# A New Low Cost, Elastic and Conformable Electronics Technology for Soft and Stretchable Electronic Devices by use of a Stretchable Substrate

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## Abstract

A growing need for ambient electronics in our daily life leads to higher demands from the user in the view of comfort of the electronic devices. Those devices should become invisible to the user, especially when they are embedded in clothes (e.g. in smart textiles). They should be soft, conformable and to a certain degree stretchable. Electronics for implantation on the other hand should ideally be soft and conformable in relation to the body tissue, in order to minimize the rejecting nature of the body to unknown implanted rigid objects. Conformable and elastic circuitry is an emerging topic in the electronics and packaging domain. In this contribution a new low cost, elastic and stretchable electronic device technology will be presented, based on the use of a stretchable substrate. The process steps used are standard PCB fabrication processes, resulting in a fast technology transfer to the industry. This new developed technology is based on the combination of rigid standard SMD components which are connected with 2-D spring-shaped metallic interconnections. Embedding is done by moulding the electronic device in a stretchable polymer. The reliability of the overall system is improved by varying the thickness of the embedding polymer, wherever the presence and type of components requires to. Manufacturability issues are discussed together with the need for good reliability of the stretchable interconnections when stress is applied during stretching.

Key words: Ambient electronics, biomedical electronic implants, moulding, PDMS, polymers, smart textiles, stretchable electronics, stretchable interconnections

## I. Introduction

Stretchable, elastic electronic interconnection technologies will be a major improvement in the development of biomedical implantable electronics and smart textiles. User comfort expressed in softness and elasticity of the electronic device is a major issue.

Our main philosophy of stretchable electronic devices is that standard SMD electronic components are used, typically being non-stretchable. They are grouped in non-stretchable functional islands. To make stretchability happen, the different islands are connected by 2-D spring-shaped copper connections. This principle is shown in Figure 1.

Copper connectors are preferred above conductive polymers, due to their high conductivity, reliability and low cost. Some research groups [1]-[6] reported already their activities on the development of stretchable metallic interconnections on or in elastic, stretchable substrates. In [7,8,9] our technology based on plating gold meanders was presented together with optimizations of stretchability by use of finite element analysis (FEA) to obtain the optimal shape of the conductor shape. The shape of the copper conductors used in this paper is based on these results.

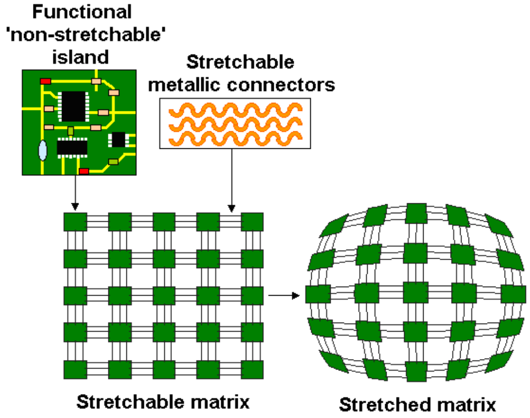

**Figure 1: Stretchable electronics' architecture principle**

## II. Method

In [7-14] a technology based on plating gold metal tracks on copper foil was presented. This approach has some major disadvantages. While processing, all metal tracks are short circuited. This gives problems when embedding batteries. Moreover, etching of a copper substrate poses environmental issues.

A new approach for embedding metal tracks and standard electronic components in elastic substrates is shown in Figure 2.

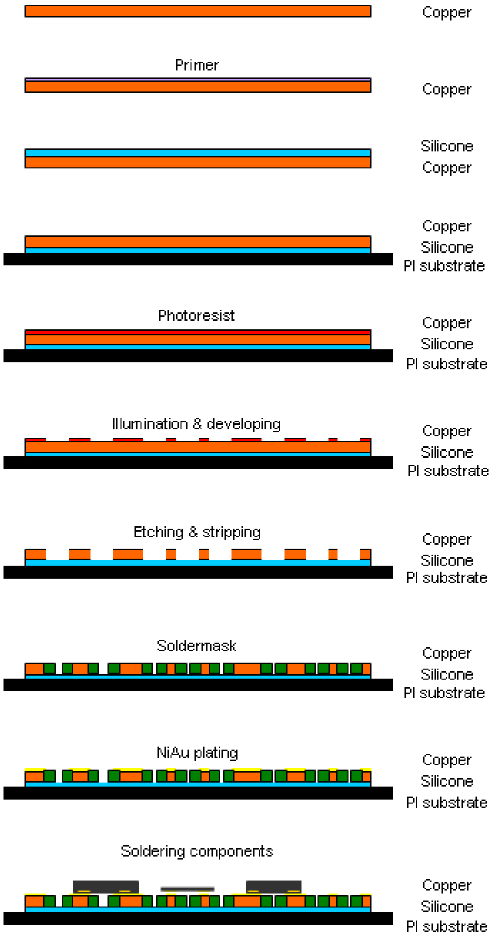

**Figure 2: Process sequence**

An 18 µm TW/YE copperfoil (Circuitfoil) is treated on the rough side with adhesion primer OS1200 (Dow Corning). A thin layer of silicone Sylgard 186 (Dow Corning) is spun or casted on it and cured at 50$^o$ C during 2 hours in air. The overall thickness of the silicone is ~100µm. The low curing temperature is needed to avoid thermal stresses gradients in between the copper and the PDMS. These give rise to problems after etching the copper: when the copper is patterned, silicone cured at high temperature would shrink and curl, making it impossible to align e.g. the soldermask on it.

The substrate is placed, with the copper on top, on a (perforated) Cirlex polyimide foil (Dupont) with thickness of 300µm. Perforation holes are recommended in order to avoid entrapment of air between the temporary PI carrier and the silicone: air bubbles would cause problems because of thermal expansion during reflow soldering at elevated temperatures.

The physical adhesion between the silicone and the polyimide keeps our stretchable substrate on the polyimide temporary carrier during processing; no temporary adhesive is needed here.

Before application of a photoresist, the surface of copper has to be prepared for cleanliness and good adhesion. Preposit-Etch E25/29 (Shipley) is used as a micro-etchant for our surface preparation. The substrates are subsequently etched in 10% HCl solution, followed by a rinse in DI water. Next, photoresist AZ4562 is spun and a lithography step takes place in order to define the copper tracks. Etching is done by use of a spray-etcher resulting in copper tracks laying on the silicone substrate.

Before application, the silicone is treated with air-based plasma, in order to make the surface hydrophilic.

After stripping the photoresist, a 25µm layer of soldermask ELPEMER SD2463 FLEX HF is applied on the substrate by screenprinting Finally an electroless Ni, finished with an electroless Au flash is deposited on the copper, to improve the solder connection reliability. Typical thickness for the Ni deposition is a few (2-3) microns; thickness of the Au is 150nm.

Components are soldered by vapour phase soldering using SAC305 alloy. Due to the high soldering temperature of 260$^o$ C, the silicone Sylgard 186 expands. The linear coefficient of thermal expansion is 330 µm/m.ΔT. The small thickness of the silicone and the adhesion to the polyimide substrate prevents the thin silicone layer to move very drastically. Soldering at lower temperatures is recommended using low-temperature solderpastes or conductive epoxy glues. Silicones with a lower Young's modulus or a lower CTE are also advisable, leading to less deformation during soldering at high temperatures.

Before embedding in a polymer, the functionality of the circuit can be tested. This is a unique feature of this technology. Components can be replaced and resoldered if necessary.

Adhesion of the metal tracks, soldermask and components to the embedding elastic material is improved by using the same adhesion primer OS1200 (Dow Corning).

Finally, the substrate is embedded using the same elastic material (Sylgard 186 by Dow Corning). This can be done by casting or by using MID technology being shown in Fig. 3. In the MID technology, the stretchable electronic circuit on the carrier is put into a PMMA or ULTEM® 1000 mould. In the mould, cavities are made in order to have thicker layers of silicone on places where components are and thinner layers on places where the stretchable interconnections are defined. During stretching, the system will stretch more in the thinner parts. The upper layer of PDMS is injected and cured.

Next, the bottom mould is removed and the flexible polyimide substrate is peeled off. Another injection mould is mounted to inject the final layer of PDMS. After curing this layer the system is unmoulded leading to a stretchable system.

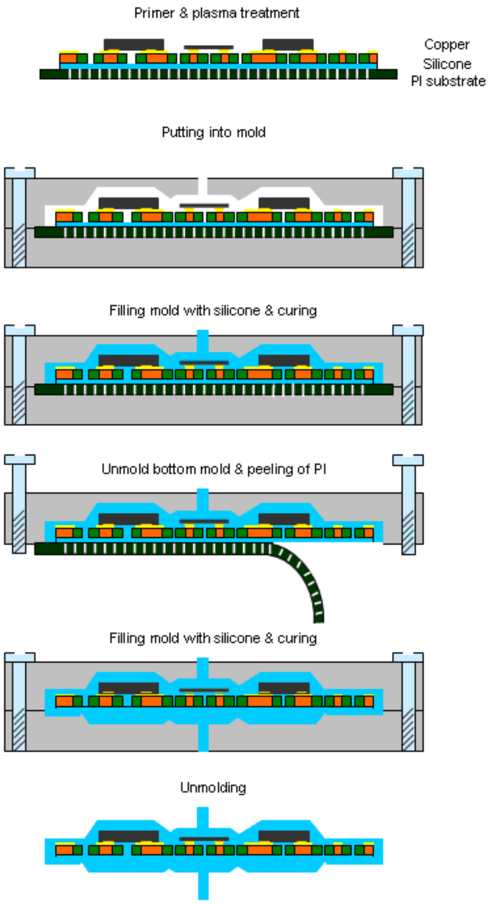

**Figure 3: Moulding process sequence**

## III. Results

In Figure 4 copper meanders are shown made on Sylgard 186. They can be used as stretchable cables between 2 non-stretchable circuits and can be soldered by use of SAC or glued by use of a conductive glue. Completely embedding of the overall circuit in an elastomer can be done.

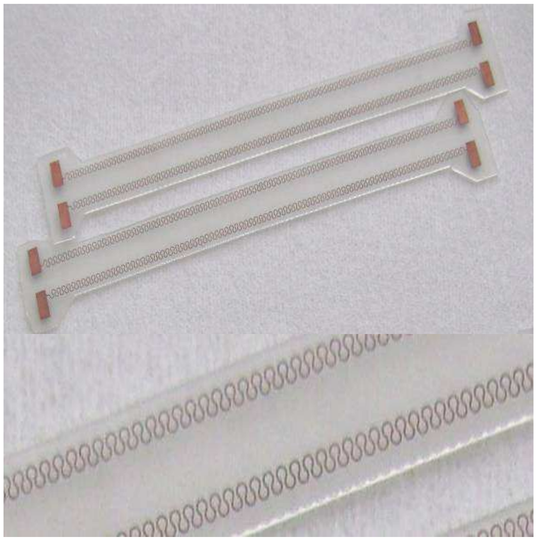

**Figure 4: Stretchable copper meanders on Sylgard 186**

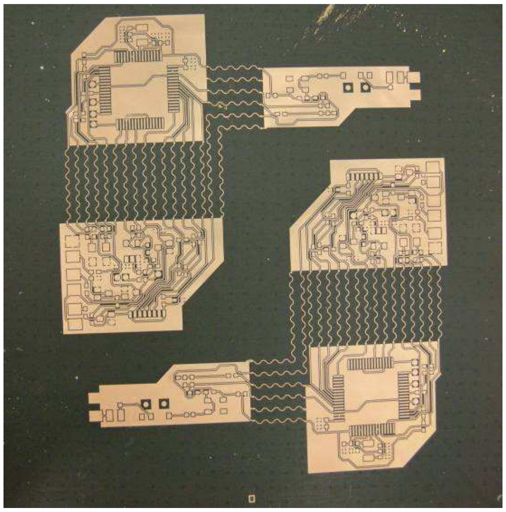

**Figure 5: Stretchable electronic circuit with stretchable interconnetions and non-stretchable functional component islands**

In Figure 5, a stretchable electronic circuit is shown where the copper is defined on a thin layer (~100µm) of Sylgard 186. In the copper, stretchable parts are defined by use of meander shaped tracks and non-stretchable parts are defined where component pads and straight tracks are surrounded with an electrical ground plane. The whole stretchable circuit is lying on a (perforated) Cirlex polyimide foil (Dupont) with a thickness of 300µm.

NiAu plating of the copper is followed and the result is shown in Figure 6.

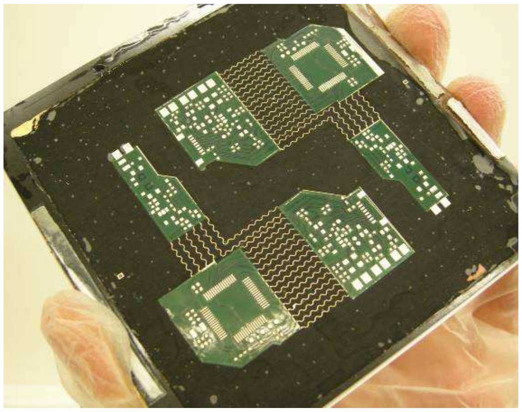

**Figure 6: Stretchable electronic circuit on a 100μm thick Sylgard 186 layer**

The following step is the mounting of components by vapour phase soldering them with SAC305 alloy. In Figure 7, the result is shown after mounting SMD components.

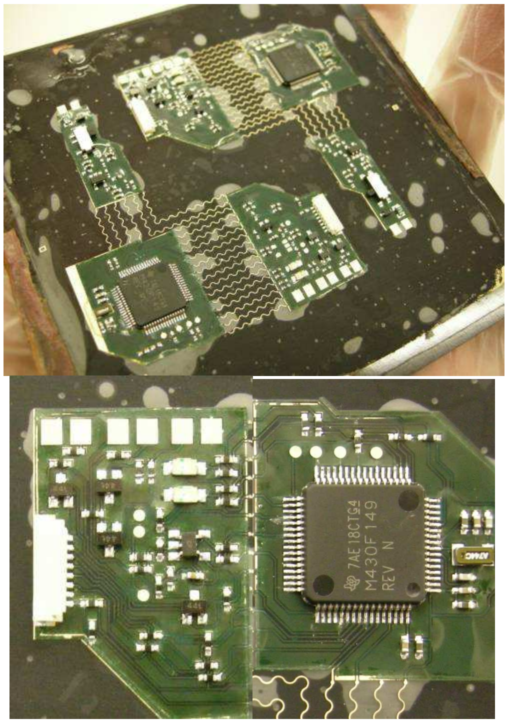

**Figure 7: Stretchable electronic circuit with soldered components**

As can be seen in Figure 7, due to the high temperature during vapour phase soldering, the Sylgard 186 has expanded and some air bubbles are created under the substrate. This can lead to soldering problems, especially for components with a lot of I/O pins. We have noticed that an air bubble can lift a component, leading to a badly soldered component. This problem can be solved by using a silicone with a lower Young's modulus and a lower CTE. Some tests were performed with Sylgard 527 (Dow Corning) which is a silicone gel and hasn't a noticeable expansion during vapour phase soldering. In the end, a different encapsulating silicone material can be used to embed the whole stretchable circuit.

In Figure 8, the good result is shown of vapour phase soldering a component with a high number of I/O pins (TQFP44 package, 0.8mm pitch) on the Sylgard 527 substrate.

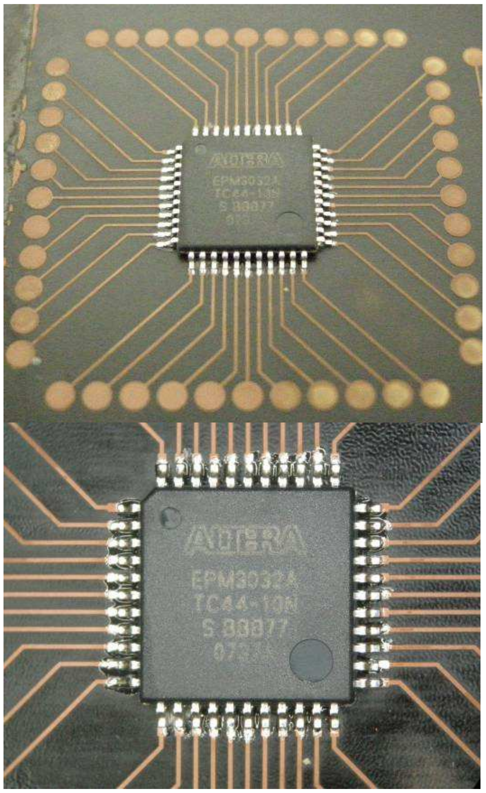

**Figure 8: Feasibility of vapour phase soldering high I/O components on PDMS elastomer**

In Figure 9, a completely embedded stretchable electronic circuit is shown. Not all components have been implemented and the embedding was done by casting a layer of Sylgard 186 on top, curing it and removing the temporary polyimide carrier and adding another Sylgard 186 layer at the back. The overall thickness is ~3mm.

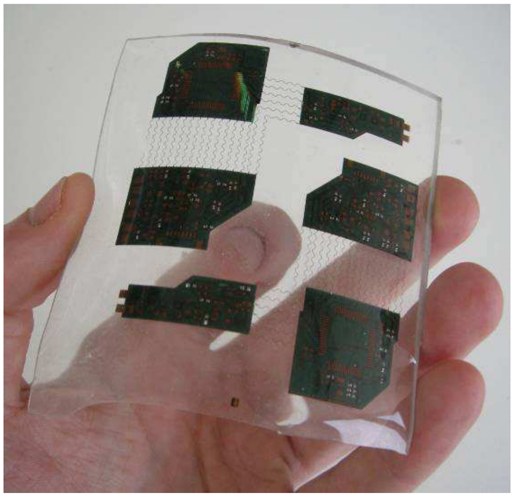

**Figure 9: Feasibility of vapour phase soldering high I/O components on PDMS elastomer**

Reliability tests have been performed for this technology by embedding meander shaped copper conductors in a 2mm Sylgard 186 substrate. An Instron 5543 has been used for this purpose in order to subject those samples to cyclic stretching (Figure 10-11) until failure (no conductivity of the meandered copper tracks). Depending on the meander shape, ~2000 cycles of cyclic stretching can be achieved for an elongation of 10% and a strain rate of 1%/s, without an increase in resistivity. This result gives an indication of the life-time of such embedded meander shaped copper conductors.

**Figure 10: Instron 5543 for cyclic stretching of the embedded meandered copper tracks**

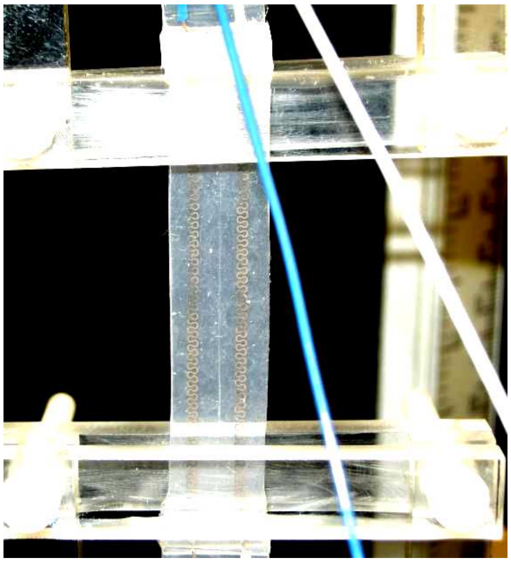

**Figure 11: Testing the reliability of the copper meanders embedded in Sylgard 186 by application of a cyclic strain of 10% at 1%/s strain rate**

## IV. Discussion

An advantage of this technology is that copper of several thicknesses can be used. The minimal copper thickness we used was 9µm, to obtain small features. Use of 18µm thick copper makes pitches of 100µm possible.

This technology is ideal for making stretchable connectors embedded in an elastomer, where stretchability and life-time till failure will be determined by the type of meander shape and the elastomer.

The problems arising during vapour phase soldering can be avoided by use of low temperature soldering pastes (based on Sn, Bi and In which have melting temperatures less than 183$^{o}$C). Also, conductive epoxy glues can be used to overcome the problem of thermal expansion at 260$^{o}$C. Another kind of elastomer, with lower Young’s modulus and lower CTE can overcome the soldering problems for components with a high number of I/O pins, as has been shown demonstrated.

Besides the further work needed to optimize the soldering steps in order to obtain reliable soldered connections - especially for components with a high number of I/O pins – this technology has a high potential to realize stretchable, conformable electronic devices.

## V. Conclusion

In this contribution a new low cost, elastic and stretchable electronic device technology has been presented, starting from a stretchable substrate. All used processes are standard PCB fabrication processes, leading to a less complicated transfer to the industry of this technology. The combination of rigid standard SMD components and 2-D spring-shaped metallic interconnections leads to a stretchable electronic system. Embedding can be done by moulding the electronic device in a stretchable substrate polymer in a way that the reliability of the overall system is improved by varying the thickness of the embedding polymer depending on the presence and type of components.

Different kinds of polymers can be used (able to withstand soldering temperatures) for other types of applications like implantable biomedical systems, smart textiles, sensors, actuators, robotic skins, etc…

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