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Mechanical and electrical contacting of electronic components on textiles by 3D printing

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Abstract

Materials nowadays become smarter and "more intelligent", containing novel functionalities or sensory components. In all areas of materials science, integrating new abilities into common materials belongs to the most important topics in research and development.

In the textile area, several functions can be achieved by finishing techniques, i.e. physical and/or chemical modifications of textile surfaces. The integration of electronic components, however, still suffers from incompatibilities between soft, flexible, bendable textile fabrics and rigid electronic parts. Connecting conductive yarns with electronic components, such as SMD-LEDs etc., cannot be performed by soldering nor by sewing. The typical connection technologies of both areas fail in these cases.

A new possibility to achieve such electrical and at the same time mechanical connections is given by 3D printing. In a recent project, we have studied chances and limitations of electric circuits combining textile fabrics with 3D printing.

Textile fabrics were woven and knitted from common yarns as well as wires, strands and different conductive yarns. 3D printing was used to connect SMD elements and other small electronic parts with these base circuits and compared with soldered and sewn contacts. The influence of conductive wires, yarns or filaments integrated in the printed elements was tested.

The article will give an overview of possibilities and problems in electrical contacting of small electronic components on partly conductive textile fabrics by conductive 3D printed connections. Additionally, an outlook to other potential areas of application, such as sensors and actuators on textile fabrics, is presented.

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Keywords: 3D printing, textile fabrics, conductive yarn, electric connection, textile electric circuits

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1. Introduction

Smart textiles combine textile materials with novel functionalities, such as sensor or actuators which are able to interact with the surrounding. They can be used to measure vital signs, such as ECG and pulse frequency [1], breathing, skin temperature, sweating etc. They can also stimulate muscles or simply illuminate garments due to safety purposes. Besides electronic components, smart textiles can also contain optical fibers [2], phase change materials [3], chemicals or other components to add new functionalities to common textiles.

In most smart materials, however, electronic sensors or actuators are used to integrate the desired interaction with the environment. While it is possible to integrate several conductive and other “smart” materials, such as optical fibers, by common textile technologies like sewing, embroidering, weaving [4], knitting, braiding, or coating, the connection between electronic components and conductive yarns etc. is still challenging [5]. Usual electronic connection methods, such as soldering or bonding, can normally not be used on textile fabrics. Typical textile methods, such as sewing, necessitate an adequate construction of the electronic components, e.g. by firstly soldering an electronic component on a flexible substrate with holes that can afterwards be used for a sewn connection to a conductive yarn in a textile fabric. Gluing with commercially available glues, finally, is normally not reliable [6].

This problem led us to the idea of testing whether 3D printing with conductive material may be an easy and dependable alternative to the aforementioned methods to contact electronic components. The technique of 3D printing is rapidly emerging, with the equipment becoming more and more affordable even for small companies or designers working in the area of smart textiles. Relatively inexpensive 3D printers are nowadays able to print accurately the defined shapes. In this way, it may become possible to connect conductive yarns or coatings especially to SMD (surface mounted device) components without leads which could be used for sewing contacts. At the same time, 3D printing could offer mechanical adjustment of the electronic component.

3D printing on textile materials and integration of fibers into 3D printed materials, however, has shown to result often in unreliable connection [7-9]. This is an additional challenge in the mechanical and electronic connection between textile fabrics and 3D printed conductive materials.

The article gives an overview of possibilities and limits of this new connection technique in the smart textile area.

2. Experimental

As textile substrates, knitted fabrics were produced on a SilverReed SK-280 hand flat knitting machine with gauge E5.5 (5.5 needles per inch). The structures under examination included single-jersey as well as different tuck and float patterns which resulted in relatively compact surfaces, allowing for an even surface and thus a good contact to the printed material on top. Rougher structures, such as double-face, exhibiting a zig-zag structure, were excluded after first experiments due to the insufficient contact to the 3D print.

The non-conductive yarns were chosen with respect to their titer (fineness, a unit for the linear mass density of fibers and yarns – the higher the number, the finer the yarn) and material. Most experiments were conducted using acrylic/polyester (Nm 30/2) and acrylic/wool (Nm 28/2).

As conductive parts, copper wires (diameter 0.2 mm) without coating and stainless steel wires (diameter 0.05 mm) were used as well as the conductive yarn Shieldex 235/34 dtex 2-ply HC + B, produced by Statex (Bremen/Germany).

For 3D printing, an Orcabot XXL (produced by Prodim / The Netherlands) was used which works with the FDM (fused deposition modelling) technology. In this technique, a filament is molten in a heated extruder nozzle; afterwards the liquefied material is deposited on the printer bed line by line where it cools down and hardens. After lowering the printing plate, the second layer can be printed on top of the first one, etc. [10]. The printer was not modified before use.

The electric connections were created using the filament Proto-Pasta – Conductive PLA (polylactid acid; distributed by Filamentworld, Ulm/Germany). The extruder temperature was set to 207 °C and the printing bed temperature to 60 °C. The layer height was 0.2 mm. The structures were filled.

The positions of the LED holders on the conductive parts of the knitted fabrics were defined using a line laser which showed the printing positions. In this way, the textile fabrics could be fixed onto the heated printing bed in the desired positions. The laser is mounted mechanically at the printer frame and can be moved to specify the printing position. This is easily done by starting a printing process, moving and fixing the laser, gluing the knitted fabric on the printing bed, and starting the printing process again. Alternatively, the coordinate system of the printer software can easily be transferred onto the glass printing bed using a fine permanent marker, making the first test print unnecessary.

The height of the printer nozzle was chosen due to the highest adhesion between textile and 3D printed polymer; more detailed information are given in Ref. 11.

The LEDs were placed in the 3D printed holders after printing was finished. The shape of the chosen LEDs was used to prepare the correct holder shape in the CAD program.

3. Results

For utilizing conductive 3D printed objects as connections between textile conduction lines and small electronic elements, it is crucial to examine and optimize the resistance of the printing material. Since in most cases these connections are quite small, the contact resistance – i.e. the resistance between printing material and connected yarns or electronic parts – is of higher importance than the intrinsic (length-dependent) resistance. An easy method to estimate the contact resistance is to apply a linear fit to the experimental determination of the length-dependent resistance; the resistance for vanishing length is identical to the contact resistance. This method works for purely ohmic contacts, which is given in the material under examination.

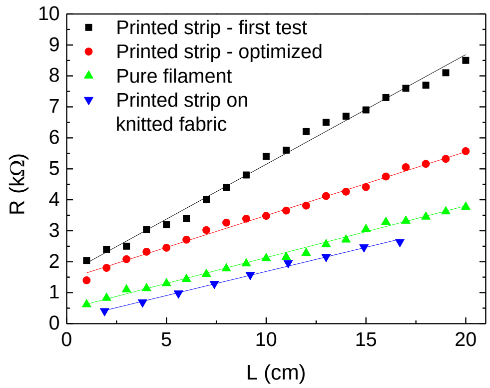

Fig. 1. Length-dependent resistances, measured for different samples.

Fig. 1 shows the resistances, measured for different lengths *L* of printed strips of dimensions 25 mm x 250 mm x 0.4 mm (2 layers of printed material) as well as the pure conductive filament (diameter 1.75 mm). For the pure printed strips and the filament, measurements were performed using common measuring tips of a multimeter.

Comparing the printed strips, printed as a first test and after optimization of the printing parameters, it becomes visible that the sheet resistance (resistance per length) can significantly be influenced by the printing parameters. The optimized parameters are given in Section 2.

The optimized strip shows a length-dependent resistance (slope) similar to the original filament but a higher contact resistance. This finding can be explained by modifications inside the conductive material during the printing process, with the conductive particles preferentially being located in the inner part of the printed strips, while the non-conductive PLA base material seems to dominate on the outside of the printed form. Measuring the resistances from the bottom of the printed strips shows nearly identical values, compared to the measurements from top which are shown in Fig. 1.

One possibility to overcome this problem is the direct printing on conductive materials. As an example, Fig. 1 shows the printed strip with the same dimensions as before (optimized printing parameters) directly on a single-jersey knitted fabric with integrated copper wires (without non-conductive coating). Measurements of the length-dependent resistance were performed using the measuring tips of the multimeter on the copper wires of different distances. The contact resistance between tips and copper wire can be neglected (~ 0.1 Ω).

It can easily be recognized that the contact resistance is significantly reduced in comparison with the original filament, while the pure length-dependent resistance is similar to the optimized printed strip. Apparently printing directly on the conductive material which is used as conductive path can be supportive in terms of the contact resistance.

To examine whether it is also possible to insert conductive yarns or wires in a printed object in order to reduce the contact resistance between both materials, further experiments have been performed with identical printed strips as used before, inserting stainless steel wires and conductive Shieldex yarns between first and second layer. Fig. 2 shows the resulting contact resistances of the measurements depicted in Fig. 1 and the additional tests with inserted yarns.

As already recognized in Fig. 1, the contact resistance of the conductive strip printed on the knitted fabric with copper wires is much smaller than the contact resistance between the original filament and measurement tips. The Shieldex yarns embedded in the printed strip shows an even decreased contact resistance. Embedding the stainless steel wires, however, results in a much higher contact resistance, comparable to the values measured between the pure printed strips and the measurement tips.

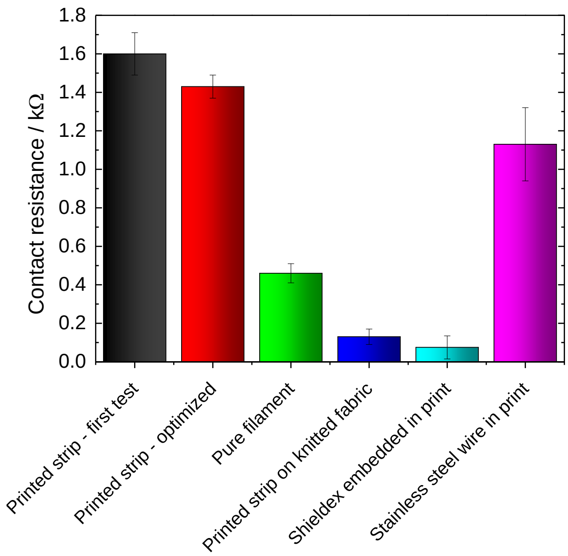

Fig. 2. Contact resistances, measured on different printed strips and the pure conductive filament. The colors are identical to Fig. 1 for the situations also shown there.

This behavior can be attributed to the small diameter (50 micron) of the stainless steel wires which apparently cannot generate a good electric connection to the printed material. Wires with larger diameters, however, such as the copper wires used in the knitted fabrics, are too thick to be inserted in the printing process without changes of the printing geometry. The conductive Shieldex yarn, on the other hand, is smooth enough to be embedded during printing and has a large conductive surface due to the large number of fine filaments, offering good electric contact to the printed form. Additionally, silver (which is used for coating the yarn) is known to produce good contacts. This material seems to be ideal in terms of combinations with conductive 3D printed objects.

Based on these findings, knitted fabrics were produced containing circuit paths from conductive Shieldex yarn, using different knitted structures. These fabrics were fixed on the printing bed. Using a self-built cross laser positioning system, the desired printing positions were aligned to the conductive paths on the fabrics.

An SMD-LED holder was designed using Autodesk Inventor. Additional to the conductive printing material (black), non-conductive PLA (white) was used to connect the conductive material mechanically and to finish the LED holder. To avoid possible problems with too high voltage drops in the 3D printed material, SMD-LEDs with a relatively high inner resistance (2 V / 2 mA) were chosen for the tests.

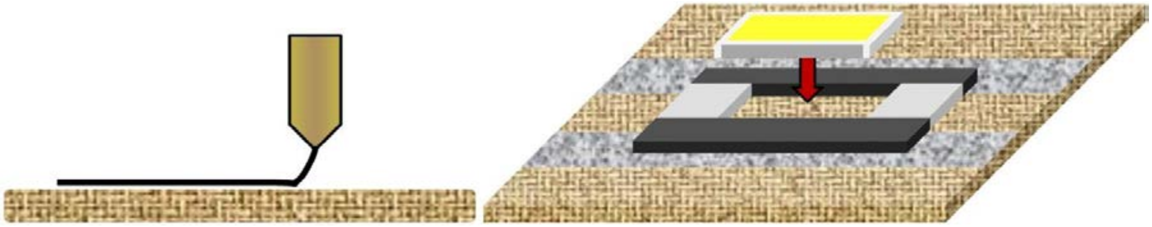

Fig. 3. Principle of the connection process: printing with conductive and non-conductive polymer on a textile fabric with conductive and non-conductive areas (left panel), placing the SMD-LED in the printed holder afterwards (afterwards).

Fig. 4 shows one of the results, using a 3 V coin cell. The LED shines brightly, even in the sunlight. The resistance of the 3D printed contact works as series resistor to protect the LED from the applied voltage which is actually too high. It should be mentioned that LEDs with lower inner resistances (e.g. 2 V / 20 mA) shine less brightly since the series connection of LED and 3D connection resistance works as a voltage divider, with higher voltage drops at the higher resistances. Thus the inner resistance of the LEDs used in such a circuit which includes a relatively high series resistance should be as high as possible.

First washing tests (40 °C, heavy duty detergent, subsequent spin cycling at 800/min) have shown the principle washability of the complete system including the inset LEDs (without battery); future tests will be used to investigate this issue further which is typical for smart textile applications.

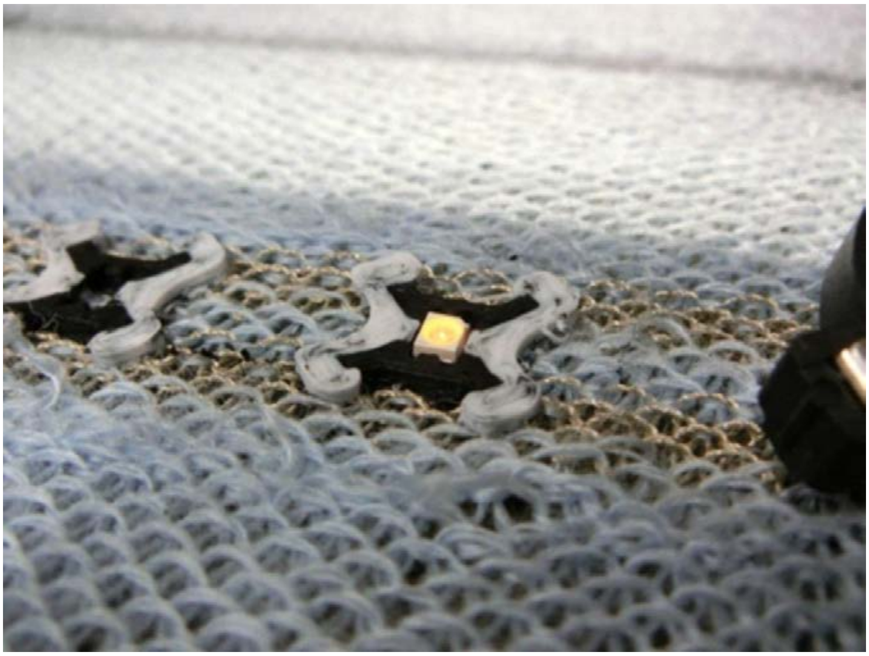

Fig. 4. Lit LED, contacted by conductive 3D printing filament (black) to conductive Shieldex yarn (silvery) which is attached to a battery holder. The LED is placed in the printed LED holder after the printing process and fixed there friction-locked. A pure printed holder without LED is visible on the left side of the photograph.

4. Conclusion and Outlook

First experiments with 3D printed objects used as contacts between textile or textile-integrated circuit paths and small electronic components have principally shown the suitability of this technique for electrical and mechanical connections. While the contact resistance between 3D printed conductive materials and conductive wires or yarns can be reduced to an acceptable level, the contact between 3D print and afterwards inserted electronic components is still non-satisfying. Thus, new ways to integrate loops from the basic conductive textile material into the 3D printed objects to allow for direct contact to the electronic parts can still enhance the results.

While LEDs and similar electronic components can already be contacted with the technique described in this article, introducing a new utilization of 3D printing in the area of smart textiles, more sophisticated solutions for yarn guiding are necessary if advanced sensors and actuators are to be connected electronically by means of conductive 3D printed forms, especially guaranteeing constant resistances for all printed connections. Different combinations of knitted structures and technologies of yarn integration in 3D objects during the printing process will be tested for this purpose in the near future.

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