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Substrate Transfer Technology for Stretchable Electronics

S. Joshi[a,b], A. Savov[a], R. Dekker[a,b]*

* [a]*Technical University of Delft, Delft, 2628CD, The Netherlands*
[b]*Philips Research, Eindhoven, 5656AE, The Netherlands*

Abstract

This paper focuses on the implementation of a new technique for the fabrication of stretchable electronic patches that can be used for medical applications. The technique is based on the Electronics on Plastics by Laser Release (EPlaR) technology which enables a one-step release of a stack of flexible/stretchable layers incorporating the active layers like interconnects and embedded devices. As a proof of concept meander shaped polyimide (PI) structures are fabricated on top of a glass substrate and then transferred to a PDMS substrate with the use of this technology. The stretchability in the device is enhanced by fabricating these meander shaped structures free from the PDMS substrate hence giving them the freedom to move out of plane.

Keywords: substrate transfer, flexible, stretchable, body patches, ultrasound

1. Introduction

Stretchable electronics are being explored for several applications [1], medical applications being one of them. Flexible/Stretchable body patches that have applications in minimally invasive devices like ultrasound patches for imaging, therapy or monitoring are investigated in this paper. However, certain requirements need to be fulfilled to make these patches compatible with the ultrasound technology. The substrate of such device needs to be (a) stretchable/flexible in nature so as to conform to the non-linear human body, (b) non-allergic and wearable for hours and (c) a good window material for the ultrasound waves. Organosilicon- Polydimethylsiloxane (PDMS), is well known for its biocompatibility and also serves as a good interface between the transducers and body and thus could

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* Corresponding author. Tel.: +31-638367225
E-mail address: s.joshi-1@tudelft.nl

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be used as a good substrate material for such devices. However, the fabrication of stretchable electronic devices directly on PDMS is cumbersome due to the incompatibility of PDMS with high temperature processing, chemicals resustance and because of handling difficulties.

An alternative approach is the transfer of a pre-fabricated circuit from a rigid to a stretchable substrate. Several transfer techniques have been proposed in literature including Transfer Printing Methods (TPM) [2] and Water-Assisted Nickel release [3]. The disadvantages of these techniques are that they require either peel off, which can easily cause stress and damage to the device layer, or require the use of chemicals for release which is not ideal with PDMS due to its high solvent uptake. In this paper we explore a substrate transfer based on EPlaR (Electronics on Plastics by Laser Release) technology. It is a post processing approach for the release of a pre-fabricated stack of layers from a glass substrate.

1.1. Theory

Before discussing the fabrication, the (EPlaR) technology that is required to release this patch from the rigid substrate and the concept of free standing interconnects which will be introduced.

1.1.1. EPlaR Technology

The EPlaR technology has been developed by Philips Research primarily for the fabrication of flexible displays [4]. The processing for this technology begins with spinning and curing a layer of polyimide on top of a glass substrate. This layer will now act as the base layer for the fabrication of a stack of device layers such as interconnects, bond pads etc. Since the PI can withstand temperatures as high as 400 °C, it acts as an ideal layer for post processing. Finally, this polyimide carrier layer along with the layers on top is released using pulses of an excimer laser from the backside through the glass substrate. Specific chemical bonds are broken in the first few 100 nm of the PI by the laser resulting in the formation of gaseous species between the layer and glass substrate, causing delamination. Advantages of this technology are: (a) it is not limited to a substrate size, and thus can be used for fabrication of really large patches, (c) it is a two-step release process thus reducing the amount of processing steps, and (b) after the release of the stack, the glass wafer can be reused.

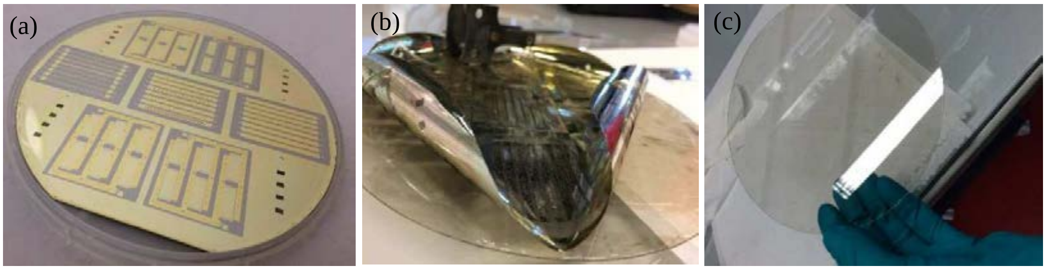

Figure 1: (a) 150 mm wafer with the PI meander patches embedded in PDMS, ready for final release, (b) the layer stack released using EPlaR and (c) glass wafer after the release and removal of the stack, completely reusable.

1.1.2. Free Standing Interconnects

The EPlaR technology as described in the section above enables the effective transfer of devices from rigid to stretchable substrates. The stretchability of any device however, is not just limited to its substrate. To achieve stretchability the device needs to have stretchability in between the rigid elements that are embedded in the PDMS [5]. For this, metal spring like interconnects are fabricated connecting the rigid islands. These springs can elongate in length when the substrate is stretched, thus providing the necessary stretchability. However, the tendency of a spring when stretched is to turn and bend out of plane which will be limited if they are embedded within the PDMS

[6]. This out of plane bending can only be possible if the meander shaped interconnects are made free standing from the substrate.

1.2. Experimental

To provide a proof of concept, the integration of the aluminum interconnects was skipped to be able to focus on the EPlaR release technology and the out of plane bending of the PI meander structures. The final patches will be integrated with a functional Al layer isolated by the PI layers in future experiments. The transfer process proposed in this paper starts with spin coating and curing of a 500 nm thick layer of polyimide on a 150 mm diameter 400 um thick AF45 glass wafer. This is followed by sputter coating of 200 nm of Aluminum (Fig. 2-a). Here, the PI and Al layers will act as a release and spacer layer respectively at the end of the process. The next steps after the fabrication of this stack, is the fabrication of the circuit to be transferred. However, in our experiments we begin with spin coating and curing a 5.2 µm thick layer of PI that is patterned into meandering horseshoe shaped structures (Fig. 2-b). The purpose of these meandering structures is to give the necessary stretchable freedom which lacks in a simple straight conducting wire. However, it has been observed in literature [6] that an embedded meander structure may still not be able to utilize its maximum stretchability. So, for a meander shaped wire to stretch completely, it needs to bend out of plane and this can only be possible if the interconnects are free-standing i.e. not attached to the substrate. To make the patterned PI structures free standing they are embedded in a 15 µm thick layer of resist that will act as a spacer layer between the PI and the finally deposited 700 µm PDMS layer (Fig. 2-c). The PDMS layer is cured at 90°C for 20 minutes in a convection oven.

After the front side processing, the backside of the wafer is irradiated with excimer laser pulses (Fig. 2-d) and as explained in the previous technology section 1.1.1, this results in the release of the stack from the rigid glass substrate.

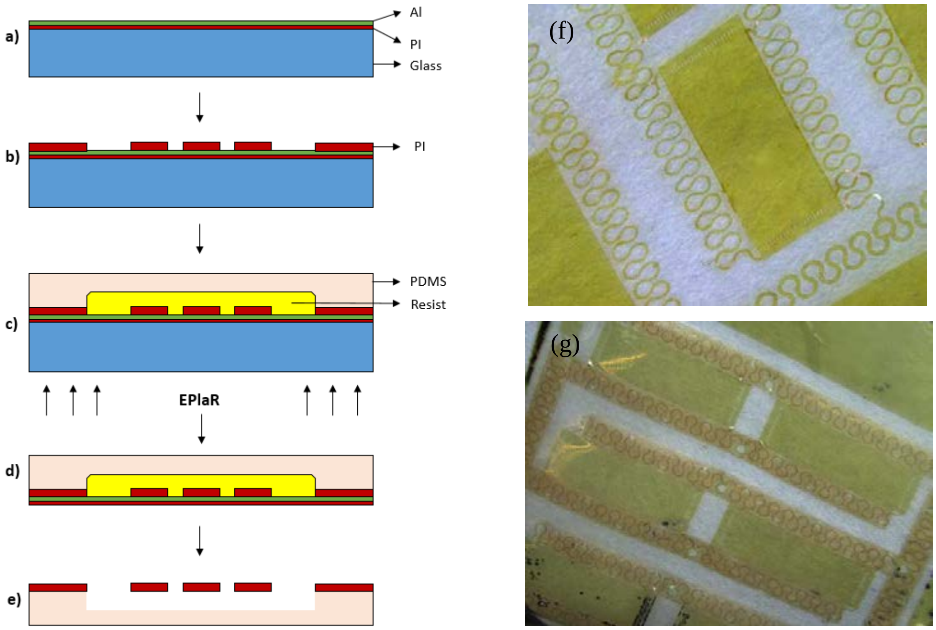

Figure 2: (a-e) Flowchart depicting the process flow for the fabrication of free standing stretchable PI meanders, (f) optical microscope image of the meander structures after PI patterning and, (g) after embedding in resist spacer layer.

After EPlaR release of the structures, the sacrificial PI and Al layers are etched in dry (O_2 plasma) and wet (PES) chemistry respectively. The spacer resist layer that separates the meanders from getting embedded in the PDMS is dissolved in cold KOH (10%) leaving the meanders free (not adhered) from PDMS substrate (Fig. 2-d-e).

1.3. Results and Conclusions

Successful release of the patch from the glass substrate is observed after EPlaR (Fig. 2). A small patch is cut from this released stack and the necessary release of the structures are performed as explained in previous section. Upon stretching, the meanders bend out of plane and upon release come back to their original position (Fig. 3). The meanders are not completely free-standing, but they also do not attach or adhere to the PDMS substrate. This aspect will be resolved in the next patch fabrication by using thicker resist spacer layer.

Although the adhesion problem of the PI/PDMS had been resolved and reported [7], it is seen that after dissolving the resist, the adhesion of PI to PDMS becomes weak. The stretchability of the meanders will be characterized in the next phase of the experiments along with the embodiment of Al between the PI sandwich layers.

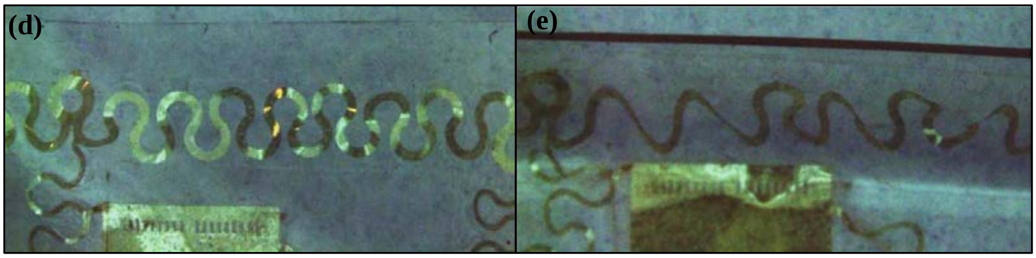

Figure 3: Observation of the patch under microscope while stretching where, (d) shows the PI meanders before stretching and (e) shows the out of plane bending of the structures after stretch is applied.

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