E-mail, E-paper, E-skin?

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The problem of restoring lost skin has accompanied man nearly from the beginnings of civilization. The earliest mentions of skin grafting come from India and are dated about 2500 years B.C. [1]. In Europe, the first major breakthroughs have occurred in Italy, during the 15th century, when Brancas succeeded in performing a nose transplant, using skin taken from the arm of the patient. Skin grafting has evolved from art to a branch of science thanks to Tagliacozzi, who in the year 1597 described the techniques used by Brancas in „De curtorum chirurgia per insitionem"[2].

Modern procedures of skin grafting have their roots in Bunger's experiments in Germany of the year 1823, who successfully performed a skin autograft in a human, as well as Reverdin in Switzerland, who is known for the first skin allograft in the year 1869. Only two years later Pollock used the above method to treat burn wounds, which paved the way to one of the currently most important applications of skin grafting [3].

Further development of those methods in the 20th century allowed many difficulties in preserving and grafting sheets of skin to be solved, as well enabled their in vitro manufacture. This didn't mean the stagnation of this branch – in 1987, the American National Science Foundation gave scientists the objective of creating an easily attainable alternative, having the biological and pharmacological properties of human skin. The effect of this research was the creation of Apligraf in 1998 – the first artificial skin which was a fruit of tissue engineering.

Merely two years ago, an interdisciplinary team of scientists from the Fraunhofer Institute in Stuttgart developed a fully automated process of manufacturing artificial skin, built from two layers, consisting of different types of cells and already work has started on creating artificial skin that would include even blood vessels. Chemists aren't lagging behind as well – recently a new type of synthetic membrane, sensitive to touch has been created. This "e-skin" as it has been dubbed by its creators is made mostly of polymers, typical as well as conducting.

Two paths to success

It is difficult to point out the only "true" creators of the e-skin, because two models [4, 5] have been proposed by individual research teams. Admittedly the functionality and parameters of the proposed materials may be considered comparative, however they significantly differ in their structure.

The material developed by scientists from Stanford University is, in fact a sheet of elastic poly(ethylene terephtalate) covered with indium-tin oxide (ITO), onto which pyramid-shaped chunks of poly(dimethylsiloxane) have been affixed [6]. If such a sheet is squeezed, the holes previously filled with air will now be filled by the polymer, effectively changing its capacitance. For measuring and registering such changes to be possible, the sheet was placed on the organic transistor; when the material is subject to pressure, the current flowing through such a transistor will change. Resolution in such a system is obtained through the use of a network of transistors, which allows the determination of pressure in certain points – pressure pixels. Currently work is being carried out in the direction of granting this material extensibility comparable to that of natural skin, while achieving biocompatibility and possibly its integration with real tissues is a goal of the future.

An alternative approach was taken by scientists of the University of California in Berkeley, utilizing semiconductor nanowires woven into the shape of a network [7]. This network was then applied to a pressure sensitive rubber that changes its electrical resistance when under pressure. In such a system, the intersecting nanowires have the functionality of transistors, which in turn are a kind of pixels – it is possible to determine the pressure applied to each of those points. Because this type of artificial skin is made mostly of rubber, it is very flexible and extensible – even bent into the shape of a letter "U", it retains its properties.

Similar to the first e-skin discussed in this article, biomedical application still lies in the far future, however the creators of this material expect it to be soon applied in robotics – due to that, they direct their research to the increase in scale, so that it is possible to manufacture enough e-skin to be able to cover a whole robot.

Summarizing, the operating principles of both the materials reduces down to inducing the change of one of the physical properties of the system through applying pressure to it, transforming it to an electric signal and their registration. While the component responsible for transforming the pressure sensed to a change of capacitance or electrical resistance is important, similarly to the flexible substrate onto which the system is affixed, the true heart of the e-skin are the transistors or nanowires replacing them.

Transistors, transistors

There are fundamentally two types of transistors that differ in the principles of operation – bipolar, utilizing semiconductors with different types of conductivity (p and n) and unipolar (or field effect), utilizing only one type of conductivity typical to semiconductors. Because one of the features characterizing e-skin should be flexibility, organic transistors on polymeric substrates are used, instead of the rigid, silicon-based transistors. Furthermore, it is desired to be able to register the state of each transistor, that is, memory – as a result of the above, the scientists have chosen organic field effect transistors with a "floating" gate [8]

In the most basic case, a field effect transistor consists of a source and drain, between which a channel is generated, through which current flows, as well as a gate, between which and the source voltage is applied to regulate the conductivity of the channel. Physically, a field-effect transistor may be built in a number of ways, dependent both on the character of the gate isolation, and on the materials from which the transistor is constructed.

The idea of a field effect transistor with a floating gate lies in adding another gate to the system, which is supposed to gather electrons or holes if sufficiently high voltage is applied between the control gate and the source [9]. The charge gathered on the floating gate partially screens the electric field generated in the system; if it is large enough, it may cause the current to stop flowing through the transistor in normal working conditions. This charge can be removed, for example in silicon-based transistors, light of a certain wavelength is used, though it is possible to achieve the same through reversing the polarization of the voltage applied. The above type of transistor is widely used in the manufacture of electronic memory (Flash EPROM).

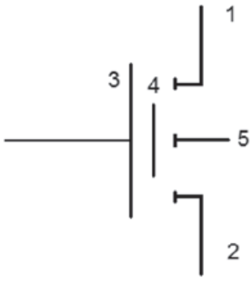

Fig. 1. Schematic diagram of a field effect transistor with a floating gate. 1 – source; 2 – drain; 3 – control gate; 4 – floating gate; 5 – base

A simple pressure sensor...

The foundation for latter models of e-skin was laid by the research team under the direction of T.Sekitani, which developed a flexible, large-area sensor, which can measure the spatial distribution of pressure applied to it and store the data for up to twelve hours[8].

This sensor is composed of three different layers, laminated together:

- Sheet of poly(ethylene naphthalate), onto which six hundred seventy six memory cells have been placed, each comprised of two transistors, so that the cells form an array of 26 x 26 cells
- Sheet of pressure-sensitive rubber
- Sheet of poly(ethylene naphthalate) with a copper electrode.

The layers have been attached to each other in such a way that the control gates of the cells were in contact with the bottom surface of the rubber layer and the upper surface of the rubber layer was in contact with the copper electrode.

Having such a sensor, the matter of its improvement through exchanging transistors to a system of nanowires or the material property being changed, while significant, does not appear to be breakthrough. Therefore, it can be said that apart from having two fathers, e-skin has also a grandfather, who made an equally significant contribution to its creation.

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