Fully Printed Transparent Capacitive Touchpads from PEDOT:PSS e.g. for Touchscreens - A Project of the HdM Stuttgart, Germany

Erich Steiner[1]

[1] **Hochschule der Medien, Stuttgart, Germany**

Keywords: Printed electronics, touch pad, printed circuitboads, silk screen printing

This paper was written by the author. The experimental work was done under his supervision and guidance by students of the HdM Stuttgart, which participated in a course with the aim to acquire practical experience. The here descripted results of the experiments have been submitted to the OE-A Competition for Multifunctional Demonstrators Based on Organic and Printed Electronics in the year 2013 and attained the second price in the category Best University Demonstrator.

Capacitive sensitive structures on PET or PEN films created either by screen printing or etching of transparent but conductive PEDOT:PSS are a cost-effective alternative to conventional structured indium tin oxide (ITO) films, which require sophisticated sputtering and patterning techniques for their production. Our new production method enhances the possibilities for film-based touchpads and touchscreens, leading to cost and weight reduction in new applications. The low costs and high performance of our production methods opens the door to a new generation of touchscreens by the possibility to implement high volume web coating and in-line patterning processes by screen printing and etching

1. Our Vision

What is the idea of our application? What advantage did we have in mind? The idea was to pick up the concept of conventional produced capacitive touchpads [1, 2, 3] and touchscreens and to turn it into completely printed applications.

Numerous digital equipment such as tablet PCs, smartphones, e-book readers, i-Pods, i-Pads, other audio and visual devices, automotive dashboards, and industrial controls uses capacitive sensors as input mechanisms. In this sensor technology the capacitance between rows and columns is locally modified, when a finger touches the panel. This shift in capacitance is used to identify the presence of a finger as well as its position. The point of contact is registered by a connected capacitive touch controller. For these capacitance sensors, usually printed circuit boards (PCBs) based on patterned transparent indium tin oxide (ITO) films are required. General advantages of capacitive sensors are their reliable operation and that they operate at low-power.
The aim of our project was to replace the conventional PCBs by screen printed or etched conductive PEDOT:PSS structures on PET or PEN films. As a result of our efforts, we have established a precise screen printing technology that fulfils the requirements to form a diversity of sensor circuits by using exclusively conductive PEDOT:PSS ink and inter-layer non-conductive ink.

Figure 1: Fully printed capacitive touchpad in front of the touchscreen of a smartphone.

Our project results not only in different designed touchpads but in a variety of demonstrators for capacitive sensors developed and successfully tested.

Figure 2: A capacitive touchpad with the evaluation electronics in interaction with a Laptop

2. The Realization of the Demonstrator

Functionality and electrode structures

The project description presented here focuses on 5x7 capacitive touchpads which are structured using a screen printing process. 5x7 corresponds to a structure with 5 vertical and 7 horizontal electrodes. At the intersection points these electrodes form capacitances whose values can be locally changes by touch e.g. due to touch of a finger. An external circuit detects this shift of capacitance. To enable the use of such panels as component of touchscreens, optical transparency has to be ensured in the touch-sensitive area of the touchpad, too. Therefore the sensitive electrode structures are realized on transparent foils with transparent PEDOT:PSS paste.

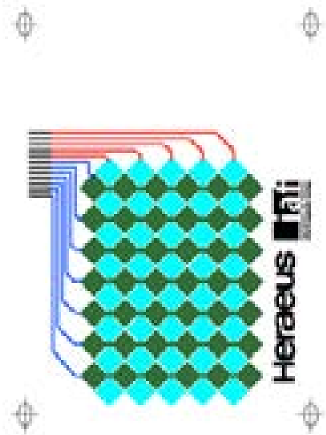


Figure 3: The layout for the screen printing of the capacitive touchpads

Even though the diamond structure features 5 vertical and 7 horizontal electrodes the capacitive touchpads has a total resolution of 9 rows and 13 columns because of the possibility to interpolate and thus determine positions between rows and columns.

The project touchpad was divided in two work packages:

- Work package 1: Determining appropriate dimensions of the electrode structures, their arrangement and the appropriate substrate thickness to ensure the functioning of a transparent capacitive touchpad. In addition an appropriate layout had to be designed to contact the electrodes.

- Work package 2: Programming and testing software to control the prototypes created in work package 1 via an USB connection with a laptop

The electrodes consist of a line of rectangular rhombuses, which are either horizontally or vertically connected and can be described as a diamond pattern. If a finger contacts the touchpad surface, the capacitance between the rhombuses of a row and the rhombuses of a column in the contacted area is altered. Through this change of capacitance the event of the contact itself as well as its location can be detected.

Additional circuitry printed on the foils connects the touchpad to a capacitive touch controller. This controller uses the signals at its input channels to detect the positions of touches and is communicating with a connected conventional microcontroller. The microcontroller performs first data processing and allows interfacing with a laptop. Thus a laptop is able to display the logged data created by the touchpad.

Structuring of electrodes

The PEDOT:PSS electrode structure was created by using two different methods.

- For the capacitive touchpads, which hereinafter are referred to as screen printed touchpads, the electrode structures were screen printed on PET foil with a special PEDOT:PSS formulation for screen printing in three different variants.

- For the capacitive touchpads, which hereinafter are referred to as etched touchpads, the used foil is on one side completely pre-coated with a PEDOT:PSS formulation by Heraeus

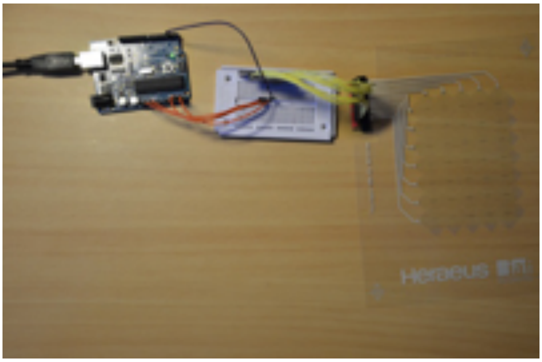


Figure 4: A highly transparent touchpad demonstrator of variant 5 on the basis of screen printed PEDOT:PSS in close-up view. As intended, the PEDOT:PSS rhombuses are hardly to see

Screen printed touchpads

- In the first successful tested variant of the exclusively screen printed touchpad, hereinafter referred to as variant 5, the horizontal electrodes are printed on the front side of a transparent foil and the vertical electrode structures on the back side of the same substrate. In this case the two electrode structures are electrically insulated from one another by the foil.

- For the second successful tested variant of the screen printed touchpad, hereinafter referred to as variant 6.1, the horizontal and the vertical electrode structures are printed on the same side of the transparent foil in two printing passes. The electrode structures are insulated from one another by an insulating clear printing varnish. This clear printing varnish is printed as a continuous film between the two printing passes for the electrode structures.

- In the third variant of the screen printed touchpad, hereinafter referred to as variant 6.2, the horizontal and the vertical electrode structures are printed with PEDOT:PSS in one printing pass on the same side of the transparent foil. However in this first printing pass the conductive connections between the rhombuses of only one of the electrode structures are included in the printed design. In a second printing pass these connection points are covered with an insulating clear printing varnish. Then the conductive connections between the rhombuses of the other electrode structure are printed with PEDOT:PSS on top of the insulating printing varnish in a third printing pass.

Etched touchpads

Capacitive touchpads that are processed using etching are based on a foil, which was fully pre-coated on a single side with a PEDOT formulation by Heraeus. To get the electrode structures, which are necessary for the functionality, a structured protective varnish is printed on top of the PEDOT:PSS coating in a screen printing step at the HdM. In the next process step the PEDOT:PSS coating can be etched in an etching bath delivered by Heraeus according to the instructions of Heraeus (under an exhaust hood due to the formation of chlorine). After this step the structures not covered by the protective varnish are electrically non-conductive and the touchpad has the same functionality as a screen printed touchpad.

Difference between entirely screen printed touchpads and etched touchpads

The partial etching of the PEDOT:PSS coating only leads to locally non-conductive structures but doesn't change their optical properties, thus delivering a completely invisible pattern. Therefore with this technique touchpads can be produced which can be favorably if highly homogeneous transparency is required.

Realization of conductor paths to contact the touchpads

Conductor paths, which are necessary to connect the touchpad to the capacitive touch controller are realized by screen printing conductive silver paste. The conductor paths run outside of the area of the actual touchpad. Therefore there is no need to have transparent conductor paths. In addition the conductivity of printed silver is orders of magnitude higher than of PEDOT:PSS and therefore leads to functional advantages, too.

Protection of the touchpads

To protect the electrode structures and the conductor paths from damages through direct touches an insulating clear printing varnish is printed on the entire front and back side of the touchpads.

Challenges to meet

For each of the different printed functional pastes the appropriate combination of parameters for the screen printing machine, the printing form (screen printing stencil) and the drying of the pastes had to be determined. For the printed PEDOT:PSS structures the screen parameters (geometry of the mesh and screen printing stencil) had to be optimized to meet the conflictive needs concerning the thickness of the PEDOT:PSS structures requiring high transparency and high conductivity at the same time.

3. What is the Target Group of our Application?

Manufacturers of conventional capacitive touchpads respectively touchscreens who intend to use the here presented production methods to reduce their costs of production and weights of their products. This opens new areas of applications for touchpads and touchscreens and may as well attract new manufacturers interested in innovative low cost capacitive touchpads, touchscreens and other sensors.

4. Advantages of Organic and Printed Electronics in our Application

The conducting structures of the touchpads as well as its connecting circuitry are completely printed, so their production will benefit from speed, simplicity and low costs of the printing process compared to conventional production. This will reduce complexity and costs of production.
The touch sensitive area can be extended to nearly every dimension and its layout can easily be adapted to new requirements of sensitivity, functionality, and size. Using our concept the application development of such sensors can be a matter of few hours, including prototyping through validation for production requirements thus reducing time-to-market by a significant amount.
Capacitive sensing finds use in all kinds of consumer, automotive, industrial, and medical applications. The popularity of this technology may further grow rapidly by reducing manufacturing cost, because

of its ability to eliminate mechanical components, and enhance product look-and-feel. Touch-screens constitute the major applications, but a growing use of this technology is also implementing capacitive keypads, wheelpads, and sliders. These applications may
also profit from our new production methods.But generally all circuit usage in areas where conducting and insolating multilayer structures are required may profit from our new production methods.

5. Electric Functionality of our Demonstrators

All our touchpad demonstrators consist of touch sensitive areas composed of a flexible foil on which a diamond structure of PEDT:PSS is printed in rows and columns. The rows and columns have to be separated by an isolating coating. This is either realized by the foil itself or an isolating varnish. When contact of e.g. a finger is made to the surface the local capacity is altered. To detect contacts and movements of the finger the local capacitances are measured using a constant DC charge current scheme and compared against threshold values. Because the area responds to near contact to its surface by any substances with a relative permittivity different from that of the air, contact can be made with any other pointing device causing a local change in capacity.

6. How is the Demonstrator Operated by the Capacitive Touch Sensor Controller?

All rows as well as all columns are connected to the input channels of a special capacitive touch sensor controller which is also which is connected to the microcontroller on a so called Arduino board.

The capacitive touch sensor controller is scanning its inputs channels that are the rows as well as the columns of the sensitive area. These scanning operations follow one another within milliseconds. During this operation the capacity of all crossings of the horizontal and the vertical structures are registered as well as checked if and where the capacity was changed.

7. What is the Function of the Arduino Board?

This row data are sent to the microcontroller on the Arduino board, which calculates the X coordinate and Y coordinate where the capacity was changed and transfers the coordinates to the via USB connected laptop to display them.

To receive the temporary position of the touching finger or other object continuously the activities described above have to be switched rapidly and repeated constantly. The source code including comments for this process is attached.

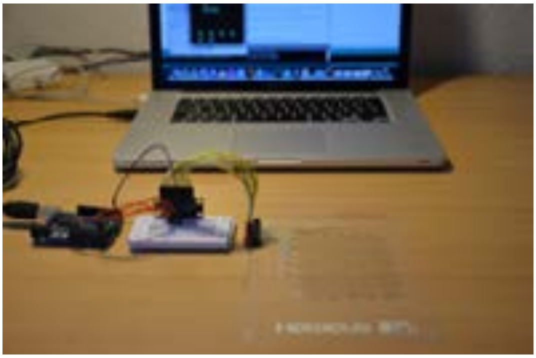


Figure 5: A capacitive touchpad demonstrator of variant 5 on the basis of screen printed PEDOT:PSS connected to a Capacitive Touch Sensor Controller MPR121, the Arduino and the laptop in close-up view.

8. How Are the Touched Coordinates Displayed?

The acquired coordinates are exported via USB port to a PC or laptop. By using the program language Processing the data are read from the laptop and displayed as single dots on its screen.

As depicted, two programs are used. First, the microcontroller reads the coordinates on the digital whiteboard and sends them to the PC or laptop, than the Processing language displays the read coordinates on its screen.

9. Printing of the Demonstrators

A dozen different demonstrator versions have been realized for tests.

Completely printed touchpads of three versions different in layer compositions as described in chapter 2 could be successful tested. Touchpads of version 5 are based on 125 Microns thick PEN foils (polyehylen-naphthalat, DuPont Teijin Films, Teonex). Touchpads of versions 6.1 and 6.2 are based on 175 Microns thick PET foils (DuPont Teijin Films, Melinex 504). As screen printable conductive polymers CLEVIOS™ PEDOT:PSS S V4 as well as CLEVIOS™ PEDOT:PSS S V4 HV from Heraeus Leverkusen have been disposed.

The etched and partly printed touchpads are based on a Clevios™ PEDOT:PSS formulation that is pre-coated on Kodak HCF-225 ESTAR™ film base. These pre-coated foils and the patterning process to structure them are developed by Kodak and Heraeus and delivered by Heraeus. The foils are highly transparent and more conductive then usual foils screen printed with PEDOT:PSS.

The patterning process using Heraeus component technologies creates invisible structures. To get the desired conductive pattern a masking polymer, Clevios™ SET S, is screen printed on the pre-coated foil. Then Clevios™ Etch is used to create the non-conductive areas. After the process is completed, the masking polymer that protected the conductive pattern is removed.

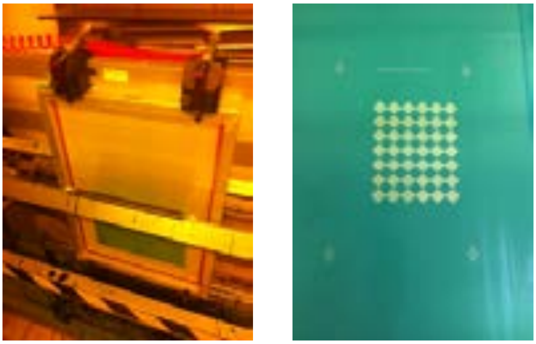


Figure 6: The picture above on left shows the silk screen frame while it is being covered with the emulsion for the stencil. The picture on right shows the silk screen exposed and developed stencil to print the structure with 7 horizontal PEDOT electrodes.

The CLEVIOS™ PEDOT:PSS for the touch sensitive area was printed with a 165-27 screen, the paste silver paste for the connectors was printed with a 77-48 screen and the isolating protective varnish was printed with a 120-34 screen. All screens are from the manufacturer Sefar and of type PET 1500. The PEDOT:PSS wet ink layer was about 5 microns thick, the resulting dry layer high of the PEDOT:PSS should be 0.1 microns depending on the number of printing passes.

Figure 7: The pictures above show the silk screen form for the PEDOT:PSS rhombuses in the screen printing machine on the left, the silk screen form for the connectors consisting of silver paste on the right

Figure 8: Screen printing of silver paste for the tracks of the connectors.

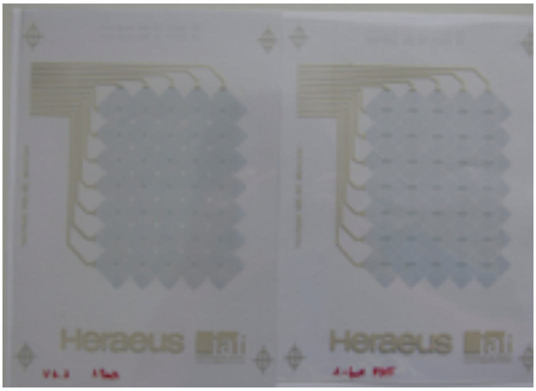


Figure 9: Finished transparent touchpad demonstrators of variants 6.1 and 6.2 whose sensitive diamond structure are realized by PEDOT:PSS. The connecting lines have been printed by silver paste. All conductive structures are covered and thus protected by an insulating ink.

Figure 10: Finished transparent touchpad demonstrators of variants 6.1 and 6.2 in front of a tablet screen. As intended, the PEDOT:PSS rhombuses are hardly to see.

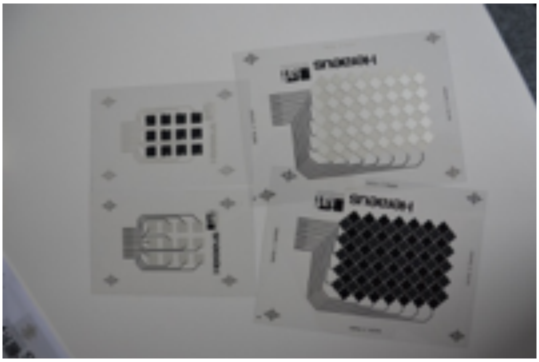


Figure 11: During our project we also realized not transparent capacitive sensors. Especially for keypads and touchwheels transparency is not always necessary. So we printed touch sensitive structures not only with PEDOT:PSS but also from silver paste as well as from carbon black paste.

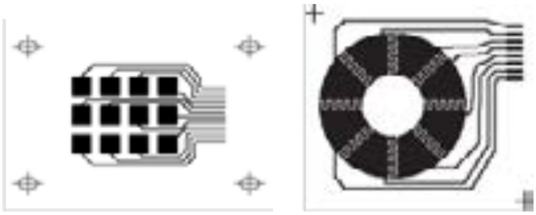


Figure 12: The layout sketch of capacitive keypads and capacitive touchwheels

10. Which Role Does Organic and Printed Electronics Fulfil in our Demonstrator?

Exclusively components of the toolbox have been use for the demonstrator:

- As substrates: PEN foils (polyehylennaphthalat, Teonex) and PET foils (Melinex 504). from DuPont Teijin Films.
- Screen printable conductive polymers CLEVIOS™ PEDOT:PSS S V4 and CLEVIOS™ PEDOT:PSS S V4 HV from Heraeus Leverkusen.
- Printable conductive material used for conductive connections of the touchpads (silver ink) as well as for not transparent capacitive keypads and touchwheels. (silver ink and carbon black ink) from DuPont Microcircuit Materials.

- Kodak HCF-225 ESTAR™ film base pre-coated with a Clevios™ PEDOT:PSS formulation.

The touch sensitive rhombuses consist of printed tracks from PEDOT:PSS ink on PET foil. Connecting conductors are printed by silver ink. Conducting materials are generally covered with insolating protective lacquer. If necessary for the correct functionality they are also separated by insolating inks.

11. Which Classical Electronic Components Are Used?

As classical hardware we used:

- A Proximity Capacitive Touch Sensor Controller MPR121[4, 5] and
- A Atmel AVR microcontroller out of the megaAVR series, e.g ATmega328

The here used Proximity Capacitive Touch Sensor Controller MPR121 has 12 capacitance sensing input channels dedicated for proximity detection. A complete capacitance measurement system is composed by sensing electrode pads connected to the MPR121 inputs. The MPR121 uses a constant DC charge current scheme for capacitance measurement. Each channel is charged and then discharged completely to ground periodically to measure the capacitance. All the channels are measured sequentially. The MPR121 is communicating with the host processor via an I2C bus and Interrupt output.

The Atmel AVR microcontroller controls the controller MPR121 and communicates with the via USB cable connected laptop. The microcontroller operates on the Physical open-source electronics prototyping platform Arduino. Arduino is an open-source based electronics prototyping platform including hardware and software. The microcontroller (e.g. ATmega328) on the Arduino board is programmed using the Arduino programming language, which is based on Wiring and runs under the Arduino specific Integrated Development Environment (IDE) which is based on Processing. Arduino projects can communicate with a laptop by a so called Serial Monitor, an integrated part of the IDE, or other software on a laptop like e.g. Processing, which was used in this project, too.

The microcontroller on the Arduino board also realizes first processing of the row data. The Laptop displays the detected coordinates and starts and stops the data sampling.

References:

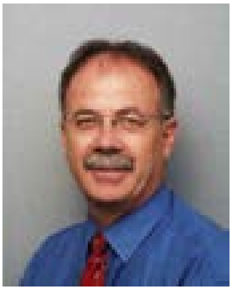
[1] Oscar Camacho and Eduardo Viramontes, "Designing Touch Sensing Electrodes, Electrical Considerations and Recommended Layout Patterns", AN3863, Rev. 4, 07/2011, from www.freescale.com/

[2] "Buttons, Sliders and Wheels, Sensor Design Guide", QTAN0079, from www.atmel.com/

[3] "Pad Layout Application Note, AN3747, Rev 1, 09/2009", from www.freescale.com/

[4] "Freescale Semiconductor, Technical Data, Advanced Information, MPR121, Rev 4, 09/2010", from www.freescale.com/, document name in the internet "MPR121 Technical Data Advanced Information.pdf"

[5] "Freescale Semiconductor, Data Sheet, Technical Data, MPR121, Rev. 12/2011"), from www.freescale.com/, document name in the internet "MPR121 Data Sheet Technical Data.pdf"



Contact:

Prof. Dr. Erich Steiner
Stuttgart Media University
(Retired)

steiner@hdm-stuttgart.de