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Editorial

Stretchable Electronics for Artificial Skin

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Human skin is the largest and most remarkable organ of the body, consisting of an integrated, stretchable network of sensors that relay information about tactile and thermal stimuli to the peripheral nervous system. It then compiles and transduces this information to the brain, which in turn sends new information back to the organs and tissues to execute responses such as biomolecule delivery (e.g. in liver, pancreas,…) or muscular action [1]. This is a clear example that human body is a complex and fascinating machine. The exceptional properties of skin have attracted the attention of scientists all around the world to develop intelligent and interactive materials and devices by mimicking them [2,3].

Electronic skin (e-skin) started becoming real since the development of what is called nowadays stretchable electronics. It is a new technology that allows obtaining devices which are stretchable, twistable and deformable into curvilinear shapes without losing their electrical properties when subjected to mechanical deformations. Therefore, the electronics of the future, that will be soft and rubbery, will enable applications that would be impossible to achieve by using the hard, brittle, rigid and planar electronics of today. Biomedical prostheses and devices, surgical electronic gloves, advanced humanoid robots or wearable health monitoring devices are a few examples of what is expected with the development of the electronic skin.

The first consideration for the development of the electronic skin is the selection of the materials that will be employed in its fabrication and the way to confer the mechanical properties of its natural counterpart (e.g. flexibility, stretchability and low modulus) as well as electrical properties. Different strategies have been followed to achieve those properties and through the use of

i) Intrinsically stretchable electronic materials or

ii) Geometrical arrangement.

Both strategies look for the ideal stretchable conductor: maintain high conductivity over a large range of strains, allowing reliable operation during stretching.

The development of intrinsically conductive stretchable is based on the incorporation of conductive materials into stretchable materials like elastomers (e.g. poydimethylsiloxane, polyurethane,...). Elastomers have received great interest because their mechanical properties resemble those of natural skin. Among conductive materials, metals are being widely investigated because of the exceptional high conductivities. Thus, metal micro- and nanomaterials- flakes, (nano) particles, (nano) wires- have shown excellent performance in stretchable conductors. However, the main drawback is the high fabrication costs limiting their applicability in large-area skin devices. On the other hand, carbon nanomaterials have also been successfully employed as conductive fillers. Although carbon black is one of the cheapest conductive fillers; its low conductivity has limited its use to certain applications. In contrast, CNT's and graphene have been successfully employed as fillers in elastic conductors as they show excellent electrical and mechanical properties. The main challenge with carbon nanomaterials is avoiding aggregation which requires optimized dispersion and mixing processes. Finally, conducting small molecules and polymers have attracted great interest. Although their electronic performance does not yet compare with that of inorganic materials, they show some advantages which make them interesting for e-skin applications: compatibility with elastic materials, low cost, tunable chemical and physical properties and deposition by large-area solution-processing techniques. Among them, Acenes, Oligothiophenes, Poly (3,4-ethylenedioxythiophene): Poly (styrenesulfonate) (PEDOT: PSS), Polypyrrole (PPy), Polyaniline (PANI) or Poly (3-hexylthiophene) (P3HT) have been commonly used.

The second strategy, based on geometrical considerations, has resulted in many stretchable conductors and devices using traditional electronic materials (e.g. silicon). The concepts that enable stretchy properties from these brittle materials are simple. One way is to pattern discontinuous structures onto the elastomeric substrate. For example, convoluted pathways such as serpentine or horseshoe-shaped structures are effective. Another alternative is to prepare wrinkled films by just depositing conducting films onto a prestretched elastomer. Therefore, the resulting device can be stretched to the value of the prestrain without inducing considerable stratin into the active components. These and related ideas provide routes to high performance electronics with the mechanical properties of a rubber material.

Significant progress has been achieved during the last years following the previous strategies. For example, Someya et al. have reported a series of increasingly more complex stretchable circuits with multiple functionalities (e.g. pressure resistive rubber mesh incorporating organic field-effect transistors, [4,5] and Bao and coworkers have investigated the use of micro structured elastomers to developed highly sensitivity capacitive mechanical sensor for pressure, lateral strain and flexion sensing [6,7]. Rogers and colleagues have pioneered the use of patterned discontinued structures for creating multifunctional devices like balloon catheters able to sense temperature, pressure and tactile stimuli, devices incorporating sensors and electrodes with high tactile feedback or epidermal electronic systems that could be transferred onto the skin like temporary tattoos for temperature, strain and electrical measurements [8,9] and Suh and coworkers [10] have developed a skin-attachable strain-gauge sensor based on two interlocked arrays of high-aspect-ratio Pt-coated polymeric nanofibers supported on thin polydimethylsiloxane layers. The reversible interlocking of these conductive nanofibers enabled the detection of pressure, shear and torsion.

Although the primary function of human skin is mechanical, more recently the scope of e-skin has expanded to include more compelling, and more technically challenging ideas: biodegradable and biocompatible, self-repair, self-power or self-responsive to external stimuli [11,12]. Although we are far from achieving this multifunctional and intelligent electronic skin version, looking at the speed of new developments in complimentary fields like nanotechnology, electronics and engineering there is no doubt that there will be rapid progress towards fully integrated electronic skins in the future.

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