Innovative Packaging Techniques for Wearable Applications using Flexible Silicon Fibres

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Abstract

A novel technology [1] that has the potential to make current wearable electronics recede even further into the background of everyday life has been developed in the form of Electronically Functional Fibres (EFF). This is achieved by building a device in silicon on insulator (SOI) [2] material and under-cutting the sacrificial SiO_2 layer by means of an isotropic etch process to leave a freestanding functional fibre.

A demonstration of functionality based on this technology was produced in the form of a PN diode on a fibre [3]. One of the key initial considerations involved with this technology is the interconnection of such flexible structures. One approach to resolving this issue is to use a flexible Printed Circuit Board (PCB) and a conductive adhesive paste [4] to interconnect the individual fibres. A prototype demonstration of this technology in the form of a flexible Light Emitting Diode (LED) circuit, using the EFF as the resistor of the circuit, will be presented in this publication.

Introduction

Current state of the art in integrating electronics with wearable systems involves starting with passive components, interconnected with each other on a printed circuit board, enclosed in a protective material or casing [5,6,7]. In the case of ubiquitous computing, and taking the VivoMetrics life vest [8] as an example, the electronics need to be removed before washing the garment. These applications are in general quite limited and act solely as demonstrations of the potential of integration that can be possible in the future. A new concept will be discussed in this paper, which involves integrating functionality into flexible fibre form to enable the introduction of functional textiles and garments. This technology is based on conventional planar processing techniques and is the next natural progression in wearable electronics.

One of the key initial considerations in integrating this technology into a wearable format is the interconnection between the individual fibres. This paper discusses the concept and the initial prototype demonstrator of a flexible LED structure interconnecting the individual EFF by means of a conductive adhesive paste, along designated landing sites on the flexible PCB.

Electronically Functional Fibre Fabrication

The EFF are fabricated on silicon on insulator material (SOI) with a top silicon device layer thickness of 2µm, a buried SiO_2 layer thickness of 1µm and a 525µm thick handle wafer. The top silicon device layer is patterned in fibre form and is subjected to diffusion doping with phosphorous and boron to create the metallurgical junction necessary for creating a PN diode [9]. The fibre is released from the handle wafer by means of an isotropic front side etch of the sacrificial SiO_2 layer, leaving a freestanding flexible functional fibre. Figure 1 shows a freestanding fibre and the I-V characteristics for before and after the release mechanism can be seen in Figure 2. The freestanding fibres are between 1-4mm in length and have a diameter between 30-35µm in the direction of the wafer diameter.

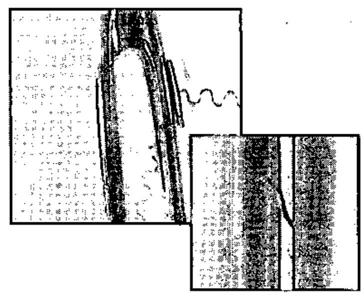
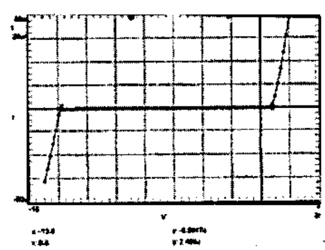
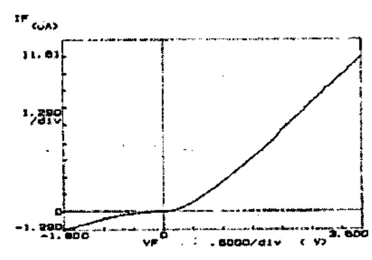


Figure 1. Freestanding fibre being threaded through the eye of a needle



Before Release



After Release

Figure 2. I-V characteristics of the fibre before and after release from the handle wafer

Flexible LED Circuit Design and Fabrication

For the initial concept demonstrator an LED circuit (see figure 3.) was selected to demonstrate the electrical connectivity. The prototype is fabricated using the EFF as the resistors in the circuit, which are interconnected using a conductive adhesive paste and a flex PCB substrate. The flex

PCB structure consists of a patterned copper (Cu) layer on a thin film of polyimide, which is also patterned to create channels for the EFF (see figure 4). The conductive adhesive paste is the interface between the EFF and the Cu track, while the patterned Cu layer acts as the metal interconnect between the LED's and the silicon fibres, which are situated along designated landing sites on the polyimide.

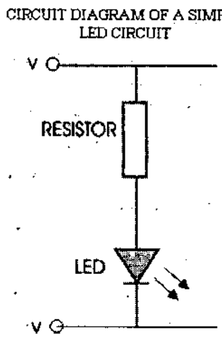


Figure 3. LED Circuit Layout

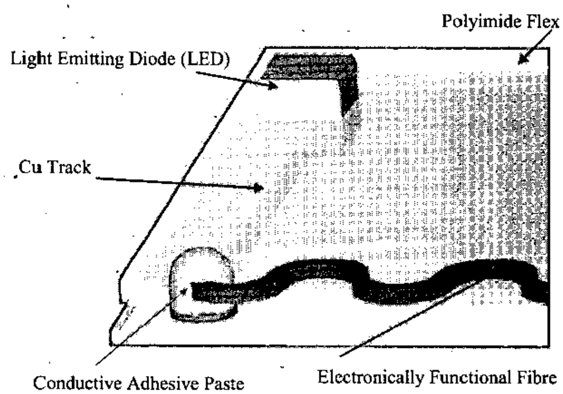


Figure 4. Flex PCB structure

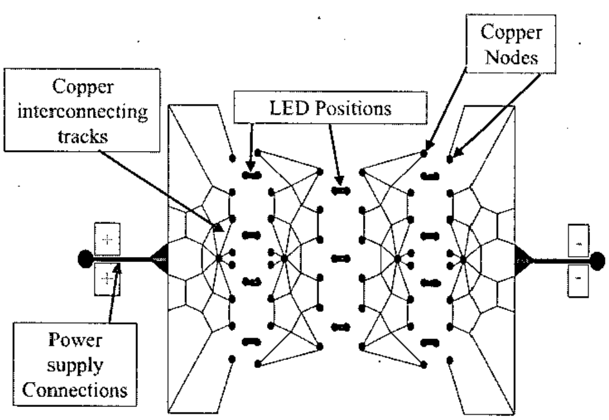


Figure 5. Flexible PCB Layout Design

Figure 5. Shows the layout for the Cu tracks, the position of each LED and the designated landing site for each EFF. The EFF selected for this demonstrator are 1mm in length and 35μm in diameter.

Figure 6. Shows the active circuit with a 5V power supply attached and the light from the LED is clearly visible demonstrating the electrical connectivity between the fibres and the LED's. There were no formal stress tests performed on the circuit however, there appeared to be no visible changes in the luminosity of the LED's due to manual stressing.

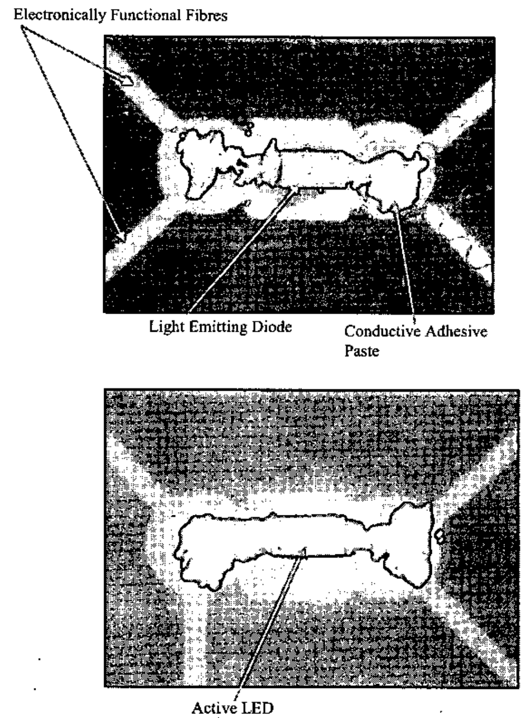


Figure 6. Flexible Active LED Circuit

Active Device Circuit Interconnection

After establishing the concept for flexible active devices and a means of interconnection between them, a more complex demonstration of functionality was investigated. Subsequent active ring oscillator circuits were designed and fabricated in fibre form [10]. An indication of the circuit layout can be seen in figure 7. and the final circuit after fabrication can be seen in figure 8.

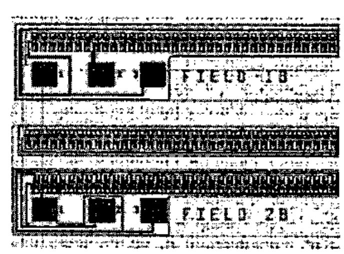


Figure 7. Design layout of a ring oscillator

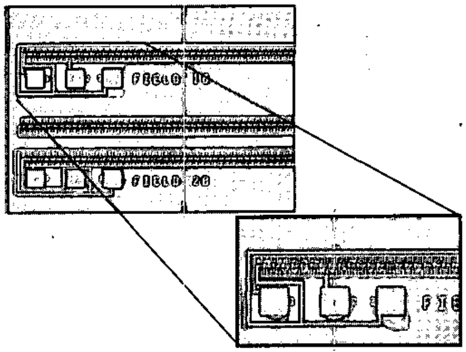


Figure 8. Final circuit after 1.5μm CMOS processing

The ring oscillator is a standard circuit for delay measurement and the waveform of a 679-stage ring oscillator can be seen to produce a frequency of 40KHz in figure 9.

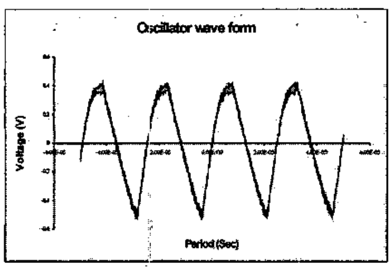


Figure 9. Waveform of a 697-stage ring oscillator

The isotropic front etch process used to release the EFF from the handle wafer outlined above, is also used for the release of the active device circuits and is currently under investigation. A section of the release mask layout is shown in figure 10. The etch process undercuts the oxide on either side of the circuit to leave a freestanding functional device.

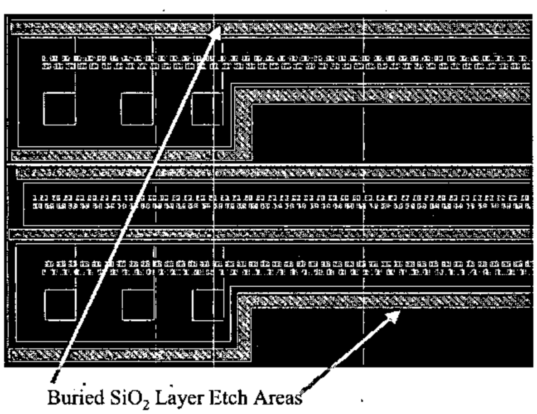


Figure 10. Release mask layout design

Future Work

The same means of interconnection previously described will be used for the active device circuits. The prototype demonstrator will consist of several ring oscillator circuits interconnected using a conductive adhesive paste and a flex PCB. The patterned Cu layer will act as the metal interconnect between the devices and the conductive adhesive paste will act as the conductive interface between the Cu tracks and the circuit bond pads, which will be positioned along designated landing sites on the polyimide. It is anticipated that the frequency of the circuit will slow accordingly due to the increased number of stages in the array of interconnected ring oscillator devices.

Conclusions

This paper has presented the work done in the realization of flexible silicon fibre technology as a novel platform developed for wearable computing applications. The electronically functional fibre technology has the potential to seamlessly integrate into everyday textiles and fabrics and provide the platform for the creation of the next generation of wearable, non-invasive, personal medical sensing systems, such as status and vital sign monitoring.

The interconnection of fibres with different functionality is a critical issue that needs to be resolved for the successful integration of fibre technology into textiles. These connections need to be mechanically sound; but in addition, it is necessary to define a connection protocol, which permits signals to be passed from one fibre to another and to the outside world in a coherent and uniform way for each EFF design. A prototype demonstration of functionality in the form of a flexible Light Emitting Diode (LED) circuit, using the EFF as the resistor of the circuit, has been presented in this paper. Subsequent active device circuits have been fabricated and tested at wafer level and the proposed interconnection of these active circuits based on the experimental interconnection approach has been discussed.

References

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