Sensor and Electronic Circuits Development on Flexible Substrates through Additive Manufacturing Technologies for Textile Applications

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***Abstract*—Printed electronics on flexible substrates have awakened special interest in the scientific community in recent years due to its potential applications. Some of these applications are directly connected to the use of textiles and fabrics as wearables. The present project has considered all the relevant topics that are needed to be taken into account in this type of development. The performance and constraints of both conductive inks and dielectric materials have been evaluated. The results achieved have been used to develop capacitive sensors that can bear the flexibility and stretchability conditions required by textile substrates, without undergoing any damage.**

Keywords - printed electronics; smart textiles; sensors; wearables; stretchable; flexible; screen- printing; textile; inkjet; flexography.

I. INTRODUCTION

Electronics that imitate the natural world by bending, flexing and stretching are becoming more and more significant as the technology is integrated into our lives, our environments and even our bodies. One of the most challenging applications is the combination of electronics with textiles or fabrics. This idea was defined as smart textiles [1] or smart fabrics [2]. The elements included in these solutions, such as conductive fibers, conductive filaments, conductive yarns, together with woven, knitted or non-woven structures, are able to interact with the environment of users [3]. Smart textiles are normally used as sensors and they are combined with external microprocessors units, in order to analyse the information and create some kind of action, such as an alert or activation. Smart textiles sensors can be mainly classified depending on their capability to measuring either resistivity or capacitance variations. On one hand, resistive sensors measure variations of resistance of a conductive structure that can be a wire or a conductive stretchable fabric [4]. On the other hand, capacitive sensors use more complex structures that allow to measure capacitance variations between two conductive materials that can be also conductive threads or conductive textiles. This idea has been successfully developed in order to measure parameters such as strain [5][6], pressure [7][8], respiration [9]-[11], humidity [12][13], gas [14] or temperature [15], among others. Moreover, sensors based on conductive surfaces such as electrocardiogram (ECG) [16][17], electromyography (EMG) [18] or electroencephalogram (EEG) [19] have also been implemented.

In addition to conductive threads or conductive fabrics, conductive particles or materials can also be printed on the surface of textiles [20]. Printed electronics [21] on flexible substrates [22][23] have drawn the attention of the scientific community during the last years, due to the great potential in terms of flexibility and possible final applications. Furthermore, these electronics have a lower cost than the current standard techniques, which is an added value [24], since they can be implemented with reel to reel industrial machines [25].

This paper is organized as follows. Section II presents the materials and manufacturing procedures used. Afterwards, Section III presents the experimental results and a discussion of them. Finally, section IV provides an overview of the conclusions.

II. MATERIALS AND METHODS

During the project, different prototypes have been developed using different technologies that can be used in smart fabrics. All of them were related to the design and development of fabrics with intelligent properties, investigating the scope and limitations of the technologies, in order to discover the potential of these applications.

Most common types of conductive inks are based on conductive nanoparticles or microparticles dispersed into a polymer matrix. These particles are based on carbon particles, metallic particles, such as silver and gold, as well as conductive oxides such as ITO or ZnO. These inks are usually dried or cured by heating; however, laser or UV curing is also possible. When the ink is cured by heat, the binder and solvent are removed, forming a conductive layer on the surface of the substrate. The required curing temperature depends on the type of ink, but the usual range covers from 100ºC to 250ºC for 5 to 30 minutes. Depending on the type of substrate, the curing procedure needs to be adjusted.

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The use of printed electronics in textiles, despite it is in an early stage, is a very promising technology within the scope of the smart textiles field. Two critical parameters in the global design of the electronic system are the textile substrate in which the printing process is carried out, and the protection process of the printed ink. Each material or element has characteristics that will have an impact on the final application. Likewise, the typology of inks, their deposition and circuit design, with the added complexity of properties such as flexibility and elasticity, pose a challenge for their use. In addition, another aspect to consider is the interconnection between the flexible electronic and the rigid PCB electronic. Therefore, the selection of the connectors and the attachment systems are crucial.

The developed prototypes comply with the requirements of functionality and resistance. A careful selection of the appropriate materials to use was carried out, as well as the optimal conditions of application and manufacture. It should be noted that the knowledge acquired throughout the project, especially the one derived from the experimentation in the application of electronic inks on fabrics, will be very useful for future developments. Thus, the results achieved can be used in new and more complex applications, or in other environments, based on the previous knowledge acquired.

III. Results and Discussion

Initially, different ink characterization tests were carried out on different substrates, evaluating temperature and optimal curing time. These tests were developed taking into account the orientation of the tissues in relation to the printing direction, as well as other parameters, such as fabric roughness, fabric materials and possible surface finishes. These tests have been performed using different printing technologies depending on the substrate. It can be observed that in the case of the fabrics with higher thickness and higher diameter of thread, the samples did not show electrical conductivity and the values of resistance obtained were very high. The rougher a substrate is, the more quantity of ink is required during the printing process to reduce the negative effect of the substrate surface. In this type of substrates, screen-printing technology offers the best performance. On the other side, technologies such as flexography or inkjet enable a more precise control of the quantity of ink added and the line thickness.

Figure 1. Conductivity test on a stretchable substrate during a contract and relax process.

In addition, the behaviour of the inks printed on different elastic substrates, in terms of their adhesion and conductivity, has been evaluated. Stretching percentages have also been studied by assessing the variations in conductivity produced as a consequence of the undergone stretching. These variations in conductivity must be considered, in order to minimize the effect in the electronic performance. Figure 1 presents the test performed using strip lines of conductive material on stretchable substrate. Another aspect to consider is the negative effect of the contract-relax stretching repetitions, that can produce a considerable damage.

During the project, several prototypes based on capacitive sensors have been developed. This type of sensor offers the advantage of better supporting the conductive limitations than other types of resistive sensors. Initially, a study of the relative permittivity of the different materials used in this work was carried out. This assessment was applied to every non-conductive material, such as fabrics, dielectric inks, adhesives and films. The effect of these materials has been considered from the fabrication process point of view, but also from the sensor performance perspective.

IV. Conclusions

The tests carried out with conductive, dielectric and resistive inks, that can be stretched or flexed, enable to improve the durability of the circuits on flexible substrates, such as textiles. For this purpose, a specific selection of materials and a proper design of the fabrication process needs to be done. In addition, the design process of the electronic circuit must consider the existing constraints, in order to adjust or minimize the negative effect. On the other hand, it was observed that it is possible to reproduce electronic circuits on textiles, taking into account certain parameters of optimization of ink application and an adequate selection of tissues that facilitate the proper application and homogeneity.

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