JOINING TECHNOLOGY FOR SMART LUMINOUS TEXTILES BY EMBROIDERY

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Abstract

Smart textiles are an expanding field with much potential and arouse interest in the R&D sphere and industry. These find vast applications in engineering, healthcare and fashion, and contribute additional functionality and intelligence to structures. Quiet often the intelligence of such smart structures is supported by electronics that ensure functions such as data transfer and analysis for monitoring systems. Moreover, many smart textile systems require also energy source. At present, there is a great variety of scenarios to implement the joining of the functional textile compounds and electronics. Nevertheless, the joining technology is one the key challenges for smart textile developers, especially regarding wearable applications. Smart luminous textiles are of great interest for applications such as clothing and interior design and visual merchandizing. Moreover, luminous textiles are beneficial for protective clothing and sportswear in order to insure better visibility of the wear and interactive design for non-verbal communication. Additionally, luminous textiles have potentials for healthcare and medicine applications such as phototherapy. At present, such smart textiles are mostly limited to LED integration. Despite well-developed techniques for LED attachment onto textiles, power sourcing and controlling of the electronics for more complex LED matrixes remains a field for technology improvement. Moreover, OLED technology is more preferable for some applications due to fragility of more sophisticated and large-scale LED matrixes.

This study presents a preliminary study for reversible joining of textiles and electronics within a novel concept for electroluminescence (EL) towards Organic Light Emitting Devices (OLED) implementations by printing technology. Technical embroidery is suggested as a promising technology that ensures continuous manufacturing of the functional textile compounds, electro-conductive paths and the joining platforms for electronic interconnections with active textiles. A novel concept for EL is developed in order to continuously implement the functional textile elements and ensure an efficient solution for the smart textile bonding with electronics. Regarding specifics of the development usage conditions, solutions for reversible joining are in the focus of the study. Finally, a concept of the bonding module for the electro-conductive platforms is described to be applied to custom developed EL structures on textiles.

Keywords: joining technology, reversible joining, technical embroidery, conductive yarns, printed EL and OLED devices on textiles

1 Introduction

At present, smart textiles are one of the focus topics in the multi-disciplinary research and target a great variety of applications. Since then, the evolution of smart textiles can be observed in a variety of applications such as design, healthcare, structural and automotive engineering. Within the technology progress, smart textiles become more sophisticated and their potentials for markets are getting expanded [1].

Although there is a great variety of smart textiles and their applications, luminous textiles are of great interest for a number of applications such as interactive design, protective clothing and healthcare. The state-of-the-art of smart luminous textiles in clothing is mostly limited to light emitting diode (LED) integration into textiles. Although there are commercially available products such as LED sequins or solutions developed within R&D environment such interactive LED matrixes, functionality of such systems is limited. For example, LED sequins integrated into clothing are robust, but their application is mostly reduced to clothing decoration due to insufficiency of luminous properties. On the other side, LED matrixes are much more sophisticated and accordingly have more potential, but such developments for protective clothing and sportswear, are too fragile.

One of the innovative optional solutions is organic light emitting diodes (OLEDs) technology. At present, this field is still in its infancy, but there are already first attempts to transfer this technology to textiles in order to develop a flexible and lightweight structure. Several approaches to develop flexible OLEDs for textile applications have been suggested. For example, a research team of Fraunhofer Institute, Germany has investigated development of miniaturized OLEDs on plastic foils and integration technique onto textiles with application of technical embroidery [2]. In the year 2013, Kim et al. have described a concept of OLED implementation on textiles for wearable display applications, but no solutions for joining the printed OLED structure with electronic were described [3]. Moreover, there are no yet established solutions to manufacture large-scale OLEDs on textiles. Neither the investigated scenarios fully correspond to wearable applications due to negative impact on textile properties such as air permeability, flexibility and robustness. Finally, efficient solutions for bonding textile-based OLEDs with electronics are lacking.

Nevertheless, despite a significant break-through in manufacturing of functional compounds such as textile sensors, actuators and circuits, quite a few of the numerous research projects reach the stage of the product. Besides socio-economic barriers that face smart textiles, the key obstacles are also originally referred to complications in technology transfer to industry due to manufacturing process complexity. Moreover, smart textiles as a complete system are still remaining quite fragile for some applications, despite textile and electronics technology have much succeeded in development of robust intelligent compounds. Both obstacles often originate in bonding of textiles and electronic components of a smart textile structure. Indeed, joining technology is a critical issue in smart textiles manufacturing and has a significant impact on the reliability and life-cycle duration of a development. Thus, insurance of the continuous manufacturing process and high reliability of the bonding can be defined as the key requirements for joining solutions for smart textiles.

At present, there is a great variety of definite approaches that ensure bonding of textiles with electronics. The method of joining corresponds to the implementation details of a smart textile, its functions and usage conditions. Some of investigated approaches are transferred from electronic and microelectronic engineering. Others originate in textile manufacturing technologies, but mostly these are compromise solutions that contribute the processing requirements of textiles and electronics. Solutions for smart textile bonding is challenging problem for smart textiles developers in R&D and industrial sphere. Although there are already some innovative smart textiles products on the market, joining solutions are mostly found in the R&D sphere. Bonding of textiles with electronics for complex systems is often a process separated from manufacturing. Although manufacturing smart textiles can be automated with pick-and-place technology, and optimizing and coupling the production stages, it is still supported by manual processing due to small series of the produced products.

Bonding methods transferred from electronic engineering such as crimping, staking and soldering are often used for interconnection of microchips and textile integrated electro-conductive buses and textile sensors. They are beneficial, when very low resistance in the joining point is required or joining points are of metal materials (Figure 2). For some types of smart textiles developments, adhesive bonding is a beneficial joining solution. Conductive adhesive materials such as silicone, polyurethane and epoxide-based films can be used for this type of joining [4]. On the other side, joining of the electro-conductive compounds can be implemented by non-adhesive bonding. This approach also originates from electronic engineering and was investigated, and adjusted to textiles by the research team of Fraunhofer Institute [5].

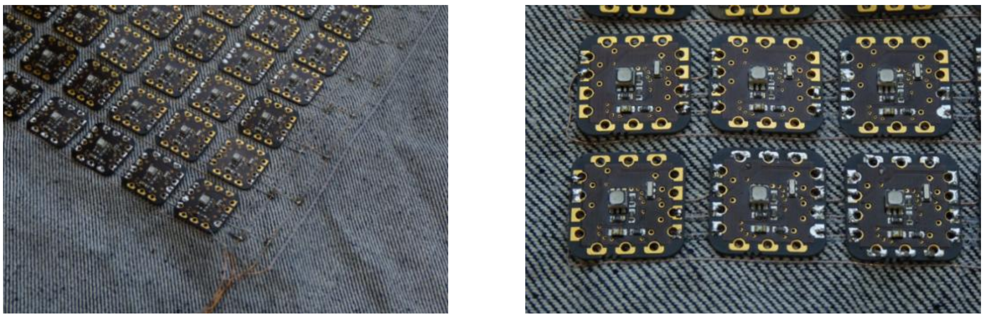

Figure 1 LED matrix integrated onto textiles with technical embroidery and soldering (ITA, RWTH Aachen, Germany)

Electro-conductive textiles are one of the most used materials in development of smart textiles structures. Moreover, electro-conductive yarns are an efficient tool to provide cabling of functional compounds on a textile. These can be processed by conventional textile technologies such as weaving, knitting, sewing and embroidery. For example, Zysset et al. have investigated an advantageous approach of printed electronics integration and cabling by weaving technology [6]. This method encourages development of sensing textiles with high accuracy, but requires additional processing of the textile cabling and the sensor substrate. On the other side, the cabling and contacting system can be easily ensured within the same manufacturing process, when a sensor or an actuator is an inseparable part of a textile structure. For these purposes, technical embroidery is an advantageous technique (Figure 1). Reliability of joining of textiles and electronic compounds by lock-stitch embroidery was investigated in detail by T. Linz in 2012 [7].

Described approaches ensure permanent joining of textiles and electronics. Although those can be advantageous for a number of applications, such joining methods require additional processing of the bonding sites or the whole system in order to ensure protection of electronics and joining from mechanical stress and other factors that influence the efficiency of the system operation. Such needs are mostly confronted in wearable applications of smart textiles. On the other side, such joining can limit the opportunities for substitution of some functional elements when repair of the system is needed. In these cases, reversible joining can be favorable. The simplest solutions to solve the issue are using fastener buttons, conductive Velcro, magnets and bolting. Nevertheless, these approaches cannot always correspond to the technical requirements of some developments due to possible negative impacts such as limited durability of the joining and irrelevant reliability of the bonding [8].

This study describes a concept of a joining solution for electronics and textiles inspired by flexible electronics technology. The main objective is investigation of a scenario for reliable reversible electro-conductive bonding for printed EL devices on textiles within EL manufacturing process.

2 Materials and methods

According to the state-of-the-art for joining technology in smart textiles, type of the bonding of electronics with textile must correspond to the specifics of the development and be chosen with concern for manufacturing process and application conditions. Hereby, the idea of printed EL devices is initially described and a novel approach to manufacturing of such devices is suggested regarding the joining solution. As the printing of the EL stack is comparable to the OLED stack, in this paper we test and characterize the proof-of-principle with the EL devices but a shift towards OLED devices, for the scope of what is discussed here, i.e. bonding and joining, afterwards is fairly straight-forward.

In this study, technical embroidery is chosen as an optional textile processing technique to screen printing due to a number of advantages. First of all, electro-conductive yarns are more likely to maintain their electro-conductive properties in comparison with printed surfaces when they are in intensive use. Moreover, embroidery technology is an advantageous approach for continuous implementation of the electrode structures, electro-conductive buses and platforms for interconnections of electronics with printed devices.

The first steps towards the development of the joining module are research activities that explore the most appropriate structure of embroidered patches for the electro-conductive patches. Then, regarding the information gained from the systematically explored state-of-the-art in the sphere, a concept for a new type of bonding is described.

2.1 Design of the joining module within the structure of EL devices printed on textiles

Printed EL devices are a highly innovative technology that is already available on the market, but there is no yet such devices implemented on textiles. In order to obtain light emitting properties different technologies must be combined and matched to one another. Light emitting materials can be realized by application of light emitting inks between two electrodes and by stimulating with a voltage power supply. The latter implies the development of electrically conductive textile layer(s). In addition, top encapsulation of the printed EL devices with a barrier plasma coating (exclusion of oxygen) is needed. Figure 2 displays a structure of an electro-luminescent device on textiles. Printing technology is the key technology for implementation of such structures, but the function of textiles is limited to this structure carrier. On the other side, electro-conductive textiles are potential candidates to supply two functions simultaneously, namely, to carry the structure and be an electrode. In order to implement this scenario, electro-conductive textiles must correspond to the technical requirements for printing technology that ensures development of the luminous layers.

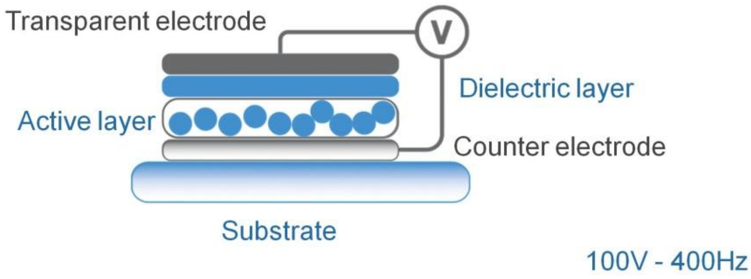

Figure 2 Principle of electro-luminescent devices on textiles based on printing technology

Although this approach brings a number of advantages by multi-functionality of the electro-conductive textile, it does not offer a solution for implementation of the printed device cathode. Moreover, an additional solution for joining must be provided. Hereby, an optional scenario was suggested to develop EL electrodes, electro-conductive buses and sites for bonding the electro-luminescent device with electronics. One of the advantageous methods for textile surface processing is embroidery, which ensures implementation of various structures on textiles. Design of an embroidery pattern implies the electro-conductive compounds that implemented within one development step (Figure 3).

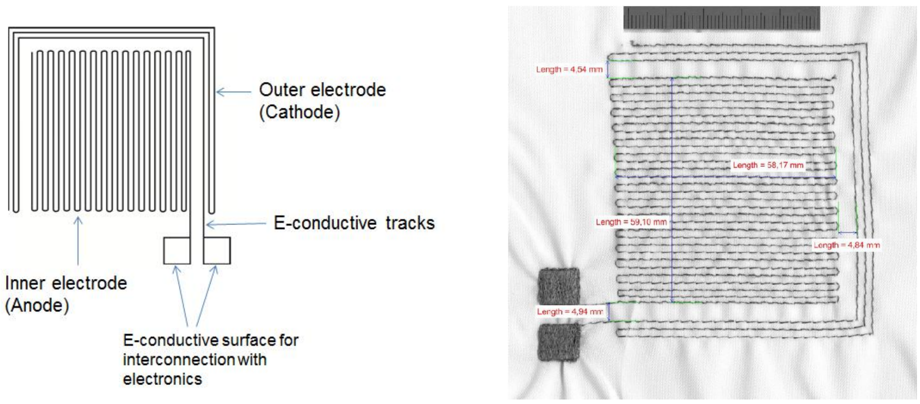

Figure 3 Principle of electro-luminescent devices on textiles based on printing technology

2.2 Embroidered Electro-Conductive Patches

The patches for bonding the textile-based electro-luminescent devices with electronics and energy sources were developed within the same manufacturing process of the textile electrodes. The embroidered patches were designed with dimensions 7x7 mm and manufactured by double lock-stitch embroidery using *Startex Bakroom Fraytec* silver-plated yarn with linear resistivity <100 Ω /cm according to the manufacture's data. This yarn was selected due to its good conductivity, fine structure and ease in processing by the selected manufacturing process.

The dimensions of the patches were selected with concern to the proportions of the printed structures for the pilot-studies investigations. The main function of the embroidered patches is establishment of effective bonding though joining the electro-conductive surfaces. Moreover, it must be considered that electrical resistance of the embroidered patches must be insufficient. In further investigations, the surface dimensions can be modified and adjusted to configurations of a device. For the experimental investigation, conductive patches with different number of layers were manufactured: one, two, three and four layers. In order to evaluate the repeatability of the results, for each type of the patch, 6 samples were manufactured. Then, after evaluation of the electric conductivity of the manufactured samples, several samples of the complete embroidered structure were developed and four samples were selected for further investigation.

2.3 Reversible Joining Module

The proposed concept for the reversible joining module for smart textile applications originates in solutions for flexible electronics [9].This type of bonding is especially beneficial for wearable applications, so the requirements for electronics encapsulation are not so demanding to be resistant to washing. On the other side, such reversible joining is advantageous also for other applications such as interior design due to better options for the system technical examination and repair.

When designing a joining module mechanical and structural specifics must be concerned. The joining module must insure good mechanical contact between the electro-conductive surfaces in order to provide reliable operation of the device. It must be also resistant to mechanical and physical stress. For electro-luminescent devices, the applications can vary from interior design to wearable applications. Hereby, the junction must be enough strong to keep the bonding of the electro-conductive surfaces. On the other side, the forces that must be applied to separate two parts of the joining, must not deform or damage the textile substrates with printed EL structures and integrated electronics.

3 Results

In total 48 samples of embroidered patches were manufactured and tested for electric conductivity properties. The electrical resistance of the samples was measured with the *Voltcraft VC265* multimeter. First, resistance of the patches with different number of embroidered layers was measured. The measurement results are displayed in the Figure 4. Resistance of the patches varies from 0,425 to 0,491 kOhm. Although the measurement values were quite similar, the best results of electrical resistivity were performed by the two-layered patches. The average resistance of the two-layer patch is 0,42±0,006 kOhm. Regarding these results, patterns of electrodes with patches were developed and measured for electrical properties. In total four samples of embroidered structures were investigated. The resistance of inner and outer electrode was measured. The results are displayed in the Figure 5. It is obvious that the length of the electrode has a significant impact on the resistance of the structure. Resistance of the outer electrode with embroidered patches varies from 2,05±0,01 kOhm to 2,16±0,02 kOhm. Measurement values for the outer electrodes varies from 4,35±0,04 kOhm to 6,51±0,08 kOhm.

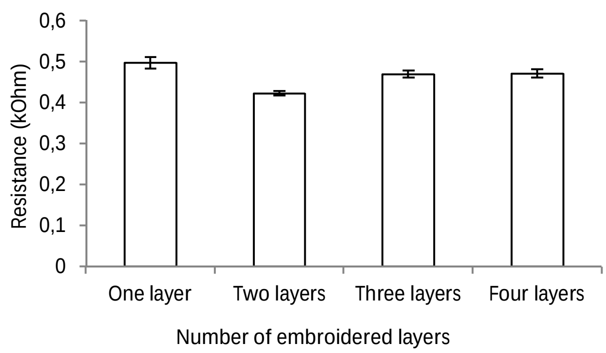

Figure 4 Resistance of the embroidered electro-conductive surfaces

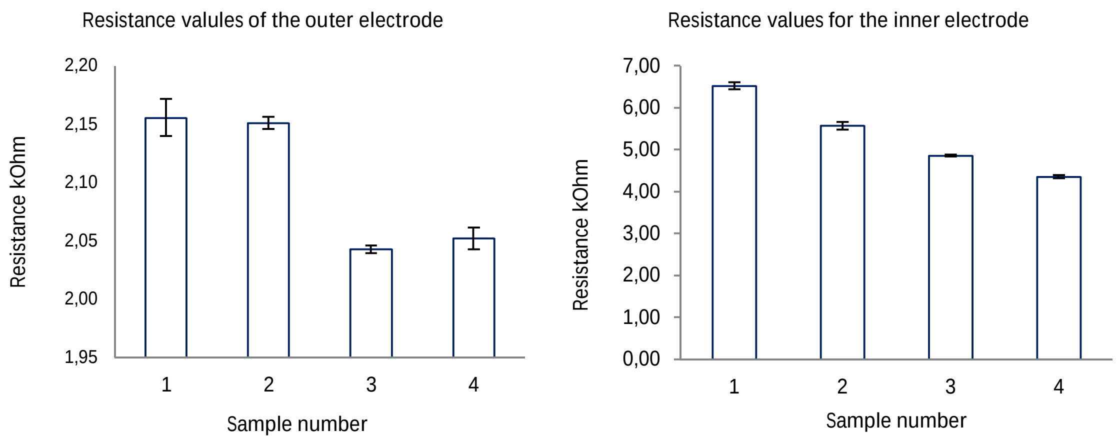

Figure 5 Resistance measurements of the two-layer embroidered electrode with electro-conductive surfaces

4 Results and Discussion

The experimental investigations have shown that application of electro-conductive yarns processed with technical embroidery has potentials for development of electro-conductive surfaces to ensure joining between the embroidered electrodes for printed EL devices and electronics. Regarding the surface roughness the suggested approach at moment can be applied to textile-based EL devices developed by printing technology. In order to achieve appropriate results for implementation of OLEDs on textiles further investigation focusing of the textile surface roughness reduction are required.

Investigations of electrical properties of the embroidered electrodes with patches have evinced that manufacturing process has obviously a significant influence on the resistance values due to mechanical damages of the yarn processes by the lock-stitch embroidery. In order to verify the data, further investigations are necessary in order to fine the optimum parameters for manufacturing. In further investigations that focus on the result improvement parameters such as structure of the yarn and the embroidery machine setting should be further investigated and evaluated in details. Nevertheless, the suggested approach has potentials for the concrete application and can be modified to other ones.

Regarding that in this paper a preliminary study was performed, a concept for the reversible joining module was designed with concern to the state-of-the-art in joining technology for smart textiles and flexible electronics. Further described joining module originates in flexible electronics and can be beneficial also for smart textiles developments. Figure 6 displays the idea of the joining module and its cross-section and give a description of the joining module compounds.

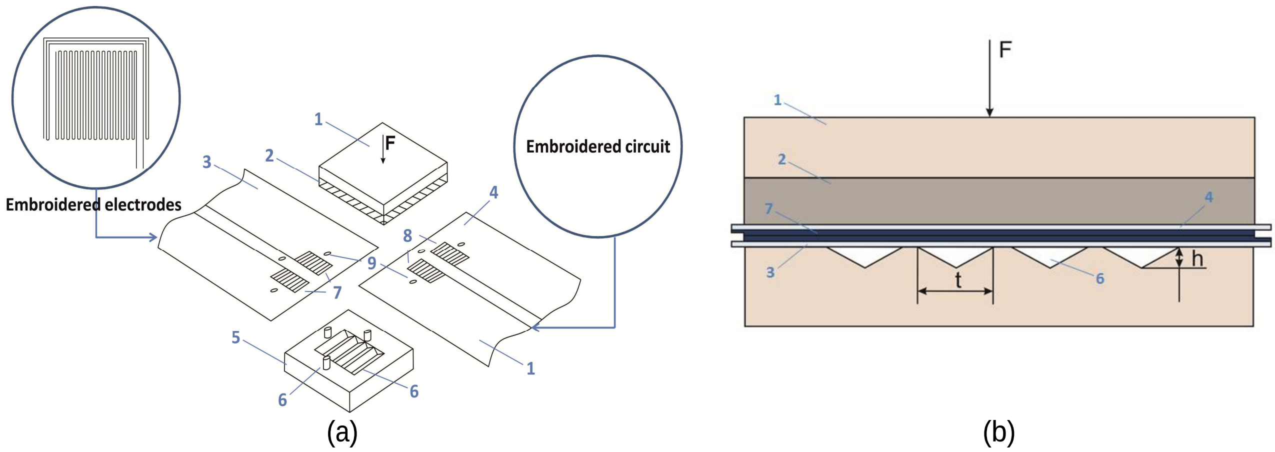

Figure 6 Compounds for the electro-conductive textile joining (a) and Cross-section of the joining module Table 2, where detail 1 and 2 is the pressure plate of the joining module;
Detail 3- the textile substrate carrying the embroidered electrode with the patches;
Detail 4- the textile substrate carrying the embroidered circuit with integrated electronics and power source,
Detail 5- the basement of the joining module;
Detail 6- the triangle profile of the basement that insure better mechanical contact of the textile parts and the pressure plate;
Detail 7- electro-conductive patches of the embroidered electrodes;
Detail 8- electro-conductive patches of the embroidered circuit;
Detail 9- the slots for the module basement bonding with the textiles.

The joining module is designed to cover both electro-conductive patches. The triangle profile of the module basement will provide better mechanical and electrical bonding of the electro-conductive surfaces. The geometry of the basement profile is descries with the fin spacing *t* and groove depth *h*. These parameters are defined by the elasticity deformation of the electro-conductive textile surfaces [9].

The groove space can be calculated as *h=5qt4/384EJ* (cm), where (1)

q is the distributed pressure created by the elastic body and can be defined empirically (Pa),
t is 0,1 to 0,2 cm and defined
E is the elasticity module of the embroidered surfaces and is defined experimentally (Pa);
I is the moment of the inertia of the patch cross-section area and is equal with $ab^3/12$ (cm^4);
a is the width of the patch and is equal with 0,7 cm;
b is the thickness of the patch which is equal with 0,1 cm.

In order to provide the calculation of the geometric parameters, additional experimental investigations of the embroidered patches will be carried out in a follow-up study. The manufactured joining modules will be tested for its influence on the mechanical and electrical properties of the bonding and operation efficiency of the whole EL device.

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