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Fabrication of Printed Switches

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Abstract

The research examines the printing of passive electrical circuit elements, specifically of printed switches. In the introduction, the functional printing and printed electronics are defined, and the composition and functioning of printed switches are explained. The aim of the research was to create printed switches of different sizes and shapes with screen printing, and to explore the optimal conditions for their operation.

In the experimental part, two types of switches were developed, namely with sensors based on two electrodes (electrical capacitor) and sensors based on a single electrode. Various forms of sensors were designed and printed on printing materials (special paper for printed electronic, recycled paper and foil) with functional conductive ink and the screen-printing technology.

Printed sensors were varnished and laminated. On each of them, measurements were performed and the influence of various factors was evaluated, i.e. the shape and size of capacitors/electrodes, printing material, air moisture, varnishing and laminating. Finally, the functionality of sensors was analysed and the sensors were applied onto a packaging as switches for turning on an LED light.

Introduction

Many people believe that printed electronics are something new; however, printed electronics have been penetrating the market that conventional electronics cannot reach for some time now, e.g. in packaging, posters. Printed electronics bring a new view on electronics and their application [1]. They are based on flexible materials, e.g. plastic foils, paper and textiles, and conventional printing processes, e.g. screen printing, flexography, gravure printing and inkjet. Conductive inks are used in the printing of printed electronics [2].

In this research, we fabricated printed capacitive-based switches or sensors which can be applied to packaging, posters and other paper products. A set of electronic circuit is needed for the operation of switches. We printed switches with the screen-printing technology, which allows printing on rigid and flexible materials. Due to economic and ecological reasons, we decided to print sensors on PC-foil, special super calendered graphic paper (SC) for printed electronics and recycled paper called VIMAX from the Slovenian company Vipap Videm Krško. We made two types of sensors, i.e. sensors based on two electrodes (electrical capacitor) and sensors based on a single electrode. When the sensors were printed, the conditions that affect their function were examined.

Touch sensors are divided into three groups (cf. Figure 1):

- zero-dimensional sensors, e.g. buttons – i.e. sensors with only one touch point;
- one-dimensional sensors, e.g. sliders, wheels – such sensors detect linear movement of a finger;
- two-dimensional sensors, e.g. touch screens – such sensors detect movement of a finger along two axes [3].

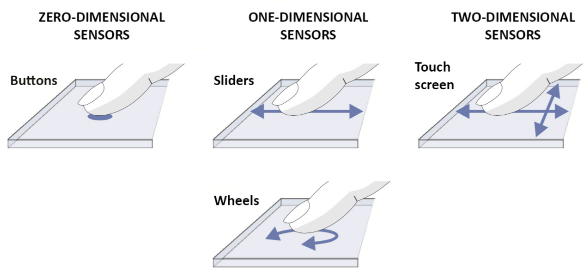

***Figure 1.** Three groups of touch sensors*

Experimental Section

Switch operation

In the research, we fabricated the sensors which are based on two electrodes and the sensors which are based on a single electrode. Both types operate on the basis of an electrical capacitor. A capacitor is an electrotechnical element which stores electric charge. It is made of two metal electrodes (plates) with the surface S and the distance between them d. Air or another dielectric material can be found between the plates. When the capacitor is connected to voltage U, it stores charge Q. This is described in the equation: $Q = CU$. The symbol C denotes the capacitance of the capacitor measured in farads F. The capacitance shows how much charge a capacitor can store at specified voltage. It depends on the surface of electrodes, the distance between them and the dielectric properties of the material between them. The capacitance can be calculated with the equation:

$$C = (\varepsilon_0 \times \varepsilon_r \times S) / d \qquad (1)$$

where ε_0 represents vacuum permittivity ($8{,}854 \cdot 10^{-12}$ As/Vm), ε_r represents the permittivity of the used dielectric material, S represents the plate surface and d represents the distance between the plates [4].

The capacitive switch operates on the principle of the change in capacitance. In normal (inactive) state, the sensor (capacitor) has nominal capacitance. When the surface of the sensor is touched, the capacitance changes (increases). This effect occurs due to the change in the permittivity of the entire system and the intake of the charge that the user brings with their finger. The change in the capacitance can only be measured with a measuring circuit (chip).

Similarly, the sensors based on a single electrode operate on the principle of electrical capacitor. The printed electrode represents one plate of the capacitor and the user's finger the other plate of the capacitor. The user brings with their finger a charge onto the electrode, which changes the capacitance. The capacitance is defined by the same equation as before:

$$C = (\varepsilon_0 \times \varepsilon_r \times S) / d \quad (2)$$

where ε_0 represents vacuum permittivity ($8{,}854 \cdot 10^{-12}$ As/Vm), ε_r the permittivity of the cover plate, S the surface of the touch and d the distance between the electrode and the finger or the thickness of the cover plate (cf. Figure 2) [5].

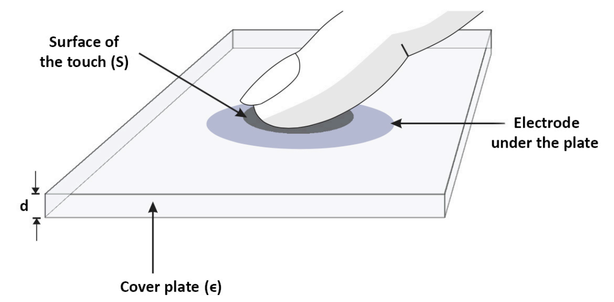

Figure 2. Graphical display of capacity equation parameters

When touching a sensitive electrode, the user changed the capacitance of the system which affected the flow of charge measured by the chip. The electrodes were bound to the circuit following the recommendation by the company Atmel. The electrode in the circuit represented the switch for turning on the LED light.

Materials

The sensors were printed on three different substrates, i.e. PE-foil, special SC paper for printed electronics and recycled paper VIMAX. The sensors were printed with the conductive silver ink CRS2442 SunChemical and were afterwards coated with the coating SG 70/15 Coates Screen or laminated with polyester foil for double-sided hot lamination. Finally, the Atmel's chip QTouch AT42QT1010 was integrated onto the sensors.

Methods

The sensors were fabricated in the following steps.

Capacitor and electrode design

For preliminary research, we designed two capacitor geometries, i.e. with lines in the form of a comb and with lines in the form of a serpentine (cf. Figure 3). They were made in two dimensions, i.e. 30 × 30 mm and 30 × 100 mm. We continued the research with smaller capacitors, i.e. 9.3 × 11.6 mm.

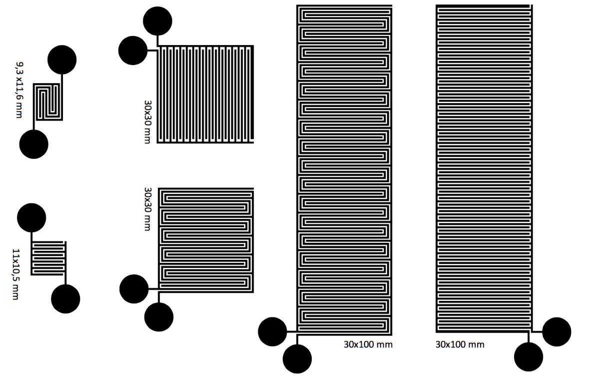

Figure 3. Capacitor geometries

With the program Adobe Illustrator, two different geometries of electrodes were designed, i.e. round and square (cf. Figure 4). For each, two versions were made, i.e. full and with pattern, in three dimensions, i.e. round electrodes with the diameter of 15 mm, 20 mm and 25 mm, and square electrodes with the side length of 15 mm, 20 mm and 25 mm. Each electrode included a 50-mm long and 5-mm wide line, which was finished with a full circle of a 9-mm diameter for an easier chip integration.

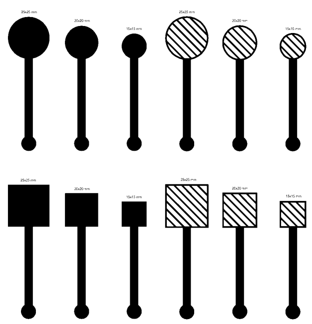

Figure 4. Electrodes different geometries

Printing and drying

After the capacitors and electrodes were designed, the printing form was prepared. A scree-printing mesh with 120 lines per cm was used. The sensors were printed on a semiautomatic screen printer. All printing materials were printed using the SunChemical conductive printing ink. After the printing, the drying process was performed in a heat dryer.

Coating and laminating

The sensors were protected from external influences and electrically isolated (touch causes short circuit). To apply the coating, a mesh with 77 lines per cm was used. For the lamination of switches, double-sided polyester foil (hot lamination) was used.

Measuring capacitance

On the sensors based on the capacitor dimensions 30 × 30 mm and 30 × 100 mm, the capacitance was measured with the impedance method. The capacitance was measured in three sensor states: without touch, with one-finger touch and with two-finger touch. On the basis of the measurements, we examined the influence of the following factors: shape and dimension of capacitor, printing material, air moisture, coating and laminating.

Chip integration

The chip QTouch was integrated onto the sensors following the recommendation of the manufacturer.

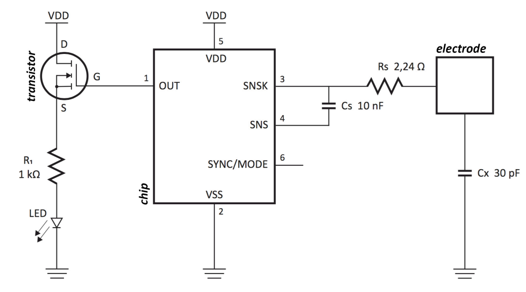

Figure 5. Circuit scheme

The main circuit components (cf. Figure 5) were the chip QTouch, printed electrode, Cs and Cx capacitor, and LED light. The chip had 6 pins, i.e.:

- OUT – output state,
- VSS – supply ground (0 V),
- VDD – power (battery 4.5 V),
- SNSK – sense pin (bound to Cs and electrode),
- SNS – sense pin (bound to Cs) and
- SYNC – sync and mode input.

When the sensitive electrode is touched, the charge is transferred to the electrode. This charge is stored on the Cs and Cx capacitors. Cs must be larger than the Cx capacitor. The chip measures the change of the charge on the Cs capacitor, which forms a bond between the SNSK and SNS sense pins. The two resistors, Rs and R1, are integrated into the circuit for an evenly charging and discharging of the capacitors, and evenly turning on and off of the LED light.

Application

The sensors were used as switches for turning on the LED light on a cardboard packaging (cf. Figure 6).

Figure 6. *Application of sensors on packaging*

Results and discussion

The capacitance was measured on the sensors based on the capacitor dimensions 30 × 100 mm and 100 × 100 mm with a digital multimetre. Since the measurements were made below the sensitivity range of the used multimetre, they were not precise. Nevertheless, the measurements were conducted to predict the behaviour of the minimized sensors 9.3 × 11.6 mm. The capacitance of these was too small to be measured. The sensors were classified into groups, as it is shown in Table 2.

Table 2: Classification of sensors into groups

	Sensors with lines in form of a comb (A)	Sensors with lines in form of a serpentine (B)
30 × 100 mm (1)	A1	B1
30 × 30 mm (2)	A2	B2

Capacitance as a function of sensor geometry was investigated and the results are shown in Figure 7. We established that larger sensors have greater capacitance and that the sensors with lines in the form of a serpentine have greater capacitance than those with lines in the form of a comb (cf. Figure 7).

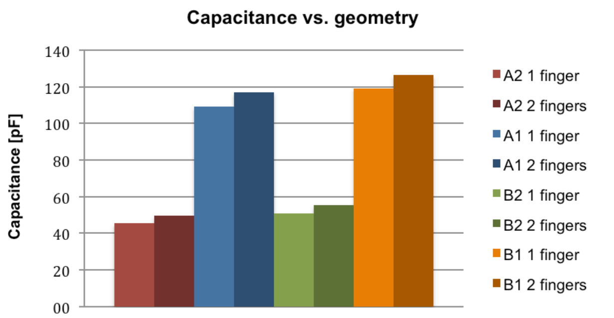

Figure 7. *Capacitance as function of sensor geometry*

Capacitance also depends on the printing material – on SC paper, capacitance was the largest, on VIMAX paper, it was smaller and on PC foil, the smallest (cf. Figure 8).

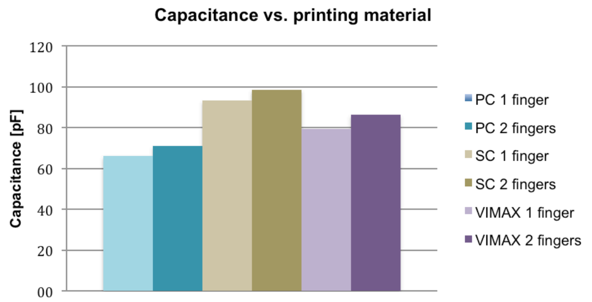

Figure 8. *Capacitance as function of printing material*

Finally, the change of capacitance was studied when the user was touching sensors with one and two fingers. The 30 × 30 mm sensors showed greater change of capacitance than the 30 × 100 mm sensors. That is due to the 30 × 30 mm sensors being smaller, which means that a larger part of them was covered when they were touched. We also found out that the sensors with lines in the form of a comb had greater capacitance than the sensors with lines in the form of a serpentine (cf. Figure 9).

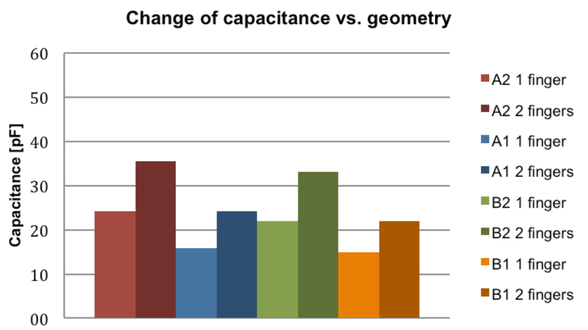

Figure 9. *Change of capacitance as function of sensor geometry*

The change of capacitance is the largest on PC foil, smaller on VIMAX paper and the smallest on SC paper (cf. Figure 10).

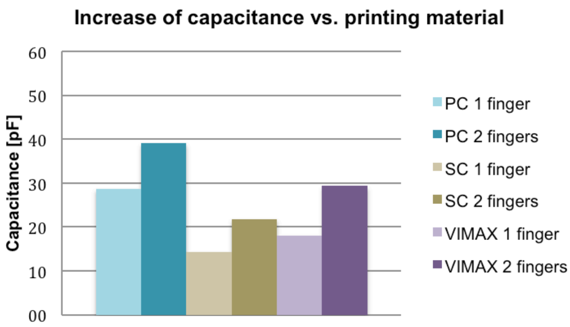

Figure 10. *Change of capacitance as function of printing material*

The measurements were also made on coated and laminated samples, which led to the findings that the coating and lamination have no influence on capacitance. The sensors were further minimized to the dimension 9.3 × 11.6 mm. When the sensors were minimized, the capacitance reduced as well and the measurements of the nominal sensor capacitance were no longer possible (even with a more precise LCR metre). We noticed an increase in capacitance when the sensors were touched; however, the measurement error was too big to perform the measurements. Afterwards, the sensors based on a single electrode were fabricated.

After the sensors were bound into the circuit, it was established that the chip detected the change of charge when the sensors were touched. This means that all sensors, i.e. sensors based on two electrodes (large and minimized sensors) and sensors based on a single electrode, function properly. That is due to both types of sensors operating on the principle of the change in capacitance, which is measured by the chip.

We found out that the sensors based on the capacitor were more effective, since all types were working successfully: sensors with lines in the form of a comb and sensors with lines in the form of a serpentine; dimensions 30 × 30, 30 × 100 and 9.3 × 11.6 mm, coated and laminated samples. In contrast, the sensors based on a single electrode did not perform well – laminated samples were not functioning. This is a consequence of the foil being too thick, which prevented the chip from detecting the change in the charge on the electrode. The coated samples were working properly, since the layer of the coating was thinner.

The sensors were integrated onto the packaging to enhance the functionality, interactivity and increase the added value of the packaging. The sensors are a suitable solution for all paper products, e.g. books, magazines, posters, packaging etc. They can also be used for making touch sensitive keyboards, remote controls and other devices with keys. The sensors are affordable; however, they are faced with the same problem as the RFID technology (Radio Frequency Identification), since they cannot massively penetrate the packaging industry as the price of many products is still too low to be able to afford that kind of technology on the packaging. Nevertheless, bright future is awaiting printed electronics on paper-based printed materials (e.g. interactive posters, books).

Conclusions

In our research, two types of sensors were made with the screen-printing technology, i.e. sensors based on two electrodes and sensors based on a single electrode. Sensors need a chip for their operation. It was proved that both types of sensors work. With capacitance measurements, the operation of sensors was analysed. The impact factors geometry of sensors, printing material, coating and laminating were examined. The sensors were integrated into the packaging where they were used to turn on an LED light. Printed switches are applicable in the whole area of the paper industry, e.g. books, magazines, posters, packaging etc. They improve product functionality and interactiveness, and consequently, increase its value.

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Author Biography

Tanja Pleša obtained her bachelor's degree in graphic design at the Faculty of Natural Sciences and Engineering, Department of Textiles, University of Ljubljana in Slovenia in 2015. She finished her undergraduate studies under Prof. Tadeja Muck (Faculty of Natural Sciences and Engineering, Department of Textile, University of Ljubljana) and Matija Mraović (Pulp and Paper Institute in Ljubljana) with the focus on the fabrication of printed switches via screenprinting. She is currently completing her postgraduate studies under Prof. Tadeja Muck at the same faculty.