senzory výšky hladiny realizovaných na flexibilním substrátu. Cílem bylo připravit vodivé elektrody tiskem stříbrné nebo PEDOT:PSS pasty na ovrstvenou PET folii. Jednotlivé kapacitory ve formě interdigitálních elektrod byly navrženy s různými vzdálenostmi / tloušťkami prstů od 300/300 µm do 800/800 µm, a délkou prstů 10 mm a 15 mm a celkovou délkou 100 mm. Natisknuté struktury byly tepelně zalaminovány krycí a ochrannou PET vrstvou. Citlivost vyrobených struktur byla charakterizována v tekutinách s různou relativní permitivitou a vodivostí (voda a olej). Největší naměřená citlivost byla 0.7 pF/mm pro vodu a 0.08pF/mm pro olej.

Annotation:
The paper reports on the fabrication and characterization of low-cost electrodes for capacitive level sensors realized on a flexible substrate. The aim is to prepare conductive electrodes by printing of silver and PEDOT:PSS pastes on coated PET foil. Individual capacitors in the form of interdigital electrodes (IDT) were designed with different finger width/spacing dimensions from 300/300 µm to 800/800 µm, a finger length 10 mm and 15 mm and an overall length of 100 mm. The printed structures were thermally laminated with covering PET foil. The sensitivity of the fabricated devices was characterized in liquids with different relative permittivity and conductivity (water and oil). The highest measured sensitivity was 0.7 pF/mm and 0.08pF/mm for water and oil respectively.

INTRODUCTION

Polymer-based electronics are currently forming a new basis for low-cost microelectronic technology on typically thin, light-weight, and mechanically flexible substrates. Low-cost sensors are highly demanded, especially with the coming of the Internet of Things, and conventional microelectronic technologies usually do not meet the criteria regarding cost-effectiveness. The future in sensing technology will therefore supposedly partly lie in additive technologies of material printing using low-cost additive processes like screen, ink-jet or roll-to-roll printing on substrates such as plastic foils or paper [1].
Capacitive sensing has gained popularity in the detection of touch [2], force [3], chemicals [4], and level measurements [5,6] due to the achievable sensitivity, accuracy, and easy processing directly with microcontrollers enabled for capacitance measurement.
Capacitance level sensors can be used for wide variety of materials in a liquid or solid form (including powdered and granulated solids). The principle of operation is based on the fact that the air, which typically surrounds the insulated electrodes, is replaced by a material with a different relative permittivity [7].

MATERIALS AND STRUCTURES

Sensor layout

The comb drive or interdigital electrode capacitor (IDC, see Fig. 1) is probably the most used structure for level measurement due to its simplicity, versatility and easy planar manufacturing. Several footprints of IDC were designed with different finger width/spacing dimensions from 300/300 µm to 800/800 µm, finger length 10 mm and 15 mm and overall length of 90 ÷ 100 mm as id depicted in Fig. 2.
IDCs are suitable for level measurement of materials with a wide range of relative permittivity from $\varepsilon_r = 1$ (air) to $\varepsilon_r \sim 80$ (water). Since the electrodes are insulated, the measurement of conductive liquids is also possible.
Capacitive level sensors are widely used in the manufacturing industry for liquid level detection in tanks or barrels, detection of fluid flow, and presence of granulated or pasty materials often in plastic or glass tubing. Highly sensitive and flexible level sensors are currently demanded by the market.

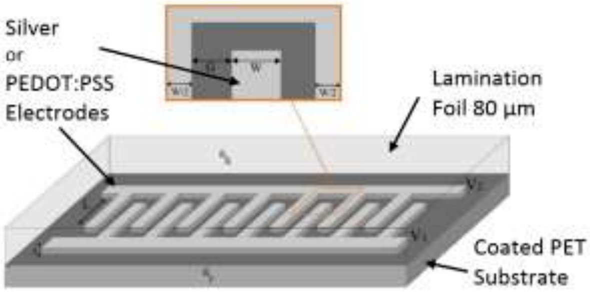

Fig. 1: Structure of the interdigital capacitor (IDC)

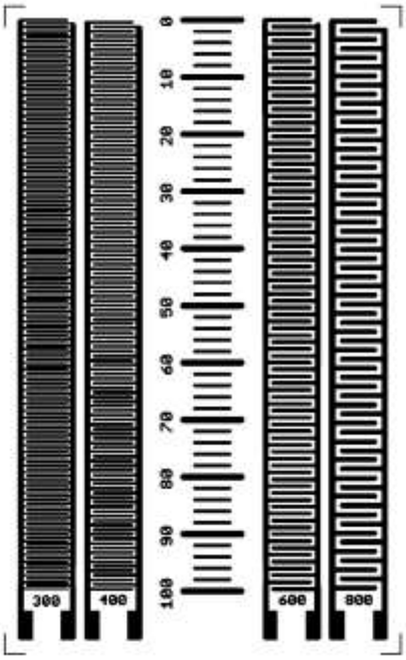

Fig. 2: Design of IDC with different finger width/spacing dimensions

FABRICATION PROCESS

The sensor structures were printed using the semi-automatic screen print machine RokuPrint SD05 (Fig. 3.). A screen printing mesh with 120/34 threads/inch was used.

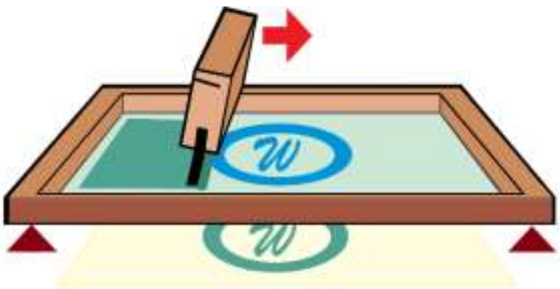

Fig. 3: Simplified principle of flat bed screen printing

The printed electrodes were then thermally cured at the recommended temperatures for each ink. Silver paste (EDAG PF050 E&C, Henkel, Düsseldorf, Germany) is cured at 121 °C for 15 min. PEDOT:PSS (Heraeus Clevios™) paste is cured at 110 °C for 5 min. Thermal curing was done in a convection oven.
The printed structures were contacted to the external terminal board using a silver adhesive and thin copper wires and then thermally laminated (at 120 °C) with covering PET foil featuring a thickness of 80 µm. The lamination of the electrodes serves both, as a protection of the electrodes and a dielectric layer, and allows immersion and proper functionality in liquids being even highly conductive (e.g., salt water). The laminated electrodes can also be stuck to the outer surface of non-conductive barrels or tanks. Moreover, PEDOT:PSS electrodes are semi-transparent (Fig. 4.). The thickness and the 3D profile of the electrodes were scanned with a Bruker Dektak XT profilometer. The thickness of the silver layer on PET substrate is 3.5 µm, thickness of PEDOT:PSS is 300nm. A photograph and a 3D scan of the IDT electrode is depicted in Fig. 5. The total thickness (including lamination) of the finished sensor is only 180 µm, and thus highly flexible.

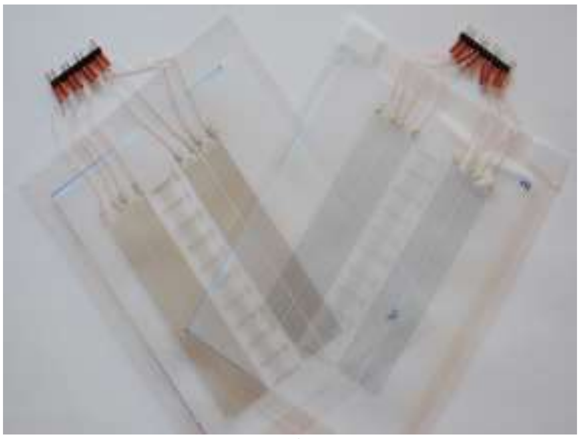

Fig. 4: Fabricated samples of capacitive level sensors with silver and semi-transparent PEDOT:PSS electrodes (IDC finger length 10mm)

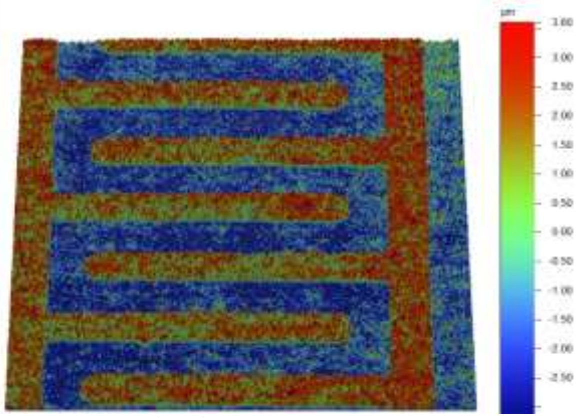

Fig. 5: 3D profile of silver interdigital electrode on PET substrate

MEASUREMENT AND RESULTS

The laminated electrodes were placed in a plastic beaker which was filled gradually by a liquid under test (water, oil). The capacitance of the sensor was measured at each step by a precision RLC meter HP 4284A. The capacitance of printed sensor linearly increases with increasing level of the liquid in all cases (for different liquids and different IDT dimensions, as is depicted in figures 6 and 7). The sensitivity of the silver and the PEDOT:PSS sensor is comparable. The lower sensitivity of the results measured for oil corresponds to its lower relative permittivity $\varepsilon_{r,oil} \sim 3$.

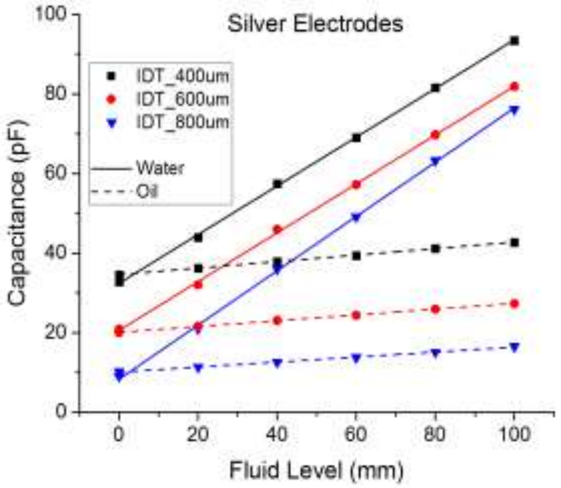

Fig. 6: Measurement results of Silver electrodes (left); PEDOT electrodes (right), showing an influence of the finger spacing and permittivity of measured fluid

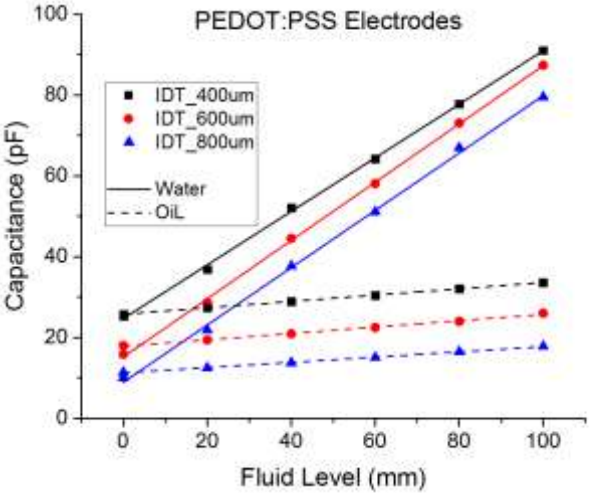

Fig. 7: Structure of the interdigital capacitor (IDC)

CONCLUSIONS

Screen printed and laminated electrodes for capacitive level sensors were successfully fabricated on flexible PET foil in the form of individual interdigital capacitors. The fabricated structures were tested in liquids with different relative permittivity (water and oil).

The sensitivity of the individual sensors to the water level is 0.61 ÷ 0.68 pF/mm and 0.66 ÷ 0.7 pF/mm for silver and PEDOT:PSS electrodes respectively. The sensitivity of the individual sensors to the oil level is 0.063 ÷ 0.082 pF/mm and 0.034 ÷ 0.061 pF/mm for silver and PEDOT:PSS electrodes respectively.

ACKNOWLEDGMENTS

This work was supported by the Linz Center of Mechatronics (LCM) in the framework of the Austrian COMET-K2 programme.

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