New Materials and Processes for Flexible Electronics

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***Abstract*— Over the last decades, we have seen an increased need for flexible hybrid electronics (FHE) especially in the mobile, wearable, and medical devices. Recently additional applications and technologies have emerged e.g. stretchable and conformable electronics. 3D and foldable smart devices enable novel applications with new levels of user convenience and human-machine interfaces.**

The range of processes and materials applied in products and research has become very broad. Various types of flexible and stretchable base materials are available with different thermal, electrical and mechanical properties. They have to match the requirements of subsequent processes and those of the final application. Besides photolithographic processes novel flexible and stretchable electrical circuits are realized by different printing technologies using conductive polymers, percolation networks or liquid metals. Alternatively, higher densities can be achieved by photolithographic structuring of meander-shaped or buckling conductors or fine meshes. The modules can finally be dynamically flexible or stretchable or they can be brought in 3D shapes by 3D printing, thermoforming, or injection molding to generate smart 3D surfaces and structures.

With the different combinations, the requirements for many applications can be met but the field has become too complex to find solutions easily. In this article, examples of flexible, stretchable, and wearable devices will be given for various technologies and materials. The applications range from antennas to lab- on-chip devices to wearables and to medical implants.

Besides the difficulty to find the optimum combination of technologies and materials for a use case, there are other obstacles as well: the ageing behavior and failure mechanisms still have to be investigated and understood.

***Index Terms*— flexible electronics, organic electronics, hybrid electronics, stretchable electronics, 3D printing, additive manufacturing**

I. Introduction

The growing need to shrink not only the footprint of an electronic system, but also to limit its thickness has led to increased interest in flexible circuits. For maximum miniaturization flexible substrates combined with ultrathin IC´s have become a pivotal technology for demanding systems [1,2]. Soft electronics are devices that can be bent, folded, stretched, or conformed regardless of their material composition, without losing the electronic functionality. In addition to adding smart functionality and compatible form factor to the conventional rigid electronics, these devices have the promise of being employed in healthcare – designing low-cost stretchable electronic skins or lightweight smart sensors conformal to human body for biomonitoring and energy harvesting applications.

One of the subsets of soft electronic devices is flexible electronics that embeds conductors in thin form factors inside a polymer matrix and retain their function while being bent. Intrinsically stiff materials, such as copper, can be rendered flexible by making them sufficiently thin. Examples of such electronics include large area flexible displays fabricated using plastic sheets—whose performance does not get altered upon bending, fully integrated and wearable sensor arrays for in situ perspiration analysis, flexible antennas, bendable inorganic thin-film batteries, and transparent, lightweight electronics that can be transferred on another object, surface, or biological tissues, i.e., human skin.

One of the drawbacks of these devices is that they are not inherently stretchable as the conductors and the off-the-shelf electronic components used in the fabrication process are rigid and brittle by nature. While flexible electronics can be bent, stretchable electronics can be elongated. Thus, stretchable electronics can be used in a wider application space while providing increased durability. To build a stretchable electronic device, in addition to having the backbone of a soft polymer matrix, it is required to pattern interconnects that are intrinsically stretchable. Using multiple patterning processes such as chemical vapor deposition, sputtering, soft lithography, and 3D printing, researchers have fabricated a variety of stretchable electronics such as optoelectronic skin for sensing and display, soft neural implants that sustain millions of mechanical stretch cycles and assist in drug delivery, stretchable batteries with wireless recharging capabilities, stretchable displays, soft silicon integrated circuits using wavy metal films, and epidermal electronics for the skin.

Stretchable electronics based on new materials and processes for substrate as well as conductors have become a key technology for many wearable and medical applications . Using the capability to conform towards non-planar bodies, even to support complex 3D surfaces and offer some dynamics, conformal systems have been developed. All these new

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properties open up innovative application areas especially in the sector of health care, mobility, robotics but also arts and fashion.

Among these emerging application areas, we find patches to monitor vital parameters like ECG, temperature and activity, prosthetic enhancements restoring haptic sensing or robotic systems capable of manipulating sensitive goods. AlsoAlso, hybrid devices like connected pieces of art in a smart home or jewelry (e.g. rings), allowing to interact with the environment as building blocks of a “smart-X” connected world are enabled by flex-stretch systems, which merge imperceptibly into the main functionality of the goods. The latter is key to customer acceptance. Lastly, implanted devices strongly benefit from flexible and soft systems, rendering rigid circuit boards enclosed in a titanium housing obsolete

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Among these emerging application areas, we find patches to monitor vital parameters like ECG, temperature and activity, prosthetic enhancements restoring haptic sensing or robotic systems capable of manipulating sensitive goods. Also hybrid devices like connected pieces of art in a smart home or jewelry (e.g. rings), allowing to interact with the environment as building blocks of a “smart-X” connected world are enabled by flex-stretch systems, which merge imperceptibly into the main functionality of the goods. The latter is key to customer acceptance. Lastly, implanted devices strongly benefit from flexible and soft systems, with the promise to render rigid circuit boards enclosed in a titanium housing obsolete.

II. Flexible Substrate Materials

Recent developments to realize high density flexible circuits have demonstrated the capability to improve production volume, cost and reliability significantly. Especially with the material of main interest, polyimide, substantial improvements in the production of high-density circuits have been achieved. In contrast to the conventional subtractive flex PCB technology, more delicate circuits can be structured by thin film multilayer processes. The layers can even include the integration of ultrathin chips into the dielectric material itself [7]. The concept of thin chip integration, albeit not a new idea by itself, has since found its implementation into the additive realization of complex circuitry.

Although polyimide is regarded as a highly versatile, robust and capable material, flex circuit realization is not limited to this. Niche materials like Parylene, silicone, PC (polycarbonate) or LCP (liquid crystal polymers) have been sided with materials targeting volume markets e.g. PU (polyurethanes), or PET (polyethylenterephthalat). Especially thermoplastic polyurethanes (TPU) have come to the attention of the industry, as processing of these results not only in flexible, but highly pliable and stretchable products if applied with a suitable structuring technology for the conductive tracks. In combination with thermosetting or thermoformable backings, these stretchable properties even allow to build electronic systems conforming to complex 3D surfaces.

III. Flexible Circuits

A. Lithography

For ultrathin high density flexible substrates, spin-on polyimide is the material of choice. Mandatory for the creation of reliable flex circuits is the proper material selection for the polymer, which is deposited in a process well understood in the wafer level redistribution industry, offering manufacturing sizes up to 300mm diameter [8, 9]. Figure 1 shows the schematic flow for a typical flow for high-density flex fabrication process, based on glass carrier wafers with a thickness <1 mm conforming to SEMI wafer standards. In a first step, a release layer of polymer is deposited on the glass surface. The release layer is only temporary present and required for the final detach of the multi-layer stack from the glass carrier. It will not be part of the final flex circuit. In a second step, the backside pads of the later flex circuits are generated by semi-additive metal structuring. The multi-layer wiring stack is now created by the sequential repetition of the steps 3 and 4 as of Fig. 1. The maximum number of routing layers, which can be processed is limited by the warpage of the carrier wafer. Due to the Coefficient of Thermal Expansion (CTE) mismatch between the carrier wafer and the deposited materials, each layer will increase the warpage after processing. Reduction of metal load and thicknesses of both metal and polymer layers as well as introduction of interruptions in the polymer layers (like scribe lines) can reduce the warpage issue. Typically, such an ultrathin multilayer circuit can be built with approx. 35µm via diameter (limited by stray light reflection and warpage), and approx. 12µm lines/space. When additional process efforts to minimize stray light influence to the via formation are considered, the design rule guidelines for the ultrathin high-density flex are improved to allow for a 10µm via diameter, and 7µm L/S, allowing for a I/O pitch of approx. 27µm. With the availability of thin bare dice (less than 25µm in thickness), driven by the mobile devices industry, the proposed process flow lends itself also to the creation of not only passive substrates, but also active systems. The main difference to the previously described sequence is the placement of the chips on the polyimide dielectric and their embedding into an additional ~25µm thick polyimide layer, which subsequently serves as slightly thicker dielectric to receive the next metallization layer. Due to the topography introduced, minimum via diameters acceptable for the next interconnect layer are limited to ~40µm.

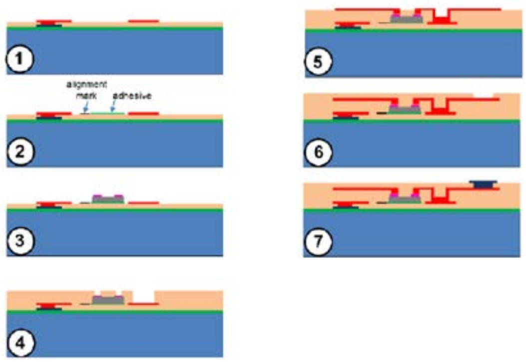


Fig. 1: Schematic process flow for the embedding of thin ICs into the flex build-up layers

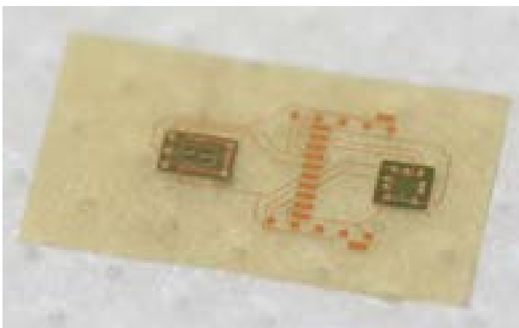


Fig. 2: Multilayer thin film flex with embedded ultrathin chips

B. *Printing*

Printing is the typical manufacturing technology for FHE. The basic printing processes are derived from conventional graphic arts techniques, including screen, gravure, flexographic, stencil and ink-jet printing. The advantages include roll-to-roll compatibility and the potential for low cost and high-throughput production. Assembly is done using conventional equipment and low temperature processes, e.g. isotropic conductive adhesive bonding (Fig. 3).

However, besides the obvious advantages, printed electronics suffer from drawbacks like insufficient functional properties of printed materials, in particular the electrical conductivity. In addition, the dependence of the resistance from different environmental parameters can cause problems.

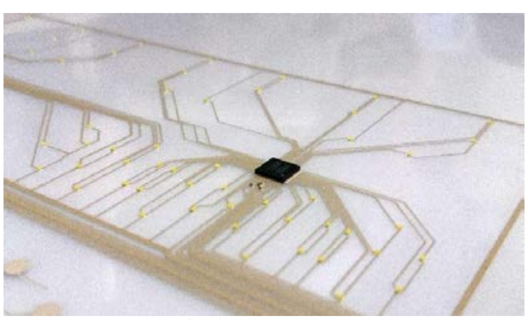


Fig. 3: Printed circuit on PC after assembly

The major challenge in paste or ink developments to match the rheology of functional ink or paste for a printing process to achieve desired printability together with sufficient wetting on the substrate to the desired functional and optical quality of printed structures. Also, the postprocessing is crucial since it is desirable to keep low process parameters but residual solvents and dispersing additives will hamper the functional properties.

C. *3D Printing*

Many methods have been developed in the past few decades to both print a 3-dimensional structures and embed conductive traces and/or componentry, doing this either simultaneously or in subsequent steps. These methods often utilize one or more typical additive manufacturing methods, such as combining: stereolithography (SLA) and direct write (DW); photocurable resin jetting and conductive inks; and powder bed fusion and inkjet (Fig. 4).

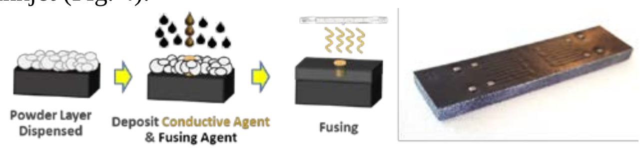


Fig. 4 - Combined powder bed fusing and conductive inkjet method for creating 3D printed electronic parts

Applications for these 3D printed electronics (3D PE) approaches are similar to flexible electronics applications, including wearables, soft-robotics, medical applications, and deformation sensing. However, there are also some distinct advantages to being able to create a final 3D form factor of interest, including:

- Quicker and cheaper time to first part, for improved prototyping and design iterations
- Less manufacturing steps, allowing for fewer mechanical and electronic interconnects, which are often prone to failure
- Increase in design complexity, especially when traces can be routed through the 3D structure being created

3D PE methods which are amenable to flexible materials have also been studied and developed, with a few key examples being particularly promising. These include a method of direct writing conductive material into a pre-polymeric silicone material which is subsequently cured after ink and component placement [12]. Many additional publications have expanded on this approach in a growing field of soft robotics and skin-mountable devices. The powder bed fusing method with conductive ink jetted materials could also be adapted to flexible materials which are amenable to powder bed fusion techniques, such as flexible TPU’s and TPA’s. Finally, Aerosol Jet Printing (AJP) has been useful for conformally printing conductive materials onto 3D substrates, which could be elastomeric, as well as growing trends to use AJP for both depositing the dielectric material (sometimes flexible) as well as the conductive material.

IV. STRETCHABLE CIRCUITS

There are mainly two strategies to achieve stretchability in electronics:

(1) make non- stretchable materials stretchable via proper design of structures to absorb applied strain (example in Fig 6);

(2) develop intrinsic stretchable materials that are applicable in electronic applications.

Generally, stretchable electronics consist of a stretchable matrix including conductive tracks which connects the rigid components (Fig. 5). This limits the component density at given matrix stretchability.

Fig. 5: Schematic for the structure and behavior of the stretchable circuit board.

Various designs, including wave/wrinkle, island-bridge, origami, kirigami, and cracks and interlocks have been developed to realize stretchable circuits based on metal tracks on elastomeric polymers such as poly(dimethylsiloxane) – PDMS to be physically deformed together. Structural design serves as a universal tool for stretchability enhancement and it is applicable to different types of materials — including organic or inorganic, lab-made or commercial materials. While 30–50% dynamic strain is easy to achieve with simple fabrication strategies, larger strain would require more complex fabrication techniques. Therefore, the maximum strain to which the materials can be stretched is limited to some extent in practice.

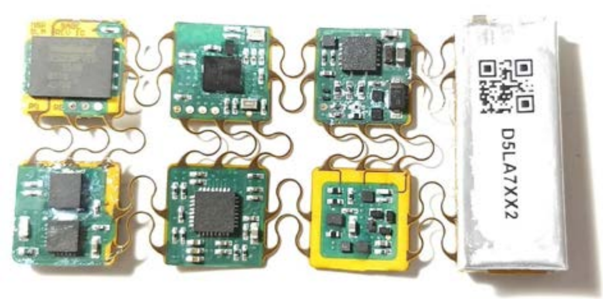


Fig. 6: Flexible assembly using rigid PCB and meandering traces

An alternate way to achieve stretchability is to utilize intrinsic soft and stretchable materials. There are multiple candidate materials that have been applied for flexible/soft electronics, including hydrogels, conductive polymers, nanomaterials, and liquid metals.

A. *Lithography*

The "Stretchable Circuit Board" (SCB) is an approach to use conventional PCB processes on thermoplastic polyurethane (TPU) - an alternative to mainstream stretchable electronics, where silicone (PDMS, polydemethylsiloxane) is used. Although TPU is not as ideal elastic as PDMS, it has a number of advantages with respect to processing in a printed circuit board fabrication environment: it is fully compatible with all wet chemical process steps (especially not contaminating the process bathes, which is typically a concern with silicones). Due to its thermoplastic characteristic it can be built-up by subsequent lamination of layers (similar to a build-up process of a conventional printed circuit board).

The process flow for the fabrication of a stretchable circuit board using processes form printed circuit board manufacturing is schematically depicted in Fig. 7. In the first step a printed circuit board grade Cu foil is laminated onto the thermoplastic polyurethane. The Cu foil is then structured by photolithography. Subsequently solder mask is applied and structured so as to form islands around component positions. A pre-cut TPU "cover-layer" is then laminated so as to overlap with the solder mask and cover all copper tracks on the surface. Finally an electroless silver finish (approx. 70 nm thick) is applied onto the open contact pads.

To achieve the stretchability of the Cu tracks meanders are designed (Fig. 8) which allow stretching up to 300%.

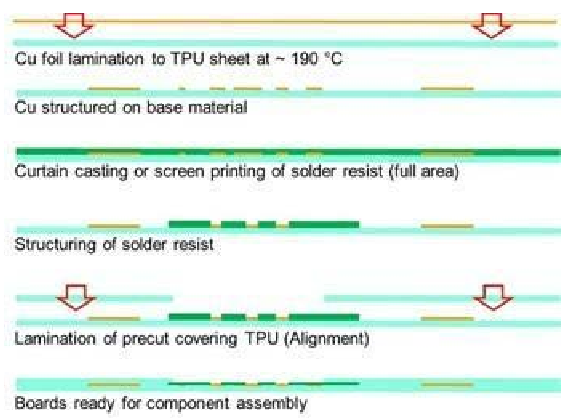


Fig 7: Schematic process flow for the fabrication of the stretchable circuit board

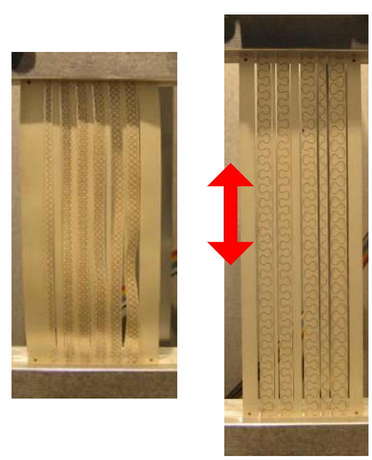


Fig. 8: Stretching of Cu meanders on TPU

B. Printing

Alternatively to the meandering Cu-tracks, the conductor lines on the thermoplastic carriers can be structured by screen printing. A number of suitable materials especially for printing on TPU have been developed and are commercially available. Two different material types are available. Stretchable conductive pastes which can be applied preferably to TPU and thermoformable conductive pastes which are only deformable at high temperatures.

C. Liquid Metal

The majority of metals and alloys is solid at room temperature. Metals are known for their physical properties of high electrical and thermal conductivity in addition to being malleable (e.g. can be hammered into thin sheets), ductile (e.g. can be drawn out into thin wires), and fusible (e.g. can be melted to their molten liquid state). In addition, metals are typically characterized by their high melting points. When liquefied, the conductivity and fluidic properties of metals make them promising candidates for applications in microfluidics and soft, flexible, and stretchable electronics. For these technologies researchers have focused their work on those metals and alloys that are liquid at or near room temperature – colloquially, known as liquid metals. Among the liquid metals and liquid metal alloys, pure gallium, eutectic GaIn (EGaIn), eutectic GaInSn (Galinstan) and derived materials are the most commonly used.

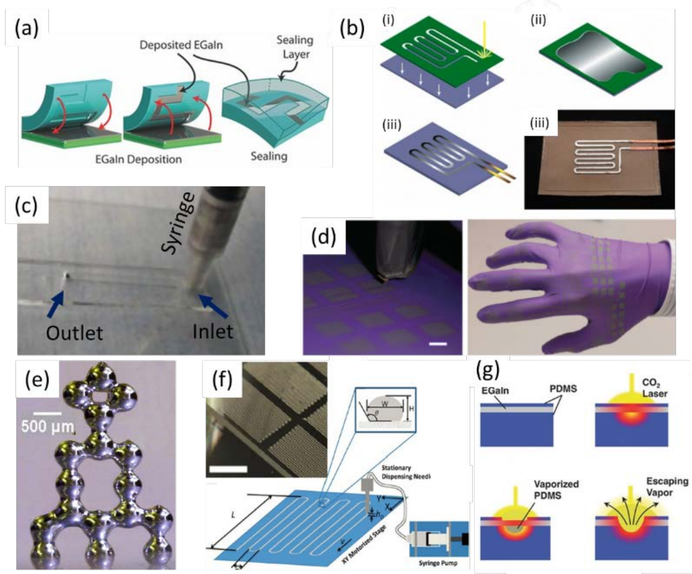


Fig. 9: Simple and popular ways to pattern liquid metal. (a) It is possible to imprint films of the liquid metal with a silicone mold. (b) Spreading liquid metal across a stencil placed on a receiving substrate is a facile way to pattern the liquid metal. (c) Injecting liquid metal into microchannels is a simple method to create well-defined and high resolution structures. (d) Inkjet printing small colloidal suspensions of liquid-metal droplets, followed by "mechanical sintering" at room temperature. (e) 3D printed liquid structures are possible due to the native oxide that forms on the metal. (f) The same concept can extend to 2D direct-writing of the metal. (g) Subtractive methods, such as laser ablation, can pattern films of liquid metal in elastomer.

Liquid metals can be used as conductive tracks on/in various materials, e.g. silicones and other thermosetting elastomers but also thermoplastic materials like polyurethane.

Structuring liquid metals is challenging but processes have been developed and describes for structuring liquid metals into circuit. There are 4 principal approaches and some examples from literature as seen in Figure 9:

- Lithography-assisted: Photolithography is utilized to create molds, stencils, and other guiding elements for patterning liquid metals into predetermined features, geometries, and traces.
- Injection: Liquid metal is injected into hollow cavities (fibers, microfluidic channels). Pattern dimensions are predetermined based on shape and size.
- Additive: Liquid metal is selectively deposited at the desired location, often using the same equipment or techniques as other additive manufacturing techniques (e.g. dispensing, jetting).
- Subtractive: Liquid metal is deposited as a layer and selectively removed to form the desired pattern.

D. Thermoforming / Injection molding

With thermoforming or injection molding of the stretchable circuits, such systems can also be turned into 3D shapes. Thermoforming is a well-established technique to bring thermoplastic materials with rigid properties at their typical operating condition into a specific shape. This has been employed for low-cost disposables, like food containers, or high-value products, like avionics interiors or medical prosthetics. Until now, adding electronic functionalities to 3D surfaces has been difficult and a labor-intensive process. With the advent of stretchable systems, offering the electronic functionality in conjunction with their intrinsic property to follow a given complex geometric shape, such integration processes have now become much more efficient

The process flow for thermoforming is modified in that way, that, e.g., the foils used for state-of-the-art in-mold decoration is replaced or supplemented by the stretchable system. The layer stack is then placed over the master mold of the thermoforming unit, heated and – by applying vacuum and pressure – conformed to the surface geometry of the mold. After cooling below the Tg, the mold clamp is opened and the product in its final shape is taken out. Fig. 10 shows a typical mold insert, a test structure that has been designed to assess the local distortion and a demonstrator of a custom-shaped LED lamp interior. In order to limit the local deformation to protect the active circuits on the stretchable system, the temperature distribution in the heater can be tailored to specifically modify the flow properties of the thermoform substrate at a given site. With this approach, both protruding as well as intruding shapes can be electronically enhanced, shaping complex geometries with sidewall angles up to 87°.

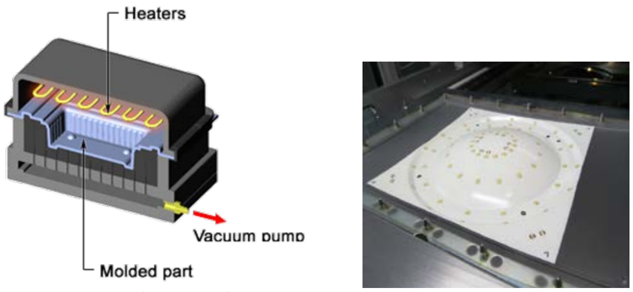


Fig. 10:Thermo-forming of thermoplastic LED module

V. *Assembly and Encapsulation*

The electronic interconnection of components to thermoplastic or printed circuits is established through a solder contact or isotropic adhesive bonding. Since lead-free solders used in most electronics today require reflow temperatures in the range of 260 °C, these solders are not suitable for the conformable substrate. Therefore, SnBi with a melting point of 143 °C and a typical reflow temperature of 160 °C is used for stretchable systems. The solder is available as type 3 paste and either stencil printed or locally dispensed onto the substrate prior to component assembly. Isotropic adhesives which cure as low as 120°C for 30 minutes are even safer for the thermoplastic materials but the interconnections are less robust.

The electronic components are typically assembled onto a thermoplastic board using automated pick and place equipment capable to assemble >100k components per hour.

For stretchability of the printed as well as stretchable metal conductors, robust encapsulant and bonding materials are required.

Liquid encapsulation with materials of different viscosities is already widely used. Good results can also be achieved with lamination of multilayer foils (Fig. 11). Local encapsulation of components can also be achieved by placing polymer preforms. This allows good control of the encapsulation shape and also the material properties (e.g. optical).

Only flexible and elastic materials matched to the circuit improve not only the reliability under climate tests but also under mechanical tests. These requirements are essentials to form the innovative integration of flexible electronics and convectional electronics or what is known as FHE.

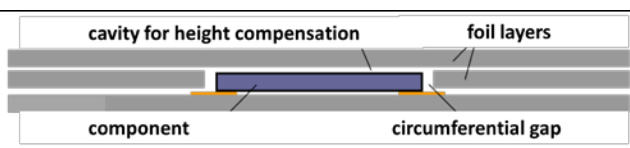


Fig. 11: Encapsulation by embedding

A typical build up with printed tracks and adapted interconnection and encapsulation processes is presented in Fig. 12.

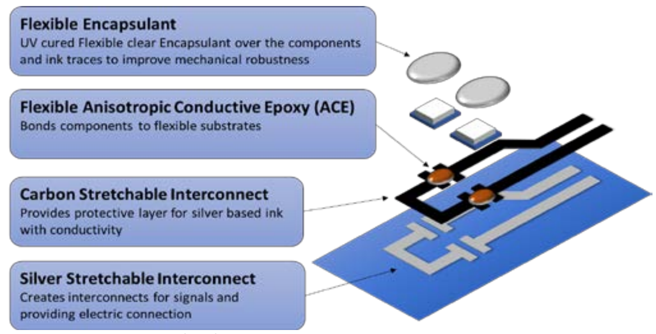
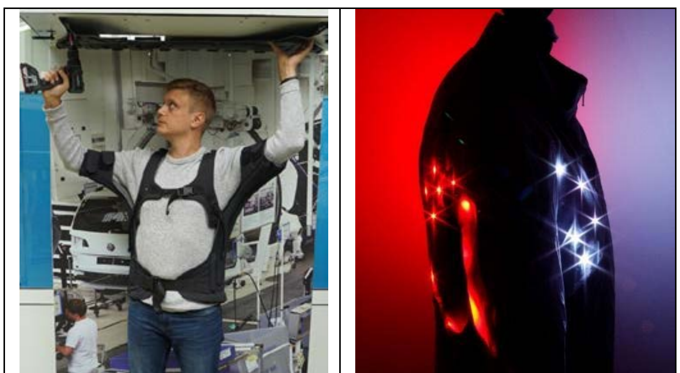


Fig. 12: Structure of a flexible printed assembly using a stretchable substrate and stretchable conductive inks

VI. Application Examples

A. *Wearables*

The range of wearable devices enabled by flexible and stretchable electronics ranges from wristbands over smart textiles to soft-robotic exoskeletons. FHE and stretchable electronics allow the integration of electronics functionalities in dynamically deforming devices molded to the shape of the human body.

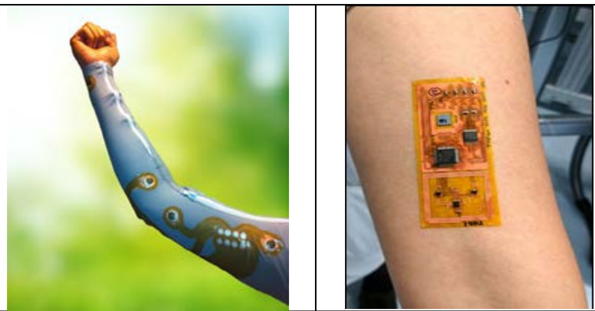


a) Supportive softrobotic vest (Fraunhofer IPK / IZM, copyright Fraunhofer IPK)	b) Utope bicycle jacket (copyright Wolfgang Langeder)

Fig.13: Wearables using stretchable electronics and FHE

B. *Medical*

Flexible electronics are enabling wearable and implantable medical devices. A major application trend is the development of patches for complex sensing (ECG, respiration, PPG, chemical analysis). Other types of wearable devices are used especially for movement monitoring, stimulation and treatment (e.g. light) for rehabilitation purposes. Miniaturized flexible modules are also required for the most innovative devices like camera pills, smart catheters or implants for neural stimulation.

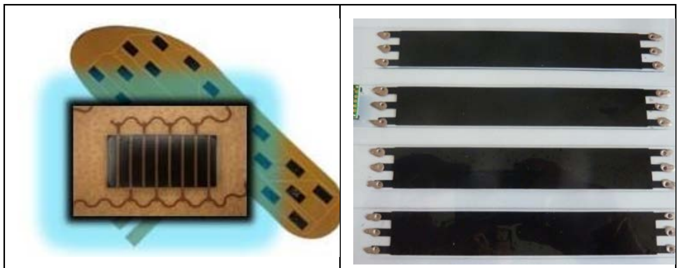


a) SCB for stimulation suit (University Boras/Fraunhofer IZM)	b) Smart patch for sweat analysis (project XPatch, Xsensio)

Fig. 14: Medical applications using stretchable electronics and FHE

C. Sensors

The use of flexible, stretchable and conformable substrates to fit the use application will not preclude the use of existing sensors available on the market. These will include ECG, temperature, pulse oximetry, motion (IMU) and other sensors. The challenge is – as for other rigid components - to ensure a reliable interconnection between the sensor and the substrate and to be able to provide the power needed to properly sense and process the data. Additionally there is a large number of new sensors based on printing processes and elastomers. Resistive, capacitive and inductive measurement principles are common. The sensors are mostly used for measuring pressure, strain or temperature. While these polymer sensors have limitations regarding accuracy, drift over time and dependence from temperature and humidity they are easy to manufacture and cost effective so that sensor arrays ad sensor distribution over large areas is feasible. The properties are typically sufficient to monitor the dynamics of the measured parameters.



a) printed pressure sensor array	b) elastomer strain sensor (Fraunhofer ISC)

Fig. 15: Printed and polymer sensors for wearables

VII. Reliability Testing

Looking at typical applications for flexible electronics, reliability is a major concern - especially for medical products. Compared to conventional rigid electronics, flexible electronic modules are challenging regarding optimized reliability as well as reliability testing. Transitions between rigid, flexible and stretchable areas are unavoidable and tend to become breaking points.

Testing of flexible devices is often based on tests performed for conventional electronics. These tests do not take into account the different material properties nor the mission profiles of the applications. Starting with the material characterization and basing accelerated test conditions and programs on the real loads will help to achieve a better assessment of technologies and their suitability for an application.

Fig. 16: Mission profile based approach to reliability testing

One approach is depicted in Fig. 16. The expected failure mechanisms are important for test planning and verification. Starting from information or assumptions about field failure rates and failure modes it is analyzed which phase of the lifetime has to be investigated. A simplified model is established to mimic the real-life load (mission profile) and based on these prerequisites the test program or test sequence is derived.

Accelerated testing is necessary, but for many of the new materials in flexible hybrid electronics the parameters are often too harsh resulting in wrong failure modes and failure rates with the risk of predicting too short lifetimes. Therefore, material characterization (e.g. modulus at different rel. humidity and temperatures) is required to obtain the boundaries of test parameters.

A. Climate Tests

The use of flexible substrates will certainly increase the sensitivity to moisture absorption into the substrate and the assembly. Most of the materials mentioned above have high moisture absorption rates. Care needs to be taken in the design to reduce any moisture sensitive components from being exposed. Standard 85C / 85% r.h. is a very harsh test and may not be useful for flexible and hybrid electronics. The test conditions needs to be adjusted closer to the final use condition along with anticipated storage requirements. Thermal cycling and thermal shock can be used and can still provide data to estimate the life of the assembly.

For wearable devices, the washing machine test is the hardest to pass, as it imposes simultaneously heat, moisture and mechanical load [16]. The dominating failure modes vary with technology but mostly result from the high mechanical load. The lack of standardization makes it nearly impossible to compare published washability results and is still a major factor in limiting the acceptance of wearables based on smart textiles [17].

B. Mechanical Tests

Mechanical testing, such as bending, torsion, and stretching, has been used to evaluate flexible electronics [18-21]. Due to the lack of industry-wide testing standards, a variety of testing conditions have been reported depending on the applications.

When subjected to bending, mechanical stresses are induced on flexible electronics to cause failure by delamination or cracking. Both dynamic and static bending testing has been conducted for flexible electronics. For example, bending radii ranging from 3 to 40 mm and cycle number of 300 to 200000 have been reported [22,23]. Testing setups designed to mimic more realistic operating conditions have also been reported, such as dome-shaped and saddle-like structures for bending and biaxial stretching [24,25].

Mechanical tests such as cyclic pulls (Fig. 17) provides a method to show the effects of stretching on the flexible assembly. Flexible inks on a flexible substrate will be able to survive over 100% stretch but will often result in permanently increased resistance of the printed traces. This concern is more to the interconnection method used. Solders and high modulus epoxies will often fail at the connection interface–if no additional measures for protection, i.e. encapsulants, are used. From our testing, this can result at strain levels as low as 20%. By using a low modulus encapsulant over the attached component and interconnect, this can substantially increase the amount of deflection permissible at the time of use.

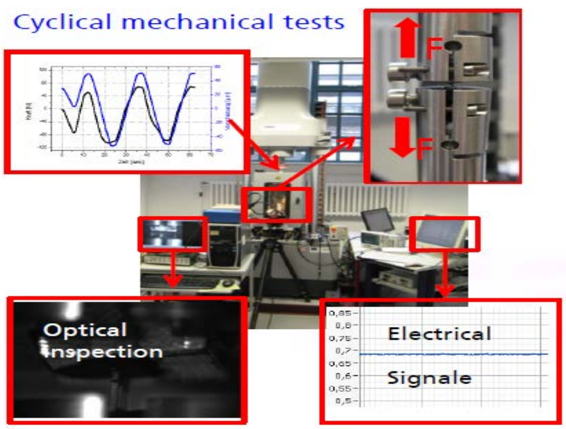


Fig. 17: Test setup for cyclic mechanical strain

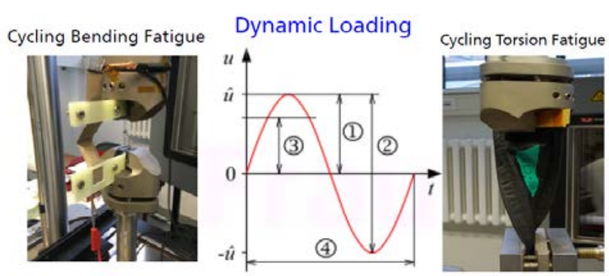


Fig. 18: Test setup for torsion tests

VIII. Conclusion

With the advent of technologies to realize advanced high density multilayer flexible substrates and the availability of thin bare dice but also with the materials and processes for stretchable and 3D electronics, the level of integration into flexible and conformable systems has reached a maturity level which opens up the perspective for a multitude of products outside the traditional perspective.

The broad spectrum of materials and processes available by now provides solutions for a wide range of requirements but at the same time makes it difficult to find the optimum solution for an application. Another challenge which slows down the market entrance of some of these innovative technologies is the lack of standards. Especially the lack reliability standards has led to unsuitable test programs for FHE resulting in misjudgment.

However these challenges seem to be solvable in short term. Therefore it can be expected that in the era of digitalization, of IoT and distributed, connected smart devices, these technologies will serve as hardware platform for our future “smart x” societies.

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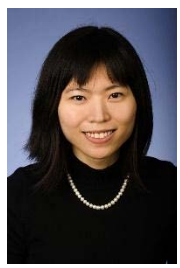

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