Stretchable Circuit Board Technology and Application

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Abstract

An innovative technology for the mass production of stretchable printed circuit boards (SCBs) will be presented in this paper. This technology makes it possible for the first time to really integrate fine pitch, high performance electronic circuits easily into textiles and so may be the building block for a totally new generation of wearable electronic systems. An overview of the technology will be given and subsequently a real system using SCB technology is presented.

1. Introduction

Today, nearly all modern electronic is based on printed circuit boards (PCBs). This inconspicuous little piece of plastic and glass fibers is one of the reasons for the enormous growth of the electronic industry. Besides the transistor it is one key for low cost, small size and powerful electronic systems. Especially for wearable devices high-end PCBs with their ultra compact multilayer structures allow an extremely high level of integration. The next big invention in this sector was the flexible PCB (FPCB). Its main benefit is the outstanding mechanical property of being flexible. This opened a huge range of new applications, because of the cost effective realization of bendable fine pitch interconnections (e.g. in mobile phones).

FPCB technology gave designers a new degree of freedom, but it is still a plastic foil which can only conform to simple surface topographies (2D conformability), because it is not stretchable. This is the reason why researchers worldwide are seeking for the next degree of freedom, the stretchable circuit board (SCB). What sounds like a curious future vision is a serious research topic worldwide and of high interest for the industry. Wearable systems that really follow the shape and movements of the body are possible (3D conformability). Technology will change from a foreign, hard object to an integral, soft part of clothing or any other suitable 'near to body' objects (e.g. shoes).

There are many ways to approach this goal and there will be many application specific solutions for this problem. A small collection of current research work can be found in [1-8].

This paper will give a short overview of the technology which is currently developed during the European research project STELLA [5]. It is a cost-effective approach mainly using well-proven techniques from the PCB industry and commercially available materials for mass production oriented research on SCBs. A more detailed description for this technology can be found in [8].

2. Technology

2.1. An Overview of the Process

This section will give a short overview of the SCB process, a more detailed description can be found in [8].

The whole process was designed to use only little special processing and to adapt to standard PCB manufacturing as much as possible.

The substrate material is an elastic foil. After intensive testing a thermoplastic polyurethane (TPU) foil from Epurex (Walopur, thickness 100µm) showed the best properties. The TPU remelts at about 170°C. This makes it possible to use the substrate material also as glue for the later application on other materials (e.g. fabrics). It is also biocompatible, easily available in big

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quantities and cost effective. Today, it is widely used especially in the textile industry. Rubber bands in underwear are made of it, or raincoats are coated with TPU.

A standard, PCB grade copper (Cu) foil (thickness=35µm) is used as conductor material. Substrate and Cu-foil are joined in a lamination process. Peel tests show an excellent adhesion of the Cu on the TPU. A peel strength of about 2 N/mm is typical. Standard polyimide FPCBs show a peel strength of roughly the half, for the adhesion of Cu on polyimide substrates.

After lamination the base material is ready for structuring, which basically can be done like for a PCB or FPCB. Currently photolithography is used and works very well. Pitches down to 100µm line/space have been realized, which is even better than what most PCB manufacturers guarantee.

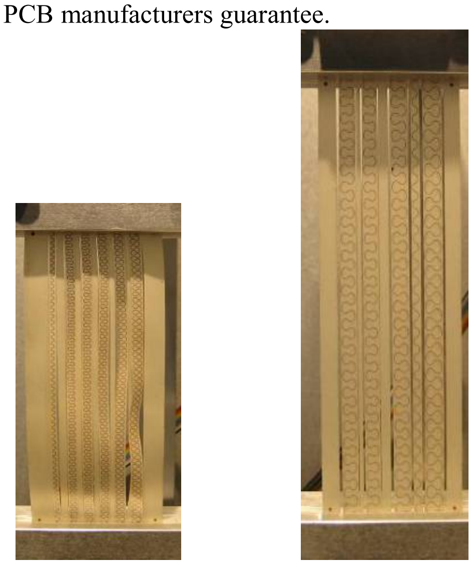

Figure 1. Relaxed (left) and elongated (right) Cu tracks on TPU

Obviously, copper is not really stretchable, it is elastic only for elongations of about 0.1%. Therefore, a specially developed wire shaping was used, in order to form two-dimensional springs out of the PCB tracks. After intensive simulations and testing, design rules for a sinusoidal pattern have been developed. This patterning allows 300% elongation for nonrecurring elongations and 10% for 1600 stretching cycles. A detailed discussion of this can be found in [8]. Extensive studies about thin, stretched metal films can be found in [1, 2]. Figure 1 shows a relaxed and a stretched sample with the spring like PCB tracks.

Other conductor materials were analyzed and tested for this application, but finally Cu has proven to be the most promising candidate. Conductive inks and pastes would also be an alternative, but their conductivity is much lower and more fluctuating if their mechanical properties allow stretching. Also soldering on those conductive pastes is not possible and the resolution of the structuring would not be sufficient. Hence, astonishingly, a pure metal shows the best properties for stretchable conductor lines.

Figure 2 shows the simplified process flow, beginning with the structured substrate.

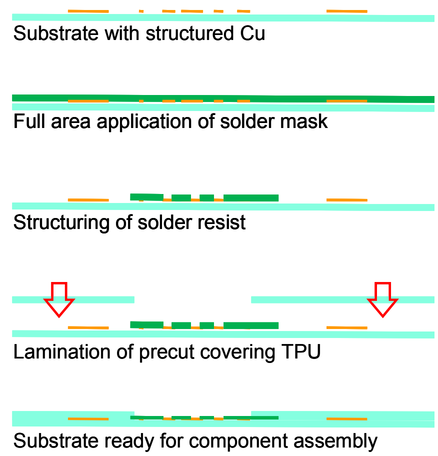

Figure 2. Process flow for SCB manufacturing

The structured substrate could basically be used as it is for simple electronic circuits, but a more sophisticated substrate is created in the following process steps. Solder resist is applied and structured, for the non-stretchable areas (e.g. high density circuits). Lamination of a precut covering TPU protects and isolates the rest of the circuit. A subsequent encapsulation of the assembled components is under development. All those steps were done using standard PCB manufacturing equipment, with only slightly modified parameters.

2.2. Mixing Hard and Soft

Now, the base material and the conductor lines are elastic, but still the electronic components are rigid. The transition between both is a critical point in the system design. If both were directly connected the strain in the interconnection would be extremely high and would sooner or later cause a break. Different techniques were developed to solve this problem. Basically a distribution of the strain over a bigger area lowers the local strain and so allows a combination of SCB and rigid components. As an example, figure 3 shows the layout of a stiffener/strain-distributor for an SMD LED.

Figure 3. Stiffener structure for SMD LED

The large copper areas are not stretchable and very stable. So the strain has a negative gradient to the outsides. Other ways of protection and strain distribution (e.g. encapsulation) can be found in [5] and [8].

Assembly of components and modules can be done by soldering or by conductive adhesives. As the substrate material melts at about 170°C, a low-temperature solder must be used. A SnBi solder with a melting temperature of 142°C showed the best results.

3. A Real System

3.1. Overview

In this chapter a real complete system, based on the SCB technology will be described. The system functions as a demonstrator for the technology and it was not intended to be a product.

The design of the dress was created together with the system design, in order to achieve a unity of design and technology. Figure 6 shows the complete dress. Only on the left side some white lights are randomly distributed over the lower part of the dress. The lights are realized by warm white small SMD LEDs, which are hidden under multiple layers of extremely light fabric material. Each of the 32 lights can be dimmed individually. For a coupling of the user's motion to the lightning pattern, an accelerometer is used. It was the intention to create an electronic feature of the dress that looks more like a discreet accessory than a Christmas tree.

3.2. System Design

Figure 4 shows the block diagram of the system. It demonstrates the practical realization of standard system building blocks and key features (e.g. system power distribution, fast communication links, standard buses, module interconnection and sensor interfacing).

Due to the excellent conductivity of the copper lines, the system does not need any conventional cables or wires, neither for power lines (over 50cm , at 100-500mA), nor for data communication (at 1MBit/s). Additionally, all lines are isolated. This is unique and shows the high potential of this technology. Especially when it is compared with other textile integration approaches like the use of conductive threads.

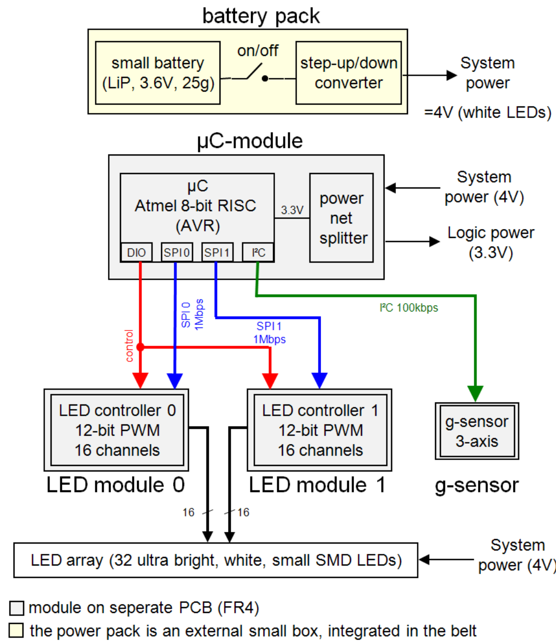

Figure 4. Block diagram of the system

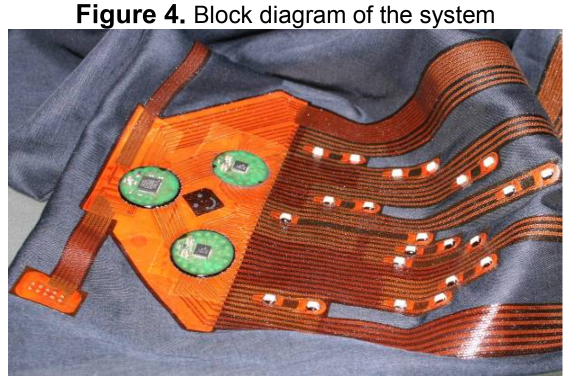

Figure 5. Assembled system on SCB/fabric

The heart of the whole system is a microcontroller (µC). An Atmel AVR (8bit RISC) microcontroller was used. Two LED drivers (TLC5940, Texas Instruments) control the brightness of the 32 LEDs. Every controller has 16 individual channels, which are operated by a pulse width modulated constant current sink. An accelerometer with an I²C interface was chosen (MMA7450, Freescale) to prove the compatibility of this standard bus with the curled conductor lines in practice (30cm at 100kHz).

Figure 5 shows the assembled modules and LEDs on the SCB, which was laminated onto light fabric material. The fabric inhibits high stretches (up to 5%)

and so improves the system's robustness. Stretchability is still crucial here as a FPCB would crinkle, break and drastically change the haptics of the light fabric.

Figure 6 shows the final product. The lightweight battery pack (30g) is embedded in the belt on the back. A SCB based flat cable was laminated onto the inside of the belt. Belt and dress are electrically connected by snap-fasteners. The battery pack powers the system for 8 hours. A demonstration video can be found in [5].

Figure 6. The complete light dress (Klight)

4. Conclusion

A technology for the creation of a new kind of wearable systems was described. Its unique appearance was demonstrated by a complete wearable system for fashion applications.

More complex systems can be created based on this technology that may include wireless links and/or advanced sensor systems. Applications could reach from simple cables or sensor connections to complete systems in the medical sector.

The technology is still under development, but high interest from the industry was recognized and will hopefully lead to production in the next years. Even now this technology could already be used for prototype or low volume systems for special high value applications, with only moderate modifications.

Of course the SCB technology will not replace the common PCB for wearable systems in general, but it may become a building block of highly innovative products in the near future.

5. Acknowledgements

The demonstrator would not look as fashionable as it does, if it was designed by us engineers. That is why we would like to thank our young ambitious designer Mareike Michel for her creative work.

All this work would not have been possible in this quality without the other project partners of the STELLA project, nor without the founding of the European Union.

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